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Renate Tobies

Iris Runge

A Life at the Crossroads
of Mathematics, Science,
and Industry

 Birkhäuser

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Iris Runge

A Life at the Crossroads of Mathematics,
Science, and Industry

With a Foreword by Helmut Neunzert

Revised by the Author and Translated by Valentine A. Pakis

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Iris Runge

Figure 1: Iris Runge at the Osram Corporation (1929)
([DTMB] Photo Album for Dr. Karl Mey)

FOREWORD

I must confess that I did not initially share Renate Tobies's enthusiasm about the "industrial mathematician" Iris Runge. It is true that she was the daughter of Carl Runge, the famous numerical analyst. It is also true that she worked for more than twenty-two years as a mathematical consultant at the Osram and Telefunken Corporations, one of the first women ever to hold such a position. But are these sufficient grounds for someone to write – let alone read – an entire book about her?

Well, it turns out that I did read the entire book, at first cautiously and selectively, then with increasing delight, and finally with genuine interest and intellectual profit. What was it that caused my attitude toward the book to make such a dramatic shift? First there is the simple fact that Renate Tobies has assembled such a wealth of instructive material, on the basis of which the reader will come to know a great deal about Iris Runge's emotions, interests, and thoughts. Above all, however, I was moved to change my mind by the remarkable substance and historical relevance of this material, which serve to make Tobies's profile of Iris Runge – truly one of the more fascinating women from the first half of the twentieth century – as interesting as it is.

In the terminology of the time, Iris Runge would have been known as a "well-bred daughter" (*höhere Tochter*), a woman born into the best of the educated middle class. Both her father's family and her mother's (the Du Bois-Reymonds) could claim a great number of scientists and even some of the few women members of the Prussian Academy of Arts. These families were part and parcel of the scientific community of the time: Iris's godparents were Marta Pringsheim and Robert von Helmholtz; the godfather of one her younger sisters was none other than Max Planck. Another network in which Iris Runge was involved consisted of her classmates in Hanover, a group that included Elisabeth Klein, daughter of the influential mathematician Felix Klein, to name only one example. From her earliest days, in other words, Iris Runge was exposed to a life of the mind, and it was just such a life that she would go on to lead on her own terms.

Iris Runge was closely associated with her father's colleagues in Göttingen and with their many doctoral students. She studied in Göttingen and Munich under the likes of Klein, Hilbert, Landau, Prandtl, Born, Toeplitz, Pringsheim, Sommerfeld, and Michelson – a list that reads like a page from "Who's Who" of the German and international scientific communities. Nearly all of these personalities figure in one or other of the stories or episodes in the book, and it cannot be denied that this makes for interesting, novel, and extremely pleasant reading.

Iris Runge earned her doctoral degree in physical chemistry. In today's terms, the method of problem solving employed in her dissertation could be called ma-

thematical modeling, an approach that she learned from her father and, above all, from Arnold Sommerfeld in Munich. The heart of applied mathematics as it is currently practiced, mathematical modeling was not yet a central feature of Felix Klein's and Carl Runge's work, even though their younger colleagues – Ludwig Prandtl in Göttingen and Sommerfeld in Munich – had already developed reputations as modelers *par excellence*. Carl Runge was predominantly concerned with developing methods, both graphical and numerical, for solving differential equations. For him it was all a matter of “computation,” as we would say today. Klein referred to this method as “approximation theory” (*Approximationsmathematik*), and such an approach, along with the use of computers, would later prove essential to the pioneering application of mathematical models and to the new role of mathematics, in general, as an applied science. Although mathematical modeling had been developed during Iris Runge's youth, complex and three-dimensional models were still beyond the comprehension of its practitioners. Simplified models were employed to enhance the understanding of industrial processes and production. Even today it remains a matter of debate – between the Oxford Center for Industrial and Applied Mathematics (OCIAM) and the Fraunhofer-ITWM (Institute for Industrial and Business Mathematics), for instance – whether industries should be content with merely “understanding” certain problems or whether they want more exact analysis of complex models that they can convert to designs. Both approaches are necessary, of course, though the latter has the larger payoff.

It was Iris Runge's task as an industrial researcher to understand the problems set before her, and it was precisely this that brought her the greatest joy. This much is made wonderfully clear by everything she wrote about her work. Why did a thirty-year-old woman scientist with great talent and influential connections seek a position in industry? Why did she simply not keep her job as a teacher at the Salem Castle School? Obviously, for the great pleasure that she derived from the work – because of her strong enthusiasm for solving problems. Thus she pursued this pleasure with fervor and managed to find it in her work at Osram, a fact that she would underscore for many years in her personal correspondence. I was left with the impression that Iris Runge's professional activity might represent the earliest manifestation of a “mathematical dream job,” a concept that Andrea Abele, Renate Tobies, and I have discussed in another context.

How did she go about her work as an industrial researcher? To begin with, she listened to the problems posed by electrical engineers and scientists and, whenever possible, she translated these problems into mathematical terms (much as in the Sommerfeldian spirit). Because so much of her work was concerned with quality control, she soon found herself in the realm of statistics. In fact, Iris Runge went on to co-author the first book on such a topic, namely on the application of mathematical statistics to the problems of mass production. Richard von Mises, the most celebrated statistician of the time, was hardly overwhelmed by the book, but he was nevertheless quick to acknowledge its usefulness. Regarding industrial mathematics, Iris Runge was faced with problems that remain pertinent today,

even if they now go by different names – with inverse problems, with homogenization, with scaling, and so on. She also did experimental work, and was more than happy to do so, as she once expressed in a letter to the famous physicist Lise Meitner. But her superiors usually considered her services too valuable for such activities. She was, above all, an esteemed and competent mathematical consultant.

Iris Runge was also highly interested and active in politics: She was a devoted Social Democrat. Lacking any extreme or bolshevist inclinations, she was able to maintain her convictions throughout different political systems, although things were more difficult during the Third Reich. She had many Jewish friends (Richard Courant, the mathematician, was her brother-in-law). Of course, her research was not irrelevant to the war, during which she was employed at Telefunken's electron tube laboratory. Her letters indicate that, given the circumstances, she lost the enjoyment that had characterized her earlier career. She would have embraced the opportunity to emigrate to America, where she could have worked as a historian of science with the famous George Sarton, but he could not keep his offer on the table, and so she took to occupying herself with the history of science in her spare time and in her home country. Her time at Telefunken was treated as nothing more than a job. After the war, by which time she was nearly sixty years old, her career in the industrial sector came to a close. Finally, in 1950, she was hired as a professor of theoretical physics by the Humboldt University in East Berlin.

Iris Runge was an active participant in several intellectual circles during the first half of the twentieth century. This fact alone, assuming that most readers will possess some familiarity with the German intelligentsia of the time, is enough to make the book a pleasant read. There is also some pleasure to be had in the fact that she was an enthusiastic industrial mathematician, and it is hoped that some of this enthusiasm will rub off on the burgeoning mathematicians of our time, many of whom are striving for a professional position similar to the one that Iris Runge so long enjoyed. Such students can learn a great deal from this book about the similarities and differences faced by the industrial mathematicians of yesterday and today. Today, of course, the opportunities in the field are far more extensive and diverse. Readers without a background in mathematics will also benefit from learning about the dreams and realities that were experienced by a female industrial researcher between the years 1900 and 1950, and they will likewise enjoy the work as a contribution to intellectual history. Let me conclude by wishing the book all the success that it undoubtedly deserves!

Helmut Neunzert

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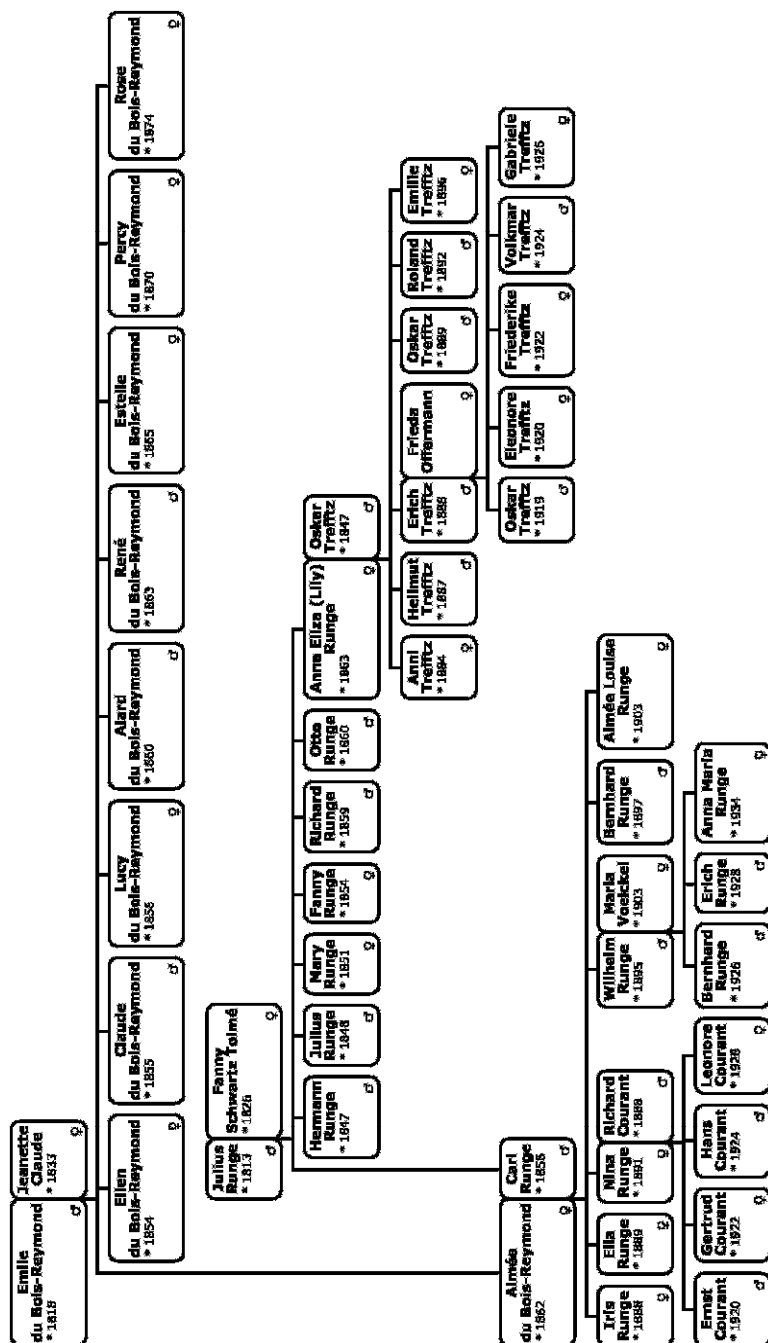


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AUTHOR'S PREFACE

Regarding my work [...] I can honestly say that it's wonderful (as always!). Sometimes I feel that it was high time for Osram to hire someone with at least some background in mathematics, for there are employees here whose mathematical abilities are unbelievably primitive. Even Jacoby wouldn't be able to capitalize on half of his countless ideas if he didn't have me around to tell him right from wrong.¹

Iris Runge wrote these words in June of 1923. By this time she had been working for just three months at the Osram Corporation in Berlin, specifically at a research laboratory directed by the inorganic chemist Richard Jacoby. The eldest daughter of Aimée (née Du Bois-Reymond)² and Carl Runge, who is remembered today for his part in developing the Runge-Kutta procedure of numerical analysis, she belonged to the first generation of academically trained women in Germany and was an intellectual product of the renowned center of science and mathematics at the University of Göttingen. Following in her father's footsteps, Iris Runge was still a student when she wrote her first academic article, a study co-authored with the theoretical physicist Arnold Sommerfeld, whose integration of mathematics, physics, and engineering had set a new standard for research. She was held in high esteem, moreover, by the number theorist Edmund Landau and she was awarded a doctoral degree for a dissertation, written under the supervision of the physical chemist Gustav Tammann, in which she applied advanced mathematical methods.

The Osram Corporation, known chiefly for its production of light bulbs and electron tubes, was founded in 1919 and quickly developed into an international enterprise with ties to General Electric and other firms. Still in its infancy, and with its headquarters in Berlin, Osram hired Iris Runge and thus acquired the expertise of a researcher who would function as a bridge between mathematics and its applications. "Calculation instead of trial and error!" – on account of her influence – became a catchphrase in the company's industrial laboratories.

This book arose from the uncommon circumstance of there being enough sources – from private letters to academic publications – to enable a reconstruction of a female mathematician's path from her childhood throughout the length of her professional career. Although certain American companies, such as the Bell Telephone Laboratories, had established mathematical research departments relatively early on, the majority of firms in the electrical industry employed only a few individuals as mathematical consultants. Iris Runge worked as such a consultant at Osram from 1923 to 1939. When the Osram electron tube factory was acquired by

1 Iris Runge to her father, Carl Runge, in a letter dated June 6, 1923 [Private Estate].

2 Aimée Runge was the daughter of the physiologist Emile du Bois-Reymond and the niece of the mathematician Paul du Bois-Reymond, who developed the so-called Du Bois-Reymond lemma in 1879 and is known for his contributions to the calculus of variations.

Telefunken in July of 1939, she found herself among a group of similar researchers. The activities of these laboratory groups at Osram and Telefunken, whose research was devoted to incandescent bulbs and electron tubes, have never been examined before. This research activity will be treated here in light of its collaborative nature both within Germany and internationally.

Writing this book was an exercise in building bridges. First of all there is the bridge that connects mathematics to science, engineering, and business. It will be shown how the construction of this *mathematical bridge* was enabled by the formation of a center of science and mathematics at the University of Göttingen (Section 2.3), and it will be demonstrated in particular how industrial laboratories constructed mathematical bridges between statistics and the quality control of mass production; between the physical and chemical methods of materials research and the concrete problems of manufacturing conductors, filaments, bulbs, and electron tubes; and between the models of theoretical physics, and the design of scientific instruments. In other words, the book will describe the foundational approach to problem solving that is still characteristic of industrial mathematics. The origins of these methods, which were developed during the golden years of broadcasting and radio tubes (1920–1945), lie at the heart of this study, as do their causes and effects.

Second, this book hopes to build a bridge between the specialized fields of mathematics and engineering, and the general culture of a particular era. In the spirit of Theodore M. Porter, who has encouraged scientists to “put the category of the technical into historical perspective,”³ industrial products and the methods of industrial mathematics will be examined in the context of the social, economic, and political developments that unfolded from the time of the German Empire until the end of the Second World War. The book will thus offer a number of fresh insights pertaining to cultural history. Included among its topics, for instance, are the representatives of the middle class who endured the catastrophe of the First World War and became increasingly active in the politics of the subsequent years. Also to be addressed is the role of certain outsiders in academia (women and Jews in particular) who had managed to secure insider positions during the Weimar Republic but soon found themselves threatened by the political pressures of the Nazi dictatorship.

Third, the book hopes to build a bridge between the history of science and industry, on the one hand, and the fields of Gender Studies and Women's Studies on the other. That its focus should be a woman scientist – and one with a broad interdisciplinary background – arose rather naturally from the fact that she was long employed as the sole mathematician at the Osram Corporation. While working there, Iris Runge was consulted as a mathematical authority by both scientists (physicists, chemists) and electrical engineers. By examining the life and work of such a researcher, insight was gained into the social and industrial conditions that

3 PORTER 2009, p. 297 (an original English quotation).

enabled a woman to achieve a prominent professional position, a position in an elite niche of industrial research that did not have to be abandoned despite the social upheavals of the time and the political opposition of the Nazi regime.

Chapter 1 presents an overview of the theoretical approaches that are adopted throughout the book. The second chapter examines why Iris Runge, a representative of the first generation of academically trained women, chose to forsake a traditional career as a schoolteacher for a position in the field of industrial research. Her roots in a large Huguenot family will be explored, as will her involvement in various extracurricular groups at an elite preparatory school, her academic training in applied mathematics and other disciplines at the Universities of Göttingen and Munich, her participation in the activities of reform-oriented secondary schools, and her engagement with certain scientific and political societies (*thought collectives*). Chapter 3 is concerned with the role of mathematics in industrial laboratories, particularly with graphical and numerical methods, statistics, and the problems that such approaches were used to solve. The structure of research laboratories and the place of mathematicians within these settings will also be discussed. Chapter 4 analyzes how social and political upheavals influenced Iris Runge's behavior and disrupted national and international cooperation among industrial researchers. Her interaction with George Sarton will also be related, as will the emergence of the history of science as a viable academic discipline. Chapter 5 summarizes the major themes of the book and casts a glance at the years after 1945. The Appendix contains a timeline of Iris Runge's life, lists of the articles and reports that she produced during her industrial career, and reproductions of other valuable source material.

The original German edition of this book was published in 2010 by the Franz Steiner publishing house in Stuttgart, and its positive reception by mathematicians, scientists, engineers, and historians of science motivated the production of the present translation.

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and with Reinhard Siegmund-Schultze (Kristiansand, Norway). A pivotal aspect of the book, namely its concern with the application of graphical and numerical methods in industrial contexts, could not have been treated in such depth without the insights that I gained at a workshop, led by Dominique Tournès and myself, which was hosted by the Mathematical Research Institute in Oberwolfach.

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Renate Tobies
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1 INTRODUCTION

New and significant findings are nearly always made when a successful bridge has been built between two or more branches of science that have hitherto been kept apart. The established methods and conclusions of one individual field will often result in unexpected applications when adopted by another, and these new applications will often, in turn, lead to the development of novel and fruitful methods of research.¹

These reflections, on the relationship between mathematics and its applications, were recorded by Iris Runge after she had worked for seven years as a researcher at the Osram Corporation. They also serve as an appropriate preamble to a conclusion of this book that should be claimed in advance: Iris Runge constructed mathematical bridges between various fields and can thus be regarded as a forerunner of the presently thriving disciplines of business and industrial mathematics.² The purpose of this introduction is to outline the methodological considerations that will inform the subsequent chapters.

1.1 THE STATE OF RESEARCH

This book represents an exploration of uncharted territory to the extent that it investigates (1) how the laboratories of the electrical industry employed mathematical methods before 1945, (2) the preconditions that were required for the application of such methods, and (3) the place of mathematicians within the organizational structures of the corporations in question.

The available sources make it possible to identify those who were engaged in mathematics at the Osram and Telefunken Corporations,³ to identify those who worked alongside them on various projects, and to evaluate the quality of the projects themselves. Laboratory reports, academic publications, collections of correspondence, and additional sources provide a window into a largely unexamined field of industrial research and also into the complex web of circumstances that defined the educational and professional development of a woman mathematician.

1 Iris RUNGE 1930a, p. 1.

2 See NEUNZERT 2003; ABELE/NEUNZERT/TOBIES 2004, ch. 4.1.

3 Osram originated as a subsidiary of three different businesses: The General Electric Power Company (*Allgemeine Elektrizitätsgesellschaft*) known as AEG, the Siemens & Halske Corporation, and the German Gas Lighting Corporation (*Deutsches Gasglühlicht A.G.*), which merged their production of light bulbs to form the new firm. The beginnings of Osram are treated in greater detail in Section 3.2 below. The Telefunken Company for Wireless Telegraphy (*Telefunken Gesellschaft für drahtlose Telegraphie*) was founded in 1903 as a subsidiary of AEG and Siemens & Halske (see THIELE 2003).

From March 1, 1923 until the end of the Second World War, Iris Runge was employed in Berlin at the incandescent light bulb and electron tube laboratories of the Osram and Telefunken Corporations. As mentioned above, this timeframe coincides with the Golden Age of the mass production of these products by internationally established companies. As of 1929, Osram's board of directors included representatives of the International General Electric Company, which held 16.6 percent of Osram's shares at the time and would purchase more in the years to come.⁴

The majority of scholarship devoted to the history of engineering in the electrical and communications industries has focused either on the physical/technical or on the economic side of things.⁵ There are also recent studies concerned with the history of broadcasting, the history of scientific instruments, the history of corporations, and with other aspects of cultural history in related fields.⁶ These studies, along with similar works on the history of engineering physics, have served as guidelines for my approach to the present book.⁷ As Dieter Hoffmann and Mark Walker have underscored, however, more work needs to be done on the physical industrial research that was conducted in Germany during the period of National Socialism.⁸

Historians of engineering have made the occasional reference to the mathematical theory underlying the engineering practices in electrical and communications engineering,⁹ and there are also studies of the mathematical foundations of systems theory, which was inspired by communications engineering,¹⁰ of the synthesis of mathematical models in the engineering sciences,¹¹ and of the relationship between mathematics and engineering in France.¹²

Detailed analyses are few and far between. There is of course the well-known case of Charles P. Steinmetz, the German-American electrical engineer who pioneered the study of alternating current circuits using mathematical methods, devised the method for solving electrical circuits using complex number notation, and who, in 1894, was appointed director of the mathematics division at General

4 See LUXBACHER 2003, pp. 314–16.

5 See CLAYTON/ALGAR 1989; OKAMURA 1994; VYSE/JESSOP 2000; LUXBACHER 2003.

6 WOOD 1994, 2000; JOERGES/SHINN 2001; THIELE 2003; DE VRIES 2006; MÜLLER 2009; SCHARSCHMIDT 2009–2010; DENNHARDT 2009; LEBETH 2011.

7 See the *Encyclopedia of 20th-Century Technology*; HEMPSTEAD/WORTHINGTON 2005; GÖÖCK 1988. On the development of engineering physics into an independent discipline in Germany, and on the use of the term “technical physics” (*technische Physik*) to denote it, see HOFFMANN/SWINNE 1994. For a detailed study on the role of physicists in Swedish industry and early studies regarding the nature of techno-science, see KAISERFELD 1996. For a study of American magnetron research during this same timeframe, see STEPHAN 2001. On the British development of cavity magnetrons, see BURCHAM/SHEARMAN 1990.

8 HOFFMANN/WALKER 2007.

9 See Alfred Kirpal's article on electrical engineering in BUCHHEIM/SONNEMANN 1990.

10 WUNSCH 1985; KÁLMÁN 1991.

11 See LUCERTINI et al. 2003.

12 See DURAND-RICHARD 2006a, 2006b.

Electric in Schenectady, New York.¹³ Noteworthy, too, is the mathematician Edith Clarke, who enjoyed a long career at General Electric and invented, among other things, the Clarke calculator, a graphical device that solved equations involving the electrical current, voltage, and impedance in power transmission lines. The device could solve linear equations involving hyperbolic functions nearly ten times faster than other known methods.¹⁴ In general, a good deal is also known about the research that was undertaken at the Bell Telephone Laboratories in New Jersey,¹⁵ and especially about the reception of Heaviside's operational methods for solving differential equations in transmission-line problems of telegraphy and telephony.¹⁶

In his profiles of the mathematicians who worked at American companies, Thornton C. Fry, who founded the Mathematical Research Department at the Bell Labs in 1928, indicated that the majority of the firms that were active in industrial research employed only a single mathematical consultant.¹⁷ Studies of this sort have been lacking in Germany. Articles about the careers of individual mathematicians, of course, have contributed somewhat to our understanding of the matter,¹⁸ and contemporary lab reports concerned with electron tubes provide insights into the mathematical and theoretical approaches of their authors.¹⁹

Moritz Epple has analyzed the measurement and computation technologies at the Kaiser Wilhelm Institute for Fluid Dynamics in Göttingen (*Kaiser-Wilhelm-Institut für Strömungsforschung*), which was founded in 1925.²⁰ His results made it possible to compare and contrast the research practices of (mainly) state funded institutes, on the one hand, and those of private industry on the other.

Among older publications of a similar sort, the biographical book *Pioniere der Wissenschaft bei Siemens* [Pioneers of Science at Siemens] discloses the near absence of women in the German electrical industry.²¹ My own research has since brought to light a number of women researchers – in addition to Iris Runge – whose biographies have been included in the latest edition of the *Lexikon der Elektrotechnik* [Lexicon of Electrical Engineering].²²

13 See KLINE 1992.

14 See BRITAIN 1985a.

15 See FAGEN 1978; MILLMAN 1984. For a comparative study of the development of applied mathematics in Germany and the USA, see SIEGMUND-SCHULTZE 2003b.

16 See PUCHTA 1997, Felix KLEIN 1927, pp. 47, 60.

17 See FRY 1941, 1964.

18 See the survey in PICHLER 2006.

19 See the internationally distributed quarterly *Physik in regelmäßigen Berichten*; RUKOP/SCHOTTKY/SUHRMANN 1935; RUKOP 1936, 1941; as well as the FIAT Reviews of German Science during the Second World War, which were prepared by German scientists by order of the English, French, and American occupying powers; COLLATZ 1948; GEPPERT 1948; GUNDLACH 1948; GOUBAU/ZENNECK 1948; KRON 1948; LOREY 1948; RUKOP 1948; SCHULZ 1948; WALTHER/DREYER 1948; WALTHER/KRON 1948; WALTHER/UNGER 1948.

20 See EPPLE 2002a, 2002b.

21 FELDTKELLER/GOETZELER 1994.

22 JÄGER/HEILBRONNER 2010; TOBIES 2008a.

1.2 GUIDING QUESTIONS

My research was motivated by the following three sets of questions:

First: What were the circumstances that encouraged a woman with an academic background in science and mathematics to take a position in industry at a time when it was rare for even male mathematicians and physicists to choose such a career?

Second: How was applied mathematics understood in different historical contexts? How did it happen that the mathematical approach to solving physical, technical, and economic problems came to be used in industrial research? In this regard there is also the question of the place of mathematics and mathematicians in the industrial research laboratory itself.

Third: Assuming that this area of research was susceptible to external influences, how did the political events of the time affect the security of mathematics and mathematicians within departments of industrial research? What role did the world view of mathematicians play in these developments?

1.2.1 The Conditions Leading to Iris Runge's Career

The first set of questions – concerned, again, with the conditions leading to a career in industrial research – requires an examination of both internal (personal) and external (environmental) factors. In this regard it should be stressed that the career paths of Germany's first generation of academically trained women have already been researched at some length.²³ Basing our work on models developed by social psychology, my colleagues and I have written comparative profiles of a great number of women who earned advanced degrees in mathematics during the first half of the twentieth century.²⁴

Because such a background has already been established, it is possible here to focus on the following questions: To what extent do the general features of Iris Runge's biography agree with those of other women who elected to study mathematics at that time? What are the distinguishing characteristics of her upbringing and education? How are the conditions to be understood that, in the end, compelled her to deviate from the accepted standards of the time, according to which a woman of her education was expected to teach mathematics and science at a secondary school?²⁵

With respect to her family background, religious denomination, primary and secondary education, university coursework, and academic ambitions, the sources reveal that Iris Runge hardly differed from other women who attended university.

23 See TOBIES 2008a.

24 See ABELE/NEUNZERT/TOBIES/KRÜSKEN 2002; ABELE/NEUNZERT/TOBIES 2004.

25 As late as 1930, nearly ninety percent of those holding degrees in mathematics worked as educators at the secondary school level (see BÖTTCHER et al. 1994).

Like the majority of the latter, she came from a household in which the father was an academic. For a woman to study in the first half of the twentieth century, it was crucial to have liberal parents with both the desire and means to support their daughter's university education. Whereas forty-five percent of the women who completed degrees in mathematics and science had academically trained fathers, this is true of only twenty-seven percent of the men who did the same.

Iris Runge belonged to the Protestant Reformed Church (*Evangelisch-Reformierte Kirche*), one of the larger Christian denominations with roots in Central Europe.²⁶ In the early decades of the twentieth century, the majority of German women who passed university examinations in mathematics belonged to the Protestant (Lutheran) religion. This can be accounted for, on the one hand, by the fact that Protestants constituted a correspondingly large part of the German population; on the other hand, however, there is also the fact that opposition to the idea of women attending universities persisted longer and was more strident in the case of the Catholic Church leaders. By later renouncing the Church in 1929 and remaining nondenominational, Iris Runge placed herself outside of this statistical norm.

At the heart of this book lies the pioneering generation of women who still had to earn the so-called *Abitur* – the prerequisite diploma for university admission in Germany – by exceptional means. They attended special courses designed for young women (in mathematics, the sciences, Latin, etc.),²⁷ and they had to take their *Abitur* examinations externally, that is, at a secondary school for boys. Little has been written until now about the instructional content of these courses, about how they influenced those who were enrolled, and about the process of external examination. Fortunately, the sources that I investigated have yielded a good deal of information about such things, as well as about the goals, expectations, and opinions of the young women in question. Thus, in addition to clarifying Iris Runge's activity at this stage of her life, I have also been able to make a more general contribution to the history of education.

It was not until the enactment of a decree – on August 18, 1908 – that public girls' schools were established in Prussia that could qualify their pupils for university admission. Along with this reform, mathematics and the natural sciences became, for the first time, a rigorous component of the curriculum at secondary schools for girls.²⁸

26 The Protestant Church is the predominant denomination in Scotland and the Netherlands. In Switzerland it falls just short of the Catholic majority. Protestant minorities have existed, from the time of the Reformation, in France (the Huguenots), Poland, Hungary, Romania, and Lithuania. Iris Runge's family has roots in the Huguenot tradition, a significant fact that will be discussed below in Section 2.1.

27 For an overview of scholarship on the history of education in Germany, see ALBISETTI 1988; KLEINAU/OPITZ 1996; HUERKAMP 1997; KRAUL/MAROTZKI 2002.

28 On the reform of girls' schools and its effects on the mathematics curriculum, see SCHRÖDER 1913. In 1910, Bavaria was the next state to institute such reforms (see TOBIES 2008a; ALBISETTI 1988).

Over the course of this book, mention will be made of numerous German universities and technical universities (*Technische Hochschulen*).²⁹ It therefore seems appropriate to provide a brief explanation of this institutional system and of the access that women had to it.³⁰ Because of their constitutional independence in dealing with cultural affairs, each of the German federal states enacted its own laws concerning the educational system.

Table 1: The Right of Women to Participate in German Higher Education:
A Legislative Timeline³¹

Year	Federal State	University	Technical University (<i>Hochschule</i>)
1900/1907	Baden	Heidelberg, Freiburg	Karlsruhe
1903/1905	Bavaria	Munich, Erlangen, Würzburg	Munich
1904/1907	Württemberg	Tübingen	Stuttgart
1906/1907	Saxony	Leipzig	Dresden, Freiberg
1907	Thuringia	Jena	
1908	Hesse	Giessen, Frankfurt/Main [founded in 1914]	Darmstadt
1908/1909	Prussia	Berlin, Bonn, Breslau, Cologne [founded in 1919], Göttingen, Greifswald, Halle, Kiel, Königsberg, Marburg, Münster, Strassburg [until 1918]	Aachen, Berlin, Breslau, Danzig, Hanover, Clausthal
1909	Mecklenburg	Rostock	Braunschweig

German universities were relatively late in allowing women to enroll, even though, in the nineteenth century, a few women were granted special status to do so.³² As of the 1890s, German women (in large part educated schoolteachers) were also able to sit in on university classes as auditors, but not without asking each profes-

29 Technical universities (*Technische Hochschulen*) are institutions of higher learning that emphasize engineering. They consisted of various departments of engineering and a department of general studies, the latter including mathematics and the sciences. German universities did not have departments of engineering at that time. Technical universities were not subordinate to universities. In Prussia, technical universities were permitted to grant doctoral degrees in engineering as early as 1899; it was not until 1919 that a doctoral degree in mathematics or sciences could be earned at a Prussian technical university, though this had already been possible in Bavaria (as of 1903) and in Saxony (as of 1912).

30 For a more detailed explanation, see TOBIES 2008a.

31 There were special decrees allowing women to enroll in technical universities (the second year in the table). In Freiberg and Clausthal, the technical universities are so-called mining academies (*Bergakademien*). Königsberg, which belonged to East Prussia until 1945, is today a city in Russia. Breslau and Danzig, then also Prussian cities, are now part of Poland (Wrocław, Gdańsk); and Strassburg (Strasbourg) has been a French city since 1918.

32 See SINGER 2003; COSTAS 2002.

sor for his permission. There were many opponents of the women's right to higher education who firmly rejected their participation. For our purposes it is noteworthy that the great majority of German mathematicians supported the measure. In the end, the German federal states enacted a series of decrees that allowed women to study as equals before the law.

In the early decades of the twentieth century, German universities did not yet offer formal degrees in mathematics or physics. Therefore most of the students who pursued these subjects – both men and women – opted to take a secondary teaching examination. Even Max Planck, the great physicist, and the mathematician Carl Runge were licensed as schoolteachers, for it could never be assumed that a career in science was guaranteed. Iris Runge began her studies at the University of Göttingen in Prussia; she enrolled as an auditor and declared her intentions of becoming a schoolteacher (*Oberlehrerin*). In 1894, Prussia authorized a so-called Women Teachers Act that enabled women to qualify, after a special course of study, to teach upper level classes at secondary schools for girls. It was customary to become certified in three subjects. Regardless of gender, the most popular combination of subjects was mathematics, physics, and chemistry; Iris Runge's combination of mathematics, physics, and geography was the second most common.

After working for some time as a teacher, Iris Runge returned to university in order to study chemistry. This course of study would leave her qualified to teach this subject at secondary schools and, what is more, would result in her acquisition of a doctoral degree. In the early decades of last century, approximately twenty percent of those who passed their secondary teaching examinations went on to earn a doctoral degree (in mathematics, physics, chemistry, and other fields), and this percentage applies to men and women alike. In terms of gender, a small difference emerges when the precise fields of study are taken into account: Women were far less likely than men to write a dissertation on applied mathematics.³³ Iris Runge numbered among the few women to receive graduate level training in this field.

The truly distinguishing features of Iris Runge's education derive from the fact that, from an early age, she was involved in various groups that promoted mathematics and its practical application. It is useful to think about these groups as *thought collectives*, a concept formulated by Ludwik Fleck. In 1935, Fleck – a Polish microbiologist, medical doctor, and scientific theorist – analyzed the origins and structures of scholarly communities. In doing so, he developed the notion of thought collectives (*Denkkollektive*). The concept is relevant to the philosophy and sociology of science in that it helps to explain how scientific ideas evolve over time, much like Thomas Kuhn's paradigm shift or Foucault's episteme.³⁴ Refer-

33 See ABELE/NEUNZERT/TOBIES 2004.

34 See FLECK 1935/1979; COHEN/SCHNELLE 1986; KUHN 1962/1970; FOUCAULT 1966/1973 [in English: Michel Foucault, *The Order of Things: An Archaeology of the Human Sciences* (New York: Vintage Books, 1971)].

ring to the governing ideas of a given thought collective, Fleck coined the term *Denkstil*, or “style of thinking.” He argued that styles of thinking are collective phenomena resulting from the socialization of closed communities, and he distinguished between *intra*-collective and *inter*-collective types of communication, the latter of which allows for outside influences to alter the thinking style of a particular group.

With respect to the formation of groups, Fleck analyzed the social effects of commonly held opinions, and he also discussed the special role that intellectual and professional acceptance can have in the life of young researchers. Even something as simple as belonging to a close family can be enough to encourage self-confident behavior; in general, the group norms to which one is exposed during childhood and adolescence can yield the defining and enduring characteristics of one’s later life. Practical and theoretical experience in one field, alongside a willingness to experiment in others, can be all that is required to become a member of a given thought collective. In this way, members of one intellectual circle can simultaneously belong to others (scientific, political, cultural) and are thus capable of transplanting divergent opinions from one circle to the next.

Iris Runge not only profited from the group norm, entrenched among her intimate circle of schoolmates, of pursuing a doctoral degree at all costs; she was also a member of an international extended family that was known for its excellent command of English and for its tradition of independent thinking. Exposed early on to her father’s thought collective, which stressed the application of graphical and numerical methods, she learned as a university student how to integrate these methods with the distinct thought collectives of theoretical physics and physical chemistry. Her interest in bringing her knowledge of applied mathematics to the new and interdisciplinary field of industrial research led to a new style of thinking that was encapsulated by the laboratory motto, mentioned above, that was coined under her influence: “Calculation instead of trial and error,” to repeat.

My analysis of various thought collectives entailed the investigation of the many individuals involved. This prosopographical method has allowed me to ascertain professional positions and organizational structures that had hitherto been obscure,³⁵ and by clarifying these things – especially with respect to women researchers – I have endeavored to contribute to the sociological discourse known as *intersectionality*. At the heart of this multifaceted approach to Gender Studies lies an analysis of career paths that, beyond gender, takes into account additional cate-

35 A a method, prosopography has become increasingly prominent among historians of science, as was made especially clear at a 2009 colloquium – “Définir, classer, compter: L’approche prosopographique en histoire des sciences et des technique” – that was held at the Laboratoire d’Histoire des Sciences et de Philosophie at the Nancy-Université. For an early prosopographical study of American mathematics, physics, and chemistry communities, see KEVLES 1979; for a prosopography of 137 American research-technologists, see Terry Shinn’s article in JOERGES/SHINN 2001; for a study of the first American women to earn PhDs in mathematics, see GREEN/LADUKE 2009; and for more on the use of this approach in the present book, and the results that it yielded, see Section 1.3.

gories of discrimination such as race and class. Although discussions of this sort have been typical of Anglophone scholarship for some time, German and French researchers have likewise begun to focus more intensely on the significance of intellectual circles (thought collectives) and larger social structures to the history of science. Much of this book was written with this trend in mind.

1.2.2 Defining Terms: Mathematics and its Applications

The second set of questions, introduced above, concerns the clarification of certain concepts. How was industrial mathematics understood during the historical timeframe under investigation? Was there, and is there still, a general procedure for finding mathematical solutions to the problems of business and engineering? What is the best way to comprehend the role of mathematics and the place of mathematicians in industrial research laboratories?

Before addressing these questions, it is first necessary to ask what is meant by *mathematics* in general. Illustrious scholars have debated this matter until they were blue in the face, and yet no consensus has been reached about whether mathematics is a natural science, a branch of the humanities, or an art form.

An especially useful definition, it seems to me, is one that regards “mathematics as the science of fundamental and potential structures or ‘patterns of order’ (*Ordnungsmuster*).”³⁶ Everything that has been devised thus far to provide us with a structured understanding of the space around us can be designated a structural element or order pattern, from the earliest conceived numerals and geometric forms to mathematical functions, algebraic structures, differential equations, numerical solution algorithms, and on to those things that mathematics has yet to discover.

Mathematicians have always been entangled in the concrete and historically determined relationship between mathematics and its practical applications. The nature of this relationship has fluctuated over time, and in this regard it is possible to identify, according to historical trends, a number of distinct eras of varying length.³⁷ If we were to survey everything from the beginning, from the formulation of the earliest mathematical constructs, we would be able to detect two types of alternating phases, one in which new mathematical discoveries were influenced primarily by practical exigencies, and another in which the development of mathematics was largely philosophical and unconcerned with solving practical problems. In the twentieth century, with its increased number of mathematicians, mathemati-

36 NEUNZERT/ROSENBERGER 1991, p. 130. For more on the definition of mathematics as the science of potential structures or “order patterns,” that is, as the science of the fundamental structures (standards of comparison) that mankind has surmised by way of abstract thinking or speculation to make sense and make use of the world, wholly or in part, see all of pages 122–142 in Neunzert and Rosenberger’s book.

37 Here I am following H.-J. RHEINBERGER 2006, pp. 171–172, which offers an analogous representation of the history of microbiology; see also RHEINBERGER 2010.

cal labor has been divided in such a way that these once distinct historical trends have come to exist side by side.

In the nineteenth century, much discussion was devoted to the following pronouncement by Immanuel Kant: “I assert, however, that in any special doctrine of nature there can be only as much *proper* science as there is *mathematics* therein.”³⁸ From around the middle of the nineteenth century, it can be said that, apart from applications in the physical sciences, most mathematicians cared little, if at all, about the applicability of their expertise to other fields. It was not until the 1890s that some contact was renewed between mathematics and engineering, for example. In order to refine the standards of business and industry and to improve upon certain developments in the natural sciences, the mathematician Felix Klein, who was influenced by his experiences in America, began to promote the study of applied mathematics at Göttingen.³⁹ This was at a time in which mathematics became a constitutive element of the newly formed technical sciences (electrical engineering, mechanical engineering, etc.). It was in this context that mathematicians first began to discuss, in concrete terms, what was meant by “applied mathematics.” Thus they ushered in a relatively long period during which the concept of applied mathematics was well defined. When, in 1907, supporters of applied mathematics gathered at the University of Göttingen, they issued the following formulation: “The essence of applied mathematics lies in the development of methods that will lead to the numerical and graphical solution of mathematical problems.”⁴⁰

This definition concentrated only on the means and methods of solving mathematically delineated problems. How to reduce a given problem to its essential aspects and to describe (or model) it mathematically was not an explicitly stated goal of the curriculum, even though this was common practice in the research seminars (see Section 2.4.2).⁴¹ Initiated by Klein and cultivated by Carl Runge, the new university course in applied mathematics focused on teaching the methods and procedures of numerical and graphical calculation, on applying these methods in other fields, and on making use of tools such as mechanical calculators, slide rules, and logarithm tables. Trained primarily at Göttingen, the students of Carl Runge and others went on to find positions not only at technical universities but in industry as well.

From here we come to a much shorter period that, though it emerged organically from the preceding developments, can be seen as constituting a historical moment of its own. As already mentioned, this period corresponds with the so-

38 KANT 1787, p. ix [in English: Immanuel Kant, *Metaphysical Foundations of Natural Science*, ed. Michael Friedman (Cambridge: Cambridge University Press, 2004), p. 6]; see also MARTIN 1974.

39 This is discussed below in greater detail in Section 2.3.

40 See Appendix 1: Statements on Applied Mathematics.

41 The teaching of modeling did not become a central component of the German mathematical curriculum until modeling seminars, introduced in the early 1980s, were offered to students of “techno-mathematics” (see NEUNZERT 2003a, 2003b).

called Golden Age of the mass production of incandescent light bulbs and electron tubes. It will be shown how, during this time and in this particular realm of industrial research, a general procedure for solving mathematical problems was developed and employed internationally. John R. Carson, a member of the Mathematical Research Department at the Bell Telephone Laboratories, provided an accurate description of the procedure as early as 1936:

The art consists in seeing how to go at a problem; in knowing what simplifications and approximations are permissible while leaving the essential problem intact, in precise formulation in mathematical terms, and finally, in reducing the solution to a form immediately interpretable in physical and engineering terms.⁴²

The art of mathematical modeling – the mathematical description and solution of a problem reduced to essential components – requires that its practitioners command knowledge not only of relevant mathematical concepts, methods, theories, and algorithms, but also of engineering and technological processes, of physical procedures, and of existing theoretical models. Without such prerequisite knowledge, they would be unable to evaluate essential data and relevant measurements, and they would thus be unable to identify an applicable mathematical theory for solving the problem before them. At a time when computers did not yet exist, other calculating instruments were called for and invented, including graphical methods, mathematical tables, and various mechanical devices. Even today, however, the fundamental approach to industrial mathematics involves the same tasks:

- Reducing the problem to its essential components.
- Describing the problem with mathematical equations and models.
- Using or determining algorithms to solve these equations.⁴³
- Visualizing and explaining the results of their implementation.

Mathematical models can be based on the (physical, technical, etc.) theories informing the problems to be solved,⁴⁴ and they can also contribute to the further

42 CARSON 1936, p. 398 (this is an original English quotation). On Carson and his part in the popularization of Heaviside's operational methods, see PUCHTA 1997. On the context of Carson's activity, see Stuart Bennet, "Technological Concepts and Mathematical Models in the Evolution of Control Engineering," in LUCERTINI et al. 2004, pp. 103–128, esp. 114–115; and WUNSCH 1985, pp. 58–59.

43 Applied mathematics is typically concerned with differential equations and other areas of mathematics in which exact solutions are seldom available. Approximate solutions, the result of so-called approximation theory, are thus determined, and therefore algorithms must be developed. For a current problem of this sort, consider the multiscale problem and the associated discovery of wavelets and (continuous or discrete) wavelet transforms. In this context, the term "wavelet" is a loan translation of French *ondelette* (see MOHLENKAMP/PEREYRA 2008; NEUNZERT/SIDDIQI 2000).

44 For a discussion of the various steps in the formulation of (physical) theories – namely data analysis, the classification of phenomena, the near-empirical development of models, their incorporation, and the modification of present theories – see HENTSCHEL 1998.

development of these theories. According to Helmut Neunzert and Bernd Rosenberger:

Physicists, biologists, economists, and engineers apply mathematics to their areas of interest in order to structure them and make them surveyable and communicable; as it must often seem to them, mathematics is the “meta-language” of their theories.⁴⁵

As is still true today, there were theories at that time for which “complete” models had been formulated, but there were also many theories for which models still needed to be developed. It was usually the case that several models were developed for any given problem. The trick is to find a model that captures the essential elements of a problem and can be quickly analyzed with either numerical or graphical methods. Of course, in order to formulate a mathematical model, mathematical structures are needed, and if none exists to suit the problems at hand, then new paradigms need to be developed or discovered.

In mathematical work of this sort, the “epistemic” (the applicable mathematical methods and theories) and the “technical” (the practical problem) are tightly intertwined.⁴⁶ Techno-mathematics and business mathematics are recognized as sciences precisely because the solution of technological and economic problems is part of their epistemological structure. Today, of course, the scope of problems that can be solved, on account of computers and the latest mathematics, is considerably broader than it was during Iris Runge’s career.

In order to evaluate the place of mathematics in industrial laboratories, it also has to be asked how mathematics was formally practiced and whether it was used as anything more than a mere auxiliary science.⁴⁷ Since I am intruding to some extent on a discourse led primarily by engineers and historians of engineering, I should stress that the focus of my investigations concerns the role of mathematics in the reformulation of organizational structures. Karin Knorr Cetina has criticized how, in certain contexts, knowledge is often regarded as a finished product and not as a process.⁴⁸ She refers to the persuasive work of Daniel Bell, who has argued that the transition to a “knowledge society” was based on a new economic dynamic in which theoretical knowledge had become a productive force.⁴⁹ This pronouncement, though hardly new, suitably characterizes the increasing application of mathematics in engineering and physical research and the increasingly prominent position of mathematicians, after 1920, within the corporate structures of the electrical industry.

It was in the 1920s that the mathematical approach to solving problems became a general practice throughout the many branches of industrial research. Just

45 NEUNZERT/ROSENBERGER 1991, p. 130.

46 See RHEINBERGER 2006, pp. 50–51.

47 On the debate over mathematics as an auxiliary science in industrial contexts, especially in the United States, see FERGUSON 1992; SEISING 2005.

48 KNORR CETINA 2002, p. 17. On science as a social process, see also RHEINBERGER 2006, pp. 47–49.

49 On the role of science in the organization of society, see BELL 1973.

before the First World War, electrical companies began to expand their research institutes from one-man laboratories to multi-divisional laboratories that were concerned not only with immediate problems but also with anticipating and solving the long-term scientific and technological problems of the future.⁵⁰ Once it was realized, shortly after the war, that science could be a powerful factor in its own right,⁵¹ and as soon as companies began to introduce comprehensive productivity standards, it was not long before corporate managers became increasingly open to the idea of employing mathematical methods. Despite the opposition of senior engineers at longstanding firms such as Telefunken,⁵² a laboratory procedure was nevertheless implemented that replaced the use of trial and error in large-scale experiments with a method involving data analysis, mathematical calculation, and sample measurements.

Mathematicians engaged in industrial research were typically stationed in experimental laboratories. On the basis of evidence gathered about the laboratories of the Osram and Telefunken Corporations, I have attempted to determine the specific role of mathematics within the *experimental culture* of these institutions and also the way in which this culture operated in general (I have borrowed the term “experimental culture” from the work of Hans-Jörg Rheinberger). In industrial research, individual laboratories are the smallest units committed to experimental and theoretical work. As such, these singular spaces for the production of scientific knowledge will be designated “experimental systems.” What I mean by “experimental culture,” to be more precise, is a complex of diverse laboratories that cooperate with one another.⁵³

Within this particular experimental culture, the capacity of research directors to communicate with one another was essential; without this ability, that is, they would have been incapable of properly evaluating and appointing the scientists who were working beneath them. Laboratories could be restructured – and researchers transferred – on account of the development of new products, of course, but also on account of new political circumstances. It will be shown whether the role of mathematics and mathematicians was affected by such factors. Moreover, by concentrating on the organizational structures of specific research institutions – on decision makers, assignments, research programs, and on the collaborations between various scientists and laboratories – I hope to demonstrate how closely connected mathematical and experimental activity were during this early stage of industrial mathematics, how problems were calculated and forecast, how the results of such calculations were experimentally tested, and how theoretical models

50 See SCHULTRICH 1985.

51 See ZIEROLD 1968; SCHULZE 1995; and FLACHOWSKY 2008 on the marriage of convenience that came to exist between private industry and the Emergency Foundation for German Science (*Notgemeinschaft der Deutschen Wissenschaft*), later called the German Research Foundation (*Deutsche Forschungsgemeinschaft*).

52 See Wilhelm Runge, “Ich und Telefunken. Erinnerungen aus 40 Jahren” (unpublished typescript, 107 pages), pp. 3–5 (in [DTMB] 4413). See also Section 3.1 below.

53 See RHEINBERGER 1997, 2007.

were refined and advanced. The mathematical configuration of problems, the numerical calculation of equations, the design and application of graphical and other mathematical tables – all of this took place in close concert with the manufacturing and inspection of industrial products.⁵⁴

Although fundamental mathematical theories already existed for quality control, electrodynamics, and especially for the production of electron tubes and circuitry, the relevance of mathematical research was still not firmly established at the beginning of the 1920s. The following remark by Hans Georg Möller, the author of a textbook entitled *Elektronenröhren und ihre technischen Anwendungen* [Electron Tubes and their Technological Applications], was hardly atypical:

The method of calculating with complex amplitudes is not familiar to everyone. [...] The reader is not eager to make mathematical calculations. He prefers to have the result of a calculation in advance and its physical repercussions made clear. Furthermore, it is often more difficult for the reader to identify the correct mathematical approach to a problem than it is for him to make the calculations themselves.⁵⁵

Nevertheless, the most important mathematical principles had indeed found their way into the majority of textbooks:

The solution of alternating current problems with complex amplitudes and their graphical representation in vector diagrams is extraordinarily simple and is therefore incorporated into most textbooks on alternating and low current engineering, wireless telegraphy, and optics.⁵⁶

It would be some time, however, before calculations were considered more trustworthy than experiments. Thus Heinrich Barkhausen, for instance, who was a prominent figure in electron tube research,⁵⁷ could say that he “regarded a concrete idea to be more valuable than a mathematical deduction.”⁵⁸ This comment

54 Historians of science have analyzed such processes in various ways; for our purposes, parallels can be drawn with Ursula Klein’s concept of “paper tools,” which she developed as an explanatory model for understanding the symbolism employed by nineteenth-century chemists (see KLEIN 2003).

55 MÖLLER 1929, p. iv. I have quoted from the third edition of this textbook; the first edition appeared in 1920.

56 MÖLLER 1929, p. 1.

57 Having studied under H. T. Simon, Barkhausen defended his dissertation in 1906 – “Das Problem der Schwingungserzeugung mit besonderer Berücksichtigung schneller elektrischer Schwingungen” [The Problem of Oscillation Generation, with Special Consideration Given to Rapid Electrical Oscillations] – at the University of Göttingen. He accepted an offer to work at the Siemens Corporation in Berlin, and in 1910 he completed his *Habilitation* at the technical university in that city. In 1911, he became an associate professor of electrical metrology, telegraphy, telephony, and the theory of electrical conduction at the Technical University in Dresden, where he created Germany’s first institute for weak-current engineering. He published an influential series of textbooks on electron tubes, the later editions of which contained detailed mathematical equations. The Barkhausen equation, named after him, governs the most important parameters of an electron tube (see Section 3.4.5.2).

58 BARKHAUSEN 1920, p. 82.

was directed against Walter Schottky,⁵⁹ who was the first to derive, on purely mathematical grounds, the parameters for a high-vacuum amplifier tube. Barkhausen, it is clear, endorsed a methodological approach opposed to the aforementioned slogan – “calculation instead of trial and error” – that was gradually beginning to take hold in the industrial laboratories of the time.⁶⁰

It was a novel turn of events when calculation began to hold sway over experimentation in the laboratory setting, and below I will explore how mathematicians fit into this specific experimental culture and what sort of reputation they came to enjoy. The research processes of these mathematicians will also be brought to light. This was made possible by evaluating and contextualizing their individual accomplishments and by examining their tendency to perceive a problem in a certain way (with a mathematical eye) and to approach it thoughtfully and appropriately (mathematically) – to approach it, in Ludwik Fleck’s terms, with their own style of thinking.

Once they have been demonstrated and explained, the organizational structures and operational methods of companies in the electrical industry will briefly be compared with those of research laboratories in other fields, including aeronautics, both in Germany and abroad.

1.2.3 Social and Political Factors

The third set of questions is concerned with political, scientific, and social contexts; it has resulted in an analysis of Iris Runge’s life – and the lives of those who belonged to the various groups in which she participated – in relation to the political instability of the German Empire, the Weimar Republic, the Nazi dictatorship, and post-war Germany. The focus will rest on representative members of a generation whose political awareness and activity were heightened by the events of the First World War. In this respect I have relied on the scholarship that seeks to distinguish one generation from another,⁶¹ and this has helped me to evaluate people and their intellectual orientations in a way that is sensitive to their shared historical experience. In this way, I have been able to draw connections between levels of society that are typically studied in isolation – namely political authority, social structure, and personal biography – and also between distinct scientific disciplines. The overarching goal has been to contribute to the burgeoning fields of transdisciplinary and interdisciplinary research.⁶²

59 On Walter Schottky, son of the mathematics professor Friedrich Schottky, see SERCHINGER 2008. On Schottky’s discovery of new mathematical paradigms while describing the noise produced by electron tubes, see DÖRFEL/HOFFMANN 2005, pp. 2–5, 16.

60 This was Barkhausen’s attitude despite his participation in the first electrical engineering seminar, in the summer semester of 1905, that was led by Felix Klein and some of his younger colleagues (see Section 2.4).

61 See REULECKE/MÜLLER-LUCKNER 2003.

62 On the terms “interdisciplinary” and “transdisciplinary,” see Section 3.4.

Peter Gay's thesis holds true in the context at hand, namely that, during the transition between the German Empire and the Weimar Republic, former *outsiders* were able to become cultural, academic, and political *insiders*.⁶³ Around 1907, Iris Runge and other Göttingen intellectuals – including the mathematician Richard Courant and the physicist Max Born, the latter of whom would go on to win a Nobel Prize⁶⁴ – began to associate with the philosopher Leonard Nelson, who figured as an outsider during the German Empire on account of his scientific, political, and pedagogical views (see Section 2.6.1). Influenced by the experience of the First World War, they became politically engaged in the years that followed. Like numerous other intellectuals of the time, they joined political parties and campaigned during elections. In Germany, women received the right to vote in 1919. I will discuss the political engagement of young Göttingen intellectuals, especially on behalf of the Social Democratic Party, in the context of the positions that they attained during the Weimar years, namely as professors (Nelson, Courant) and, in the case of Iris Runge, as an industrial researcher. Iris Runge's professional transition from the classroom of a girls' school to the industrial laboratory, which took place in the early years of the Weimar Republic, can be interpreted as a manifestation of the newfound possibility, as far as women were concerned, of moving from the periphery to the center.

The industrial laboratory turned out to be a place in which Iris Runge's awareness of social problems was further sharpened. At the Osram Corporation, for instance, there were both liberal and progressive (*linksliberal*) factions. Her membership in the Social Democratic Party led not only to her involvement in the Workers' Samaritan Federation (*Arbeiter-Samariter-Bund*) and the Children's Friends Association; through her contact with Hendrik de Man, a Belgian Social Democrat, she also found herself enmeshed in international politics. Just as Iris Runge, both as a woman and as a researcher, warmly welcomed the new opportunities afforded to her by the Weimar Republic, her numerous friends and colleagues (many of whom were Jewish) were no less enthusiastic about the era.

My analysis of the activity at industrial laboratories can be seen as participating in discussions pertaining to the role of *creative niches*. On the one hand, such discussions have revolved around women researchers who, on account of existing laws, were degraded as outsiders by universities, and who consequently sought opportunities as industrial researchers. Though this often came with the price of having to participate in military research,⁶⁵ studies have shown that women at this time were nevertheless able to achieve secure and rewarding positions in life that would have been unthinkable a few years earlier.

On the other hand, discussions have focused on the creative niches that were occupied by preeminent Jewish inventors and industrial researchers who were

63 See GAY 2003.

64 On the life and work of Richard Courant and Max Born, see REID 1976 and BORN 2002, respectively.

65 See, for instance, VOGT 2000.

allowed to enjoy academic careers as early as the German Empire and who often found positions in industrial laboratories or, in some cases, founded companies of their own.⁶⁶ Science historians have brought to light a number of previously obscure electrical engineers, physicists, chemists, and mathematicians who, during the Nazi era, maintained their jobs in private industry long after others were forced to leave government positions.⁶⁷ My findings concerning the personnel of the Osram and Telefunken Corporations can thus be regarded as a contribution to *exile studies*. Until now, research on the effects of National Socialism on mathematics and the natural sciences has concentrated, in large measure, on the employees of public and not private institutions.⁶⁸

By exploring the extent to which researchers working on a key technology (electron tubes, a fundamental component of communications engineering) were mired in the political system of their time, I have also positioned this book within the ongoing and relevant discourse that was initiated Jeffrey Herf's classic study, *Reactionary Modernism: Technology, Culture, and Politics in Weimar and the Third Reich* (1984).⁶⁹ How do we judge a woman researcher whose work contributed to the production of technologies that were used by both civilians and, later on, by the military? Does this judgment change depending on the political eras in question? In general, I would like to underscore the Janus-faced nature of "Classical Modern Science," which can be creative and emancipatory (in creating new disciplines such as industrial mathematics), but can also produce new results – "epistemic objects" and "epistemic methods" – that are at risk of being (mis)used in the name of war.⁷⁰ In the case of Iris Runge, the sources are clear regarding her opposition to the Nazi regime. That said, she also regarded her work in mathematics – the very thing that might benefit the regime she opposed – as the "only thing keeping me alive" at a time when so much of human life was under threat.

Whereas my investigations into the nature and environment of Iris Runge's work required knowledge of industrial mathematics, my efforts to reveal something about the person behind the researcher have been informed by the field of

66 See, for instance, Shaul Katzir, *From Academic Physics to Invention and Industry: The Course of Hermann Aron's (1845-1913) Career* (Berlin: Max-Planck-Institut für Wissenschaftsgeschichte, 2009).

67 See TOBIES 2006; RAMMER 2002; HENTSCHEL 2005.

68 See especially DEICHMANN 2001; MEHRTENS 1994; RENNEBERG/WALKER 1994; HENTSCHEL 1996; MEINEL/VOSWINCKEL 1994; SIEGMUND-SCHULTZE 2009; BERGMANN/EPPLE 2009; WOBBE 2003.

69 See also the issue of the journal *History and Technology* 26.1 (2010), the whole of which is devoted to the subject of technology and politics.

70 On the technological requirements of war and how they have influenced mathematical research, see MEHRTENS 1996; DAHAN-DALMEDICO 1996; REMMERT 1999; EPPLE/REMMERT 2000; EPPLE 2002a, 2002b; BOOB-BAVNBEEK/HØYRUP 2003; SIEGMUND-SCHULTZE 2003a.

Gender Studies.⁷¹ For a long time, Iris Runge has been known almost exclusively as her father's biographer.⁷² The sources, however, reveal a far more complex picture, namely of a woman scientist who cannot be fully understood without acknowledging her integration of mathematical and social activity and her engagement in interdisciplinary and transdisciplinary processes. As a woman involved in mathematics, the natural sciences, and industry, she can be regarded as a historical example of the type of synthesis that is pursued in so much of today's interdisciplinary scholarship. The richness of available sources has enabled me to produce a "thick description" of the field⁷³ and to follow the call of Theodore M. Porter, who has urged scholars to build a bridge between mathematical-technical fields and contemporary education and culture.⁷⁴

1.3 EDITORIAL REMARKS

This section provides a brief overview of the sources that have been consulted and the ends to which they have been used. It will also clarify the citation method employed in the book and other editorial matters.

I began my research on this topic by reading the published reports of the light bulb and electron tube laboratories at Osram and Telefunken and by scrutinizing the relevant volumes of the *Zeitschrift für technische Physik* [Journal of Technical Physics], the *Technisch-wissenschaftliche Abhandlungen aus dem Osramkonzern* [Technical and Scientific Papers from the Osram Corporation], and the trade journal *Telefunken-Röhre* [Telefunken Tube]. It is from the wealth of information gathered in these publications that I was able to draw fresh conclusions about such a broad scope of themes. Studies with multiple authors, moreover, supplied me with the names of numerous researchers who have all but escaped attention.

In order to identify these many collaborators, most of whom were little-known industrial researchers, I examined the *Jahresverzeichnisse der deutschen Hochschulschriften* [Annual Indices of German University Publications] in search of their dissertations, years of graduation, and alma maters. University records concerned with the conferral of doctoral degrees allowed me to establish whether certain people had studied electrical engineering, chemistry, physics, or mathematics, as well as whether their research had been predominantly experimental or theoretical. My investigations into the backgrounds and contributions of such individuals revealed, first of all, the previously obscure structure of electron tube laboratories. These investigations also brought to light the small number of mathe-

71 Among other works, see CREAGER/LUNBECK/SCHIEBINGER 2001; SCHIEBINGER 2008; BECKER/KORTENDIEK 2008; LUCHT/PAULITZ 2008.

72 Iris RUNGE 1949. This biography will be discussed in Section 4.4 below.

73 On the idea of "thick description," see the article "Thick Description: Toward an Interpretive Theory of Culture," in GEERTZ 1973.

74 See PORTER 2009.

maticians who were employed at such laboratories and the way in which their work was evaluated by their contemporaries. Thanks to my earlier prosopographical research on German mathematicians, I was already aware of the few research directors – Karl Steimel, Hubert Plaut – who had held doctoral degrees in mathematics.⁷⁵ By continuing this type of analysis, I came across a number of unexpected and enlightening sources, including a report written by Steimel, then the director of the electron tube developmental laboratory at Telefunken, about the mathematical work that was conducted by one of his researchers (see Appendix 6). Moreover, my prosopographical approach revealed that the interdisciplinary research seminars at the University of Göttingen (on applied mathematics and physico-technical subjects) had been a prominent educational gateway into the field of industrial research (see Section 2.4.2). The members of Carl Runge's thought collective, too, came into higher relief, as did Iris Runge's participation in it and the extent to which she remained in contact with her father's doctoral students. These included, among others, Max Born and Friedrich-Adolf Willers, whose own students, in turn, would later be exposed to Iris Runge's research. Though his work has largely been neglected, the notable influence of Hermann Theodor Simon, a professor of applied electricity, quickly came to light.⁷⁶ As it turns out, Simon directed the research of a number of men – including Heinrich Barkhausen, Karl Willy Wagner, Hugo Lichte, Reinhold Rüdenberg, August Žáček – who would later become eminent inventors.

Housed in the archive of the German Museum of Technology in Berlin, the *Akten der Röhrenlaboratorien von Osram (Fabrik A) und Telefunken* [Records of the Electron Tube Laboratories at Osram (Factory A) and Telefunken] served as another foundational source. The laboratory reports contained in these records are often more detailed – even in their mathematical descriptions – than published studies. There are, of course, other relevant but unpublished laboratory records (see Appendix 5), and from these it was discernable how mathematics played a part in collaborative research, how laboratories were structured (see Section 3.2), and what tasks were assigned to which groups and individuals (see Appendix 4).

The State Archive (*Landesarchiv*) in Berlin contains a remarkable number of records pertaining to the Osram Corporation (though the name occasionally appears as OSRAM, the lower-case spelling is preferred in this book). From these holdings it was possible to ascertain the general structure of the company, the structure and evolution of its research laboratories, its research directors, and the assignments of various personnel to committees, laboratories, and research groups. The company's telephone directories allowed me to establish in which rooms certain mathematicians were situated and among whom these rooms were shared. The archival documents also reveal how political developments affected the corporation.

⁷⁵ See TOBIES 2006.

⁷⁶ Hermann Theodor Simon began working as an associate professor in 1901 and was promoted to full professor in 1907; see also Section 2.3 below.

Kept in the Berlin State Library (*Staatsbibliothek Preußischer Kulturbesitz*), the comprehensive Runge/Du Bois-Reymond estate contains important correspondence, certificates, degrees, diaries, and poems – among other things – that illuminate a great deal about the decisions, attitudes, and opinions of various family members.

Especially valuable was Iris Runge's private estate, which is held in Ulm and was kindly put at my disposal by Ms. Anna Maria Elstner (née Runge). Along with other documents, Iris Runge's letters to her parents (from her school days to 1927), to her mother (until 1941), and to other relatives (until 1946) not only clarify the precise reasons behind her career decisions but also reveal her precocious enthusiasm for mathematics; her opinions about colleagues, friends, books, periodicals, and politics; and her attitude toward the First World War, anti-Semitism, and National Socialism. Her regular correspondence contains information about industrial researchers, workplaces, research assignments, the role of her superiors in the promotion (or demotion) of mathematical methods, the independent activity of mathematicians in various laboratories, and the reasons for leaving one laboratory for another – among other things. Her letters offer authentic insight into research laboratories, her private life, and political events, as well as into her opinions, attitudes, and behavior.

Beyond these primary texts, I consulted a number of other sources pertaining to Iris Runge's professional associates and personal acquaintances. These can be found in the bibliography, as can all of the works that are cited in the footnotes in an abbreviated form. In this regard, abbreviations of archival sources appear in [square] brackets, and the names in SMALL CAPITALS refer to scholarly literature. Complete bibliographical information is provided in the footnotes for those sources – certain dissertations, for example – that are relevant only to the special context under discussion. These works are not included in the bibliography.

In order to reflect, as accurately as possible, the undertakings and views of its central characters, this book contains numerous direct quotations. All of these have been translated here into English for the sake of seamless reading, and those wishing to see the quotations in their original form are encouraged to consult the German edition of the book. Iris Runge's letters contain the occasional English, French, or Italian word; these have been preserved or annotated accordingly.

In the Index of Names at the end of the book, persons are listed alongside their biographical dates and their professions (when appropriate). Nationalities are also indicated in the case of non-Germans. It should be noted that American English has been used for this translation; the German word *Elektronenröhre*, for instance, appears as *electron tube* and not as *thermionic valve*, which would be its British equivalent. So as not to cause any inconsistencies, German notations have been preserved in the quoted formulas (U instead of V for voltage, for instance).

2 FORMATIVE GROUPS

This chapter will examine the groups and associations (thought collectives) that helped to shape Iris Runge's opinions, behavior, and style of thinking.¹ My central concern will be to locate the motivations behind her pursuit of mathematical learning and her delight in solving mathematical problems – the motivations, that is, that would ultimately lead to her career in industrial research. I hope to demonstrate, too, that her professional path cannot be disentangled from her social beliefs and activism. Attention will be paid to the following distinct groups:

1. The united and closely knit Runge and Du Bois-Reymond families.
2. The group of young women with whom she attended special preparatory courses to qualify for university admission.
3. The thought collective of her father, Carl Runge, which was devoted to applied mathematics, that is, to teaching numerical and graphical methods and their practical application.
4. The intellectual circle of Arnold Sommerfeld, a theoretical physicist whose work integrated mathematics, physics, and engineering, and who encouraged and initiated Iris Runge's first scientific publication.
5. The philosophical and political circles that she participated in during her years as a university student – especially the group associated with the philosopher Leonard Nelson – and during her time as a schoolteacher.
6. The community of scientists surrounding the physical chemist Gustav Tammann, under whose supervision Iris Runge completed a dissertation with both mathematical and experimental implications.

Some of the most important thought collectives of the time were located in Göttingen, where there existed an internationally renowned center of mathematical and scientific research. In order to clarify the role of this center in both Iris Runge's education and in that of others who would become industrial researchers in Germany and elsewhere, this chapter also contains a historical excursus on its foundation at the University of Göttingen.

Awarded a doctoral degree in physical chemistry by this institution at the age of thirty-four, Iris Runge decided to leave behind her established career as a schoolteacher and become an industrial researcher. It will be shown that this decision was a logical consequence of her involvement in these diverse and formative intellectual circles.

1 On the notion of *thought collectives*, see Section 1.2.1 above.

2.1 THE RUNGE AND DU BOIS-REYMOND FAMILIES

[...] we members of the Du Bois-Reymond family have quite a reputation for being indifferent to the opinions of others – (sometimes too indifferent).

Iris Runge made this remark in a letter to Hendrik de Man on June 28, 1931.² At this time she was working at the radio tube laboratory of the Osram Corporation and she had already cultivated a large network of scientific, political, and private contacts. The quotation reflects her self-confidence, her independent spirit, and her close identification with her extended family, a family with Huguenot ancestry on both its paternal and maternal sides.³ The Du Bois-Reymonds were well established in the French Huguenot communities of Berlin and Potsdam, whereas the Runges were international merchants based in Bremen.

On August 9, 1887, shortly after having received a professorship at the Technical University in Hanover, Carl Runge married Aimée du Bois-Reymond, whom he had first met at the house of the mathematics professor Leopold Kronecker. In contrast to his fellow mathematicians trained in Berlin, who were staunchly opposed to applied mathematics, Carl Runge consciously devoted himself to this very subject. His intensive research in the field of spectroscopy, which he conducted along with the physicist Heinrich Kayser, happened to be instigated by the work of Emile Heinrich du Bois-Reymond, as Iris Runge reports in her father's biography.⁴ This is just one example of the close connection between the Runge and Du Bois-Reymond families. Carl Runge's research in spectroscopy not only led to the development of his groundbreaking numerical methods (see Section 2.4); it also earned him an early international reputation. Thus it comes as no surprise that he gave his first child, who was born on the first of June in 1888, a name that reflected his interest in various spectra – Iris means *rainbow* in Greek.

Carl and Aimée Runge went on to have five more children in Hanover:

Ella (b. December 7, 1887) was awarded a doctoral degree in medicine and worked for the rest of her life as a pediatrician.⁵

2 [IISH]. On Hendrik de Man, a Belgian Social Democrat, see Section 4.2.2.1 below.

3 Since c. 1560, the term Huguenot has been used to designate a group of French protestants that was influenced by the teachings of John Calvin. On October 18, 1685, Louis XIV issued an edict requiring all French Protestants, under threat of imprisonment, to convert to Catholicism. Shortly thereafter, Friedrich Wilhelm, the Elector of Brandenburg, responded by issuing the Edict of Potsdam, which encouraged Huguenots to immigrate to his principality by guaranteeing them freedom of religion and by offering them additional incentives: relief from taxes, financial support for construction, their own religious leaders and judges, etc. Of the nearly 200,000 Huguenots who fled from France, approximately 20,000 immigrated to Brandenburg-Prussia (see HENRY 1832; GILMAN 1962).

4 Iris RUNGE 1949, pp. 53–54. Emile Heinrich du Bois-Reymond was named after Jean-Jacques Rousseau's 1762 treatise *Émile: Or, On Education* (see HENTSCHEL/TOBIES 2003, p. 140). On his life and work, see DIERIG 2006.

5 In 1917, Ella Runge passed her preliminary medical examination (*Physicum*) in Berlin; her final medical examination was taken in Göttingen in 1919; and she was awarded a doctoral degree by the University of Munich for a dissertation entitled “Über zwei Fälle schwerer

Nerina (b. November 23, 1891), who went by the name Nina, was trained as a violinist. In 1917 she became engaged to the (Jewish) mathematician Richard Courant, whom she married on January 22, 1919.⁶ Along with their four children – Ernst, Gertrud, Hans, and Leonore – she and her husband went into exile, first to Great Britain and a year later to the United States, where Richard Courant would found the Courant Institute of Mathematical Sciences at New York University.

Wilhelm Tolmé (b. June 10, 1895) earned a doctoral degree in the field of high-frequency engineering from the Technical University in Darmstadt. He became a research director at the Telefunken Corporation, where he encouraged the use of mathematical methods in problem solving (see Section 3.1). On August 1, 1925, he married Maria Voelckel from Darmstadt. Settled in Berlin, he and his wife would have three children: Bernhard Tolmé, Erich, and Anna Maria.

Bernhard Emile (b. March 2, 1897), a volunteer soldier, was killed on October 21, 1914 in the First World War.

Aimée Louise (b. January 1, 1903), who was called Bins or Binsi, was a trained gardener who, beginning in November of 1927, worked at the University of Göttingen's Botanical Institute under Friedrich von Wettstein. When the latter went to teach at another university, she pursued vocational training as a laboratory assistant in Berlin. After 1945, she worked as a secretary for the Institute of Chemistry at the University of Göttingen and married Dr. Wolfgang Luther, a lecturer at the University of Marburg.⁷

When Carl Runge recorded the event of Iris's birth in his epistolary diary, which he kept jointly with the physicist Max Planck and other former classmates,⁸ he mentions it in the same breath as his many scientific affairs:

I am pleased to announce the birth of a healthy daughter. She arrived on the first of June, not long after I had mailed off our book for the last time. Therefore, Max, my wife has taken a lively interest in your son [...].⁹ The mother and child are doing extremely well, especially because both of them are staying at the country home of my wife's parents in Potsdam and are thus receiving as much fresh air and sunshine as the miserly sky has been willing to grant us this summer. I, too, am feeling very well, having put the end of the semester and the stress of my work behind me. The hearty activity of swimming, rowing, and tennis has restored me in no time at all. I am considering attending the British Association for the Ad-

Anämie beim Säugling" [On Two Severe Cases of Infant Anemia]. She died of typhoid fever in 1945 ([DTMB] 4413, p. 27).

6 Iris Runge discussed the couple's engagement in a letter dated June 3, 1917 [Private Estate]. On the wedding, which took place without any religious component – "in the absence of spirituality" – see Carl Runge's letter to his brother Richard dated February 2, 1919 and archived in [STB] 526, p. 4. Courant's first marriage, to the Jewish mathematician Nelly Neumann, lasted from the summer of 1912 until the winter of 1916 and was childless (see TOBIES 2005a). On Courant's life and work, see REID 1976.

7 Their marriage is mentioned in the following archival sources: [STB] 552, p. 76; [Private Estate]; and [UAB] R. 387, vols. 1–2.

8 For biographical information on Max Planck, see HEILBRON 2000.

9 Karl Planck, the eldest son of Max Planck, was born on March 18, 1888 and fell in battle, in 1916, during the First World War.

vancement of Science in September [...], which is scheduled to take place in Bath. At the end of September I intend to return for the baptism of our daughter, who will be named Iris Anna. The first part of the study that I wrote with Kayser will soon appear in print. It has been accepted for publication by the Berlin Academy of Sciences, and I have already received the first set of proofs.¹⁰ This section, which is really an introduction, concerns the iron spectrum. In addition to measurements, the paper includes an atlas of the iron spectrum, reproduced in collotype, that provides a good enough picture to be of some use alongside the tables of data.

Yours, with kind regards, C. Runge (Potsdam – August 16, 1888)¹¹

The importance of the Berlin-Potsdam region to the family is underscored by the facts that the baptism took place at a Protestant church in Potsdam and not in Hannover (Iris Runge's birthplace), and that her godparents included Marta Pringsheim and Robert von Helmholtz.¹² With each summer, their network of relations in this area became more and more expansive, for Aimée Runge would typically spend the summer months with her children at her family's spacious estate – known as “El Arenal” – in Potsdam.¹³ One of the godparents of Carl and Aimée Runge's second daughter, Ella, was Max Planck, who had been Carl's close friend since their university days and who, having accepted an appointment as the chair of theoretical physics at the University of Berlin, moved to that city in 1889.

Aimée Runge not only established regular correspondence with her siblings and children, she also took care – as the family's center of communication – to ensure that letters were exchanged and redistributed among her relatives.¹⁴ Her correspondence with her eldest daughter reveals the latter's keen awareness of her family's characteristic features. When Aimée Runge once wondered whether her children's upbringing might explain why “nothing proper” has become of them, Iris Runge responded by accrediting an “immensely strong trait of our family [...] that could hardly be altered by our upbringing. In one way or another, all of us are

10 Heinrich Kayser and Carl Runge, “Über die Spectren der Elemente,” *Abhandlungen der Kgl. Academie der Wissenschaften zu Berlin* 1888, III (Berlin, 1889), 93pp. The swift acceptance of this article, written as it was by scientists who were not members of the Academy, can be explained not only by the fact that Kayser had been Hermann von Helmholtz's assistant, but also by the fact that Runge's father-in-law had been a member of the Academy since 1851 and was currently the executive secretary of its mathematics and physics branch.

11 Quoted from HENTSCHEL/TOBIES 2003, p. 108.

12 Aimée Runge wrote in her diary: “Iris Anna Runge entered the world at 10:45 AM on a beautiful June 1, 1888. [...] On the sixth of June I traveled with her to Potsdam, and she was baptized by Pastor Nessler on September 28. Among her godparents, only Marta Pringsheim and Robert von Helmholtz were present” ([STB] 519). Marta Pringsheim, daughter of the railroad industrialist and mine owner Rudolf Pringsheim and his wife Paula (née Deutschmann), was the sister of the mathematics professor Alfred Pringsheim, whose lectures Iris Runge would later attend in Munich. Robert von Helmholtz, the eldest son of Hermann and Anna von Helmholtz, held great promise as a physicist before his premature death in 1889. His obituary can be read in *Naturwissenschaftliche Rundschau* 4 (1889), pp. 567–568.

13 Estelle du Bois-Reymond, “El Arenal: Unser verlorenes Paradies, 1859-1922” ([STB] 298).

14 In a letter dated December 14, 1936, Iris Runge referred to her mother, who had just returned from a trip to America, as an “information hub” [Private Estate].

carefree and indolent – we heed a higher principle.” Having evoked their Anglo-French origins and anticipated their future success, she added: “We are modest, in a way, but we are also so convinced of our self-worth that it hardly seems necessary for us to exert ourselves for the sake of success.”¹⁵

The following distinctive features of the Runge and Du Bois-Reymond families will be treated in greater detail below: their willingness to grant liberal and costly educations to both male and female family members, which resulted in the latter’s independence and self-confidence; their scientific world view; and their special engagement on behalf of women’s education and other social issues.

2.1.1 The Extended Du Bois-Reymond Family

Even Iris Runge’s great great grandfather, Felix Henry du Bois-Reymond, distinguished himself by advocating the expansion of women’s rights. Born into a Swiss family of glassworkers, he lost his father at an early age and moved to Berlin, where he benefited from the support of the French community. He attended university while working as a tutor, and in 1816 he married Minette Henry, daughter of the Huguenot pastor Paul Henry.¹⁶ As a privy and expert councilor in the Prussian Ministry of Foreign Affairs, Felix Henry du Bois-Reymond supported measures that were far ahead of the times – measures for improving mathematical education, for co-education, for establishing preparatory schools for girls, and for the equal legal status of husbands and wives. In the estimation of his grandniece, Eugenie Rosenberger, he never lost sight of his humble origins.¹⁷ In 1789, his mother-in-law, the painter Suzanne Henry (née Chodowiecka),¹⁸ was made the first female member of the Prussian Academy of Arts. Another female relative, Louise Henry (née Claude), would become a member of the same prestigious academy in 1833.¹⁹

Emile Henry du Bois-Reymond – Felix Henry du Bois-Reymond’s son and Iris Runge’s grandfather – provided his daughters with a broad education and promoted a scientific world view that would be passed on to his grandchildren.²⁰ Like that of his friend Hermann von Helmholtz, his research integrated physiology and

15 A letter from Iris Runge to her mother dated November 22, 1916 [Private Estate].

16 Paul Henry enjoyed close relations with the Prussian royal household (see HENRY 1832; [STB] 22–28).

17 See ROSENBERGER 1912.

18 Suzanne Henry was the daughter of Daniel Chodowiecki – the famous engraver, etcher, drawer, and painter – and Johanna Marie Barez, who was the daughter of a Huguenot silk embroiderer from Amsterdam.

19 Susanne Henry’s membership certificate, dated November, 11, 1789, is preserved in [STB] 99; for the certificate authenticating Louise Henry’s appointment as an honorary (*außerordentlich*) member of the Academy, dated March 1, 1833, see [STB] 142.

20 Emile du Bois-Reymond’s siblings were Julie (b. 1816), who married Otto Rosenberger; Félicie (b. 1828), who married Julius Ewald, a great uncle of the physicist Peter Paul Ewald; Gustave (b. 1824); and Paul (b. 1831), a professor of mathematics.

physics, and he was one of the founding members of the Society of Physics in Berlin. Moreover, he served as chairman of the Physiology Society, which was founded in 1858 in the same city. Known as an “experimentalist” (*Handwerksgelehrte*), he founded experimental electrophysiology, discovered nerve action potential, and helped to refine several measuring instruments, including the galvanometer. His efforts culminated in the development of the electrocardiogram and other tools that redefined medical diagnostics. Emile du Bois-Reymond was a firm opponent of vitalism, the notion that the functions of all living organisms derive from a special life force, the *vis vitalis*. On the contrary, he was convinced that all living phenomena can be substantiated, measured, and explained in chemical and physical terms, that is, without recourse to such a metaphysical concept as “life force.” He was a vocal supporter of Darwinism,²¹ and he is also known for promulgating the maxim *ignoramus et ignorabimus* “we do not know and will not know,” which he evoked in an acclaimed lecture – “Über die Grenzen des Naturerkennens” [On the Limits of Our Understanding of Nature] – that he delivered to an audience of medical doctors and natural scientists in 1872.²² As a professor at the University of Berlin, he also lectured about the developmental history of important scientific methods. This interest in the history of science would not only be carried on by his sons; the tradition would extend to Iris Runge as well.

The marriage between Emile du Bois-Reymond and Jeanette Claude, a niece of Louise Henry, produced nine children.²³ These children, along with their own offspring, can be said to constitute the core of the extended Du Bois-Reymond family in the Berlin-Potsdam area: Ellen (b. 1854), Claude (b. 1855),²⁴ Lucy (b. 1858), Alard (b. 1860),²⁵ Aimée (b. 1862), René (b. 1863),²⁶ Estelle (Dolly) (b. 1865), Percy (b. 1870), and Rose (b. 1874).²⁷

21 His advocacy for Darwinism would later be reflected in Iris Runge’s opinions on the matter; see, for example, the letter to her mother dated October 10, 1927 [Private Estate].

22 The lecture is printed in Estelle du Bois-Reymond, ed., *Reden von Emil du Bois-Reymond*, 2 vols. (Leipzig: Veit, 1886–87), vol. 1, pp. 441–473. On the implications of this speech, which initiated a prolonged debate about the limits of our scientific knowledge, see REICHENBERGER 2007.

23 Jeanette Claude, who came from a family of refugees, spent much of her youth in Valparaíso (Chile) and England. Her mother, Wilhelmine Claude (née Reklam), lived at the “El Arenal” estate until her death in 1899. Like that of her husband, Jeanette Claude’s lineage can be traced back to the engraver and designer Daniel Chodowiecki.

24 Claude du Bois-Reymond was an ophthalmologist who worked, from 1907 to 1913, as a professor of medicine in Shanghai, China.

25 Alard du Bois-Reymond, an engineer and patent lawyer in Berlin, was married to Lily Hensel (a sister of the mathematician Kurt Hensel); she became an author after her husband’s early death. During the First World War, Alard du Bois-Reymond was an associate at an engineering firm in Kiel that produced, among other things, a hydroacoustic and ultrasonic instrument; the firm also produced one of the first devices for wireless telegraphy (see Section 2.6.5). Along with his son Roland, he died in a boating accident on the Baltic Sea; see Iris Runge’s letter dated September 10, 1922 [Private Estate]; and [STB] 553.

26 René du Bois-Reymond – a physicist, biologist, and professor at the University of Berlin – was married to Frieda Baeumler. He edited a collection of his father’s writings: Emile du

All of the children spoke fluent English, received a broad education, and were raised to be open-minded, tolerant, and athletic. Like their brothers, the five sisters could row, ice skate, and play tennis. It would not be far amiss to call them blue-stockings (Aimée would be the only one to marry).²⁸ Even though these women, like the others of their generation, were excluded from universities, they still participated in scientific projects and were active as writers and artists.

Estelle du Bois-Reymond's activity as a translator and editor is an excellent example of this. Together with Anna von Helmholtz, the wife of Hermann von Helmholtz, she produced a German translation of *Modern Views of Electricity*, a book by the British physicist Oliver Joseph Lodge.²⁹ This work not only presages Iris and Wilhelm Runge's later research on radio tubes and broadcasting (Lodge was a pioneer of the radio who designed spark plugs, vacuum tubes, and speakers); it also foretold Aimée and Iris Runge's participation in a scientific translation project that was initiated by Carl Runge (see Section 2.4.4).

The artistic achievements of the Du Bois-Reymond women were perpetuated by the painter Lucy du Bois-Reymond, who was educated in Paris, and by Rose du Bois-Reymond, who was a successful scientific illustrator.³⁰ Their relative Clara Ewald (née Philippson) also participated in this artistic tradition.³¹

Clara Ewald's son, Peter Paul Ewald (b. 1888), became a prominent theoretical physicist and turned out to be an important contact for Iris Runge, who shared his interests. Because his father, Paul Ewald, had died three months before his birth, he was raised by his mother alone. After stays in Paris, Cambridge, and Montreux, he joined his network of grandparents, uncles, aunts, and cousins in

Bois-Reymond, *Vorlesungen über die Physik des organischen Stoffwechsels*, ed. René du Bois-Reymond (Berlin: Hirschwald, 1900). With Ludwig Darmstaedter, he published a tabulated history of the exact sciences: *4000 Jahre Pionierarbeit in den exakten Naturwissenschaften* (Berlin: J. A. Stargardt, 1904), the second edition of which appeared as *Handbuch zur Geschichte der Naturwissenschaften und der Technik* (Berlin: J. Springer, 1908).

27 For family photographs, see Plate 2 at the end of the book.

28 See Iris RUNGE 1949, p. 48. The history of the word “bluestocking” goes back to the 17th century; in the 19th century it was used pejoratively to denote educated and “unfeminine” women who acted at odds with the “feminine ideal” of the time (see ROBINSON 2009).

29 Oliver Lodge, *Neueste Anschauungen über Elektrizität*, trans. Estelle du Bois-Reymond and Anna von Helmholtz (Leipzig: Barth, 1896). The two also collaborated on a translation of John Tyndall's *New Fragments*, namely: John Tyndall, *Fragmente: Neue Folge*, trans. Estelle du Bois-Reymond and Anna von Helmholtz (Braunschweig: Vieweg, 1895). Until she was ninety years old, Estelle du Bois-Reymond worked as a research assistant at the university library in Göttingen (see GRUBER 1956, p. 532).

30 Rose du Bois-Reymond conducted botanical research and, encouraged by the zoologist Alfred Kühn, produced scientific illustrations in the fields of zoology and pathological anatomy for academic institutes in Göttingen (see GRUBER 1956).

31 The painter Clara Ewald belonged to the artist colony known as “Scholle” [a clod of earth], which was located in Holzhausen (Bavaria). Along with her son Peter Paul and his family, she went into exile to Great Britain in the 1930s (see BETHE/HILDEBRANDT 1988; ECKERT 2011). Clara Ewald is related to Iris Runge by way of the latter's great aunt, Félicie du Bois-Reymond, who was married to Julius Ewald.

Berlin and Potsdam. During his years in Göttingen, where he lived as a student (1906–07) and where he worked as an assistant to the mathematician David Hilbert (1912–13), Peter Paul Ewald was hosted by the Runge family. He and his wife, Clara, repaid this hospitality by playing host to Iris Runge in Munich, where she studied during the winter semester of 1910.

The philosopher Leonard Nelson, a trained mathematician who would influence Iris Runge's social thinking during her years in Göttingen, had long been a member of the Potsdam intellectual circle (see Section 2.6.1). About him, Iris Runge would later write: "I have known Leo Nelson since childhood. Since he was a descendant of the Mendelssohn family, like my aunt, he spent a great deal of time at my uncle's house in Potsdam."³² Iris Runge's early development was influenced by her lengthy stays in Potsdam and Bremen (here with her paternal grandmother), and it is thus no surprise that she later chose to work in these regions. Her employment as an industrial researcher in Berlin, after 1923, and her earlier activity as a schoolteacher in Bremen, from 1915 to 1918, must be seen in light of the many close relations that she enjoyed in these cities.

2.1.2 The Open-Mindedness of the Runge Family

Carl Runge's family had risen from working-class origins to become established merchants. It was as a tradesman in Havana that Julius Runge, Carl's father, met and married the Englishwoman Fanny Tolmé. The first four of their children were born in Cuba: Hermann (b. 1847), Julius (b. 1848), Mary (b. 1851), and Fanny (b. 1854). Of these, the eldest three would settle with their families in Great Britain. Carl Runge, their fifth child, was born in Bremen (1856), as were his four younger siblings: Gustav (b. 1858), Richard (b. 1859), Otto (b. 1861), and Lily (b. 1863).³³

Fanny Tolmé Runge, the eldest daughter of the English merchant Charles David Tolmé and his wife Maria Eliza, came from a family with Huguenot roots. After the early death of her husband, the worldly Fanny Runge ensured that each of her children received a strong and liberal education, just as her youngest son,

32 Quoted from [FES] Leonard Nelson's Estate, 1/LNAA000513. Nelson's mother was a granddaughter of the famous mathematician Johann Peter Gustav Lejeune Dirichlet, whose own mother was a fifth-generation descendant of Moses Mendelssohn, the Enlightenment philosopher. The Mendelssohns are a German-Jewish family of scholars, bankers, artists and scientists (see HENSEL 1879, trans. 2007). Iris Runge is referring to her uncle Alard du Bois-Reymond and his wife Lily (née Hensel). The prominent mathematician Kurt Hensel, the fourth child of Sebastian and Julie Hensel, is a great great grandchild of Moses Mendelssohn. On account of their early conversion to Christianity, members of the Mendelssohn family were, for the most part, not treated as Jews during the Nazi era; they were not, however, entirely exempt from persecution and discrimination.

33 In 1883, Anna Eliza (Lily) Runge married the Leipzig merchant Oskar Trefftz, who was sixteen years her elder. Iris Runge developed a close friendship with their daughter Anni, who was born in 1884, and with their second son Erich, who became a professor of applied mathematics and mechanics.

Carl Runge, would later do for his own.³⁴ Upon her grandchildren, who were exposed at a young age to the international branches of their family, she imparted her love of art and music – of concerts, exhibits, the theater, and the opera. Iris Runge, who learned to speak English, French, and some Italian, clearly profited from the many visits made to and by her family.³⁵ She also accompanied her father during some of his scientific travels, for instance to Cambridge, where they visited the famous physicist Joseph John Thomson in 1906 (the year he received the Nobel Prize). In Cambridge, too, she attended the Fifth International Congress of Mathematicians in 1912, where her father presented a report entitled “The Mathematical Training of the Physicists in the University”.³⁶

Thus it can be said that Carl and Aimée Runge perpetuated the traditions of both their families when they agreed “not only to allow their daughters to pursue their intellectual interests, but also to provide them – no less than their sons – with a practical education that could lead to intellectual and professional independence.”³⁷ From an early age, their first-born daughter received instruction from private tutors, as Carl Runge attests in a letter to Max Planck:

[...] We have fallen for the same idea as you, Max, in that we have allowed Iris to be instructed for four hours a week. She is being tutored along with the daughter of my colleague Kohlrausch, and both of the children have been happy and enthusiastic with the arrangement.³⁸

Active beyond the family circle, Carl Runge accepted a seat on the board of the Organization for the Reform of Women’s Education in Hanover (*Verein Frauenbildungsreform*).³⁹ Max Planck, on the contrary, followed the middle-class conventions of the time by providing only his sons with an early education. He oriented the education of his twin daughters toward household management and, in general, he could only imagine women attending university in the most excep-

34 Lily Trefftz described their free and uninhibited upbringing in her memoirs, which can be read at <http://www.cis.gvsu.edu/~trefftzc/Family.html>. Carl Runge turned a blind eye to the idiosyncrasy and stubbornness of his eldest daughter, and he continued to promote his sons’ practical learning even while they repeatedly failed Latin and Greek. About Max Planck’s excessively strict attitude toward his son Karl – who, his studies left unfinished, would die in battle during the First World War – Carl Runge commented: “It’s as if happiness and the *animal spirits* were somehow less important to him than schoolwork” (a letter from Carl Runge to his wife dated April 29, 1903 and archived in [STB] 514, p. 104). The English term *animal spirits* appears in the original.

35 On Iris Runge’s language skills, see her answers to a 1949 questionnaire in [UAB] R 387, vol. 1, p. 1.

36 Carl RUNGE 1913. The trip to see Joseph John Thomson was undertaken while the Runiges were already in England for the sake of celebrating, in June of 1906, Fanny Runge’s eightieth birthday; see [STB] 688 and letters from the [Private Estate].

37 Iris RUNGE 1949, p. 104.

38 An entry by Carl Runge, dated January 8, 1894, in his and Max Planck’s epistolary diary; quoted from HENTSCHEL/TOBIES 2003, p. 130. Wilhelm Kohlrausch was a professor of electrical engineering at the Technical University in Hanover.

39 [STB] 514, pp. 116, 118.

tional of circumstances. It should not go unmentioned that Max Planck did, in fact, supervise the doctoral studies of several outstanding women scientists. It was under Planck in 1912, for instance, that the renowned Austrian physicist Lise Meitner – whom Iris Runge would later befriend – became the first female research assistant to receive a salary from the University of Berlin.⁴⁰

When Carl Runge left his position at the Technical University in Hanover for a professorship at the University of Göttingen, he found himself at *the* international center of mathematical and scientific research (see Section 2.3), and also at a place where educational reform – concerned with the rights of women, among other things – was in full swing. Under the leadership of Felix Klein, mathematicians and natural scientists were not only advocating for their fields to be granted a higher and more appropriate standing within the general curriculum; they also argued, on the basis of what had been accomplished by foreign women, that German women should have access to a normal course of study. It is noteworthy, in this regard, that Carl Runge had been friends with the Russian Sofia Kovalevskaya, who was the first woman in the nineteenth century to receive a doctoral degree in mathematics (awarded *in absentia* by the University of Göttingen in 1874) and who, in 1884, became a professor of that subject in Sweden.⁴¹ In Berlin, the two of them had the same doctoral supervisor, namely Karl Weierstraß, who was one of the most influential mathematicians of the nineteenth century.

Appointed a member of the academic senate at the University of Göttingen in his first year there, Carl Runge immediately began to advocate for the right of women to matriculate. In 1905, the Prussian Ministry of Culture allowed the matter to come to a vote, since other federal states in Germany had already permitted women to attend universities as regular students (see Section 1.2.1). Even though the opponents of the measure within the Göttingen senate managed to win by a slim majority, Carl Runge and the historian Max Lehmann nevertheless co-authored a dissenting opinion in its favor.⁴² Two years later, they and other members of the faculty supported a failing measure aimed at allowing women to conduct post-doctoral research and complete a *Habilitation*, which would qualify them to teach as university professors. In 1915, they advocated especially on behalf of Emmy Noether, whose *Habilitation* – despite their efforts – would not be approved until 1919.⁴³

40 For a comprehensive study of Lise Meitner's life and work, see SIME 1997.

41 See Iris RUNGE 1949, pp. 43–45.

42 See [STB] 568.

43 On February 7, 1907, the following Göttingen professors voted in favor of allowing women to complete a *Habilitation*: Carl Runge and Max Lehmann; the mathematicians David Hilbert, Felix Klein, and Hermann Minkowski; the chemist Gustav Tammann; the theoretical physicist Woldemar Voigt; and the geophysicist Emil Wiechert. However, because the conservative majority of professors at Prussian universities voted against the measure, the Prussian Ministry of Culture passed a decree that forbade women from achieving this academic status. Although this decree was not overturned until 1920, a few women nevertheless completed a *Habilitation* on an exceptional basis in the years 1918 and 1919. Among these

2.1.3 The “Plato Society” in Potsdam

Carl Runge’s eldest daughter internalized the family tradition at a young age. Even her very first lesson, with the tutor Gertrud (Trudi) Kohl, had excited her enthusiasm for learning. Later, Iris Runge noted that her early instruction was somewhat colored by religion, so that she “began to have faith with a childish reverence and piety.” She continued:

I have vivid memories of the observations and resolutions that I made when I turned seven years old. I figured that I was now a big girl; from experience I was able to distinguish right from wrong, and I resolved that I should be a good person, something that seemed extremely easy and almost obvious to me at the time. At that time, too, I determined that I would instruct my own children, from the very beginning, about God, and that I would also pray with them in the evening, a practice that was familiar to me from books and from Trudi Kohl. That my mother did not do this with us, however, hardly struck me as abnormal; in fact, it seemed entirely natural to me and just as right as the alternative.⁴⁴

As a schoolgirl in Hanover, Iris Runge grappled with ethical questions, and in 1901, during her summer vacation in Potsdam, the thirteen-year-old initiated a so-called “Plato Society.” Members of the club included her younger cousin Felix du Bois-Reymond and the future artist Eva Roemer, with whom Iris Runge enjoyed an especially close friendship.⁴⁵ The purpose of this Plato Society was to engage with the problems of religion and philosophy that had arisen from the young pupils’ readings of such classical authors as Friedrich Schiller, Johann Wolfgang von Goethe, and Heinrich Heine:

I started school at the age of nine, and instead of Trudi’s loving and heartfelt stories I now had to endure the rather dry religion classes that were taught by a variety of our school’s teachers, one of whom – a horrible person – we even despised and detested. I no longer know when things changed for me, but I can say with certainty that it was not long before I stopped believing anything that was taught in these classes. I was probably already aware of

was Emmy Noether, the first woman mathematician to achieve such a status in all of Germany. Her pioneering work would change the face of modern algebra, and she was forced to emigrate (to the USA) in 1933 (see TOLLMEN 1990, KOREUBER/TOBIES 2008).

44 [STB] 770, p. 12. Aimée Runge discussed her children’s upbringing with her brother René, who advocated for the separation of church and state and once wrote, on November 2, 1910, “that it should finally be possible to claim no religion” ([STB] 384, p. 125v). It was not until 1919 that the Weimar constitution stipulated that those working in the public sector (at schools, universities, etc.) did not have to belong to a church.

45 Felix du Bois-Reymond, the son of Alard du Bois-Reymond, was awarded a doctoral degree in 1917 for a dissertation – “Zur Symptomatologie der Occipitaltumoren” [On the Symptomatology of Occipital Tumors] – that he wrote under the supervision of Ernst Siemerling, the director of the psychiatric clinic at the University of Kiel. Felix du Bois-Reymond, who eventually became an orthopedist in Berlin-Zehlendorf, was decidedly opposed to Hitler’s regime (see Wilhelm Runge’s remark in [DTMB] 4413). Eva Roemer’s parents (Fanny, née Hensel, and the sculptor Bernhard Roemer) died at Helgoland in 1891; she was raised by her grandparents (Sebastian Hensel and his wife) in Berlin and by her aunt Lily (Hensel) and Alard du Bois-Reymond’s family in Potsdam. Twenty-two of her letters to Iris Runge, written between 1903 and 1906, survive in [STB] 688.

the scientific theories about the origin of the earth, and I took it as a matter of fact that every rational person understood religion to be fundamentally untenable. Though I was unsure of why the whole edifice of religious ideas was kept standing, I assumed that it persevered on account of the many foolish and uneducated people whose faith – I supposed – was better left intact.

When I was thirteen, I began to busy myself with more profound thoughts. I had already read a good deal; Schiller, especially, I read with great fervor, and I had been deeply influenced by his belief in immortality, by the exuberant religiosity of his youth, and by the romantic piety of his *Virgin of Orleans*. I had consumed large portions of Goethe, though I hardly understood a thing of it and was already remarkably prejudiced against him on account of the negative assessments that I had so often heard at home; my mother had little esteem for Goethe, and thus I was naively certain that – as every reasonable person surely knew – Goethe had written nothing but unintelligible slop [...] and was absurdly overvalued. As opposed to Schiller's simple and noble virtue, Goethe struck me as either too frivolous or too cynical. Heine's cynicism, however, was far more tolerable, for it captured the suffering of people whose blatant contradictions appealed to me. I also associated Heine with the romanticism of the exiled protest singer and with that of the persecuted Jew. (This is not for reasons of my own biography; it simply aggravated me that I had to defend him against the anti-Semitism of my classmates.) In any case, by this time I had read enough to cast some doubt on the unequivocal atheism that I had embraced a few years before.

Over the course of a conversation with Felix du Bois in Potsdam, we realized that we were struggling with nearly the same questions. Felix involved Eva Roemer, who was also pondering such things, in our later discussions, and so, in the summer of 1901, the three of us formed a Plato Society in which we could hold confidential debates over questions of religious faith, virtue, and immortality. This coalition of friends became the heart of my existence. Eva seemed to me the purest and most heavenly creature on earth; on account of her piety, her longing for her dead mother, and her tender affinity for nature, she was simultaneously the most touching of people and the most exalted of ideals. Of course, I was still struggling rather fiercely to overcome my atheistic and arrogant inclinations. [...] I lived in a perpetually distressed state of passion, hatred, rage, ebullient joy, remorse, impudence, and yearning; Eva was gentle and benevolent and often sad. (At least she seemed as much to me.) I loved her fervently – I nearly idolized her, and to know that she loved me in return would rescue me from my darkest moods. During this time, in any case, I learned that religion, far from being a fallacy rejected by all intelligent people, was a highly viable phenomenon. Though I was never touched by the historical forms in which religion was presented, I was moved by the warm and personal content of religion that I had experienced for myself. All of those people who espouse a specific form of religion at the expense of all others, as it seemed to me then, were mired in error and worthy of contempt.⁴⁶

Iris Runge's early letters and notes reveal the deeply reflective and emotional side of the budding mathematical genius, and this side of her cannot be dismissed when assessing her later opinions and activities – including her social activism. In 1929, when she decided to leave the church once and for all, she knew that her decision would earn her mother's endorsement (her father was dead by this time):

My impression is the same as yours, namely that people who associate their strong religiosity with one of the established ecclesiastic traditions are hardly sympathetic. [...] (Last year, incidentally, I went so far as to leave the church – it was quite easy.)⁴⁷

46 [STB] 770, pp. 12–13, a hand-written account by Iris Runge (undated).

47 A letter from Iris Runge to her mother dated December 14, 1930 [Private Estate].

On a report card from March 22, 1902, Iris Runge received a grade of *good* for religion, whereas her grade for mathematics and the natural sciences was *very good*.⁴⁸ This evaluation, however, would have no bearing on her consideration for university admission, since there were still no girls' schools that could qualify pupils for that end. In order for young women to achieve the goal of attending university, special courses were established to prepare them for the necessary examinations.

2.2 AN AMBITIOUS AND ELITE CIRCLE OF CLASSMATES

In Hanover, where her father was a professor at the local Technical University, Iris Runge was fortunate to benefit from the accomplishments of the women's movement, which had begun to make waves in a few German cities.⁴⁹ In 1902, with approximately 235,700 residents, Hanover had nine secondary schools for boys, three secondary schools for girls, and a program of special coursework that prepared girls for the university entrance examination (*Abitur*). These latter courses were taught by male and female teachers who were already employed at one of the local public schools. By way of comparison, the city of Göttingen, a university town with just over 30,000 residents, had only two secondary schools for boys and one for girls. In Göttingen there was no special program – and thus little opportunity – for young women who wished to attend university.⁵⁰

The special preparatory courses for girls taught the same material that was taught at the secondary schools for boys, of which there were three types: the so-called *Humanistisches Gymnasium*, which concentrated more intensely on the classical languages than on the natural sciences; the *Realgymnasium*, where the focus was more on science, mathematics, and modern languages (Latin was also taught; Greek was not offered); and the *Oberrealschule*, which – forsaking the classical languages altogether – stressed mathematics, science, and modern languages. As of 1900, the diplomas awarded by these three types of schools were considered of equal value. Based as they were on the system for boys, the special courses for girls also consisted of three different types (the regular secondary schools for girls would not offer their own *Abitur* until 1908).

Iris Runge attended such courses (of the *Realgymnasium* sort) from the spring of 1902 to the spring of 1905, and then from the spring of 1906 until her final examinations. The interruption of her schedule, from 1905 to 1906, occurred because it was during this time that her family moved to Göttingen, where Carl

48 [STB] 747, p. 5.

49 Little has been written about the special preparatory courses for girls that will be discussed in this section. They were first established in Berlin (1889), followed by Leipzig (1894), Baden-Baden (1897), Königsberg (1898), Hanover (1899), Breslau (1900), Munich (1900), Frankfurt (1901), and Hamburg (1901); see HEINSOHN 1996, p. 151.

50 See KUNZE 9 (1902), p. 370; and KUNZE 12 (1905), vol. 2, pp. 108–109.

Runge had accepted a new professorship. Iris Runge was among the few young women of the time who qualified for university admission by external examination. In 1906, there were fewer than three hundred women who accomplished this in all of Germany. By 1915 the number had grown to more than six hundred, but this was still a strikingly small minority – in that year there were nearly 160,000 young women attending a total of 497 schools.⁵¹

This section will outline the group norms that characterized Iris Runge's elite circle of classmates. It will also illustrate the components of her curriculum that may have influenced her decision to study physics and mathematics.

2.2.1 Group Norms

In Hanover, the special preparatory courses were attended by young women of varying ages. One of the youngest members of her class, Iris Runge cultivated close relationships with a number of her fellow classmates, including Anna Goslar,⁵² who was one year her senior and who would later become a medical doctor; Elisabeth (Putti) Klein, the youngest daughter of the mathematician Felix Klein,⁵³ who would go on to be a school director; and Cora Berliner,⁵⁴ who became a professor of economics in Berlin and, in addition, the first woman to work as a high-level government official (*Regierungsrätin*) in Germany's history. Iris Runge was also a close friend of Hedwig (Hedi) Ehrenberg,⁵⁵ three years her junior, who was the daughter of the Göttingen law professor Viktor Ehrenberg and who, in 1913, would marry the physicist Max Born.

Almost from the beginning, this small group of pupils agreed upon the common goal of pursuing a doctoral degree. They were inspired to this end by the success of former Hanover pupils who were now on their way to becoming "doctors." Their role models included future medical doctors – Dora Wedde and Luise Brinck⁵⁶ – and the philologist Eva Rotzoll, whose father was the president of the Royal Monastic Chamber (*Königliche Klosterkammer*) of Hanover.⁵⁷ In any case, their goal was largely fulfilled. In 1913, Anna Goslar earned her doctorate under a

51 See HEINSOHN 1996, p. 152.

52 Written between 1904 and 1915, thirty-one letters and three postcards from Anna Goslar to Iris Runge are archived in [STB] 692.

53 For biographical information on Elizabeth Klein (later Staiger), see TOBIES 2002b, 2008e.

54 Both born in Hanover, Iris Runge and Cora Berliner would also maintain close contact in Berlin (see Section 4.3.2).

55 Iris Runge and Hedi Ehrenberg later studied mathematics together in Göttingen; for photographs of the two, see Plate 6 at the end of the book.

56 Dora Wedde (later Jörgensen-Wedde) descended from an Uelzen family; Luise Brinck died of a work-related illness (scarlet fever) in 1912.

57 See [STB] 692, p. 13. Eva Rotzoll was awarded a doctoral degree from the University of Heidelberg for a dissertation entitled "Das Aussterben alt- und mittelenglischer Diminutivbildungen im Neuenglischen" [The Disappearance of Old and Middle English Diminutive Forms in Modern English].

renowned pathologist in Freiburg.⁵⁸ Their elder classmate Anna (Annie) Huffelmann, who was born in 1872, defended a dissertation in history and became a lecturer in Hanover.⁵⁹ Cora Berliner, who studied under the economist and cultural critic Eberhard Gothein in Heidelberg, was awarded a doctoral degree with the highest honors.⁶⁰ Although Iris Runge would not achieve this academic rank until 1921, it is clear that she had made it her goal from an early age.

Another important group norm was the notable religious tolerance that prevailed among the classmates. This tolerance was manifest, for instance, in Iris Runge's friendship with her Jewish classmate Anna Goslar, who had attended a girls' school in Celle (her birthplace) before enrolling in the special courses in Hanover. With her, Iris Runge continued the discussions – begun in her “Plato Society” – about the nature of virtue, and she developed a more critical stance toward society. One letter by the seventeen-year-old Anna Goslar, written in response to the news that Iris Runge would have to interrupt her coursework, reveals a good deal about latter's general character and literary disposition:

[...] You have meant *so much* to me during the two years that we have been together, and I am incapable of expressing how much you will be missed. From you I have learned how to formulate judgments about so many things; you have enlightened me about the works of so many fabulous poets and encouraged me delve more deeply into their beauty in order that I might better understand them. Along with your sound judgment, your confident feeling for all that is good and beautiful has brought clarity to several questions, the answers to which I had sought in vain without you. Your remarkable talent as a poet and, above all, a story teller have afforded me many pleasant hours.⁶¹ Now, since the hour of your departure is near, I am compelled to spill my heart to you once again.

Initially I was disappointed when I arrived in Hanover. At my former school I had been the best in my class, and yet here I found myself feeling incredibly stupid. Later I noticed, however, that I was not the least intelligent, and this realization somewhat restored my confidence. When I then met you, and came to learn your sound opinions about your own worth and value, my own attitude toward life also seemed to fall into place. – I am Jewish, and we have so often discussed the groundless affronts that Jewish people have had to suffer in all aspects and affairs of life. Yet I have to repeat to you once again how relieved I was to have left my former school, where I was often ridiculed and insulted by my classmates, and to

58 Anna Goslar's dissertation, written under the supervision of Ludwig Aschoff, was entitled “Das Verhältnis der lymphocytären Zellen in den Gaumenmandeln vor und nach der Geburt” [The Proportion of Lymphocytic Cells in the Palatine Tonsils before and after Birth].

59 Annie E. Huffelmann's dissertation was published as *Clemenza von Ungarn, Königin von Frankreich* [Clemenza of Hungary, Queen of France] (Berlin: W. Rothschild, 1911).

60 Cora Berliner's thesis was published as *Die Organisation der jüdischen Jugend in Deutschland: Ein Beitrag zur Systematik der Jugendpflege und Jugendbewegung* [The Organization of the Jewish Youth in Germany: A Contribution to the Systematic Study of Youth Services and Youth Movements] (Berlin 1916). Her research was inspired by Emil Lederer, who emigrated in 1933 and co-founded the famous “University in Exile” at The New School for Social Research in New York City.

61 Regarding Iris Runge's literary activity, she wrote poems, short stories, and satirical novels, among other things. I mention these works periodically in the book – and I have even found occasion to reproduce some of her poems – but it would have taken me too far afield to analyze them at length.

have found myself here among a circle of unprejudiced and free-thinking people. That I am a Jew, in my heart and soul, either despite or perhaps even because of the offenses I have suffered – this much you know. Perhaps there is a good dose of desire in me, as there is in many people, to become a martyr, but I can say with certainty that I feel especially drawn to my disdained and tormented people. I will do everything in my power to help us procure a respected status in society [...].⁶²

Since the middle of the nineteenth century, Jewish women had occupied important positions in the German women's movement,⁶³ and Anna Goslar indicates some of the motives for this engagement. Like many Jewish women, she regarded education as the chief instrument of social change. She believed that women should be well-educated in the arts, sciences, and in business, and that they should take pains to oversee their children's upbringing:

Thus I hope to demonstrate that a university education is indispensable to us. If a woman chooses not to marry, she would then be able to support herself with her scientific career no less than her many male colleagues do with theirs. If she does marry, however, then she would be able to use her learning – now more than ever – for the benefit of humanity.⁶⁴

For her part, Iris Runge wrote this about the influence of her Jewish friend:

In the spring of 1902 I enrolled in the preparatory courses for girls and thus entered a new and very small circle of talented and ambitious classmates, all of whom were older than I (and some of them significantly so). I soon befriended Anna Goslar, with whom I held long and almost daily discussions about nearly all the matters that we were capable of discussing. She was the first Jew with whom I developed a close relationship, and from her I was able to experience something of the Jewish disposition and manner. Everything she told me about the small slights that she had been subjected to as a Jew strengthened my passionate repudiation of anti-Semitism. Other social problems were also brought to light during my conversations with Anna; this was largely on account of her insights, for she had much more exposure to life than I did, given that I lived almost entirely in books. Crime, prostitution, marital problems, and the like, were all touched upon in our discussions, and the awareness that such things existed colored our outlook with an occasionally exaggerated pessimism. We thought we were witnessing the deep injustices of the prevailing social system, against which we felt aligned with the revolutionary campaigns of the day.⁶⁵

From an early age, these representatives of the first generation of academically trained women struggled with the social problems of their time. Their notions of value and appropriate conduct, which began to develop during their school days, provided the foundation for their later student activism and for their political engagement after the First World War (see Section 2.6).

62 [STB] 692, pp. 2, 2v (the letter is dated November 9, 1904).

63 See Uri R. Kaufmann, "Jüdische Mädchenbildung," in KLEIN/OPITZ 1996, vol. 2, pp. 99–112.

64 [STB] 692, p. 3.

65 [STB] 772 (undated). Anna Goslar, who worked as a medical doctor in Berlin, died in 1916 after having suffered through an ear disease, two operations, and meningitis; see the letter from Iris Runge to her mother dated November 11, 1916 [Private Estate].

2.2.2 General Education

In Hanover, most of the subjects of the girls' preparatory curriculum were taught by older male instructors from the local school district. English was the only class that was taught by a woman. Especially inspiring were their lessons in German literature, which were taught by Ernst Heyn.⁶⁶ One indication of their enthusiasm for the subject is the fact that Anna Goslar, in some of her letters to Iris Runge, opened with "Dearest Caesar" and closed with "Your Brother, Manuel," which are allusions to Friedrich Schiller's drama *The Bride of Messina*. The pupils were also full of praise for Franz Kluge's Latin classes and for the physics and chemistry labs with Paul Bräuer.⁶⁷ The dullness of Wilhelm Briecke's lectures on biology and geography, however, was a regular theme of their letters to one another.⁶⁸

After her hiatus away from Hanover (1905–06), Iris Runge had to take a series of tests in order to re-enroll with her former class. Her account of this experience reveals a good deal about her knowledge at the time:

The teachers were all very nice during the test [...]. First there was English, with Miss Voigt,⁶⁹ which went somewhat poorly because I didn't know a thing about grammar – in the end, however, I was saved by my reading and speaking abilities. Then there was the history test with Prellberg,⁷⁰ which went splendidly; he asked me clear and factual questions, and I knew everything right away (which I'm rather proud of, given that I learned everything on my own). French was extremely easy. Friesland was sweetness itself – he asked me about four questions, each of which I answered correctly, and gave me a grade of *good*.⁷¹ Latin was also quite pleasant; Kluge assured me repeatedly that it was just a formality to test me, that it was altogether unnecessary and so on. Realizing that I had learned quite a lot from Atzert,⁷² I made quick and proper sense of the sentences. I had to translate a few lines from Livy and a few more from Vergil, I answered a few grammatical questions, and then it was

66 Ernst Heyn had been teaching at one of the secondary schools for girls in Hanover – the *Sophienschule* – since 1906 (see [BBF] Personal Profile; [STB] 689, pp. 1–5; 692).

67 Franz Kluge taught at the Kaiser-Wilhelm-Gymnasium (see [BBF] Personal Profile), and Dr. Paul Bräuer was a full-time employee at the boys' *Realgymnasium*, where the girls went to participate in his laboratory classes (see [BBF] Personal Profile; [STB] 692, pp. 6–9).

68 See [STB] 692. As of 1901, Wilhelm Briecke was a senior faculty member at the *Sophienschule* for girls. The results of his examination qualified him to teach only at middle schools and secondary schools for girls (see [BBF] Personal Profile).

69 Anna Voigt was certified as a language teacher in Hanover on February 6, 1899; two months later she began teaching preparatory courses for girls (see [BBF] Personal Profile).

70 As of April 1, 1902, Dr. Karl Prellberg taught history, geography, religion, and Latin at the *Oberrealschule* in Hanover (see [BBF] Personal Profile).

71 As of April 1, 1904, Karl Friesland taught French, Latin, Greek, and Religion at the Hanover *Realgymnasium*; he also wrote several textbooks, including a student edition of Molière's *Les femmes savantes* (see [BBF] Personal Profile).

72 Carl Runge had asked Friedrich Leo, a professor of classical philology at Göttingen, to recommend him a student who might be willing to tutor Iris Runge in Latin ([STB] 514, pp. 175v, 195). The student turned out to be Karl Atzert, who was certified to teach Latin, Greek, and history on July 26, 1907; earned a doctorate at Göttingen in 1908; and became a school director ([BBF] Personal Profile).

over. Heyn tested my knowledge – and Miss Judenberg’s, too⁷³ – of Church history and the Bible, and neither of us knew a thing about either subject. Then he moved on to literature, which went somewhat better. Although I knew less than I should have about Lessing’s contemporaries, he nevertheless graded me as *sufficient*. [...] Bräuer conducted the physics and chemistry tests. Physics went well, Chemistry considerably less so, but he told me that I would catch up soon enough. I was not tested at all in mathematics [...].⁷⁴

The curriculum did not include any instruction in music or the arts, for which private teachers had to be hired. Iris Runge’s extracurricular experiences included an educational trip to northern Italy, in the May of 1905, and drawing classes taught by her aunt, the painter Lucy du Bois-Reymond.⁷⁵ Her letters document her multifarious interests: She played tennis and bicycled regularly,⁷⁶ she learned to play the guitar, she received voice lessons twice a week, and together with Elisabeth Klein she sang in a choir that was directed by Agnes Hundoeegger. The latter was well-known for her refinement of the “Tonic Sol-fa” method of teaching vocal music, which she employed in her instruction of Carl Runge’s children.⁷⁷

Although slightly younger than Elisabeth Klein, Iris Runge was a year ahead of her in school. She not only persuaded Elisabeth Klein to take singing lessons under Agnes Hundoeegger, but she also influenced her decision to study mathematics and physics. Elisabeth Klein enrolled in the Hanover preparatory courses after her graduation from a girls’ secondary school in Göttingen and after two years of private instruction in Berlin. In 1906, she entered the class beneath Iris Runge’s, and the two of them lived together in a boarding house.⁷⁸ During this particular school year, however, the members of Iris Runge’s class (the so-called *Oberprima*) and those of the class beneath her (the *Unterprima*) were taught in common. In addition to the time that they spent together outside of school, that is, Iris Runge and Elisabeth Klein also shared classes in mathematics, physics, Latin, English, French, and religion. Only German, history, and chemistry were taught separately to the two groups.⁷⁹

73 Johanna Judenberg, one of Iris Runge’s classmates, was the daughter of a Lutheran engineer from Braunschweig. She later became a lecturer of French, English, and Geography (see [BBF] Personal Profile).

74 A letter from Iris Runge to her parents dated April 22, 1906 [Private Estate].

75 Along with her aunt Estelle (Dolly), Iris Runge traveled to Italy by way of Frankfurt (where they visited the Goethe Museum), Worms, and Strassburg. In Italy she toured Milan and its surroundings, where her mother was taking a rest cure (see [STB] 663). The drawing classes took place in April of 1906; they were also attended by Hedi Ehrenberg; Elli Husserl, daughter of the philosopher Edmund Husserl; and by Professor Gustav Tammann’s eldest daughter, Edith, who would marry the geophysicist Gustav Angenheister in 1914.

76 It was at this time that bicycling began to gain popularity. In 1899, Carl Runge began to ride his bike every day to the Technical University in Hanover, which was ten kilometers from home (see Iris RUNGE 1949, p. 101).

77 See Agnes Hundoeegger, *Leitfaden der Tonika-Do-Methode für den Schulgebrauch* (Hanover: Tonika-Do-Verlag, 1897; repr. 1967); and Iris RUNGE 1949, pp. 104–105, 129.

78 They lived together in the house of a certain Miss Bräuer, on Wiesenstraße 4 in Hanover (see [STB] 670).

79 See [STB] 692, pp. 41–42.

2.2.3 “Our Mathematical Genius”

Iris Runge’s reputation as a strong mathematician had spread early on throughout her school. About the mathematics instructor Otto Krüger,⁸⁰ who had a position at the Lutheran *Oberrealschule* in Hanover, she reported to her parents:

Krüger had simply left the building, saying: Miss Runge does not need to be tested! And he had never even taught me before! At first I thought he would test me the next day, but he never came, and by now we have already had one math class. I think that I’m just as far along as the others; at least I have already learned some analytic geometry from Dad, and that is what we are just beginning to work on now – slowly and cautiously at that.⁸¹

Krüger, it should be said, could not be counted among his reform-minded colleagues. Iris Runge and Elisabeth Klein had not only been tutored by their fathers, but also by the Göttingen teachers Otto Behrendsen and Eduard Götting, who had been active in the curricular reforms that were still underway with regard to mathematics and the natural sciences – the so-called *Meraner-Reform* of 1905 – and who had also written new textbooks along those lines.⁸² This new method of teaching considered the concept of the function to be a fundamental principle; it favored analytic over synthetic geometry; it promoted the teaching of basic calculus; and it encouraged pupil-centered experiments. Having been exposed to this approach, the young women were rather critical of Krüger, who still preferred to teach according to the old techniques. Elisabeth Klein wrote:

I have been bored stiff in my other classes, and especially in mathematics. I’m telling you, it’s absolutely dreadful; his entire approach gets on my nerves. I hardly noticed this before because we were together and could occasionally chat with one another, but now!!! [...] We treat parabolas synthetically. The whole class consists of him reading sentences out of the book. Now that’s teaching! And if one happens to know everything already – to flip through Müller-Hupe’s textbook is enough to know everything in advance – then it’s all the more horrible! What should I do to kill the time!⁸³

Not all of her classmates, of course, were this gifted in mathematics. About the results of one of their mathematics assignments, for instance, Anna Goslar wrote:

80 Otto Krüger was certified to teach mathematics, physics, zoology, botany, geography, gymnastics, and swimming; see [BBF] Personal Profile; and KUNZE 13 (1906), p. 140.

81 A letter dated April 22, 1906 [Private Estate].

82 See Carl Runge’s letters to his wife – dated July 12, 1905 and July 15, 1905 – in [STB] 514, pp. 196v, 197. The textbooks in question are: Otto Behrendsen and Eduard Götting, *Lehrbuch der Mathematik nach modernen Grundsätzen A: Unterstufe* (Leipzig: B. G. Teubner, 1909); *Lehrbuch der Mathematik nach modernen Grundsätzen B: Für höhere Mädchenanstalten* (Leipzig: B. G. Teubner, 1911); and *Lehrbuch der Mathematik nach modernen Grundsätzen C: Für sechsklassige Realanstalten, Oberstufe* (Leipzig: B. G. Teubner, 1912).

83 A letter to Iris Runge dated May 7, 1907 [STB] 689, pp. 3, 3v. The reference to Müller-Hupe is to Heinrich Müller and Albert Hupe, *Synthetische und analytische Geometrie der Kegelschnitte, darstellende Geometrie* (Leipzig: B. G. Teubner, 1902); see also LIETZMANN 1909, pp. 38–41.

Last week our work turned out to be rather shabby. In mathematics, Lene [Rath], Irene, and Miss H[uffelmann] each earned a 4, while Grete and I were given a 3. (Considering that I am currently the best pupil in arithmetic, you now have some idea about *how bad* the others must be.) You're sorely missed!⁸⁴

Later she reported: "Mathematics is dreadful. Lene and I received a 4, Miss H.[uffelmann] a 3.5, and Irene a 3. Now we're reviewing trigonometry, goniometry, and stereometry."⁸⁵ Iris Runge was regarded as a mathematical genius by her circle of friends:

I come to you, our mathematical genius, as a humble lamb. On top of having to write a class project about mathematical series and a German essay, we also have to solve four mathematical problems by next Monday. The problems are as follows:

- I. Given the position of the axis and two tangent lines to a parabola, determine its focus, vertex, and points of tangency.
- II. Construct a triangle given one side, its height, and the ratio of the midpoints of the two other sides ($c, h_c, t_a : t_b = m : n$).
- III. Construct a triangle given the sum of two sides, the difference of the projections of these two sides on the base, and the angle that they form.
($a + b = 221$ m; $p - q = 17$ m; angle $\gamma = 80^\circ 28' 22''$)

The fourth problem I figured out on my own (whether I did so correctly is another matter). The third problem has been tormenting me to death, as has the second. The first I haven't even dared to attempt. And so now I have come to you with a rather shameless plea for help and direction regarding these few calculations.⁸⁶

Iris Runge was more than willing to lend a hand, and all of the young women in her class went on to pass their qualifying examinations at a boys' secondary school in Lüneburg (the famous *Johanneum*). They had no say over where they could take the examination; the matter was predetermined by the school board in Hanover. Because it has been rather unclear what the procedure of external examination actually entailed, Iris Runge's letter to her parents about this occasion, which also reveals something about the attitude of the male examiners toward women's education, is a particularly valuable source of information. For the opportunity to extend their education, nine young women traveled by train from Hanover to Lüneburg, where they occupied the third floor of a local hotel (Iris Runge shared a room with Anna Goslar):

We have checked into a hotel (at six Marks a day) for at least six days, however the case may be. All of us have been eating together in a private dining room, which has been very pleasant. Yesterday was especially amusing; we talked about nothing but the exam – and thus I broke a personal rule of mine that forbids such conversation – but the topic simply could not be avoided. Yesterday morning, all nine of us visited the school director and the teacher who will test us in German literature. The two of them, who were extremely uptight and dismissive, are clearly opposed to women's education. This is a pity, for the German

84 A letter dated September 23, 1905 and archived in [STB] 692, p. 19. Regarding grades, 1 was the best and 5 the worst. The classmate referred to as Grete is Margarethe Schrödter, who was born in Einbeck and whose father owned a printing press.

85 A letter dated February 1, 1906 and archived in [STB] 692, p. 46.

86 A letter from Anna Goslar to Iris Runge dated December 5, 1905 ([STB] 692, pp. 32–33).

teacher seemed to be a distinguished old gentleman, both conscientious and humane. Well, perhaps we'll be able to enchant him somehow – he is the history examiner, too, and I will need to be treated as kindly as possible during that test (especially because he seems to be such a distinguished history teacher). This morning we took the written component of the test, which did not go very well. Both the director and the teacher were even more inapproachable and haughty than they were during our visit, and this put us all in a dour mood; [...] yesterday evening, moreover, our hotel held a holiday celebration – commemorating the emperor's birthday – and we stayed up late talking and reveling, so that hardly any of us had a good night's sleep. Thus this morning we were all in poor spirits – tired and spent – and our essays could not have benefited from this. The topic was: In what ways was the invention of the printing press one of the greatest advancements of human culture? That is a terribly broad theme, not to mention a little boring, but anyway [...].⁸⁷

Whereas the school director and the German and history teacher were plainly unsupportive of women attending universities – a fact, incidentally, that did not prevent them from giving Iris Runge high grades – the mathematics teacher cordially welcomed the studious young women. He also happened to be a proponent of the curricular reforms mentioned above, which Iris Runge referred to as “[Felix] Klein's reforms”. As was customary, the examinees visited the home of the mathematics teacher, Dr. Heinrich Möller,⁸⁸ before the day of the examination:

We split into two smaller groups to visit the mathematics teacher. It was a very nice visit, for he is an amicable person who spoke very kindly to us and even had a sense of humor. His name is Möller and, having studied mathematics in Berlin, he knows all about you, Dad. Though he is fairly young, he is, as it seems, a very capable mathematician. I have heard that, since Möller arrived, all the other teachers complain that their pupils have time for nothing but mathematics. He is enthusiastic about Klein's reforms – he prefers graphical methods and has begun to teach his current class the basics of differential calculus. I'm happy that I will be tested by such a person; it will be difficult, admittedly, but all the more rewarding. If for no other reason than that he knows Dad, he has taken an interest in me, and I hope that I can live up to his expectations. Compared to the other teachers, at least, he is truly magnificent. [...] His wife welcomed us inside with a few affable remarks – “You must be the examinees. Are you terribly anxious about the tests?” and so on – and he told us about his pupils and about how difficult it had been for him to come up with problems for our examination. Soon we felt very much at ease, especially after having had to deal with those two grim curmudgeons, the director and the German teacher.⁸⁹

87 A letter to her parents dated January 28, 1907 [Private Estate]. As of April 4, 1902, the director of this secondary school was Dr. August Nebe, a certified teacher of Latin, Greek, German, and religion (see [BBF] Personal Profile). The teacher of German was Albert Treuding, who also taught Latin, Greek, religion, and history (see [BBF] Personal Profile). Iris Runge received a grade of *very good* for her written German examination, and a grade of *good* for history; see her secondary school certificate in [STB] 747, pp. 8–9. Regarding the holiday, Kaiser Wilhelm II's birthday was celebrated on January 27.

88 As of April 1, 1894, Heinrich Möller taught mathematics, physics, chemistry, geography, and French at the *Johanneum* secondary school in Lüneburg. He had taken his teaching examinations in Rostock, where he had also been awarded a doctoral degree, in 1887, for a dissertation entitled “Zur Transformation der Thetafunktionen” [On the Transformation of Theta Functions] (see [BBF] Personal Profile).

89 Quoted from a letter dated January 28, 1907 [Private Estate].

It was far from ordinary that Möller was teaching his pupils the basics of calculus, for there had been serious deliberations about whether this should be done. Engineers and scientists argued that students should not have to wait until their university years to be taught differential and integral calculus, and Felix Klein had wholeheartedly supported this idea. Many secondary school teachers, however, considered these subjects to be beyond the scope of *general* education. On account of this opposition, the *Meraner Reform* of 1905 declared calculus to be a recommended – but not required – component of the new curriculum.⁹⁰

Already familiar with these elements of reform, Iris Runge was beaming with self-confidence. She closed her letter from January 28, 1907 with the words: “Many greetings! My poor classmates have been grumbling somewhat, whereas I alone – ever the odd one out – am laughing, confident of having passed the exams! Yours, the Oddball.”⁹¹ According to her secondary school certificate, she received the grade of *good* in mathematics, English, and Latin; *very good* in physics (on the written component); and *sufficient* in religion, French, geography, chemistry, and the natural sciences.⁹²

In his epistolary diary, Carl Runge proudly reported that his eldest daughter had successfully passed her qualifying examinations and that she intended to study mathematics and physics in Göttingen.⁹³ She did indeed go to Göttingen, and there she found herself at one of the foremost centers of research for her chosen fields. Before moving on, it will be fitting to describe how the University of Göttingen acquired this elite status.

2.3 EXCURSUS: THE DEVELOPMENT OF GÖTTINGEN INTO THE PRUSSIAN CENTER OF SCIENCE AND MATHEMATICS

The establishment of centers of teaching and research was one of the consequential structural changes that were made at German universities during the final third of the nineteenth century. The reasons for this particular change include the dramatic developments of science itself as well as the rapid economic and industrial growth of the country, both of which resulted in the need for a new policy of higher education. As the largest German federal state, Prussia had the most universities (see Section 1.2.1), and in Germany there were no private institutions of higher learning. Because of limited financial resources, low tax revenues, high

90 It was not until 1925 that differential and integral calculus became obligatory subjects at secondary schools (see TOBIES 2000).

91 [Private Estate]. Here, in the original German, Iris Runge twice refers to herself as *Tschutschr*, an invented word that was probably formed in imitation of Slavic words meaning ‘strange’ (thus the translations “odd one out” and “Oddball”).

92 See [STB] 747, pp. 8–9.

93 See the diary entry dated April, 9, 1907 in HENTSCHEL/TOBIES 2003, p. 163.

military expenditure, and the growing costs of equipping scientific institutions, the state was incapable of developing all universities in a uniform manner.⁹⁴

The influential official Friedrich Althoff, who began working in the Prussian Ministry of Culture in 1882, was a proponent of establishing centers according to existing traditions of excellence, and this he did. With Althoff's endorsement, a center of mathematics and physics was created in Göttingen; Protestant theology was promoted in Halle-Wittenberg; the study of classical antiquity, history, and fine art in Berlin; Netherlandic studies in Bonn; Scandinavian languages in Kiel; Slavic studies in Breslau; historical sciences, archival studies, and German dialectology in Marburg; and centers of experimental therapy and hygiene were established in Marburg and Frankfurt.⁹⁵ At this time, all Prussian (non-technical) universities consisted of four faculties: theology, medicine, law, and philosophy, the latter including history, philology, science, and mathematics. Given the existing strengths of the different universities, it made sense to promote and develop focused centers of research and teaching excellence.

Empirical scientific research had long played an important role at the Georgia Augusta University in Göttingen, which was founded in 1737. The physicists Georg Christoph Lichtenberg and Wilhelm Weber, not to mention the chemist Friedrich Wöhler, had all been active there. Through the work of Carl Friedrich Gauss, pure and applied mathematics acquired a place of prominence at the university that would further be strengthened by the achievements of Johann Peter Gustav Lejeune Dirichlet and Bernhard Riemann.

This chapter will illustrate how new subjects such as physical chemistry, geophysics, applied electricity, and applied mathematics and mechanics – among others – were established at Göttingen around 1900, also how the establishment of the research center at Göttingen proved to be a complicated process. In this regard, the decisive factor was Althoff's policy of encouraging the appointment of visionary scientists to Göttingen, scientists who both embraced his ideas and were able to implement them. His confidants in Göttingen included the mathematician Felix Klein, the economist Wilhelm Lexis, and the philologist Ulrich von Wilamowitz-Moellendorff.⁹⁶ Together, they designed new approaches for attracting young researchers from Germany and abroad.

94 This section is based on TOBIES 2002a.

95 See VOM BROCKE 1991. Althoff was the leading politician in the Prussian Ministry of Culture and far more influential than the various ministers of culture who came and went throughout his tenure there. He had direct access, moreover, to Kaiser Wilhelm II, the last emperor of Germany and the King of Prussia.

96 In 1887 Lexis became the chair of national economics at Göttingen. As of 1893, he additionally worked as an "external assistant" to Althoff in the Prussian Ministry of Culture, for which he organized a number of different projects, including extensive data compilations about German universities (1893), the reform of secondary education in Prussia (1902), and the reform of education in Germany at large (1904). On the work and influence of Ulrich

2.3.1 Felix Klein's Initiative to Create a Center of Mathematical and Scientific Research

Having been a full professor at the University of Erlangen, the Technical University in Munich, and the University of Leipzig, Felix Klein joined the University of Göttingen on April 1, 1886. He had gained international recognition with his significant achievements in the fields of geometry, algebra, and the theory of functions, and he had established a scientific approach to mathematics that was adopted by mathematicians both in Germany and internationally.⁹⁷ In 1881–82, in competition with the French mathematician and theoretical physicist Henri Poincaré, Klein had made important contributions to the theory of uniformization. These findings would be among his most influential. Klein's appointment was made with the hope "of reviving the justifiable pride of the University of Göttingen in its magnificent tradition of mathematics, which dates back to the time of the great mathematician and astronomer Carl Friedrich Gauss."⁹⁸

These expectations were fulfilled in every respect, even if it was difficult, at first, for Klein to implement his ideas. Shortly after arriving in Göttingen, Klein developed long-term strategies for integrating mathematics, the natural sciences, and the technological disciplines.⁹⁹ In a memorandum submitted to the Ministry of Culture in 1888, Klein used convincing examples to illustrate the importance of such interconnections to scientific progress. However, his call for the establishment of an association of universities and technical universities encountered considerable resistance, and his idea of reorganizing the Göttingen Academy of Sciences – to include technical disciplines – was also coldly received. In 1890, Klein managed to persuade his Göttingen colleague, the physicist Eduard Riecke, to bolster his idea of forming a special curriculum for students of mathematics and physics, but the initiative failed to win the endorsement of the mathematician Hermann Amandus Schwarz and the astronomer Ernst Schering.¹⁰⁰

Klein thus began to bypass the faculty and to correspond directly with the influential Friedrich Althoff. In these letters he presented and justified his ideas so persuasively that his proposals were ultimately put into effect. His letters reveal an interest in the general development of mathematics and the natural sciences, as is clear by his efforts to obtain better working conditions for the experimental studies of the psychologist Georg-Elias Müller, by his support for the creation of a new

von Wilamowitz-Moellendorff, see the numerous studies by William M. Calder, especially CALDER/FLASHAR/LINDKEN 1985.

97 See TOBIES 1981. On Klein's American students and his influence on American mathematical research, see PARSHALL/ROWE 1994.

98 [STA] Rep.76 Va Sec. 6 Tit. IV No.1, vol. XI, 313.

99 See MANEGOLD 1970.

100 The proposal is archived in [STA] Rep. 92 Althoff B, No. 92, 73, 73v. It should be noted that both Hermann Amandus Schwarz, who had studied under Karl Weierstraß in Berlin, and Ernst Schering had voted against Klein's appointment to the Göttingen faculty.

institute of geophysics, and by his promotion of the field of physical chemistry.¹⁰¹ Realized during the 1890s, these ideas were already present in the plan that Klein had developed in 1889: “My efforts to convince those involved to prepare a joint report concerning the proposed geophysical institute have failed. In what follows I will thus have to confine myself to describing my own opinion on the matter.”¹⁰² Klein’s goal of combining not only magnetism and meteorology but also the more abstract branches of geology, geography and geodesy into a single institute initially failed owing to a lack of suitable personnel. For decades, meteorology had been part of the physics institute directed by Eduard Riecke, and the geomagnetic observatory was still headed by Ernst Schering. Neither of them was willing to forfeit control over certain areas of study. Klein suggested: “If it is impossible to combine all of these fields, we can still persist in our idea of establishing an independent unit for geophysics without losing sight of our long-term goal.”¹⁰³ This idea would indeed be implemented later on.

In this same letter, Klein alludes to the difficulties involved with establishing the field of physical chemistry in Prussia:

And physical chemistry? I fear that nothing about it, too, can be done here. In principle, all of my colleagues are in agreement about the need, but as soon as talk turns to doing something about it, difficulties arise. Of course, one would assume that a few rooms could be found in our large chemistry laboratory, within which physical chemistry could be installed as an independent unit (independence is my primary concern), but everyone maintains that this is clearly inadmissible.¹⁰⁴

The impulse to establish physical chemistry came from the Prussian Ministry of Culture. Since the mid-nineteenth century, organic chemistry in particular had enjoyed remarkable growth, and thus most chairs of chemistry were held by organic chemists. In 1887, Wilhelm Ostwald was appointed to the chair of physical chemistry at the University of Leipzig.¹⁰⁵ At this time, the electro-chemical industry was in need of appropriately trained chemists, and this need resulted in the 1894 establishment of the German Electrochemical Society (*Deutsche Elektrochemische Gesellschaft*), which consisted of both chemists and members of the che-

101 Geophysics and physical chemistry were among the new fields that Althoff, with Klein’s support, was trying to establish at Göttingen. On the development of the field of geophysics, see GOOD 2000. The term “physical chemistry” was first used in a 1752 series of lecture by Mikhail Lomonosov entitled *A Course in True Physical Chemistry*. Lomonosov intended to investigate the constitution of composed bodies in light of mathematics and physics. In Germany, the first chair of physical chemistry was held by Hermann Kopp at the University of Heidelberg (see SZÖLLÖSI-JANZE 1998, pp. 68, 72).

102 A letter to Althoff dated May 18, 1889 (in [STA] Rep. 92 Althoff B, No. 92, p. 69).

103 Ibid., pp. 69, 69v.

104 Ibid., p. 70v.

105 The American chemist Willis Rodney Whitney, who founded the General Electric Research Laboratory in 1900, had obtained his doctorate under Wilhelm Ostwald at the University of Leipzig in 1896.

mical industry.¹⁰⁶ The society was headed by Ostwald (chairman) and a representative from the Elberfelder Farbwerke [Dyeworks], Henry Theodore von Bötttinger (vice-chairman), both of whom were devoted to establishing a full professorship in physical chemistry at the University of Göttingen. The position was created, and it was accepted by Walther Nernst, an outstanding representative of the discipline who had studied under Hermann von Helmholtz in Berlin and Ludwig Boltzmann in Graz.¹⁰⁷ Nernst conducted his doctoral research under the supervision of Friedrich Kohlrausch in Würzburg and worked as one of Ostwald's assistants at the University of Leipzig, where he completed his *Habilitation*. In 1891 he received an associate professorship at Göttingen, and his early achievements there – in addition to attracting many students from Germany and abroad – played a major role in the foundation of physical chemistry at the university.

In 1894, when Nernst was presented with an opportunity to become Ludwig Boltzmann's successor at the University of Munich, Klein traveled personally to Berlin to negotiate the terms of his retention in Göttingen. His interest in keeping Nernst was particularly strong on account of the latter's sound application of mathematical methods, as had already been showcased in his textbook on theoretical chemistry. Nernst's espousal of mathematics was further demonstrated in another textbook – *Einführung in die mathematische Behandlung der Naturwissenschaften* [The Application of Mathematics to the Natural Sciences: An Introduction] – which was co-authored with Arthur Schönflies. Both works appeared in several German and English editions and helped to elevate the position of applied mathematics during the process of curricular reform that was then underway, both in Germany and elsewhere.¹⁰⁸ Successfully retained, Nernst was appointed full professor of physical chemistry in 1894 and given his own institute, the first institute of physical chemistry in Prussia. In 1897, using an incandescent ceramic rod, he invented the so-called Nernst lamp, an electric lamp that was to be the precursor to the incandescent light bulb. His research was also concerned with osmotic pressure and electrochemistry, and in 1905 he established what he referred to as his "New Heat Theorem." This would later be known as the third law of thermodynamics – it describes the behavior of matter as temperatures approach absolute zero – and its discovery would earn Nernst the 1920 Nobel Prize in chemistry. When he left, in 1905, for a new position at the University of Berlin, Nernst was replaced in Göttingen by Gustav Tammann, a worthy successor.¹⁰⁹

106 See JAENICKE 1994.

107 See BARKAN 1999.

108 See NERNST 1893 (first English edition published in 1904); NERNST/SCHÖNFLIES 1895 (first English edition published in 1900). In 1917, Iris Runge began to use Nernst's textbook on theoretical chemistry for self study (see section 2.6.4). For a general history of mathematics textbooks used at the university level, see REMMERT/SCHNEIDER 2010. In 1891, having been influenced by Felix Klein, Arthur Schönflies used mathematical group theory to demonstrate the existence of 230 crystallographic space groups.

109 See Section 2.7 below.

In 1892, a number of changes took place that served to increase Felix Klein's influence. His major opponent, the mathematician Hermann Amandus Schwarz, left for Berlin and was replaced by Heinrich Weber. With Schwarz out of his way, Klein was free to hire Arthur Schönflies as an associate professor of applied mathematics (descriptive geometry) and also to found, together with Weber, the Göttingen Mathematical Society, which became an important center of communication between mathematicians, physicists, and astronomers. It was also in 1892 that Klein appointed Weber to the editorial board of the famous Journal *Mathematische Annalen*.¹¹⁰ Beginning at that time – and under Klein's leadership – instruction in mathematics and physics was regularly coordinated according to a general plan of studies. Weber supported the trend of incorporating applied mathematics into the university curriculum, and he continued to do so after receiving a professorship at the University of Strassburg.¹¹¹ After Weber's departure, Klein was able to attract the mathematician David Hilbert to Göttingen, something he had long hoped to do. Klein had referred to Hilbert as a rising star as early as 1890, and the latter – who did indeed become one of the leading mathematicians of his day – succeeded Weber in April of 1895.¹¹² An excellent judge of young talent, Klein wrote the following to Althoff on December 22, 1894: "Now that Hilbert has received the full professorship and Nernst has been appointed, I owe you my sincere thanks for both of these men; in them we once again have two young scientists with whose help we should remain at the forefront for years to come."¹¹³

In July of 1892, Klein was offered a chair at the University of Munich, and this offer served to strengthen his position at Göttingen. On July 15, 1892, Althoff, Klein, and the university trustee Ernst von Meier ratified a generous list of pledges, made by the Prussian Ministry of Culture, that encouraged Klein to turn down the offer from Munich. The concessions included a pay raise of 2,000 Marks; financial support for the departmental reading room amounting to 3,000 Marks; a grant of 6,000 Marks (distributed over a period of about 10 years) for the university library to purchase, at Klein's request, literature on mathematics, physics, and astronomy; and a 1,200 Mark increase in the salaries of the assistants who were working at the collection of mathematical instruments and models. Moreover, the concessions included a remarkable organisational instrument for the future, namely a declaration of intent to establish associate professorships of applied mathematics and geophysics, the latter to be converted from Schering's full professorship.¹¹⁴

110 See TOBIES/ROWE 1990.

111 See WEBER 1900.

112 In a letter to Althoff – dated October 23, 1890 – Klein referred to David Hilbert as "the rising man" (in English); see [STA] Rep. 92, Althoff B, No. 92. On Hilbert's achievements and influence, see ROWE 1989, 1997; REID 1996.

113 [STA] Rep.92 Althoff A1 No. 138, p. 19.

114 [STA] Rep.76 Va Sec.6 Tit.IV No.1, vol. 15, pp. 66–67v.

It was also in 1892 that Klein, together with Ulrich von Wilamowitz-Moellendorf – then the rector of the University of Göttingen – managed to restructure the Göttingen Academy of Sciences. The biblical scholar Paul Anton de Lagarde, who died in 1891, had been attempting to do this since 1885, and in his will he left the society a sum of money to be used toward its reorganization.¹¹⁵ With these resources, the Göttingen Academy of Sciences was converted from a local establishment into an organization of international importance; it was the only Prussian academy, for instance, to participate in the International Association of Academies, which promoted large-scale research projects. Among other things, this international cooperation concentrated on projects concerned with measuring gravity, on the bibliographical plans of the Royal Society of Great Britain, on the creation of a botanical station, and also on the monumental undertaking that was the *Encyklopädie der mathematischen Wissenschaften mit Einschluss ihrer Anwendungen* [Encyclopedia of Mathematics and its Applications].¹¹⁶

Felix Klein's trip to America, undertaken in the fall of 1893, left him with insights that he would apply toward expanding the institutions at Göttingen and also toward promoting the admission of women to the university. While abroad he attended the Chicago World's Fair (the Columbian Exposition). One of the exhibition halls constructed for this event was the so-called Women's Building, which was designed by the architect Sophie Hayden, and among its diverse participants were the Westinghouse Electric Company and General Electric. German industries were similarly well represented, and there was also an exhibit devoted to universities and schools that featured mathematical books and instruments. In Chicago, too, Klein also took part in an international congress of mathematicians.¹¹⁷ In a letter to Althoff dated December 10, 1893, Klein elaborated upon his ambitions, which included granting women the right to study, increasing the number of students of mathematics and the natural sciences, and enhancing the collaboration between mathematicians, scientists, and engineers. These ideas were intimately connected, for it would have been unrealistic to establish a center of science and mathematics without a sufficient number of students. Klein wanted the new degree to enable its holders "to take up a practical profession instead of teaching, should the need arise."¹¹⁸ He considered it vital to establish closer ties with the engineering disciplines; believing that the "task of the technical universities, as they see it, is restricted to giving the masses an average education," the University of Göttingen should provide supplementary scientific education that would include, "in addition to our lectures on mathematics and physics, lectures on advanced ques-

115 LAGARDE 1894, pp. 164–191. It should not go unmentioned that Lagarde's anti-Semitism contributed to a foundational aspect of National Socialist ideology.

116 This ENCYCLOPEDIA also exists in a French edition; the plan to produce an English translation, however, never materialized (see TOBIES 1994a).

117 See E. H. Moore et al., eds., *Mathematical Papers Read at the International Mathematical Congress Held in Connection with the World's Columbian Exposition, Chicago, 1893* (New York: Macmillan, 1896); and PARSHALL/ROWE 1994.

118 [STA] Rep. 92, Althoff B No. 92, p. 94v.

tions of engineering and technology.”¹¹⁹ Klein changed his own lecture program accordingly to address matters of technical mechanics and descriptive geometry. His lectures on the theory of the top (*Kreisel*), for instance, which were further developed by his assistant Arnold Sommerfeld, are renowned.¹²⁰

Only two days after receiving Klein’s letter, Althoff replied:

“[...] I fully agree with what you have written about the admission of women. As to the teaching candidates, I will discuss this matter with our department of secondary education. I also concur, at first glance, with your remarks about interacting with engineering, and Göttingen does strike me as being very suitable for a trial in this regard. But all of this, as you mention yourself, must be considered in detail and can only be implemented if the financial situation allows for it.”¹²¹

Regarding the right of women to study, Klein managed to receive unprecedented permission from the Prussian Ministry of Culture to allow two American women and an Englishwoman – Mary F. Winston, Margaret E. Maltby, and Grace Chisholm, respectively – to enroll in coursework at the University of Göttingen. The three began their studies in the winter semester of 1893, and two years later each of them was graduated with a doctoral degree – Winston’s and Chisholm’s in mathematics (under Klein), and Maltby’s in physics (her research was inspired by Nernst but officially directed by Eduard Riecke). Altogether, Klein supervised approximately fifty doctoral students, including the two women from abroad. David Hilbert was pleased to carry out Klein’s intentions; six of his sixty-nine doctoral students were women. Four of the latter – Lucy Bosworth, an American, and the Russians Ljubowa Sapolskaja, Nadjeschda von Gernet, and Vera Lebedjewa – completed their doctorates before 1907, the year of Iris Runge’s matriculation, and the two other women would finish in 1909.¹²² During Iris Runge’s student years at Göttingen, women also received doctoral degrees there in the fields of applied electricity, theoretical physics, astronomy, organic chemistry, philosophy, and experimental psychology.¹²³

119 Ibid., pp. 94v–95.

120 See Felix Klein and Arnold Sommerfeld, *The Theory of the Top*, trans. R. J. Nagem and G. Sandri, 2 vols. (Boston: Birkhäuser, 2008–10). For further discussion of Sommerfeld’s intellectual circle, see Section 2.5 below.

121 A letter dated December 12, 1893 and archived in [UBG] Cod. Ms. Klein II A, pp. 1–2.

122 On Klein’s and Hilbert’s female doctoral students, see TOBIES 1999. Klara Löbenstein and Margarete Kahn, whose biographies I summarized for *Jewish Women: A Comprehensive Historical Encyclopedia* (TOBIES 2005a), completed their doctorates in 1909; see also KÖNIG/PRAUSS/TOBIES 2011.

123 On the dissertations written by these women, see BOEDEKER 1933. Especially noteworthy is Gertrud Lange, whose dissertation – “Beiträge zur Kenntnis der Lichtbogenhysteresis” [Contributions to the Understanding of Arc Hysteresis] – was supervised by Hermann Theodor Simon and was published in *Annalen der Physik* 337 (1910), pp. 589–647.

Some more time was needed to solve the financial problem of equipping the laboratories that these new disciplines required. While in the United States, Klein had seen how industries provided funding to universities, and back in Germany he endeavored to reproduce this model by creating a novel organization that brought academics and industrialists face to face.

2.3.2 The Göttingen Association for the Promotion of Applied Physics and Mathematics

Referring to their exchange from the previous year, Klein updated Althoff on the “development of the facilities at Göttingen with regard to technical physics.”¹²⁴ Conscious of the limited amount of state funding and inspired by what he had seen in America, Klein did not wait for Althoff to make any financial concessions; instead, he went straight to industrialists without the ministry’s knowledge:

I spent a few days in my home town [Düsseldorf] and have brought about a new turn of events that I am eager to report right away. Convinced that industry itself must have a very strong interest in the matter, I contacted certain outstanding industrial leaders and have thus managed to organize a committee, the purpose of which is to secure material support for our goals.¹²⁵

This committee included Emil Schröter from Düsseldorf (the director of the Association of the German Iron Industry), the aforementioned Henry Theodore von Böttinger (a member of the Prussian parliament and the director of the Elberfelder Dye Works), Wilhelm Beumer (the general secretary of the Economic Union for Rhineland and Westphalia), Professor Otto Intze of the Technical University in Aachen (the chief engineer of the dam at Remscheid), Adolf Kirdorf (a steel industrialist and former schoolmate of Klein), and Fritz Asthöwer (the technical director at the Krupp Steel Company in Essen).

Later kept abreast by Klein, Althoff wholeheartedly endorsed these new methods of financing research. To Böttinger he declared his intention of developing Göttingen into an “emporium of science.”¹²⁶ In order to win the support of industrialists, Klein initially cited practical scientific problems and deliberately downplayed the issue of education. He stated: “First of all it is a question of the physical characteristics (elasticity, stability, etc.) of crystals, then of solids in general, in their reciprocal dependence and in their relationship to the chemical constitution. From these men I would like to request 100,000 Marks, distributed over a period of five years, to investigate this question. Of course, this would only be the beginning; more funding would have to follow as soon as any initial success has been achieved.”¹²⁷ But these arguments failed to attract a sufficient number of sponsors;

124 A letter to Althoff written in March 1894 (in [STA] Rep. 92 Althoff A 1 No. 138, p. 2).

125 [STA] Rep. 92 Althoff A 1 No. 138, pp. 2v–3.

126 [STA] Rep. 92, Althoff C 14.

127 A letter to Althoff dated March 24, 1894 (in [STA] Rep. 92, Althoff A1, No. 138, pp. 2–2v).

moreover, they failed to dispel the reservations of both the technical universities and the Imperial Institute of Technical Physics (*Physikalisch-Technische Reichsanstalt*), both of which were concerned that the University of Göttingen might become a competitor.¹²⁸ These failures encouraged a change of tactics, and thus Klein began to place greater emphasis on teacher training and on the creation of new career possibilities for students of applied mathematics.

The years 1894 to 1896 were marked by the continued expansion of the facilities in Göttingen, and the fact that Klein and Wilhelm Lexis served as the deans of the philosophical faculty during this period is largely responsible for the growth. In this regard it was also auspicious that, in the spring of 1894, Ernst Höpfner was appointed the new trustee of the university. Höpfner, who had previously been an official at the Ministry of Culture, was receptive to the plans of expanding the Göttingen center of science and mathematics and supportive of increasing the contact between science and industry.¹²⁹

Klein began to cultivate a relationship with the Association for the Advancement of Mathematical and Scientific Education (*Verein zur Förderung des mathematischen und naturwissenschaftlichen Unterrichts*), founded in 1891.¹³⁰ He first attended their annual meeting in 1894 with the aim of interesting secondary school teachers in the burgeoning institutes at Göttingen, and he managed to convince the Association to hold its next convention there. In an address, Klein extolled Göttingen's outstanding facilities, its well-planned lecture programs, and the scope of its mathematical and scientific teaching and research. About mathematics he added: "At most universities, one or another of the mathematical disciplines stands at the center of things [...]. At Göttingen, the characteristic approach to mathematics is rather different. We aim to understand science, no matter how multifarious it may be, as an inseparable whole whose individual components are always interacting with one another. In Göttingen, mathematics maintains direct contact with the related disciplines of astronomy, physics, and so on."¹³¹

An attempt was soon made to establish a department of technical physics. In December of 1894, Klein wrote a new memorandum, this time together with Nernst, to attract the interest of industrialists from the chemical sector and to win support from the Krupp Company. The correspondence between Klein, Althoff, and Krupp reflects both the reservation of industrialists and the skepticism of technical scientists and engineers; however, it also illustrates the persistence and inventiveness with which Klein and Althoff attempted to secure financial donations from industrial leaders. In the end, Klein recommended that a technical physicist be appointed "discreetly" to teach mechanical engineering courses at the

128 On this subject and on the so-called anti-mathematical movement among professors of engineering at technical universities, see HENSEL et al. 1989.

129 See MANEGOLD 1970, p. 177. Arnold Sommerfeld, who has already been mentioned, became Klein's assistant in 1894. He married Ernst Höpfner's daughter, Johanna.

130 See TOBIES 2000.

131 KLEIN 1895, p. 5.

agricultural institute, someone who could possibly develop technical physics under Riecke at the same time.¹³² This is precisely what the Ministry did. With the close involvement of Klein's former colleague Carl von Linde, who had given up his professorship at the Technical University in Munich to found a refrigeration company (Linde AG today), Richard Mollier was hired in 1897 "with the expressed aim of procuring the anticipated Böttinger-Linde donation [...]."¹³³ The honorary doctoral degrees awarded to Linde and Böttinger in June of 1896 are also indicative of the efforts made to attract the financial support of wealthy individuals.¹³⁴ Around Christmas of that year, Böttinger, Linde, and the locomotive manufacturer Georg Krauss promised to contribute 20,000 Marks, a donation that would form the cornerstone of technical physics at Göttingen. Richard Mollier used this funding to start a laboratory for general technical physics, a project that was continued by Eugen Meyer and Hans Lorenz and later became, under the direction of Ludwig Prandtl, the Institute of Applied Mechanics.

During this same period, an electrical laboratory was inaugurated and run by Theodor Des Coudres, who had been an associate professor of applied electricity at Göttingen since 1897.¹³⁵ Under Hermann Theodor Simon, this laboratory evolved into the Institute for the Applied Science of Electricity. In 1899, he discovered that one of his inventions, the so-called "singing arc," could successfully function as a microphone, and with Max Reich he developed a system of radio telephony.¹³⁶

Finally, on February 28, 1898, the Göttingen Association for the Promotion of Applied Physics (*Göttinger Vereinigung zur Förderung der angewandten Physik*) was established, and in December of 1900 it was expanded to include applied mathematics. Böttinger was made the chairman and Felix Klein the vice-chairman of this association, the purpose of which was to provide financing for the establishment of new scientific institutes. In addition to professors at the University of Göttingen (see Table 2), the Association included fifty powerful individuals as supporting members, among whom were well-known representatives of the chemical, electrical, steel, and iron industries from all of Germany.¹³⁷

132 [STA] Rep. 92, Althoff A1, No. 138, p. 158v.

133 [STA] Rep. 76 Va Sec.6 Tit.IV No.1, vol.XVI, pp. 401, 401v.

134 See MANEGOLD 1970, p. 165.

135 KLEIN 1900, p. 8.

136 The English electrical engineer William Duddell, who is famous for the invention of the oscillograph, invented a similar singing arc lamp at the same time. There is also the famous case of Hertha Ayrton (née Marks), an English engineer, mathematician, and inventor who conducted substantial research on the electric arc and established the formula for the inverse proportionality between arc amperage and voltage known as "negative resistance." She was the first woman to be made a member of the Institution of Electrical Engineers on the basis of her research (see *Jewish Women: A Comprehensive Historical Encyclopedia* 2005).

137 See MANEGOLD 1970, p. 176. In 1921, the Göttingen Association for the Promotion of Applied Physics and Mathematics was absorbed by the Helmholtz Association for the Promotion of Physical and Technical Research (*Helmholtz-Gesellschaft zur Förderung der physikalisch-technischen Forschung*).

Anton von Rieppel, an engineer and industrialist, described the founders' aims as follows:

In addition to Mr. Von Böttinger, the founders of the association from the industrial sector included several engineers, namely director Schmitz from the Krupp Company, Professor Von Linde, the distinguished industrialists Krauss and Kuhn,¹³⁸ and myself. In his presentations, Klein set forth the following goals for our enterprise:

1. To strive above all for the improved training of future teachers.
2. To enhance the research conducted in the applied sciences.
3. To influence the politics of higher education in such a way that universities restore their former concern with practical exigencies.

We agreed unanimously that the first point was the most important, for we had repeatedly been confronted with young engineers who had to overcome their insufficient and impractical training and learn things on the job that, in our opinion, they should have been exposed to at university. Such a system greatly hinders the professional effectiveness and advancement of engineers, and it was the improvement of this situation that most motivated the formation of our alliance in Göttingen.¹³⁹

Over time, the Association became more and more reluctant to grant funds without government participation. By 1906, scientific initiatives at Göttingen had received 220,900 Marks from the Association alongside contributions amounting to 185,000 Marks from the state. In terms of winning government support, the personal influence of Henry Theodore von Böttinger, the chairman of the Göttingen Association, is well documented. He negotiated on several occasions with the Prussian ministers of culture and finance and as a member of the Prussian parliament (beginning in 1891) he helped to garner approval for Göttingen's designs. Up until the 1920 establishment of the Emergency Foundation for German Science (*Notgemeinschaft der deutschen Wissenschaft*), which is the German Research Foundation today, the contributing members of the Göttingen Association supplied approximately one million gold marks in funding.¹⁴⁰ As early as 1908, it had already enabled the establishment of multiple new institutes, including those for applied mathematics, applied mechanics, applied electricity, geophysics, inorganic chemistry, aeronautics, and wireless telegraphy.¹⁴¹

2.3.3 The Establishment of New Examinations and Their Effects

The University of Göttingen adhered to Humboldt's principle of the unity of teaching and research, and thus new directions in research required a new curriculum. The result was the foundation of new lecture series, the acquisition of new laboratory equipment, and the installation of new lecturers, professorships, and institutes.

138 Ernst Kuhn was the chairman of the Württemberg Society of Engineers from 1893 to 1894.

139 [UBG] Mathematiker-Archiv, No. 50²⁹, pp. 20–21.

140 [STA] Rep. 92 Schmidt-Ott C55, p. 109.

141 See KLEIN 1908.

During the early 1890s there was only one course of study available to students of mathematics and physics who were unable to pursue an academic career, namely teacher training. Yet the secondary schools were overcrowded with teachers at that time, and it was therefore necessary to find or create new career possibilities for students educated in mathematics. Thus Klein, together with Wilhelm Lexis, created what would be the first of several new lines of study by establishing the Royal Department of Insurance Science at Göttingen, which included a division of actuarial mathematics. It was the first German university to have such a department, and the time involved in its establishment was remarkably short: The original idea was conceived in Chicago (1893), its organizational structure was discussed at the 1894 Natural Science Conference in Vienna, and the new institute was made a reality in October of 1895.¹⁴² This department provided graduates in mathematics with new career possibilities in the insurance industry, and it was also a springboard for research in statistics and financial mathematics. At the time, researchers in these fields included Georg Bohlmann, Martin Brendel, and Felix Bernstein (see [Table 2](#)).

Klein and Lexis also drafted new examination requirements for prospective secondary school teachers; these were passed on September 12, 1898 and went into effect in April of the following year. The decisive change for teacher trainees in mathematics was that, for the first time, it was possible to obtain a special certificate for teaching applied mathematics. In order to receive this, students had to focus on descriptive geometry, geodesy (with probability theory), or graphical statics. Other possibilities, implemented later, included astronomy and actuarial mathematics, meteorology and geophysics, applied mechanics, and the technical sciences. The ratification of this new field of examination was an important step for the center of science and mathematics at Göttingen,¹⁴³ if for no other reason than it lent legitimacy to the expansion of laboratory facilities and to the creation of new lectureships and professorships. In the first decade of the twentieth century, it was only at the University of Göttingen that full professorships were established for specific branches of applied physics and mathematics, although these were tied to the individuals appointed to the positions (the positions were known as “personal” full professorships). In a letter dated February 6, 1902, Klein wrote: “I would indeed like to see the representatives of the applied sciences receive full professorships, but then we would need to appoint at least two new faculty members, one for applied mathematics and one for applied physics. Excluding Brendel and Bohlmann, we still have four applied scientists on staff – Schilling, Wiechert, Lorenz, and Simon.”¹⁴⁴

¹⁴² See GROSS 1981.

¹⁴³ See WEBER 1900; KLEIN/RIECKE 1900.

¹⁴⁴ This letter was addressed to the mathematician August Gutzmer, who arranged similar institutions, curricular requirements, and professorships at the University of Jena with the support of the Carl Zeiss Foundation (see [UBG] Ms Cod. Klein IX 509; TOBIES 1984).

When Hilbert, a member of the Göttingen Association, was offered a full professorship at Berlin in June of 1902, he turned down the opportunity on the condition that a third full professorship of mathematics would be established at Göttingen and that his friend, Hermann Minkowski, would be appointed to the position.¹⁴⁵ The matter was settled in less than a month. In a letter to the Ministry of Culture (dated June 25, 1902), Lexis proposed that the university could convert “the still vacant full professorship of inorganic chemistry” into this third chair of mathematics.¹⁴⁶ This suggestion was implemented without, in the end, hindering the development of chemistry.

Chemistry had made such rapid progress that organic chemistry, physical chemistry, inorganic chemistry, and chemical technology were taught at the majority of universities. Although the educational focus fell largely on organic chemistry, various industries were in need of inorganic chemists. At Göttingen there was a chair of organic chemistry, a chair of physical chemistry, and an associate professorship of chemical technology (see Table 2). In July of 1899, Althoff launched an initiative to establish a new full professorship of inorganic chemistry, but there was a shortage of suitable candidates.¹⁴⁷ In 1901, however, a chair of inorganic chemistry was ultimately approved and awarded to the Baltic German physical chemist Gustav Tammann.¹⁴⁸

A full professorship of mathematics and astronomy at Göttingen was held by Ernst Schering, but theoretical astronomy and geodesy, which belonged to his purview, were not yet well established. After Schering’s death in 1897 it became possible to divide his full professorship into two associate positions, just as Klein had intended several years before. Martin Brendel received the position for theoretical astronomy and geodesy, and his main project would be to edit, under Klein’s supervision, the unpublished writings of Carl Friedrich Gauss.¹⁴⁹ Emil Wiechert was named associate professor of geophysics with the aim of reviving the university’s geomagnetics tradition.¹⁵⁰ Having transferred his *Habilitation* from Königsberg to Göttingen, he became one of the most distinguished researchers in this field. In 1897, while still in Königsberg, Wiechert had discovered the electron at nearly the same time that this discovery was made by the British physicist Joseph John Thomson (the discovery, for which the latter won the Nobel Prize, is typically attributed to Thomson alone). Wiechert was given his own institute of geophysics, and together with Klein and Riecke he took advantage of the possibilities made available by the International Association of Scientific Academies.

145 David Hilbert, Hermann Minkowski, Emil Wiechert, and Arnold Sommerfeld had all earned their doctoral degrees at the University of Königsberg.

146 [STA] Rep. 76 Va Sec.6 Tit. IV No.1, vol. XIX, p. 10.

147 [STA] Rep. 92, Althoff A1 No. 139, pp. 65v, 66.

148 See Section 2.7.

149 Felix Klein and Martin Brendel, eds., *Materialien für eine wissenschaftliche Biographie von Gauss*, 8 vols. (Leipzig: B. G. Teubner, 1911–1919).

150 Emil Wiechert’s employment contract is archived in [STA] Rep. 76 Va Sec.6 Tit. IV No.1, vol. XVII, p. 26.

In 1903, for instance, Wiechert was one of the founders of the Association Internationale de Séismologie.

After several changes in the associate professorships for applied mathematics and applied mechanics, stability was gained in 1904 with the appointment of Carl Runge as the first full professor of applied mathematics in Prussia, and with the appointment of Ludwig Prandtl to an associate professorship of applied mechanics. With considerable personal commitment on the part of Klein, who capitalized on the financial strength of the Göttingen Association, “personal” full professorships were established for Wiechert in 1904, for Prandtl in 1907,¹⁵¹ and also for Hermann Theodor Simon in the field of applied electricity. The negotiations made for appointing a successor to the astronomer Wilhelm Schur also show that here, too, a considerable effort was devoted to attracting first class candidates.¹⁵² Karl Schwarzschild became an associate professor of astronomy in 1901, and a year later his position was converted into a full professorship.¹⁵³ With Schwarzschild’s support, and in preparation for the convention of the astronomical society (*Astronomische Gesellschaft*) to be held in Göttingen (in August of 1902), it was possible to secure funding for the improvement of the observatory.¹⁵⁴

In order to incorporate the use of mathematical methods into the techniques of solving problems in a variety of fields, Felix Klein conducted joint seminars with his new colleagues, including function theory and mechanics with Hilbert (1896–98); astronomy with Schwarzschild (1902); the principle of mechanics (1902–03), graphic statics and the theory of stability (1903), and hydrodynamics (1903–04) with various colleagues; the theory of probability with Schwarzschild and Brendel (1904); the theory of elasticity with Prandtl, Runge, and the theoretical physicist Woldemar Voigt (1904–05); electrical engineering with Prandtl, Runge, and Simon (1905); hydrodynamics with Prandtl, Runge, and Wiechert (1907–08); and actuarial mathematics with Felix Bernstein (1908).¹⁵⁵ Concerning the field of industrial research, it should be underscored that the seminar on electrical engineering focused heavily on the theories of instruments (such as harmonic analyzers and oscillographs) that were standard in the laboratories of the day. It is no wonder that some of its participants would become research technologists who worked closely with metrological theory and instruments.¹⁵⁶

151 The Göttingen Association paid Prandtl, who became one of the most prominent researchers in the field of fluid dynamics, a guaranteed lecture fee of 6,000 Marks and additional sums for teaching and research (see [STA] Rep. 92 Schmidt-Ott, B43, p. 16; C55, p. 126).

152 See Althoff’s letter to Klein – dated September 29, 1901 – in [UBG] Cod Ms. Klein II A, pp. 32–33.

153 [STA] Rep. 76 Va Sec. 6 Tit.IV, No.1, vol. XVIII, pp. 163–165.

154 [STA] Rep. 92, Althoff B No. 92, pp. 238–239v. This international astronomical society was founded in Heidelberg in 1863.

155 On Klein’s seminars, see the third volume of his collected writings (KLEIN 1923), his [Seminar Records], and CHISLENKO/TSCHINKEL 2007.

156 For more on this seminar, see also Section 2.4.2. It is safe to say that Iris Runge was trained as a research technologist in the sense proposed in JOERGES/SHINN 2001.

Additional joint seminars were held by Hilbert, Minkowski, Wiechert, and Gustav Herglotz on the theory of electrons.¹⁵⁷ In 2003, Arne Schirmacher analyzed the “social map” of mathematicians and physicists at Göttingen around the year 1913 and felt that the disciplinary structure had been turned on its head. This he thought because Hilbert lectured on electron and molecular theory while Woldeimar Voigt lectured on vector analysis.¹⁵⁸ However, the theoretical physicist Voigt had a necessarily strong command of mathematics, and by that time Hilbert had shifted his focus to applying mathematics to theoretical physics. Moreover, Schirmacher’s list of institutions that, in his opinion, constituted the “social space” at Göttingen contains only those entities that were in existence at other universities: the Academy, the Mathematics Society, student unions, housing communities, etc. He overlooked the interdisciplinary research seminars that fostered the creative potential of the Göttingen scientific community and that ultimately captured the attention of other universities and a variety of industries in Germany and abroad.

The establishment of Göttingen as a center of science and mathematics during the Althoff era demonstrates how much can be achieved when a visionary administration acts in the interest of scientific development, when private and government funds are effectively used to finance new facilities and institutes for teaching and research, and when a consortium of experts from several disciplines coordinate their teaching and research to serve the aims of a single organization. Given these propitious circumstances, it is no surprise that the University of Göttingen came to attract more and more students, including women and foreigners. This rise in popularity is clear to see in the number of doctoral theses that were written there; at Göttingen, more German and foreign students – including several Americans – completed doctorates in mathematics than at any other university in Germany.¹⁵⁹ This is true of other fields as well. The American Nobel laureate Irving Langmuir, for instance, earned a doctoral degree in physical chemistry at Göttingen before making his groundbreaking contributions at General Electric (his research concerned incandescent lamps and electron tubes).¹⁶⁰

157 See PYENSON 1985, pp. 101–136. These joint seminars were also conducted during the 1920s by Hilbert and Max Born, among others.

158 SCHIRRMACHER 2003, pp. 22–23.

159 See the tables on pages 17–18 in TOBIES 2006.

160 The Brooklyn-born Langmuir completed his doctoral studies in five semesters at Göttingen. He began his research under Walther Nernst, who subsequently moved to the University of Berlin, and he completed it under Friedrich Dolezalek. For notices of Langmuir’s dissertation, which was entitled “Über partielle Wiedervereinigung dissociierter Gase im Verlauf einer Abkühlung” [On the Partial Recombination of Dissolved Gases During Cooling], see JAHRES-VERZEICHNIS 19 (1906), p. 192; POGG. V, VI, VIIb. W. R. Whitney, who was mentioned above, headed the research lab of General Electric. In 1915, he had about 250 staff members, Irving Langmuir and William David Coolidge among them. They worked on vacuum- and gas-filled lamps, the wireless telegraph, and X-ray technology. All three – Whitney, Coolidge, and Langmuir – had earned a doctorate at a German university (Coolidge at the University of Leipzig in 1899).

The great success of science and mathematics at Göttingen owed much to the pervasive use of applied mathematics that was encouraged there. Richard von Mises attributed this success to Felix Klein's comprehensive approach to higher education, to his persistent struggle to overcome the stubborn biases of scientists, and to his conscious effort to perforate disciplinary boundaries.¹⁶¹ It should also be stressed that applied mathematics was not promoted at the expense of "pure mathematics" in Göttingen, where – in addition to Hilbert and Minkowski – there were also illustrious practitioners of number theory (Edmund Landau), analysis (Richard Courant), and modern algebra (Emmy Noether). All of this progress came to an unfortunate halt in 1933.

Table 2: Full and Associate Professors of Mathematics, Physics, Astronomy, and Chemistry at the University of Göttingen (ca. 1886–1914)¹⁶²

Mathematics

Ernst Schering	Associate (1860–68) and full professor (1868–97) of mathematics and astronomy
Hermann A. Schwarz	Full professor of mathematics (1875–92)
Felix Klein*	Full professor of mathematics (1886–1913)
Heinrich Weber	Full professor of mathematics (1892–95)
David Hilbert*	Full professor of mathematics (1895–1930)
Hermann Minkowski*	Full professor of mathematics (1902–09)
Edmund Landau*	Full professor of mathematics (1909–34)
Constantin Carathéodory*	Full professor of mathematics (1913–18)

Descriptive Geometry and Applied Mathematics

Arthur Schönflies	Associate professor of descriptive geometry (1892–99)
Friedrich Schilling*	Associate professor of descriptive geometry (1899–1904)
Carl Runge*	Full professor of applied mathematics (1904–24)

Financial and Actuarial Mathematics and Statistics

Georg Bohlmann	Lecturer (1895–1901) and associate professor (1901–02) of actuarial mathematics
Martin Brendel	Lecturer of actuarial mathematics (1902–07) and associate professor of actuarial mathematics, theoretical astronomy, and geodesy (1898–1907)
Felix Bernstein*	Associate professor of actuarial mathematics (1911–21) and full professor of statistics, financial, and actuarial mathematics (1921–33)

¹⁶¹ See Richard von Mises, "Hermann Amandus Schwarz," *Zeitschrift für angewandte Mathematik und Mechanik* 1 (1921), pp. 494–496, where he also stressed Schwarz's one-sidedness.

¹⁶² Asterisked names indicate members of the Göttingen Association for the Promotion of Applied Physics and Mathematics.

Astronomy, Geodesy, Geophysics

Ernst Schering	Associate (1860–68) and full professor (1868–97) of theoretical astronomy and director of the geomagnetic observatory
Wilhelm Schur	Full professor of astronomy and director of the observatory (1886–1901)
Martin Brendel	Associate professor of theoretical astronomy and geodesy (1898–1907)
Emil Wiechert*	Associate (1898–1904) and full professor (1904–28) of geophysics and director of the geophysical institute
Karl Schwarzschild	Associate (1901–02) and full professor (1902–09) of astronomy and director of the observatory
Leopold Ambronn*	Associate (1902–18) and honorary full professor (1918) of astronomy
Gustav Herglotz	Associate professor of theoretical astronomy (1907–08); full professor of mathematics (1925–47). Herglotz was Carl Runge's successor.
Johannes Hartmann*	Full professor of astronomy and director of the observatory (1909–21)

Physics

Eduard Riecke*	Associate (1873–81) and full professor (1881–1914) of physics
Woldemar Voigt*	Full professor of physics (1883–1919)
Theodor Des Coudres*	Associate professor of applied electricity (1897–1901)
Hermann Theodor Simon*	Associate (1901–07) and full professor (1907–18) of applied electricity
Richard Mollier*	Associate professor of technical physics (1897–98)
Eugen Meyer*	Associate professor of technical physics (1898–1900)
Hans Lorenz*	Associate Professor of technical physics (1900–04)
Ludwig Prandtl*	Associate (1904–07) and full professor (1907–46) of applied mechanics

Chemistry

Viktor Meyer	Full professor of organic chemistry (1885–89)
Otto Wallach*	Full professor of organic chemistry (1889–1915)
Walther Nernst*	Associate (1891–94) and full professor (1894–1904) of physical chemistry
Ferdinand Fischer*	Associate professor of chemical technology (1897–1912)
Gustav Tammann*	Full professor of inorganic (1902–07) and physical chemistry (1907–29)
Friedrich Dolezalek	Associate professor of physics and chemistry (1905–07)
Richard Zsigmondy*	Associate (1907–19) and full professor (1909–29) of inorganic and colloid chemistry
Alfred Coehn*	Full professor and head of the photochemical department (1909–28)

2.4 A NEW STYLE OF THINKING: CARL RUNGE AND APPLIED MATHEMATICS

The purpose of this section is to clarify Carl Runge's special understanding of applied mathematics, to introduce the foremost members of his thought collective, and to elaborate upon Iris Runge's place within this group.¹⁶³

In a diary entry from November 18, 1907, Carl Runge noted: "This winter my eldest daughter, Iris, will be attending my course on graphical methods – four hours of lectures and four more of exercises."¹⁶⁴ In this same entry he enthusiastically discusses a visit by representatives of a bridge construction company from Gustavsburg, an affiliate of a machine factory in Nuremberg whose director – Anton von Rieppel – was one of the founding members of the Göttingen Association for the Promotion of Applied Physics and Mathematics.¹⁶⁵

Because professional mathematicians had long neglected such matters, industrial engineers had to develop, on their own, graphical and numerical methods for solving technical problems. In order to learn and better appropriate these methods, Carl Runge spent nine days in the field with engineers during the summer vacation of 1907. There he learned firsthand, as he wrote, "the drafting and arithmetical methods with which they approached their iron construction projects."¹⁶⁶ He incorporated these methods into his teaching and research at the University of Göttingen and used them to develop general graphical and numerical mathematical methods of his own.

2.4.1 Applied Mathematics at the University of Göttingen

That Carl Runge brought something new and exiting to the University of Göttingen, having accepted the first full professorship of applied mathematics there in 1904, is evident in that fact that Felix Klein abandoned his own, discipline-based understanding of the subject. Beginning with the new examination requirements that were established in 1898, the heart of the applied mathematics program in Prussia had been the fields of descriptive geometry, technical mechanics (including graphical statics and kinematics), and geodesy (including probability theory). Influenced by Runge's ideas, Klein shifted the focus of the program considerably: "Ever since our colleague Runge has been among us, we have understood applied mathematics to denote the teaching of mathematical principles, namely numerical and graphical methods [...]."¹⁶⁷

163 On the terms "style of thinking" (*Denkstil*) and "thought collective" (*Denkkollektiv*), see Section 1.2.1.

164 Quoted from HENTSCHEL/TOBIES 2003, p. 167.

165 See Section 2.3.2.

166 Quoted from HENTSCHEL/TOBIES 2003, pp. 166–167.

167 Minutes taken at the meeting of the Göttingen Association for the Promotion of Applied Physics and Mathematics on November 30, 1912 (quoted from TOBIES 1989, p. 246).

Since the middle of the nineteenth century, applied mathematics had been scorned for being “impure.” In 1844, Carl Gustav Jacob Jacobi repeated a commonly held belief when he intoned that it was the main glory of science “to be of no use” and that “the loftiest achievements in science and art have always been impractical.”¹⁶⁸ Against longstanding notions of this sort, the University of Göttingen endeavored to restore and strengthen the connections between mathematics and other fields, an effort that also served to benefit the field of mathematics itself.

All appearances aside, mathematics is not a self-generating and self-contained scholastic system whose higher reaches are of interest to experts alone. Nor does its general significance derive simply from the formal perfection that it attains as a tool of logic and pedagogy. It is rather a capable and proven method of development that should be employed wherever there are problems of a quantitative nature. In the broadest sense, engineering and physics are also disciplines with which mathematics should remain in constant contact.¹⁶⁹

Carl Runge was fully committed to Klein’s reformed program. For eighteen years, and on the basis of a sound theoretical education at the Universities of Munich and Berlin, he had conducted successful research in several applied disciplines at the Technical University in Hanover. He had not only investigated, as already mentioned, the periodic regularities in the spectra of elements, but he had also immersed himself in alternating current engineering and won a name for himself in the fields of geodesy and astrophysics. Carl Runge had made use of a calculating machine to solve the complex numerical equations that these research fields required, and it was with the aid of such a device that he would ultimately formulate his general methods of numerical analysis.¹⁷⁰ His programmatic article “Über angewandte Mathematik” [On Applied Mathematics], which appeared in an 1894 issue of *Mathematische Annalen*, and one of his letters to Felix Klein – in which he explicates his numerical methods for solving first order differential equations, according to which differential quotients are approximated by difference quotients – provided the foundation for a new style of applied mathematics. Inspired by the work of Carl Runge and Karl Heun, the latter known for his numerical method of solving initial value problems for ordinary differential equations, Wilhelm Kutta refined their calculations in his 1900 dissertation and produced what is known today as the Runge-Kutta procedure of numerical analysis.¹⁷¹

168 Quoted from BIERMANN 1988, p. 187.

169 Felix Klein, in [UAG] Kuratorialakten 4 I 88a.

170 Carl Runge’s scientific career is treated at length in the biography written by his daughter (Iris RUNGE 1949) and also in a more recent dissertation (RICHENHAGEN 1985).

171 Wilhelm Kutta was a long-term assistant of Walther Dyck, a former student of Felix Klein who was then a professor at the Technical University of Munich. Dyck supervised Kutta’s dissertation, “Beiträge zur näherungsweise Integration totaler Differentialgleichungen” [Contributions to the Approximate Integration of Total Differential Equations]; see HASHAGEN 2003, p. 253. The Technical University (*Technische Hochschule*) in Munich, however, was still not authorized to grant doctoral degrees. In order to obtain this title, Kutta had to present his thesis to the mathematics faculty at the University of Munich.

When, at Felix Klein's request, Carl Runge and Rudolf Mehmke of the Technical University in Stuttgart assumed the editorship of the *Zeitschrift für Mathematik und Physik* [Journal of Mathematics and Physics], they decided to devote its pages exclusively to the promotion of applied mathematics, a field which they delineated as follows:

Though it remains a matter of dispute what counts as “pure” and what counts as “applied” mathematics, we hope that our readers will approve if we refrain from drawing the sharpest lines between the two subjects. In addition to the fields discussed in volumes 4–6 of the *Enzyklopädie der mathematischen Wissenschaften* [see *ENCYCLOPEDIA*] – namely mechanics (especially technical mechanics), theoretical physics (including mathematical chemistry and crystallography), geophysics, geodesy, astronomy – and in addition to the essential fields of probability and regression analysis, statistics, and actuarial mathematics, we are also interested in cultivating the following disciplines: numerical analysis, approximate calculation (“approximation theory”), the theory of empirical formulas, descriptive geometry (in conjunction with shadow generation and perspective), and graphical analysis. It is with the methods employed in these fields, above all, that applied mathematics is executed to its fullest capacity. Moreover, we would like to devote considerable attention to the technical instruments that are used by the practitioners of these fields, including numerical and graphical tables, mechanical calculators, and graphical instruments.¹⁷²

By using the term “approximation theory” (*Approximationsmathematik*), Carl Runge, Mehmke, and Klein were consciously associating themselves with Karl Heun, who had been the first to use the expression, and Klein also borrowed similar ideas from Heinrich Burkhardt's inaugural address, delivered in Zurich in 1897, entitled “Mathematisches und naturwissenschaftliches Denken” [Mathematical and Scientific Thinking].¹⁷³ Because approximate calculations were frowned upon by pure mathematicians and yet absolutely indispensable to applied mathematics, Klein felt compelled, in a lecture held in 1901, to explain the difference between the empirical and the ideal sides of the field:

Contrary to fields of empirical research, the ideal subject of arithmetic is not constrained by thresholds of exactness; rather, the precision with which numbers are defined or regarded is unlimited. The difference between limited and unlimited precision, which can be seen, for instance, in any empirical measurement of practical geometry as opposed to the precise definitions of abstract arithmetic, becomes apparent whenever abstract mathematics is compared to practical fields that require empirical observation. This is true in the case of measuring time, in the case of all mechanical and physical measurements, and especially in the case of numerical calculations. For what is a calculation made with the help of seven-digit logarithms but a calculation made with approximate values, the precision of which extends only to the seventh decimal? Then again it is possible, as we shall see, to make use of absolutely precise axioms that are appropriate to whatever empirical questions might lie before us; by doing so, we superimpose an idealized abstraction upon an empirical reality.

172 MEHMKE/RUNGE 1901, pp. 8–9. Both Mehmke and Carl Runge contributed to the *Enzyklopädie der Mathematischen Wissenschaften mit Einschluß ihrer Anwendungen* [The Encyclopedia of Mathematics and its Applications], see MEHMKE 1902; Carl RUNGE 1899; RUNGE/WILLERS 1915.

173 See KLEIN 1928, p. v (Preface to the first edition of *Präzisions- und Approximationsmathematik*).

The distinction between absolute and limited precision, which is the central theme of this lecture, entails that mathematics be divided into two branches. That is, we differentiate between:

1. Precise mathematics (calculation with the real numbers themselves), and
2. Approximate mathematics (calculation with approximate values).

The words “approximate mathematics” are not at all meant to disparage this branch of the subject (what we are dealing with here, after all, is not so much approximate mathematics as it is the precise mathematics of approximate relations). The whole of mathematics will escape us unless we comprehend both of its sides:

*Approximate mathematics is that part of our science that is actually used in applied fields; precise mathematics is the secure latticework, so to speak, upon which approximate mathematics is free to climb.*¹⁷⁴

With his numerical and graphical methods, Carl Runge developed this “precise mathematics of approximate relations.” In March of 1907, shortly before Iris Runge began her studies, a conference of applied mathematicians was held in Göttingen. Here, in words similar to Klein’s, Carl Runge underscored the unity of mathematics in a presentation entitled “Über angewandte Mathematik” [On Applied Mathematics]:

The problems faced by empirical scientists using mathematical methods require solutions with concrete, quantitative results. Physicists and engineers cannot be satisfied with formal solutions; they need to be able to calculate the value of measurements that are unique to the case at hand. To this end, graphical or numerical methods are needed to produce the desired results. The formulation and refinement of such methods is, in my opinion, the true essence of applied mathematics. It is an integral component – not a mere offshoot – of pure mathematics.¹⁷⁵

The numerical analyst Lothar Collatz referred to Carl Runge as the founder of “modern numerical mathematics.”¹⁷⁶ His legacy is defined by more than the Runge-Kutta method of approximating solutions of ordinary differential equations: He also invented foundational new approaches to solving partial differential equations, and he is known for his unique method of executing Fourier analysis.¹⁷⁷ He designed his mathematics courses along the lines of the laboratory sessions common to physics and chemistry, and he instructed his students in the use of plotting tables and drawing boards, compasses, slide rules, four-digit logarithm tables, and mechanical calculators. In terms of Herbert Mehrten’s distinction between modernity and anti-modernity,¹⁷⁸ it is safe to say that Carl Runge’s development of a new type of numerical mathematics is just as modern as the several other mathematical disciplines that took shape at the beginning of the twentieth century.

174 Ibid., pp. 4–5. For further discussion of this distinction, see EPPLE 2002b.

175 Carl RUNGE 1970b, p. 497.

176 COLLATZ 1990, p. 274.

177 Carl RUNGE 1908; see also the opinion in COLLATZ 1990, pp. 272–273

178 See MEHRTENS 1990.

2.4.2 Carl Runge's Thought Collective

While working at the Technical University in Hanover, Carl Runge's activity was somewhat restricted by the limited number of mathematically gifted students who came his way. This was not the case at Göttingen, where he was not only welcomed by the professors of mathematics there – Klein, Hilbert, and Minkowski – but by the natural scientists as well. The theoretical physicist Woldemar Voigt, for instance, even sacrificed some of his own salary and pension in order to ensure that Carl Runge could be hired.¹⁷⁹ As a full professor at Göttingen, the latter was able to develop his methods of applied mathematics, to discuss his findings with colleagues and advanced students, and to direct the research of doctoral candidates.

Among the premises of applied mathematics that were formulated by its German practitioners in 1907, interdisciplinary research seminars, such as those initiated by Klein in the 1890s, are given special mention as an effective way of introducing students to the subject (see Appendix 1). The nature of these research seminars was such that a given empirical subject would be reduced to its calculable elements, at which point the insights of mathematicians became desirable. During his first years at the University of Göttingen, Carl Runge participated in the following seminars of this sort:

Winter Semester 1904/05: Klein, Prandtl, Runge, Voigt: *Selected Topics in the Theory of Elasticity* (a course with 26 different student lectures);

Summer Semester 1905: Klein, Prandtl, Runge, Simon: *Electrical Engineering* (21 lectures);

Winter Semester 1907/08: Klein, Prandtl, Runge, Wiechert: *Hydrodynamics* (11 lectures);

Summer Semester 1908: Klein, Prandtl, Runge, Wiechert: *Ship Theory and Dynamic Meteorology* (12 lectures);

Winter Semester 1908/09: Klein, Prandtl, Runge: *Theories of Structural Design* (10 lectures);

Summer Semester 1909: Klein, Prandtl, Runge: *Theory of Strength* (12 lectures).

In the first joint seminar listed above,¹⁸⁰ the newly hired professors Carl Runge and Ludwig Prandtl were given the opportunity to introduce themselves with lectures of their own. At the beginning of the course, Klein announced as its purpose the discussion of ordinary differential equations of elasticity; as for the foundational text on the topic, Klein cited the two-volume *Treatise on the Mathematical Theory of Elasticity* (1892–93) by the British mathematician Augustus E. H. Love.¹⁸¹ These seminars, in general, were marked by an awareness of international

179 Financially secure and independent, Woldemar Voigt was unconcerned with the amount of his pension; see [STB] 514, pp. 126v, 133v.

180 [Seminar Records] vol. 21, p. 1. The only preserved seminar records are of those in which Felix Klein participated. There are no records, that is, of the seminars that Carl Runge taught without Klein's involvement.

181 Augustus E. H. Love was also the author of the contribution "Hydrodynamik: Physikalische Grundlegung" [The Physical Foundations of Hydrodynamics] (1901) in the fifth volume of the *Encyklopädie der Mathematischen Wissenschaften mit Einschluß ihrer Anwendungen*.

scholarship. In his lecture, Carl Runge modeled the tensions between elastic bodies by means of partial differential equations, and Prandtl – with whom Runge had been friends since his days in Hanover and whom Lothar Collatz also counted among the significant contributors to numerical analysis¹⁸² – devoted his seminar lecture to the singularities of stress trajectories. There were twenty-six participants in this course on elasticity, most of them students, and each presented a lecture of his own. Among the more noteworthy participants were Wilhelm Hort, who later worked in Berlin and who, as a future editor of the *Zeitschrift für technische Physik* [Journal of Technical Physics], would accept several of Iris Runge's articles for publication; the aforementioned Heinrich Barkhausen, who completed his doctorate under Hermann T. Simon and became one of the leading researchers in the field of electron tubes; and Max Born, who gave a lecture on the stability of elastic tapes, a theme that he would develop into his dissertation. Already very independent as a student, Born employed novel methods of calculus of variations that he had recently learned in one of David Hilbert's lectures. Carl Runge's fourth doctoral student, Hugo Koch, also participated in this first seminar, for which he presented on the topic of tension distribution in cones.¹⁸³

Table 3: Carl Runge's Doctoral Students

- Max Born.* Oral examination passed *magna cum laude* on July 11, 1906 (mathematics, physics, astronomy). Dissertation: "Untersuchungen über die Stabilität der elastischen Linie in Ebene und Raum, unter verschiedenen Grenzbedingungen" [Studies on the Stability of the Elastic Line in Two and Three Dimensions under Various Boundary Conditions].
- Friedrich-Adolf Willers.* Oral examination passed *magna cum laude* on December 19, 1906 (applied mathematics, mathematics, theoretical physics). Dissertation: "Die Torsion eines Rotationskörpers um seine Achse" [The Torsion of a Rotating Body around its Axis].
- Horst von Sanden.* Oral examination passed on January 29, 1908 (applied mathematics, geometry, physics). Dissertation: "Die Bestimmung der Kernpunkte in der Photogrammetrie" [The Determination of Central Points in Photogrammetry].
- Hugo Koch.* Oral examination passed *cum laude* on May 19, 1909 (applied mathematics, mathematics, physics). Dissertation: "Über die praktische Anwendung der Runge-Kutta-schen Methode zur numerischen Integration von Differentialgleichungen" [On the Practical Application of the Runge-Kutta Method for Integrating Differential Equations].
- Manfred Jäger.* Oral examination passed *cum laude* on August 5, 1909 (applied mathematics, geometry, physics). Dissertation: "Graphische Integrationen in der Hydrodynamik" [Graphical Integration in Hydrodynamics].
- Cornelius Veithen.* Oral examination passed *cum laude* on November 29, 1911 (applied mathematics, mathematical analysis, physics). Dissertation: "Über die Verwendung der Rechenmaschine bei der Bahnbestimmung von Planeten" [On the Use of Mechanical Calculators for Determining Planetary Courses].
- S. Douglas Killam.* A Canadian-born British citizen. Oral examination passed *cum laude* on June 19, 1912 (applied mathematics, mathematical analysis, astronomy). Dissertation:

182 See COLLATZ 1990, p. 271.

183 [Seminar Records] vol. 21, pp. 49–58 (on Hugo Koch), 60–72 (on Heinrich Barkhausen), 75–83 (on Carl Runge), 90–91 (on Ludwig Prandtl), and 182–188 (on Max Born). See also Max Born, *My Life: Recollections of a Nobel Laureate* (New York: Scribner, 1978).

“Über graphische Integration von Funktionen einer komplexen Variablen mit speziellen Anwendungen” [On the Graphical Integration of Complex Functions and its Special Applications].

Walther Rottsieper. Oral examination passed *cum laude* on July 8, 1914 (applied mathematics, mathematical analysis, geophysics). Dissertation: “Graphische Lösung einer Randwertaufgabe der Gleichung $\Delta u = \partial^2 u / \partial x^2 + \partial^2 u / \partial y^2 = 0$ ” [A Graphical Solution of a Boundary Value Problem for the Equation $\Delta u = \partial^2 u / \partial x^2 + \partial^2 u / \partial y^2 = 0$].

Wilhelm Friedrich Carl Arndt. A South African-born British citizen. Oral examination passed *cum laude* on June 7, 1916 (applied mathematics, mathematical analysis, physics). Dissertation: “Die Torsion von Wellen mit achsensymmetrischen Bohrungen und Hohlräumen” [The Torsion of Shafts with Axially Symmetric Bores and Cavities].

Vitalis Geilen. Oral examination passed *cum laude* on November 15, 1916 (applied mathematics, mathematical analysis, physics). Dissertation: “Spiegelungs- und Drehungs-Gruppen in graphischer Behandlung mit besonderer Berücksichtigung der kristallographischen Gruppen” [The Graphical Treatment of Reflection and Rotation Groups, with Special Attention Accorded to Crystallographic Groups].

Hermann König. Oral examination passed *magna cum laude* on October 1, 1919 (applied mathematics, mathematical analysis, physics). Dissertation: “Die Bewegung des rotierenden Langgeschosses” [The Motion of a Rotating Cylindrical Bullet] (co-directed by Ludwig Prandtl).

Klaus Zweiling. Oral examination passed *cum laude* on November 20, 1922 (applied mathematics, mathematical analysis, physics). Dissertation: “Über die Anwendung graphischer Methoden bei der Bahnbestimmung der Himmelskörper” [On the Use of Graphical Methods for Determining the Course of Celestial Bodies].

Of Carl Runge’s doctoral students, Max Born went on to achieve success as a physicist, Klaus Zweiling as a philosopher, and the following enjoyed careers in mathematics: Friedrich-Adolf Willers became a professor at the Freiburg Mining Academy (1928–34) and at the Technical University in Dresden (1944); Horst von Sanden received professorships at the Clausthal Mining Academy (1918) and at the Technical University in Hanover (1922); Hermann König worked in the same capacity at Clausthal beginning in 1922; Vitalis Geilen, who completed his *Habilitation* in Münster (1918), taught applied mathematics as a lecturer at the University of Marburg until 1924 and ultimately accepted a position as a secondary school teacher. At that time, the majority of those with doctoral degrees in mathematics taught at secondary schools, and such were the career paths of Carl Runge’s other students, Hugo Koch and Walther Rottsieper. The latter died in the First World War, as did Manfred Jäger.¹⁸⁴

In the lecture halls and laboratories at Göttingen, of course, students of various other disciplines were taught who would later make successful use of mathematical methods. Carl Runge’s influence on the subsequent generation of researchers, that is, extended far beyond the few doctoral students listed above. His methods were also employed by students of Prandtl, Simon, and other colleagues, as well as by visiting students and doctoral candidates at other universities. Here it

184 For brief biographies of those awarded doctoral degrees in mathematics by German universities, see TOBIES 2006, a resource that is regularly updated on the homepage of the German Mathematical Society: <http://www.dmv.mathematik.de/m-die-dmv/m-geschichte.html>.

will suffice to demonstrate Carl Runge's broad influence with just a few examples (a comprehensive study of his legacy is unfortunately lacking).

During the summer semester of 1905, the aforementioned seminar on electrical engineering – in which the theory of measuring instruments was also discussed – was attended by Reinhold Rüdenberg, who gave presentations on the principles of the theory of alternating currents, and on the distribution of power in branched wires. In 1908 Rüdenberg was hired as a calculation engineer by the Siemens-Schuckert Company in Berlin. He became a renowned inventor of laboratory instruments, and he also developed a close friendship and working relationship with Iris Runge.¹⁸⁵ At its heart, this electrical engineering seminar focused on the theory of electrical currents that could be solved mathematically by linear ordinary differential equations with constant coefficients. The books used in the class included Galileo Ferraris's *Wissenschaftliche Grundlagen der Elektrotechnik* (1901), Paul Janet's *Leçons d'électrotechnique générale* (vol. 1, 1900), Frederick Bedell and Albert Crehore's *Alternating Currents* (a German edition of which was issued in 1895), as well as specialized articles by Oliver Heaviside, John Hopkinson, and Charles Steinmetz.¹⁸⁶ The twenty-one participants in the seminar discussed how fundamental problems of electricity and alternating currents – especially regarding the theories behind harmonic analyzers and oscillographs – could be represented by differential equations and solved approximately. The seminar relied heavily on various numerical, graphical, and instrumental methods of Fourier analysis, among other approaches.¹⁸⁷

Heinrich Hochschild, who participated in the joint seminar on ship theory during the summer semester of 1908, completed a dissertation on flow phenomena,

185 See [Seminar Records] vol. 22, pp. 168–176; 177–185. Rüdenberg was known to Iris Runge as early as her school days in Hanover (see [STB] 692). In 1906 he was awarded a doctoral degree by the Technical University in Hanover, where he was supervised by the electrical engineer Wilhelm Kohlrausch, for a dissertation entitled “Energie der Wirbelströme in elektrischen Bremsen und Dynamomaschinen” [The Energy of Eddy Currents in Electric Brakes and Dynamos]. From 1906 to 1908 he worked as Hermann Theodor Simon's assistant in Göttingen. In a letter dated August 24, 1911 [Private Estate], Iris Runge wrote to her mother: “On Sunday [...] I happened to see Rüdenberg, who was sunburned but very much the same, though somewhat less of a jokester. I don't know if this is because of his old age or because of his toilsome dealings with the businessmen from Berlin, about whose unintelligence he was quick to complain. In any case, he would like to come visit us when I am in Potsdam.” In 1919, Rüdenberg married Lily Minkowski, the daughter of the Göttingen mathematician Hermann Minkowski and his wife Auguste (née Adler); see RUDENBERG/ZASSENHAUS 1973.

186 See [Seminar Records] vol. 22, pp. 1–2. The book by the American physicist Frederick Bedell was valuable above all for its wide use of graphical methods. John Hopkinson, a British electrical engineer, applied Maxwell's theory of electromagnetism to problems of electrostatic capacitance and residual charge; he demonstrated mathematically that it was possible to connect two alternating current dynamos in parallel.

187 Harmonic analysis is the branch of mathematics that studies the representation of functions or signals as the superposition of basic waves. It investigates and generalizes the notions of Fourier series and Fourier transforms.

which he submitted to the Technical University in Berlin. In this thesis it is clear that Hochschild's theoretical observations about flow potential depend on methods of solving differential equations that Carl Runge had first taught, in his course on graphical methods, during the winter semester of 1907/08.¹⁸⁸

Although Erich Trefftz, Carl's Runge's nephew and research assistant at Columbia University in 1909–10, did not officially study under his uncle (his doctoral supervisor was Richard von Mises in Strassburg), Carl Runge nevertheless considered Trefftz to be his most legitimate academic successor.¹⁸⁹ As a counterpart to Ritz's method, Trefftz formulated a (now eponymous) method of approximating the boundary values of partial differential equations.¹⁹⁰

Carl Runge was able to introduce his mathematical methods to international audiences not only by teaching and participating in conferences abroad, but also by instructing the many international students who came to study at the University of Göttingen. At no other university in the world – with perhaps a few exceptions – were graphical integration and nomography incorporated into the curriculum to the extent that this was done in Göttingen, and we know this because Carl Runge, on behalf of the International Commission of Mathematical Instruction, distributed a survey on this very matter to representatives in France, Italy, Austria, Germany, Switzerland, the Netherlands, Great Britain, and the United States.¹⁹¹

According to the Ukrainian scientist Stephan P. Timoshenko, who studied for several years at Göttingen, Carl Runge's lectures were exemplary. As a participant in the seminar on strength theory during the summer semester of 1909, Timoshenko delivered a presentation on the utility of normal coordinates to that field, and later in his life he earned fame for his contributions to engineering mechanics, elasticity, and the strength of materials. Employed by the Westinghouse Electric Company in 1923 and later a professor at Michigan and Stanford, Timoshenko regularly applied numerical and graphical methods to his materials research. In his autobiography he made the following remarks about Carl Runge's lectures:

I had first met Runge in 1905 in Göttingen while I was attending lectures during the summer semester. His lectures were remarkable for their clarity and elegance of exposition. In lecturing talent I would compare him with our own Kirpichev. At meetings of the Applied-Mathematics Seminar and Mathematical Society, what he said was always very interesting.¹⁹²

Each of the students of Carl Runge who went on to work as professors at technical universities approached their teaching of applied mathematics according to their

188 See Heinrich Hochschild, *Versuche über die Strömungsvorgänge in erweiterten und verengten Kanälen* (Berlin: Springer, 1912), pp. 23–27.

189 See Carl Runge's letter to his wife dated August 11, 1917 (in [STB] 515, p. 310).

190 See COLLATZ 1990, p. 284; QIN 2000. For Walter Ritz's numerical approach to the boundary value problems of partial differential equations, see RITZ 1908 and also RITZ 1911.

191 Carl RUNGE 1913.

192 TIMOSHENKO 1968, p. 265. On Timoshenko's seminar lecture, see [Seminar Records] vol. 27. Carl Runge's lectures are here being compared to those of V. L. Kirpichev, who was a professor of theoretical and applied mechanics in St. Petersburg, Kharkov, and Kiev.

supervisor's model, and in doing so they created a third generation of disciples. Alwin Walther, who first attended Runge's lectures as a post-doctoral researcher at Göttingen, established what he called a *mathematical laboratory* once he became a full professor at the Technical University in Darmstadt; concerning the name of this new research space, he stressed: "The term was inspired by the singular founder of modern practical mathematics, Carl Runge." At his laboratory, he continued, he required his students "to learn how to operate slide-rules, [...] mechanical calculators, planimeters, mirror straightedges, mechanical integragraphs, harmonic analyzers, stencils, and other useful instruments with confidence and accuracy."¹⁹³ Alwin Walther's own doctoral student, the Hungarian Paul Terebesi, invented stencils, made of cardboard, for harmonic analysis that relied upon Carl Runge's methods.¹⁹⁴ In harmonic analysis (Fourier analysis), numerical calculations could be complex enough to require several hours to complete. With Terebesi's stencils, however, such calculations could be made relatively quickly even by assistants who did not understand the mathematics involved. Iris Runge, in fact, would later recommend that these stencils be used in industrial research.

Carl Runge's children, Iris and Wilhelm, can also be numbered among his students, even though their doctoral degrees were not technically in applied mathematics. The two of them applied and refined their father's methods in the fields of materials research, physics, electrical engineering, and communications engineering. When Iris Runge later described the relationship between her father and her brother Wilhelm, she could just as well have been writing about herself:

From Wilhelm's letters, Carl Runge gained numerous interesting insights into the problems of high frequency engineering, about which Wilhelm consulted him more than once in pursuit of mathematical methods for their solution. It was a great joy for him to see his son successfully carry on his tradition of approaching problems systematically and with the tools of mathematics.¹⁹⁵

Carl Runge prepared the way for his children's careers, as he had done for those of so many others. When, shortly after his death, Iris Runge reflected about her own relationship with her father, she took a rather independent stance; nevertheless, she could not help but acknowledge his overarching (if indirect) influence:

I can't really say that I was strongly dependent on him regarding my professional development. This is because – perhaps like all children of academics – I was somewhat reluctant to consult or exploit him directly. We all want to prove to ourselves that we are capable of standing on our own two feet. Of course, everything that I learned from his books and from his lectures has been extremely useful to me. Beyond that, his influence can be boiled down to the fact that I have always found myself imagining what he would have to say about one matter or another, and this is a habit that will certainly stay with me forever.¹⁹⁶

193 WALTHER 1936, p. 7.

194 See Paul Terebesi, *Rechenschablonen für harmonische Analyse und Synthese nach C. Runge* (Berlin: J. Springer, 1930). For biographical details, see TOBIES 2006, p. 333.

195 IRIS RUNGE 1949, p. 194.

196 A letter from Iris Runge to her mother dated January 16, 1927 [Private Estate].

2.4.3 Graphical Methods

Graphical methods were developed for the sake of avoiding complex numerical calculations. In his essay on numerical calculation in the monumental *Encyklopädie der mathematischen Wissenschaften*, Rudolf Mehmke also treated the subjects of graphical calculation and mechanical calculators. He stressed that graphical calculation, in its broadest sense, includes any method of problem solving that involves graphical representations. Although he cited early historical cases of algebraic equations being treated geometrically, he emphasized that the great advancements in these methods, thanks to engineers who were careful draftsmen, were made in the middle of the nineteenth century.¹⁹⁷ These new methods were applied most widely for solving problems of structural engineering.¹⁹⁸ Before the invention of the computer, in fact, graphical methods were the preferred means of making calculations by engineers in the field. Mehmke underscored: “In comparison to numerical methods of calculation, graphical methods are generally clearer to read and easier to comprehend. These methods, moreover, still represent the sole direct procedure in the case of certain equations.”¹⁹⁹

In an encyclopedia article subsequent to Mehmke’s, Carl Runge and his student Friedrich-Adolf Willers addressed advanced methods of calculation, including the integration of partial differential equations.²⁰⁰ The article incorporated the very latest research in this area, for five of Runge’s doctoral students had written recent dissertations involving graphical methods, and Runge himself had formulated new methods of his own. As a visiting professor at Columbia University (1909–10), he presented these findings in a series of lectures that would be published in English as *Graphical Methods* (1912); the German translation of this book appeared in three revised editions.²⁰¹ Appreciative of the work of engineers and interested in the applications of his methods, Carl Runge was of the opinion that the development of general procedures requires a mathematical point of view:

[...] it will not do to leave it to the astronomer, to the physicist, to the engineer or whoever applies mathematical methods, for the reason that these men are bent on the results and therefore they will be apt to overlook the full generality of the methods they happen to hit upon, while in the hands of the mathematician the methods would be developed from a higher standpoint and their bearing on other problems in other scientific inquiries would be more likely to receive proper attention.²⁰²

197 MEHMKE 1902, pp. 1007–1008.

198 See SCHOLZ 1989; KURRER 2008; FERGESON 1992.

199 MEHMKE 1902, p. 1007.

200 RUNGE/WILLERS 1915. – Willers wrote additional books, published in the Göschen Series, on graphical methods (1920), numerical methods (1923), and mathematical instruments (1926), the themes of which he later summarized in his *Methoden der Praktischen Analysis* (1928; repr. 1971). The latter book was translated into English as *Practical Analysis: Graphical and Numerical Methods* (New York: Dover, 1948). See also KÜCHLER 1983.

201 See Carl RUNGE 1907a, 1911, 1912, 1914, 1919, 1928.

202 Carl RUNGE 1912, introduction.

Carl Runge considered the generalized approach of mathematicians to be crucial for developing new mathematical paradigms and for the recognizing the utility of these paradigms across various disciplines. He systematically incorporated such findings into both his research and his teaching, and his students – and his daughter Iris, in particular – acquired the ability to apply his graphical methods with accuracy and ease. Two pieces of evidence reveal beyond a doubt that Iris Runge had been exposed to her father's methods from rather early on.

First, she gave her own lecture notes and graphical drawings from one of her father's lessons to Friedrich Pfeiffer, who was then Felix Klein's assistant. Called upon to serve as Carl Runge's substitute, Pfeiffer had to give a lecture on graphical methods as part of a university training course for teachers working at secondary schools for girls. The program was organized by Klein, and both Iris Runge and Elisabeth Klein were involved as assistants. To her father, who was working in New York at the time, Iris Runge reported:

It is truly a pity that you and Erich [Trefftz] – and your graphical methods, too – are not here right now. I have recently had to lend Pfeiffer my own sorry notes on these methods, along with the less than thorough drawings that I once made during one of your lessons. Supposedly he needs them to give a talk on the uses of graphical techniques in secondary school math classes.²⁰³

Because it involves aeronautics, industry, international connections, and the collaboration of her immediate family members, the second piece of evidence deserves a section all to itself.

2.4.4 Graphical Methods and the Translation of F. W. Lanchester's *Aerial Flight*

In the letter to her father just cited, Iris Runge also notes: "I'm extremely pleased that Mr. Lanchester sent me a copy of his *Aerodnetics*. By now I am ready to continue my translation of Chapter 4 [...]."²⁰⁴ Between 1907 and 1908, the British engineer and automobile manufacturer Frederick William Lanchester published a two-volume book on the subject of "aerial flight," the second volume of which was entitled *Aerodnetics*.²⁰⁵ This work, though coolly received in Britain, aroused considerable interest in Göttingen.

Since the 1890s there had been little doubt that a dirigible airship would one day be constructed.²⁰⁶ While the general enthusiasm for aviation was as present in Göttingen as it was elsewhere,²⁰⁷ the involvement there in this enterprise was un-

203 A letter to Carl Runge dated October 5, 1909 (in [STB] 546).

204 Ibid.

205 See LANCHESTER 1907/08. The full title of the first volume is *Aerodynamics, Constituting the First Volume of a Complete Work on Aerial Flight*, and that of the second is *Aerodnetics, Constituting the Second Volume of a Complete Work on Aerial Flight*.

206 See BOLTZMANN 1893.

207 See IRIS RUNGE 1949, p. 136; and also HÖHLER 2001; MEIER 2010.

usually rich. Before the mathematical evidence for the possibility of flight was even discovered,²⁰⁸ for instance, Felix Klein had already secured financial support for foundational aeronautics research.²⁰⁹ At the University of Göttingen, atmospheric electrical studies were undertaken by the geophysicist Emil Wiechert and the experimental physicist Eduard Riecke; balloon rides were taken for scientific purposes; and Ludwig Prandtl, an engineer and fluid mechanics researcher, was made a faculty member.²¹⁰ Moreover, the professors Klein, Wiechert, Prandtl, and Runge were appointed to the scientific advisory board of the Society for the Study of Motorized Aircraft (*Motorluftschiff-Studiengesellschaft*), which was created in Berlin on August 31, 1906,²¹¹ and they were also founding members of the Scientific Society of Aeronautics (*Wissenschaftliche Gesellschaft für Flugtechnik*), which was inaugurated in Göttingen on April 3, 1912.²¹²

Like his brother-in-law Alard du Bois-Reymond, Carl Runge was personally acquainted with Otto Lilienthal. Aimée and Iris Runge, too, were aviation enthusiasts and were there to witness some of the first attempts at human flight. In the biography of her father, Iris Runge described the mathematical methods that he had developed for balloon aviation – interpolation methods, special slide rules, astronomic localization with curve sheets – and stressed that, “far from taking an interest in their significance to the military, he was chiefly concerned with the thought of improved transportation and, more generally, with expanding the limits of human accomplishment.”²¹³ Even if it was the case that Carl Runge’s interest in aviation was primarily scientific, it is also true that the interest of academics in this scientific advancement cannot easily be separated from its overwhelming importance to the military, an importance that was promptly recognized by the industrial sector and the state.²¹⁴

208 Around the same time that the Wright brothers’ flying machine made its first flight in 1903, W. Kutta and N. J. Joukowski independently developed the fundamental mathematical principles behind aerodynamics, a contribution known today as the Kutta-Joukowski theorem.

209 See KLEIN 1909.

210 Ludwig Prandtl’s theory of boundary layers in flowing liquids explained the causes of fluid resistance, and he explained air resistance analogously. He assumed that the overall effect of air resistance on any given part of an aircraft could be estimated if the investigator simply focused on the narrow field of air, the so-called boundary layer, that flows just along the surface of the area in question (see PRANDTL 1905; ECKERT 2006).

211 [STA] Rep. 92, Althoff A I, No. 139, p. 131.

212 The inaugural event was attended by Kaiser Wilhelm II. On April 27, 1914, the organization was renamed the Scientific Society for Aviation (*Luftfahrt*).

213 Iris RUNGE 1949, p. 135; on this biography see Section 4.4. In a letter written to his mother from Paris – dated September 8, 1908 – Carl Runge remarked: “Today I have begun my work by visiting the Voisin brothers, makers of the best flying machines. I suppose it will take fewer than twenty years before humans will be able to fly faster than the fastest birds. This event will be of greater consequence to world history than even the discovery of America or the invention of the printing press” ([STB] 460, p. 259v).

214 See TRISCHLER 1992; ANDERSON 1999; ECKERT 2006.

It is thanks to the scientific and linguistic competence of the Runge family that foreign research in the field of aviation made its way so quickly to the Göttingen community. Not only did Carl Runge introduce the French term “turbulence” to his colleagues,²¹⁵ he also translated, together with his wife and daughter, Lanchester’s comprehensive book on aerodynamics. The project was undertaken, in part, because of its immediate value to the joint seminars that Carl Runge conducted with Prandtl, whose knowledge of English was poor.²¹⁶ Even though Iris Runge’s contributions to the book were substantial, only Carl and Aimée Runge are officially credited as its translators. Iris Runge spent the 1909 summer vacation at the Ewald household in Holzhausen, where she became acquainted with Paul Ewald and the physicist Max Laue.²¹⁷ While there, she wrote a letter to her mother in Potsdam (her father was already in America at this time), which reveals both her precise contributions to the translation of the second volume as well as her general enthusiasm about the graphical methods employed in the book:

I have been making good progress with Lanchester. The second chapter is already on your desk in Göttingen, the third I have completed here, and I should soon be finished with the fourth. I have not yet begun to convert the British measurements, for it would be dismal to do so without a slide rule and a conversion table. It dawned upon me, however, that I could perhaps ask Dr. Laue to lend me a slide rule. I have also been too lazy to sit down and figure out which figures will have to be changed and how to do this in such a way that the new figures are both practical and sensible round numbers and yet still approximate to Lanchester’s original data. The graphs will also have to be changed accordingly, or is that not so? Please ask Dad whether the Teubner press will simply reprint the illustrations from the English original, in which case it will be necessary to convert the data exactly to ensure that the new numbers correspond to the graphs. [...] I am, in general, extremely enthusiastic about the book; its graphical methods are so well thought out! I am eager to experiment with them and construct some curves of my own.²¹⁸

In the second chapter of his *Aerodonomics*, Lanchester advanced what he called the phugoid theory, which concerned the longitudinal stability of an aircraft and the form of its flight path. He coined the word *phugoid* – somewhat inappropriately, as he knew – from Greek *phugē* and *eidōs* (‘flight-like’),²¹⁹ and he used it in such terms as phugoid chart, phugoid curve, phugoid oscillation, and phugoid equation, the latter being a partial differential equation for the motion of a body in flight. For the solution of this equation, Lanchester presented twelve graphical approximations, a method that he had developed independently in 1897 (though he

215 See ECKERT 2006, p. 51.

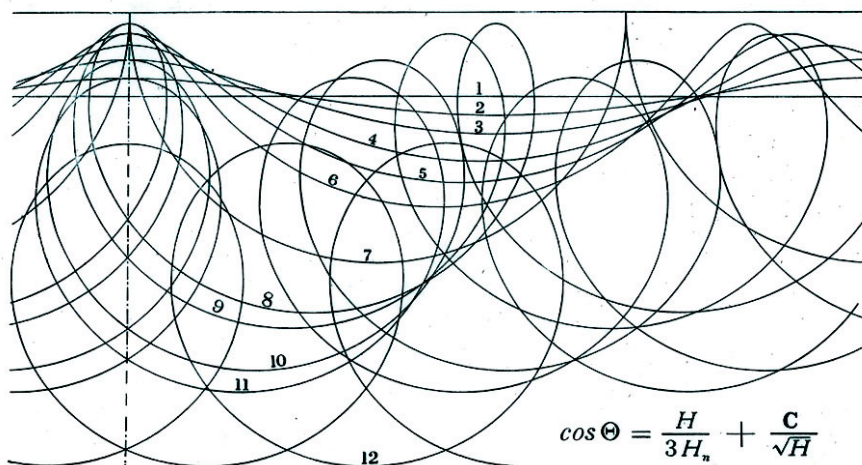
216 See IRIS RUNGE 1949, p. 137.

217 Max Laue was a lecturer in Berlin before he came to work under Arnold Sommerfeld in Munich (see Sections 2.5.1–2 and 2.5.4). When his father was admitted into the nobility in 1913, his last name was changed to “von Laue.”

218 A letter from Iris Runge to her mother dated August 25, 1909 [Private Estate]. On the use of graphical methods by aeronautical engineers, see HASHIMOTO 1994.

219 In a footnote to his glossary, Lanchester explains: “The appropriateness of the derivation is perhaps diminished by the fact that the word *φύγη* means flight in the sense of *escape* rather than the act of flying in the present signification” (LANCHESTER 1908, p. 348).

would correctly acknowledge the physicist Charles Vernon Boys as its discoverer).²²⁰ He explained the corresponding graph, the so-called phugoid chart, in a chapter entitled “Elementary Deductions from the Phugoid Theory,” and he also selected it to be the frontispiece of his book.



THE PHUGOID CHART. THE FLIGHT PATH PLOTTED FROM THE EQUATION.

Figure 3: F. W. Lanchester's Phugoid Chart

Iris Runge also devoted much of the following summer break to this translation:

Regarding Lanchester's book, I don't know how it has come about, Dad, that you have not received the fourth chapter. I translated all of chapters two through five, and I gave Mom the manuscript to pass along to you. Because she has already done chapter six, I have skipped ahead to chapter seven – “Lateral and Directional Stability” – which I will certainly be able to finish here, along with at least half of chapter eight – “General Conclusions” – so long as time allows.²²¹

The graphical and numerical methods that Iris Runge had learned from her father and so appreciated in Lanchester's book would also play an important part in her further university coursework. For instance, in one of her final written examinations for teaching certification, assigned by Woldemar Voigt, she applied Walter Ritz's new methods of integration to the problems of (parabolic) membrane oscil-

²²⁰ See LANCHESTER 1908, p. 41: “At the time of making the plottings of the curves of flight or *phugoids* given in the present volume (1897), the author imagined the method adopted [...] to be entirely new. It would appear, however, to have been no more than an application originated by Professor C. V. Boys to facilitate the plotting of the generating curve of a capillary surface.” For the contribution in question, see C. V. Boys, “On the Drawing of Curves by their Curvature,” *Philosophical Magazine* 36 (1893), pp. 75–82.

²²¹ A letter from Iris Runge to her father dated August 30, 1910 [Private Estate].

lations.²²² Even in the 1920s, Carl Runge was actively promoting the use of graphical methods among engineering physicists and also making efforts to increase his daughter's visibility as an expert in this technique (see Section 3.4.1.1).

Table 4: Courses Attended by Iris Runge, 1908–1912²²³

University of Göttingen

Winter Semester 1908/09

Mechanics	Professor Felix Klein
Descriptive Geometry	Dr. Paul Koebe (Lecturer)
Exercises in Descriptive Geometry	Dr. Paul Koebe (Lecturer)
Physics Lab	Professor Woldemar Voigt
The Buddha and Buddhism	Professor Hermann Oldenburg

Summer Semester 1909

Number Theory	Professor David Hilbert
Mechanics	Professor Felix Klein
Physics Lab	Professor Eduard Riecke
Exercises in Mechanics	Dr. Conrad Heinrich Müllter (Lecturer)
Infinite Series	Professor Edmund Landau
Thermodynamics Lab	Professor Ludwig Prandtl

Winter Semester 1909/10

Electrodynamics	Professor Woldemar Voigt
The Theory of Functions	Professor Edmund Landau
Physics Lab	Professor Eduard Riecke

Summer Semester 1910

Optics	Professor Woldemar Voigt
Exercises in Optics	Professor Woldemar Voigt
Basics and Principles	Professor David Hilbert
The Theory of Electrons	Dr. Max Born (Lecturer)
Integral Equations	Dr. Otto Toeplitz (Lecturer)
Archimedean Mathematics	Dr. Conrad Heinrich Müller (Lecturer)
Introduction to Human Geography	Professor Hermann Wagner

²²² This examination, the text of which no longer exists, is known only by its title (see [STB] 747, p. 17). Walter Ritz, who died of tuberculosis shortly after completing his *Habilitation* in 1909, was influenced above all by the work of David Hilbert and Woldemar Voigt. For his dissertation on spectroscopy (1903), he also personally consulted Carl Runge, who was still living in Hanover at that time (see Iris RUNGE 1949, pp. 110, 134–135).

²²³ [STB] 747, pp. 10–16. Because Iris Runge was enrolled in them as an auditor, there is no record of which lectures she attended at the University of Göttingen from the summer semester of 1907 to that of the following year, nor of those attended at the Technical University in Munich during the 1909/10 winter semester. However, from a letter to her cousin Erich Trefftz – dated April 25, 1907 – we learn that she attended Constantin Carathéory's calculus lectures, in which “five or six of the fifty participants were women,” and Eduard Riecke's course on experimental physics (see [STB] 664). In 1907, Iris Runge's mother Aimée was also an auditor at the university, and both of them attended lectures by the historian Max Lehmann, who was an early supporter of the women's right to study (see [STA] Rep. 76 Va Sekt. 1 Tit. VIII No. 8 Adhib. I Bd. VII, pp. 54–55).

University of Munich*Winter Semester 1910/11*

Definite Integrals and Fourier Series

Analytical Mechanics

Seminar: Exercises in Mechanics

Geometrical Optics

Professor Alfred Pringsheim

Professor Arnold Sommerfeld

Professor Arnold Sommerfeld

Professor Arnold Sommerfeld

University of Göttingen*Summer Semester 1911*

Light Waves

Numerical Calculations (with Exercises)

Physical Geography

Mediterranean Geography

The Geology of Hanover

Cartography

Physical Works

Professor Albert A. Michelson²²⁴

Professor Carl Runge

Professor Hermann Wagner

Dr. Ludwig Mecking (Lecturer)

Professor Josef Felix Pompeckj

Professor Josef Felix Pompeckj

Professor Woldemar Voigt

Winter Semester 1911/12

Partial Differential Equations

Seminar: Historical Authors on

Differential and Integral Calculus

Europe

Individual Assignments in Geography

Professor Woldemar Voigt

Professor Felix Klein²²⁵

Professor Hermann Wagner

Professor Hermann Wagner

2.4.5 The Applied Mechanics Tea Party

The Runge family ran an open home in Göttingen, and the daughters played an active role in social events, holiday celebrations, and even in many professional activities. As early as 1905, Elisabeth Klein and Iris Runge were permitted to accompany their fathers on the walking tours that they often arranged with their students and colleagues at the end of semesters.²²⁶ The girls were associated with

224 Carl Runge befriended Albert Abraham Michelson in 1897 during his first visit to the United States. Michelson, born into a Jewish family in Strzelno, Prussia (now Poland), emigrated with his family to the United States when he was two years old, and later he returned to Europe for part of his studies (Berlin, Heidelberg, Paris). In 1907 he became the first American to receive a Nobel Prize in the sciences, this for his work in the field of optics. Today he remains famous for the so-called Michelson-Morely experiment (1887), the results of which, it is thought, influenced Albert Einstein's formulation of the Theory of Relativity. Michelson came to teach for one semester at the University of Göttingen as part of the same German-American exchange program that had brought Carl Runge to New York during the previous academic year (for more on this program, see BROCKE 1981).

225 Iris Runge gave two reports in Klein's seminar, on Guillaume de l'Hôpital's differential calculus and on infinitesimal calculus in the works of Hegel ([Seminar Records] vol. 29, pp. 159–161; 265–267).

226 Leonard Nelson also took part. For a detailed report on the event, see Carl Runge's letter to his wife dated July 15, 1907 (in [STB] 514, pp. 197–197v).

young scientists at the tennis club, in student groups, at the homes of various professors, and also as part of a special circle of applied scientists. A few letters from the summer of 1907 illuminate the scene:

Sunday at the Schwarzschilds was fantastic. [...] Naturally there was a big crowd, including Mrs. Speyer and Messrs. Prandtl, Rüdenberg, Wilke, and Pütter [...]. We played catch, observed sunspots, and sat on the lawn telling stories about hot air balloons. At the end of the evening we climbed to the roof of the observatory, where the view is glorious.²²⁷

The children are really living it up – on Wednesday they strolled with the philologists, on Thursday they were at the Kleins while I was visiting Riecke, today they'll attend a party at Leo's home with magicians, and Clara Ewald is hosting yet another event on Sunday. [...] Yesterday a hot air balloon was launched by Gerdien, Pütter, and Bestelmeyer, and we were there to see it with Clara and everyone else in Göttingen.²²⁸

Ludwig Prandtl, Reinhold Rüdenberg, and Heinrich Hochschild had started a tradition in Göttingen which they referred to as the “Tea Party of Applied Mechanics” (*angewandt mechanischer Thee*). In 1909, they celebrated an anniversary of the event's founding, as described by Aimée Runge in a letter to New York:

Rüdenberg and Hochschild must have been behind it all, for Pfeiffer, Renner,²²⁹ and Courant were up to all sorts of shenanigans, and Pfeiffer supposedly gave a hilarious speech about the origins and history of the tea party, complete with Ella's illustrations.²³⁰ He began with the words: “The time was $t = 0$,” and then some of the men, each wearing a big sign with a blue letter T (that playfully designated a T-beam), brought the tea cups into the room. (This was Iris's idea, but this time she stayed in the background and left its execution to “lesser functionaries”!). One of the men made up a double T beam by carrying two trays of tea. When he dropped one of them, it was declared that “the strength of the T-beam has been miscalculated!” [...]. Then a model airship was brought in, which delivered two tea balls for Mrs. Föppl and Mrs. Prandtl. [...] Putti was given an alarm clock and Iris a notebook and an assistant chef's apron as tokens for their help with the teacher training course. Pfeiffer (Klein's assistant until then) received a broken fetter, whereas Hecke (Klein's newly appointed assistant) had to wear a set of handcuffs, which were put on him by Putti.

227 A letter from Iris Runge to her mother dated July 17, 1907 [Private Estate]. At the end of the semester, Carl Runge was living in Göttingen with his daughters Iris and Ella, while his wife was staying in Potsdam with the younger children.

228 Letters from Carl Runge to his wife dated July 20 and August 6, 1907 (in [STB] 514, pp. 332, 344). The classical philologist Friedrich Leo had been a professor at the University of Göttingen since 1899 and served as the rector in 1903; his daughter Erika was a friend of Iris Runge. Hans Gerdien earned his doctoral degree under Woldemar Voigt in 1903, completed his *Habilitation* at Göttingen in 1907, and began a career with Siemens in Berlin (see Section 2.7.3). August F. R. Pütter, who wrote a dissertation in medicine, was working as a research assistant at the Institute of Psychology. Written under the supervision of Eduard Riecke, Adolf Bestelmeyer's dissertation – “Die Bahn der von einer Wehneltkathode ausgehenden Kathodenstrahlen im homogenen Magnetfeld” [The Trajectory of Cathode Rays Emitted from a Wehnelt Electrode into a Homogeneous Magnetic Field] – was published in the *Nachrichten der Königlichen Gesellschaft der Wissenschaften zu Göttingen* (1911).

229 Albrecht Renner was awarded a doctoral degree in medicine on August 15, 1915 (JAHRES-VERZEICHNIS 31 [1916], p. 161); in 1918 he married Emilie Treffitz (Ducca).

230 Ella Runge had drawn the invitations to the event.

Hilbert, moreover, received a doll with a large scroll under its arm that was supposed to represent a female student carrying the proof to Fermat's last theorem.²³¹

This intellectual circle comprised the majority of Göttingen's mathematicians, including their assistants, students, and daughters. Even David Hilbert, who devoted most of his attention to theoretical physics after the premature death of Hermann Minkowski (January 12, 1909), could be numbered among its participants. It was only Edmund Landau, Minkowski's successor, who "loftily dismissed anything connected with the applications of mathematics as *Schmieröl*, or grease."²³² This may be somewhat overstated, however. As noted above, Landau was a member of the Göttingen Association for the Promotion of Applied Physics and Mathematics (see Table 2), and we learn from Richard Courant that Landau and his wife Marianne, the daughter of the Nobel laureate Paul Ehrlich, were central figures in the Göttingen social life. They held several parties, for instance, to which Iris Runge was invited. As early as 1910, Landau offered a highly positive evaluation of her talents, and the physicist Woldemar Voigt is known to have done the same:

I thought I should write you quickly to let you know that Voigt has had very good things to say about Iris. He recently met with her in his office because she had not fully understood everything in his course. His wife told me today that he considered her to be an extraordinarily gifted student with an admirable knack for difficult problems. Landau, too, has recently praised her. He told her that hers was the second best work in the entire class, and he has begun to call her a "true mathematician."²³³

Iris Runge had attended Landau's lectures on infinite series during the summer semester of 1909 and also his course on the theory of functions during the following term (see Table 4). Regarding Woldemar Voigt, his 1908 book – *Magneto- und Elektrooptik* [Magneto- and Electro-Optics] – presented a comprehensive theory of magneto-optics within the framework of classical electrodynamics. From him, Iris Runge learned important principles with which she was later able, during a semester spent away from Göttingen, to apply mathematical methods to problems in the field of optics.

231 A letter from Aimée Runge to her husband dated December 3, 1909 (in [STB] 523, p. 87). In 1909, Ludwig Prandtl had just married the daughter of his doctoral supervisor August Föppl, who was a professor of technical mechanics and statics at the Technical University in Munich. After completing his dissertation under David Hilbert in 1909, Erich Hecke worked as Klein's assistant until 1912 and then as a professor in Basel (1916), Göttingen (1918), and Hamburg (1919). Fermat's Last Theorem states that no three positive integers a , b , and c can satisfy the equation $a^n + b^n = c^n$ for any integer value of n that is greater than two. On the history of the efforts to prove this theorem and on the successful proof from 1996, see Israel Kleiner, "From Fermat to Wiles: Fermat's Last Theorem Becomes a Theorem," *Elemente der Mathematik* 55 (2000), pp. 19–37. During his career, David Hilbert served on a prize committee that had to review many (false) proofs of this theorem.

232 Such was Richard Courant's assessment. The quotation, originally in English, is taken from REID 1976, p. 26.

233 A letter from Aimée Runge to her husband dated February 4, 1910 (in [STB] 523, p. 137).

2.5 A SEMESTER AT THE UNIVERSITY OF MUNICH

It was not uncommon at the time for students to spend a semester away from their home institution. Sixty-five percent of mathematics students, for instance, changed their place of study at least once, and this statistic applies both to men and to the few enrolled women of that pioneering generation.²³⁴ Despite the fact that the University of Göttingen was then the leading institution in mathematics and physics, Iris Runge nevertheless exhibited her independent spirit by wanting to study elsewhere for a time. She shared this desire in common with a number of her friends, and thus in the winter of 1910 she wrote to her father in New York:

I would like to remain in Göttingen for the summer semester and to attend Voigt's lectures on optics, but after that I would very much like to study elsewhere. Is this even a possibility? Around Easter of next year, Putti intends to go to Strassburg and ultimately to take her exams there.²³⁵

As it happened, Elisabeth Klein (Putti) did not transfer to Strassburg but rather to Bryn Mawr, a women's college in the United States.²³⁶ Iris Runge was given permission to go to Munich, where her father had also studied for a few semesters and where she could expect the support and hospitality of Clara and Paul Ewald. Both her frugality and her correspondence with her mother suggest that this time away from Göttingen would be an expensive opportunity that could not be taken for granted. At that time the Runges had to watch their money carefully, for Aimée Runge's healthcare had been costly after the birth of her sixth child, and savings had to be set aside for each of the children's education.

During her recent summer vacation with the Ewalds in Holzhausen, Iris Runge had already been offered a taste of the city where she would spend a semester. While on this vacation, that is, she not only worked on the translation of Lanchester's book and passed the time with swimming, sailing, and tennis, but she was also taken on a tour of Munich by Paul Ewald. There she went to the theater and visited art museums, such as the Old Pinakothek, and she was able to see the university as well. Iris Runge was ebullient about the beauty of the city and also about the exhibits at the famous German Museum of Science and Technology (*Deutsches Museum*):

234 See the analysis in ABELE/NEUNZERT/TOBIES 2004; also TOBIES 2008c.

235 A letter from Iris Runge to her father dated January 14, 1910 (in [STB] 546).

236 Founded in 1885, Bryn Mawr College promised women a more ambitious academic program than any other in the United States. Charlotte Angas Scott, who was the first British woman to earn a doctoral degree in mathematics and who made significant contributions to algebraic geometry (one of Felix Klein's research fields), chaired the Bryn Mawr mathematics department from its inception. She kept in close contact with mathematicians in Göttingen, sending her own students there for postdoctoral research and publishing an article in the journal *Mathematische Annalen*. It was at Bryn Mawr, too, that Emmy Noether was offered a teaching position in 1933 (see chapter 7.1 in ABELE/NEUNZERT/TOBIES 2004).

It was with special pleasure that Paul led me to the wing of the museum concerned with electricity, where he showed me Geissler tubes and X-rays. He also took me to the exhibit containing Runge and Precht's photograph of the radium spectrum.²³⁷

The following discussion will concentrate on the groups in which Iris Runge participated during her stay in Munich, and especially on the intellectual circle surrounding Arnold Sommerfeld, who instigated and co-authored her first publication. It will also address additional aspects of her academic and private life that, having surfaced during this time period, are indicative of her desire for self-reliance.

2.5.1 In Sommerfeld's Circle

As the chair of theoretical physics at the University of Munich, Arnold Sommerfeld oversaw one of the most impressively equipped institutes for this field. Having conducted his doctoral research in Königsberg,²³⁸ he completed his *Habilitation* at the University of Göttingen, where he was strongly influenced by Felix Klein. He was the chair of mathematics at the Clausthal Mining Academy from 1897 to 1900 and the chair of technical mechanics at the Technical University in Aachen from 1900 to 1906. In the latter year he accepted the appointment in Munich, where his research continued its shift away from mathematics on account of his editorial role in the production of the fifth volume of Klein's ongoing *Encyklopädie der mathematischen Wissenschaften*.²³⁹ The young researchers who flocked around Sommerfeld were influenced by his interests in carrying out calculations "to their ultimate conclusion" and in selecting research projects according to the applicability of mathematical methods. His lists of potential thesis topics,

237 A letter to her mother dated August 12, 1909 [Private Estate]. Geissler tubes, precursors to cathode ray tubes, have an electrode on each end and are filled with one of a number of rarefied gasses. When a high voltage current is made to flow through such tubes, different spectral lines will be created depending on the type of gas that they contain. The reference to her father's work is to Carl Runge and Julius Precht, "Über das Funkenspektrum des Radiums," *Annalen der Physik* 14 (1904), pp. 418–422, which analyzes, in light of the Zeeman effect, the seven principal lines in the spark spectrum of radium. Today, the theory of spectral lines named after Pieter Zeeman is often known as Runge's rule. It was this study that secured Carl Runge's fame in the fields of spectroscopy and astrophysics.

238 Sommerfeld's dissertation, which was directed by Ferdinand Lindemann (a former student of Felix Klein) and defended in 1891, was entitled "Die willkürlichen Funktionen in der mathematischen Physik" [Arbitrary Functions in Mathematical Physics]. On Sommerfeld and his circle, see ECKERT 1993, 1997; ECKERT/MÄRKER 2000/2004; SETH 2010.

239 The fifth volume (physics) appeared between 1902 and 1925; it included an article by Carl Runge – on the laws governing the spectrum series of certain elements – as well as many significant articles written by foreign scholars. In the 1890s, Sommerfeld and Felix Klein had traveled to Great Britain and the Netherlands, where they were able to attract contributions from international researchers (see *ENCYCLOPEDIA*, vol. 5.1, p. III). Sommerfeld, incidentally, had already contributed to the second volume of the *Encyklopädie* (on analysis) with an article entitled "Randwertaufgaben in der Theorie der partiellen Differentialgleichungen" [Boundary Problems in the Theory of Partial Differential Equations].

which he jotted on library cards, ranged from matters of hydrodynamics to coil inductance to wireless telegraphy, and they typically involved the solution of partial differential equations with special boundary conditions.²⁴⁰ In 1910, Sommerfeld's students included Peter Debye, Max Laue, and Paul Ewald.

Peter Debye, a Dutchman, had studied electrical engineering in Aachen, where he had worked as Sommerfeld's assistant at the Institute of Technical Mechanics. While in Munich, he earned his doctoral degree (1908), contributed a lengthy article on stationary and quasi-stationary fields to the *Encyklopädie* (1909),²⁴¹ and completed his *Habilitation* (1910) in quick succession. According to Iris Runge, a course that Debye offered during the 1910/11 winter semester, on radiation theory, "was the one truly challenging lecture" that she did not yet have the courage to attend in Munich.²⁴² Years later, however, she would enroll in his Göttingen course on the kinetic theory of gases (see Table 5).

Max Laue was introduced to theoretical physics by Woldemar Voigt in Göttingen and he went on to write a dissertation in the field of optics (specifically on interference phenomena in plane-parallel plates) under the direction of Max Planck in Berlin. Having returned to the University of Göttingen for an additional four semesters, he passed the secondary school teaching examination; in 1906 he began his postdoctoral research in Berlin, which he subsequently transferred to the University of Munich in 1909. While, at Sommerfeld's invitation, Laue was writing an article on wave optics for the *Encyklopädie*, he began a discussion with Paul Ewald (who was then finishing a dissertation on crystal optics) that led to the novel idea that X-rays could be diffracted by crystals.²⁴³ In 1912, having convinced the experimental physicists Walter Friedrich and Paul Knipping to help them with the appropriate experiments, they discovered X-ray interference and thus demonstrated for the first time that X-rays are a form of short-wave electromagnetic radiation. Sommerfeld declared this to be the greatest event in the history of his institute. Laue explained the discovery by means of a geometric theory that he and Paul Ewald later refined with a theory of dynamics. In 1912, too, Laue was hired as an associate (*außerordentlicher*) professor by the University of Zurich, and two years later he was awarded the Nobel Prize in physics.²⁴⁴

240 See ECKERT/SCHUBERT 1986, p. 91.

241 See ENCYCLOPEDIA, vol. 5.2, pp. 395–480. On Debye, see also HOFFMANN/WALKER 2011.

242 Iris Runge recorded this assessment on November 8, 1910 [Private Estate].

243 See BETHE/HILDEBRANDT 1988.

244 The 1915 Nobel Prize in physics was given to William Henry Bragg and his son William Lawrence Bragg, who together formulated, on the basis of Laue's discovery, a method of analyzing crystal structures with X-rays. Similarly influenced by this discovery, Manne Siegbahn and his assistants in Stockholm invented X-ray spectroscopy, for which they earned the Nobel Prize in 1924. Peter Debye and Paul Scherrer developed a method in 1916 for determining the atomic structure of microcrystalline (powder) samples by means of X-rays (the so-called Debye-Scherrer method). Scherrer would go on to apply this method to fluid and to colloidal particles, and Debye was awarded the 1936 Nobel Prize in chemistry.

The results of this discovery, which was made two years after Iris Runge's semester in Munich, proved to be important to her later work on materials research. That she was enthusiastic about the analysis of crystal structures is evidenced by the fact that, many years later, she described the methods of doing so to her younger sister Aimée (Bins):

Bins, I'm pleased that you have found my explanation of X-ray diffraction useful and that you are now fully immersed in the matter; it really isn't so difficult in itself, and it is uncommonly satisfying how an entire crystal structure can be determined from a few diagrams. I once read a wonderful book by William Bragg that dealt with the topic beautifully, but I'm sure that by now his approach is already somewhat outdated.²⁴⁵

Because of her acquaintance with Paul Ewald, Iris Runge quickly became a member of Sommerfeld's circle. She took up residence, on the recommendation of Clara Ewald, in a boarding house not far from the Ewalds' apartment, where she would be entertained regularly.²⁴⁶ There, according to Paul, Iris Runge was able to discuss the scientific issues of day in a more lively and intelligent manner than anyone else in all of Munich.²⁴⁷ Fascinated by Sommerfeld's graceful harmonization of mathematical and physical problems, Paul Ewald took Iris Runge to meet the professor before the beginning of the semester.²⁴⁸ Sommerfeld immediately proposed a research topic for her to work on independently, which she regretfully declined at the time on account of the brevity of her stay in Munich.²⁴⁹ Inspired by Sommerfeld's lectures, however, she decided in the end to take on the project, though she did not lose sight of her professional goal of becoming a teacher:

Sommerfeld is outstanding; his approach to mechanics is altogether inspiring, and I am eager to pass it along one day to a classroom of my own. He begins straight away with Newton's Laws, which of course express the only known truths. This is not the common method in schools, where a hodgepodge of principles are abstracted from a "simplicity machine" that yields nothing but half-truths; nor is it Felix Klein's way of doing things, who first confuses students with mile-long orthogonal transformation formulas before moving on to matters of concrete mechanics. (Only Sommerfeld is reasonable!)²⁵⁰

245 A letter dated November 3, 1940 [Private Estate].

246 Iris Runge lived in the Pension Thurner at Schellingstraße 41, and the Ewalds lived on the nearby Friedrichstraße.

247 See the letter from Iris Runge to her parents dated October 21, 1909 [Private Estate].

248 On Paul Ewald's admiration for his teacher, see EWALD 1968, p. 539.

249 In a letter dated October 30, 1910 [Private Estate], Iris Runge wrote: "On Monday I went with Paul to meet Sommerfeld. He was most kind, and he fervently tried to deter me from his course on mechanics by saying that he planned to make things as boring as possible and that he dreaded the willful ignorance of the Bavarian candidates for teaching licensure. I remained firm, however, and Paul supported my decision by mentioning that Sommerfeld's lectures always turned out to be more valuable when he introduced topics at an elementary level. Sommerfeld asked me three times, each time with more urgency than the last, whether I might want to begin an independent project of my own, and three times I said 'No', though I deeply regretted having to do so. I assure you that it was all very dramatic. But if I will only by here for a single semester [...]."

250 A letter from Iris Runge to her parents dated November 8, 1910 [Private Estate].

Having taken mechanics in secondary school with Eduard Götting and at the university level with Felix Klein, Iris Runge was now attempting to reach her own conclusions on the subject – “to unify [her] understanding of mechanics into a logical system,” and “to cease looking at the matter through the eyes of [her] teachers,” in her own words.²⁵¹ Although most of her coursework in Munich proved to be rather unchallenging, Sommerfeld and his circle always had something stimulating to offer. For instance, Sommerfeld’s course on optics, which was far more promising than that on mechanics, provided the impetus for Iris Runge’s first original scientific study: “Only Sommerfeld’s course on geometric optics promises to be highly advanced, and I hope that I will be able to understand everything.”²⁵² The fact that she built her own optical instruments at her boarding house and demonstrated diffraction images to her fellow tenants, as she had learned from her father in Göttingen, only provides additional evidence of her enthusiasm for the subject: “The diffraction images produced by rectangular, triangular, and parallelogram-shaped apertures are turning out very well indeed. It has been effective, too, to rotate the slit 90 degrees in front of a point light source.”²⁵³

Through Paul Ewald, Iris Runge also gained access to a physics colloquium at the University of Munich, where the latest research findings were discussed:

Paul showed up on Wednesday afternoon and took me along to the “physics colloquium,” an organization founded by young lecturers and research assistants (Sommerfeld is the only bigwig who attends). The whole thing, I think, was spearheaded by Paul. Research was presented and lively discussions ensued.²⁵⁴

Iris Runge began to delve further into some of the ideas that came to her in Sommerfeld’s course on geometric optics. She not only met with him after his lectures and at the physics colloquium, but also privately at his home. At one point she even went ice skating with Sommerfeld and his wife Johanna: “It was fun to go skating with him; he began to talk about mathematics right away, so you can imagine how at ease I felt!”²⁵⁵ Iris Runge bolstered her understanding of geometric optics with the help of a book on the theory of elliptical functions, and she used a book by Reinhold Hoppe, lent to her by her father, to translate optical formulas into the language of vectors.²⁵⁶

251 A letter from Iris Runge to Leonard Nelson dated November 4, 1910 [FES].

252 Noted by Iris Runge on November 8, 1910 [Private Estate]. For Sommerfeld’s work in this field, see also Arnold Sommerfeld, *Mathematical Theory of Diffraction*, trans. R. J. Nagem et. al (Boston: Birkhäuser, 2004).

253 A letter from Iris Runge to her parents dated November 8, 1910 [Private Estate].

254 Ibid. See also EWALD 1968.

255 A letter from Iris Runge to her parents dated January 14, 1911 [Private Estate]. As another example of the connections between the Runge (Trefftz) and Sommerfeld families, it should be noted that Johanna Sommerfeld, the daughter of the Göttingen literary historian and university official Ernst Höpfner, enjoyed a close friendship with Lily Trefftz (née Runge). (See p. 35 of the latter’s self-published memoirs).

256 See the letter cited in the previous note.

2.5.2 A Publication with Arnold Sommerfeld

On April 17, 1911, Arnold Sommerfeld and Iris Runge submitted a co-written article – “Anwendung der Vektorrechnung auf die Grundlagen der geometrischen Optik” [The Application of Vector Calculus to the Foundations of Geometric Optics] – to the journal *Annalen der Physik*. She received the proofs as early as July, and in August her father proudly noted the following in his epistolary diary:

Regarding my family, I should report that Iris has returned to us after her semester in Munich. It did her well to be there, both physically and intellectually. Sommerfeld was extremely friendly to her, and he even instigated her first scientific publication, which has appeared with both of their names on it in the *Annalen der Physik*.²⁵⁷

The article begins with the words: “The purpose of the present study is to offer a method for representing the familiar laws of geometric optics in an especially clear form. The method lies in denoting each point in the direction of light rays with a unit vector, a procedure that reveals the utility of vector analysis to our field.” The first footnote explains: “The methods were developed by Sommerfeld in a lecture (Munich 1910) and executed by I. Runge in the special case of curvilinear light rays, as well as in sections 7 and 11.”²⁵⁸

The sections identified in the footnote are, respectively, “Der Malussche Satz” [Malus’s Law] and “Brechung an einer Kugelfläche” [Refraction at a Spherical Surface], but it is clear that Iris Runge contributed to the rest of the article as well. Some of her later studies, for instance, allude to the conclusions drawn in the ninth section of the article, “Das Eikonal und die Grenzen der geometrischen Optik” [The Eikonal Equation and the Limits of Geometric Optics], which establishes a connection between the “method of ray vectors, H. Bruns’ method for solving the eikonal equation, and Hamilton’s general theory of characteristic functions.”²⁵⁹ Peter Debye, who was known to explain the interrelations between physics and mathematics better than any other teacher,²⁶⁰ contributed an essential observation to this section. His contribution concerned the derivation of a partial differential equation, and the authors underscored its relevance:

In a private conversation, Mr. Debye observed that this differential equation could be obtained by a limiting procedure from the differential equation of wave optics, namely: $\Delta u + k^2 u = 0$, where u denotes the light amplitude, reduced by the factor $e^{i\mathbf{v} \cdot \mathbf{r}}$, as measured either by its electric or magnetic component, and k designates the “wave number” $2\pi/\lambda$, which is a very large quantity as measured by cm^{-1} .²⁶¹

Judging from the reception of this article, it is clear that it was regarded as a significant contribution to geometric and wave optics alike. In his article on wave

257 The diary entry – dated August 23, 1911 – is quoted from HENTSCHEL/TOBIES 2003.

258 SOMMERFELD/RUNGE 1911, p. 277.

259 Ibid., p. 289.

260 See EWALD 1968, p. 541.

261 SOMMERFELD/RUNGE 1911, pp. 290–291. See MEHRA/RECHENBERG 2001, pp. 519–520.

optics for the *Encyklopädie*, for instance, Max Laue regarded Sommerfeld and Iris Runge's approach to geometric optics as being of transitional importance to his field, noting: "Following a thought by Debye, Sommerfeld and Runge have shown how it is possible to arrive at the eikonal equation of geometric optics from the scalar wave equation $\Delta u + k^2 u = 0$."²⁶² Erwin Schrödinger, too, referred to their article in the second installment of his great article on wave mechanics, "Quantization as an Eigenvalue Problem" (1926): "In the further development of the q -space optics in the sense of the wave theory it will be necessary, to *maintain* the analogy, to take care precisely that we do not depart appreciably from the limiting case of geometric optics; perhaps by choosing the *wavelength* sufficiently small [...]." To this he added the following footnote:

For the optical case, see A. Sommerfeld and Iris Runge, *Ann. d. Phys.* 35, p. 290 (1911). It is shown there (developing an oral remark by P. Debye) how the equation of the *first* order and *second* degree for the *phase* ("Hamiltonian equation") can be derived accurately from the equation of the *second* order and *first* degree for the wave function ("wave equation") in the limiting case of vanishing wavelengths.²⁶³

Whereas Schrödinger completed the transition from classical mechanics to wave mechanics, Sommerfeld and Runge had made a similar transition from wave to geometric optics. Sommerfeld observed the parallelism between the two approaches in a later lecture that he gave on the eikonal equation. Referring to his and Iris Runge's article from 1911, he noted: "In our first seven equations we made the transition from wave optics to geometric optics. Schrödinger, in a sense, accomplished the same thing in reverse when, inspired by Hamilton's comprehensive ideas, he forged the transition from classical to wave mechanics."²⁶⁴

A number of researchers, moreover, directly adopted Sommerfeld and Iris Runge's application of vector analysis to ray optics. The physicist Philipp Frank described their work as a "very elegant representation of ray optics in isotropic media," and pointed out that, following their lead, the mathematician Rudolf Rothe had applied vector analysis to differential geometry.²⁶⁵ Frank himself extended their method to his work on light rays and moving bodies.²⁶⁶

The knowledge that Iris Runge gained through her collaboration with Sommerfeld proved to be valuable to her later in life. She would put these same theoretical findings to use as an industrial researcher, and she went on to earn a reputation among theoretical physicists as an expert in the field of colorimetry.

262 VON LAUE 1915, p. 439.

263 SCHRÖDINGER 1926b, p. 496. Quoted here from the following English translation: Erwin Schrödinger, "Quantization as an Eigenvalue Problem (Second Communication)," in *Wave Mechanics*, ed. Gunter Ludwig (Oxford: Pergamon, 1968), pp. 106–126, at 113–114.

264 SOMMERFELD 1950, p. 213; see also BENZ 1974, pp. 238–239.

265 FRANK 1933, p. 4.

266 For additional evidence of Sommerfeld and Runge's influence, see HERZBERGER 1931.

2.5.3 Heinrich Burkhardt and the Goal of Earning a Doctoral Degree

During this same semester away from Göttingen, Iris Runge also established contacts at the Technical University in Munich, where Heinrich Burkhardt held a professorship in the principles of higher mathematics. Like Sommerfeld, Burkhardt was also closely associated with the scientific community in Göttingen; he completed his *Habilitation* there in 1899, and he was also a significant contributor to Klein's *Encyklopädie*. Just as Sommerfeld was entrusted with editing the fifth volume of this project (on physics), Burkhardt was responsible for the second volume, which concerned analysis. For this he had been able to commission contributions from prominent function theorists, especially because of his close ties to French mathematicians. Burkhardt came to Munich in 1908 after working for nearly a decade at the University of Zurich, and one of his courses during the winter semester of 1910/11, on the applications of function theory to physical problems, was well-suited to Iris Runge's program of study:

I have dropped Hartog's algebra course, which was far too elementary for me.²⁶⁷ Though his lectures were well done, I could not see myself benefitting from sitting through four hours of them. Now I am simply working through Netto's algebra book in the reading room of the library, and I will certainly learn everything more quickly in this way.²⁶⁸ During most of the work week I have a free hour from 11 to 12 (between mechanics and Pringsheim's course), and this is an ideal time to sit in the library. [...] For home study I have checked out Weber's edition of Riemann's lectures, which I have been devouring with great pleasure – it's amazing how much progress can be made! [...] I have been attending a good course at the Technical University, namely Burkhardt's on the application of function theory to physics. I think that it will turn out very well, and its content happens to dovetail with that of Weber's book, which I have been busy plowing through. From what I've witnessed so far, Burkhardt does not give the most polished lectures; he often repeats himself, and two days ago – the poor man – he lost his train of thought entirely. But his approach to things is precise, sound, and even geometrically clear. Today he won my heart by telling us what can be disregarded and what cannot. This is something that is never mentioned in my other lectures, as though it would be too obvious to say as much! [...] The course with Pringsheim (definite integrals and Fourier series) is quite amusing. He's a funny man. Paul [Ewald] had already warned me that he looks like his own coachman, and I couldn't agree with him more! Unfortunately, his lectures are almost "offensively intelligible." That is, he explains everything with horrifying pedantry, as if no one there had ever heard of such a thing as, say, an upper limit. In general, the lectures here in Munich have certainly not distinguished themselves by their difficulty. Indeed, Sommerfeld already expressed this same opinion to me. In the end, however, no harm can come from this.²⁶⁹

267 Friedrich Hartogs had been one of Alfred Pringsheim's students. He received an associate professorship in Munich immediately after completing his *Habilitation* there in 1910. His most significant research concerned complex function theory.

268 Eugen Netto, *Vorlesungen über Algebra*, 2 vols. (Leipzig: B. G. Teubner, 1898–1900).

269 A letter from Iris Runge to her parents dated November 8, 1910 [Private Estate]. For the edition of Riemann's lectures referred to, see Heinrich Weber, ed., *Die partiellen Differential-Gleichungen der mathematischen Physik, nach Riemann's Vorlesungen*, 2 vols. (Braunschweig: Vieweg, 1900–1901).

During Heinrich Burkhardt's lectures, Iris Runge sat next to Wilhelm Deimler, with whom she was already acquainted from Göttingen. In November of 1909, before he finished his doctorate,²⁷⁰ Deimler had been made the assistant of Sebastian Finsterwalder, a professor of mathematics at the Technical University in Munich.²⁷¹ Iris Runge had long discussions with Deimler about mathematical problems in physics and aeronautics, she went skiing with him, and she accompanied him to the German Museum of Science and Technology. Her letters to her mother suggest that she could have imagined being with him on intimate terms, but Deimler – whose father (an evangelical missionary in India) had died early and who did not have a secure job – was not in a position to marry at the time, as is implied in one of his letters to her:

My graphs and calculations of Kutta's fluid flow are requiring an enormous amount of time (at times I have had to make calculations with ten-digit logarithms!),²⁷² and on top of that I have had to teach a great deal (I've been a bit short on money lately). [...] For now my lessons are primarily concerned with dynamics, and so I have been forced once again to work with vectors and the like. This means that I might even be able to understand your seminal article when you send it along to me.²⁷³

In her discussions with Deimler, Iris Runge realized that the two of them were on equal footing, at least as far as their scientific abilities were concerned.²⁷⁴ He completed his *Habilitation* in pure and applied mathematics, in 1913, with a study entitled "Konforme Abbildung des ganzen Erdellipsoids auf die Kugel" [A Conformal Map Projection of the Entire Earth Ellipsoid onto a Sphere]. For her part, Iris Runge had to forgo her first opportunity to conduct research as a graduate student, an opportunity that had been offered to her by Heinrich Burkhardt. As we read in another letter from Deimler:

It's a shame, it's really a great shame that you had to turn down the assistantship with Burkhardt, but of course I realize that, in present circumstances, it would have been nonsensical for you to accept it. Your first priority must be to pass the teaching examination, and then

270 Ludwig Prandtl, Wilhelm Deimler's doctoral supervisor, gave the latter's dissertation – "Stabilitätsuntersuchungen über symmetrische Gleitflieger" [Studies in the Stability of Symmetrical Gliders] – the lowest possible grade and required numerous revisions. However, Deimler had passed his oral examination *cum laude*, which was conducted by Prandtl, Hermann Minkowski, and Eduard Riecke. Carl Runge participated in Deimler's degree as the chairman of his dissertation committee (see [UAG] Phil. Fak., Prom.-Spec. D, Vol. I, 1906–1913, No.11). His doctorate was ultimately awarded on February 26, 2010, and his dissertation was published in the *Zeitschrift für Flugtechnik und Motorluftschiffahrt* 1 (1910), pp. 49–53, 64–66, 91–96, 106–108.

271 Deimler, who died in the First World War, worked as Finsterwalder's assistant from 1909 to 1912. For obituaries, see FINSTERWALDER 1915a, 1915b.

272 For the results of these efforts, see Wilhelm Deimler, "Zeichnungen zur Kuttaströmung," *Zeitschrift für Mathematik und Physik* 60 (1912), pp. 373–396.

273 A letter from Wilhelm Deimler to Iris Runge dated May 4, 1911 (in [STB] 706). Deimler is referring to Iris Runge's collaborative article with Arnold Sommerfeld: SOMMERFELD/RUNGE 1911.

274 Fifteen postcard and fourteen letters from Deimler to Iris Runge survive in [STB] 706.

things will be somewhat different. From what I've seen and heard, incidentally, Burkhardt does not expect much work from his assistants, not half as much as Finsterwalder requires, for instance. Indeed, I think you would be more than able to complete your own doctoral research alongside these duties, in the event that you decide to accept the position later on. I consider it quite likely that Burkhardt would be willing to offer it to you again (even without me having to kill off one of his assistants, as you suggested I might have to do!).²⁷⁵

Iris Runge's correspondence with Deimler reveals how deeply interested she was in continuing her scientific research, and her parents were supportive of this idea even before she passed her teaching examination. In 1912, she visited Burkhardt in Munich to see whether he could still use her as an assistant, and later reported the following to her mother:

He no longer has any private assistantships available. For the time being he is content with his official research assistant, and he doesn't know whether he will need any additional help next winter. If a position does open up, however, he said that either he or Sommerfeld would be happy to supervise my doctoral research.²⁷⁶

After her graduation, Iris Runge spent the years 1912 to 1914 completing her pedagogical training (which involved another round of examinations), and she was called upon to fill teaching vacancies at secondary schools after the outbreak of the First World War. Heinrich Burkhardt died on November 2, 1914, and so her plans to earn a doctoral degree had to be postponed.

2.5.4 "Women should not be permitted to study, for this might take away their desire to marry."

As a young woman in Göttingen, Iris Runge had not been averse to practicing her "feminine charms."²⁷⁷ There she fell in love with several men, most deeply of all with her cousin Erich Trefftz.²⁷⁸ They ended this relationship for obvious reasons, however, and Iris Runge was moved to memorialize their separation in a poem:

275 A letter from Wilhelm Deimler to Iris Runge dated May 14, 1911 (in [STB] 706).

276 A letter from Aimée Runge (quoting her daughter) to her husband dated April 9, 1912 (in [STB] 523, p. 208).

277 See the letter from Aimée Runge to her daughter dated October 29, 1906 (in [STB] 666).

278 See, for instance, a letter from Iris Runge to Erich Trefftz dated April 25, 1907 (in [STB] 664): "It was a wonderful springtime dream, on which I will always look back with fondness; and a memory such as this is indeed more enriching than it is impoverishing. [...] My mom was so terribly nervous in the evenings and the young children were so unruly – I even considered walking away from it all and simply losing myself in my feelings for you. [...] Cicero is now going very poorly without you, but we are slowly managing to get things together. [...] My friend Grelling is here again, as are P. Ewald, and Nelson with his wife." Iris Runge and her acquaintances frequently staged theater performances (see the photograph at the bottom of Plate 6, which is appended toward the end of the book); the reference to Cicero is to a character in a play, perhaps Shakespeare's *Julius Caesar*.

Märzabend²⁷⁹
Iris Runge

Zu unsern Füßen glitt der Strom
 graugrün und ewig ruhelos.
 Dicht überm Wasser raschen Flugs
 die Möwe hin und wieder schoss.

Wir aber standen Hand in Hand
 und blickten in den Dämmerchein.
 Wir wussten es: zum letzten Mal.
 Und morgen muss geschieden sein.

Herz, klage nicht! Denn dieses Tags
 verschleiert Glück ist süß genug.
 Grell schreit die Möwe. Durch den Wald
 gehts wie ein Frühlingsatemzug.

An Evening in March
by Iris Runge

The current glided at our feet,
 greyish green and ever restless.
 Just above the water and rash,
 the seagull darted at its will.

We stood together hand in hand
 and looked into the twilight sky.
 This would, we knew, be the last time.
 Tomorrow we would have to part.

Do not lament! On such a day
 let veiled joy suffice as sweet.
 The gull's call is shrill and pierces
 the forest like a springtime gasp.

These words were written three years before her semester in Munich. In the meantime Iris Runge had turned twenty-two years old, and her mother sent her a letter in which she proclaimed: "In our last exchange, Lanchester alleged that young women should not be permitted to study, for this might take away their desire to marry. It seems as though he is right!"²⁸⁰ Lanchester had fallen for one of Iris Runge's sisters, all of whom were encouraged to marry but not to do so for the sake of marriage itself. Lanchester's proposal, for instance, was rejected on account of him being too old. At the time, love and affection were largely regarded as the minimum prerequisites for marriage by the educated middle class, but this was still not always the case. When Ludwig Prandtl asked for the hand of August Föppl's daughter, for instance, he did not even specify which daughter he had in mind (he was offered the eldest).²⁸¹ Aimée Runge, who had married her husband Carl out of love, commented as follows about Prandtl's marriage: "I think that Prandtl went about the matter somewhat deviously; even so, I can certainly extend warmer congratulations to him than I was able to muster for Wiechert last year."²⁸² In the matter of marriage, Carl and Aimée Runge let their daughters decide for themselves.

When Max Laue approached Carl Runge – on July 30, 1909 – to ask for Iris's hand, Carl Runge wrote a few curt remarks to his wife on the same day: "I had a visit today from Dr. Laue, who has taken an interest in Iris: A physicist in Munich,

279 [STB] 371.

280 A letter from Aimée Runge to her daughter dated February 9, 1911 (in [STB] 666).

281 On Prandtl's marriage, see KÁRMÁN/EDSON 1967, p. 38.

282 A letter from Aimée Runge to her husband dated October 16, 1919 (in [STB] 522). In the summer of 1908, Emil Wiechert had married Helene Ziebarth, the daughter of a late law professor at Göttingen; the marriage remained childless.

Planck's former assistant."²⁸³ It is apparent from Aimée Runge's response that, before then, Laue had never tried to establish any personal relationship with their daughter: "Your laconic report about Dr. Laue's visit was rather mysterious. Who is this person and since when has he been 'interested' in Iris? When does Iris ever travel to Munich?"²⁸⁴

As already mentioned, Iris Runge spent the late summer of 1909 with the Ewald family in Holzhausen, which is near Munich. She met Max Laue several times during this vacation, and even took a boat out with him onto the Ammersee, but she could not develop any fondness for him. She found him somewhat shy and awkward, and she was frustrated by the fact that he could not speak any English (there was a British guest at the Ewalds).²⁸⁵ Laue, it seems, was in a great rush to marry, and Iris Runge's lukewarm reception hardly deterred him from looking elsewhere for a bride. The next time she saw him was at the physics colloquium in November of 1910, hardly a year later, and about this reunion she wrote: "Laue was also there, and he's already married! He looks plump and healthy, but he could not have greeted me in a more rigid and timid manner."²⁸⁶ Iris Runge wanted to remain on good terms with him despite his coldness, as is clear from her account of the subsequent meeting of the colloquium:

Today at the physics colloquium I had the opportunity to meet Mrs. Laue; she is very kind, not to mention pretty, healthy, and amicable. I simply asked him to introduce us, even though he was clearly reluctant to greet me himself (whether out of ill-will or abashment, I don't know). But that seemed to be the polite thing to do, and I am intent on doing my part to make things as normal as possible between us.²⁸⁷

Iris Runge never regretted her decision not to marry Laue, even after he became a Nobel Prize winner and renowned professor in Berlin, where she would meet him at various gatherings of physicists later in her life:

Oh, please! You only asked because of Laue. No, I must say that he's no King Thrushbeard to me.²⁸⁸ Admittedly, he has become a famous man and, what is more, a kind and virtuous man whose behavior has been beyond reproach. Several of my friends – Julie Berg and even Nina – have sung his praises to such an extent that I'm even beginning to believe them. One or two years ago, however, I was sitting next to him one evening and could not help but

283 A letter from Carl Runge to his wife (in [STB] 541, p. 16).

284 A letter from Aimée Runge to her husband dated August 1, 1909 (in [STB] 522).

285 See Iris Runge's letter to her mother dated August 17, 1909 [Private Estate]: "The ever-present Laue also showed up on Sunday afternoon, which complicated things somewhat because he can't speak a word of English."

286 A letter from Iris Runge to her parents dated November 8, 1910 [Private Estate]. On October 6, 1910, Max Laue married Magdalena Degen, who spent her childhood in Switzerland and spoke fluent French. The two of them would have two children (on Max Laue's life and work, see ZEITZ 2004).

287 A private account made by Iris Runge on December 12, 1910 [Private Estate].

288 The reference is to the Grimms' fairy tale, "King Thrushbeard," in which an arrogant princess ridicules and rejects a suitor who turns out to be a powerful king (in the meantime, however, she finds herself humbled and unwittingly married to this very man).

think: I can't bear this man for a minute. Everything about him gets on my nerves. If I had to live with him, I'd run away from home, and I can say this even despite the great respect I have for him. [...] If only I could be as certain about everything I have done in my life as I am about my decision to reject him, I would be a very happy person indeed.²⁸⁹

In January of 1911, while still in Munich, Iris Runge also rejected a written marriage proposal from Hugo Dingler. At the time, Dingler, whose *Habilitation* in mathematics at Technical University of Munich had been rejected in 1910, was living in the same boarding house as she was, and over meals they discussed such topics as non-Euclidean geometry.²⁹⁰ Personally she felt no attraction to Dingler, who was somewhat older than she was, but rather to Wilhelm Deimler, with whom – as mentioned above – she attended lectures and spent some of her free time. Deimler's financial situation, however, was not the only thing that prevented them from sharing a future together, for they also held divergent opinions about certain social issues that were close to Iris Runge's heart. The nature of their disagreements is revealed quite directly in a letter that Deimler had written to her after his return from a scientific expedition in the Pamir Mountains:

Dear Iris,

Since Sunday I have been back in the Holy German Empire [...]. While in the wilderness I was terribly eager to receive a word from you and to hear something about your activity in Göttingen, your plans, and your opinions. Surely we would have carried on our little debates had we not been separated by 6,000 kilometers, despite the fact that we share nearly the same views about all of these social issues. It is only about the implementation of these views that we have really butted heads.²⁹¹

To discuss social issues is one thing, but to do something about them is another matter entirely. Whereas Deimler was clearly not ready for such engagement, Iris Runge considered social activism to be an essential part of her life. Her involvement in various political and philosophical circles began as early as her first years at the University of Göttingen.

289 A letter from Iris Runge to her sister Ella dated April 25, 1938 (in [STB] 834, p. 17v).

290 See the letters from Hugo Dingler to Iris Runge – dated January 24 and 25, 1911 – in [STB] 718; and the letter from Iris Runge to Leonard Nelson dated November 4, 1910 (in [FES]). Dingler ultimately completed his *Habilitation* at the University of Munich in 1912 with a study concerned with the methodology, pedagogy, and history of mathematics. His political inclinations (he was pro-Nazi during the period of National Socialism) would have clashed with Iris Runge's in any case; see WOLTERS 1992; HASHAGEN 2003, p. 256; FOLKERTS 2005, p. 443; METZLER-TROTT 2007.

291 A letter from Wilhelm Deimler to Iris Runge dated November 29, 1930 (in [STB] 706).

2.6 POLITICAL AND PHILOSOPHICAL ASSOCIATIONS

When I began to involve myself in politics under Leonard Nelson and Wilhelm Ohr, one of the first speakers I heard was Erkelenz, and I was interested in what he had to say as a member of the working class.²⁹²

Exhibiting the social consciousness that was characteristic of the extended Du Bois-Reymond family, Iris Runge participated in various political organizations while a student at the University of Göttingen. These groups, which comprised part of the youth movement of the time, were closely tied to progressive cultural Protestantism, an aspect of Protestant intellectual life in Germany that sought to reconcile general cultural developments with the spirit of Christianity. Middle class exponents of this agenda included Wilhelm Ohr – who had founded the National Association for a Liberal Germany in 1907 and cooperated closely with both the student and the women’s movements – and the philosopher Leonard Nelson.²⁹³ As one of many students influenced by Nelson, Iris Runge taught continuing education courses to members of the working class and she developed, over the course of the First World War, a political mindset that led to her join the Social Democratic Party. During this same period, she also began a career as a teacher that she would ultimately abandon for another path. The present section will address this and other changes of heart, as well as her political engagement.

2.6.1 Leonard Nelson’s Private Assistant

Together with the mathematician Gerhard Hessenberg, Leonard Nelson formulated the notion of “critical mathematics” as a philosophical alternative both to Gottlob Frege’s logicism and to Henri Poincaré’s conventionalism.²⁹⁴ Nelson’s ideas, which were based on the work of Friedrich Fries, represented an attempt to perpetuate Kant’s critical philosophy, and his position was thus independent of such philosophical trends as skepticism and historicism. Although his polemical views brought him into conflict with many professors of philosophy, they also earned him considerable support among mathematicians. In his early work, which was concerned with the epistemological foundations of mathematics, Nelson strove to develop philosophical arguments in support of David Hilbert’s axiomatic system, and over the years his following included Kurt Grelling, Richard Courant, Max Born, and Iris Runge.²⁹⁵ Nelson’s style of lecturing is said to have been

292 A letter from Iris Runge to her mother dated November 9, 1930 [Private Estate]. Anton Erkelenz, an editor of a proletarian newspaper and one-time member of the liberal German Democratic Party, joined the Social Democratic Party in 1930.

293 See HÜBINGER 1994.

294 See especially PECKHAUS 1990; FRANK 1997.

295 Kurt Grelling completed his doctorate under David Hilbert in 1910, and in three of her letters – dated November 10, 1910; January 14, 1911; and May 28, 1912 [Private Estate] – Iris Runge mentions that he was interested in having a private relationship with her. Though

highly mathematical, with each of his sentences supported by scrupulous proof.²⁹⁶ He associated professionally with mathematicians, taking part in their conferences, and he was one of Carl Runge's regular tennis partners.

As of her second semester, Iris Runge worked as Nelson's private assistant. She organized his library, managed his paper work, and participated in his intimate discussion groups, which typically included eight to ten people. It is clear that Carl Runge was supportive of this activity:

Iris is making headway with her studies here in Göttingen. Mathematics and physics – and now even philosophy – seem to have captured her interest. I think that it is very important for students to engage with the principles of thought. Philosophy, or at least what I have gathered from it, has been very valuable to me.²⁹⁷

In January of 1908, Nelson wrote the following to Iris Runge from Berlin:

Please rummage through only as many of my books as you can, and do feel free to borrow anything you like. Regarding the third volume of Fries's *Kritik der Vernunft* [Critique of Reason], please take the copy that is bound in black leather. [...] I have indeed brought the things you were looking for with me; this is fine, for Kant's *Ethik*, at least, probably wouldn't be worth your while right now. If you would like to read something that is as light as it is beautiful – in addition to being philosophically educational – I encourage you to borrow my copy of Fries's *Julius und Evagoras* or Apelt's *Epochen der Geschichte der Menschheit* [Epochs in the History of Mankind]. Regarding *Julius und Evagoras*, which is incidentally a work of very practical philosophy, do not be deterred by the antiquated form of the dialogue. I recommend that you skip over the expanded introductory chapter of the second edition and simply begin with the chapter entitled "Julius und Evagoras" [...]. If you have any additional philosophical questions, as you mentioned that you did, please address these to me in a letter (the date of my return is still uncertain).²⁹⁸

As part of Nelson's circle, Iris Runge participated in discussions of ethics and natural philosophy in which Kant's *Critique of Practical Reason* and Fries's philosophy played a guiding role. Kant's initiative to derive the concept of morality directly from human reason – that is, not from divine laws – appealed to the athe-

a Protestant, he was regarded as Jewish by the Nazi regime; he lost his position as a secondary school teacher in 1933 and died in the Auschwitz concentration camp (see [BBF]). Later, Emmy Noether's doctoral student Margarete Hermann also belonged to Nelson's circle, as did the Chinese student Si-Luan Wei, whose research was supervised by Richard Courant (see HENRY-HERMANN 1985; FRANKE 1993; MILLER/MÜLLER 2001).

296 See FISCHER 1999.

297 This diary entry, which Carl Runge recorded on March 24, 1908, is quoted from HENTSCHEL/TOBIES 2003, p. 169.

298 A letter dated January 25, 1908 (in [FES] 1/LNAA000201). The books mentioned are: Jakob Friedrich Fries, *Julius und Evagoras, oder: Die Schönheit der Seele*, 2nd ed., 2 vols. (Berlin: Carl Winter, 1822) [for excerpts of this book in English, see Jakob Friedrich Fries, *Dialogues on Morality and Religion*, ed. D. Z. Phillips (Oxford: Basil Blackwell, 1982)]; and Ernst Friedrich Apelt, *Die Epochen der Geschichte der Menschheit: Eine historisch-philosophische Skizze*, 2 vols. (Jena: Hochhausen, 1845–1846).

ism that Iris Runge's had espoused by that time.²⁹⁹ Whereas her friend and fellow participant Anna Goslar had to put down one of Nelson's essays – on the metaphysical presuppositions of science – because of its difficulty,³⁰⁰ Iris Runge would later find confirmation for its ideas in one of Sommerfeld's lectures:

These days I have had to think a great deal about the idea of "science without metaphysics." In Sommerfeld's course I have been attempting to organize my fundamental notions of mechanics into a coherent logical system, and in doing so I have come to a (belated and hard-earned) understanding of the meaning of your essay. Sommerfeld goes about things very well. He begins with Newton's laws, which of course were derived from experience, but one does not have to think long about it before realizing that this "experience" is not simply empirical, but rather it already contains a metaphysical component. Of course, this is not to say that metaphysics reveals anything about the actual laws of motion. I think that I'll learn an enormous amount here, both because Sommerfeld is an outstanding teacher and because I have begun to approach matters in an independent way.³⁰¹

Nelson's position as an outsider among philosophers also owes itself to the fact that he consistently sought to convert philosophical theory into substantive praxis. With this in mind he formulated a system of ethics that entailed political engagement; based on ethical principles, Nelson's socialism accepted the notion of class conflict while denying its foundation in Marxism.³⁰² Iris Runge reported in a letter:

In Nelson's tutorials we discussed Karl Marx's teachings, among other things. It was argued that, according to Marx, the new social order will necessarily and naturally arise from the increased concentration of capital in fewer and fewer hands, and that this idea could never function as a practicable agenda for any political party.³⁰³

Even though she would ultimately disassociate herself from Nelson's circle – in order to avoid an "overly rigid view of the world" – it was from his disquisitions on ethics that Iris Runge came to regard political engagement as a necessary component of her life:

In one respect, however, Nelson did indeed influence me in a lasting way, and this is in a matter to which I have openly devoted my energies. I think it was during the winter semester of the ethics seminar that Nelson convinced all of us that it was the duty of every citizen to be involved in politics. He did not demand us to join a political party right away, something that the young students were mostly unwilling to do. But there was this one association that had recently been founded, the *Freibund* [...].³⁰⁴

299 In a letter to her mother dated September 23, 1907 [Private Estate], Iris Runge noted: "I am an adamant heathen."

300 A letter from Anna Goslar to Iris Runge dated January 18, 1909 (in [STB] 692). The essay "Ist metaphysikfreie Naturwissenschaft möglich?" [Is a Science Without Metaphysics Possible?] was published in *Abhandlungen der Fries'schen Schule* 2 (1908), pp. 244–299.

301 A letter from Iris Runge to Leonard Nelson dated November 4, 1910 (in [FES] 1/LNAA000201).

302 See FISCHER 1999.

303 [FES] 1/LNAA000513, p. 3. The original letter survives in Iris Runge's [Private Estate].

304 Ibid. This was a letter from Iris Runge to the American historian Martin H. Schaefer, who was gathering material for a biography of Leonard Nelson.

2.6.2 The Student Movement and the *Freibund*

Established as a political organization, the so-called *Freibund* [Free Union] had close affinities with the liberal Progress Party. One of the more engaged members of this party was Friedrich Naumann, who was in contact with Leonard Nelson from 1907 to 1908 and whose 1906 book – *Neudeutsche Wirtschaftspolitik* [New German Economic Policy] – was read closely by Iris Runge.³⁰⁵ The *Freibund* movement, which spread from Berlin in 1907, began as a liberal faction of the nondenominational Free Student Societies and sought to accommodate the growing number of independent students in Germany, that is, students who were not affiliated with any of the numerous fraternities of the time. Unlike the majority of such fraternities, which were typically exclusive and elite, the Free Student Societies included members of the lower middle class. They were active in developing various forms of student aid, they advocated for making university education accessible to a broader contingent of society, and they participated in special courses designed for the working class. The activity of these societies in Jena and Göttingen (though to a lesser degree) has received some scholarly attention, but the involvement of women has yet to be examined in any detail.³⁰⁶

Women student organizations – which began to appear with growing frequency in 1900 and soon, in 1906, united as the Union of Female Students in Germany³⁰⁷ – aligned themselves with the Free Student Societies against the conservative agenda of the traditional fraternities. These organizations advocated above all for women's civil rights, and they usually did so as a politically neutral (in terms of party politics) and nondenominational body. In Göttingen, Iris Runge and Elisabeth Klein were the leaders of the local Union of Female Students, and they also participated – with their parents' knowledge and consent – in the *Freibund*.³⁰⁸ Some of their former schoolmates from Hanover were involved in the

305 Iris Runge discusses this book in a letter to her mother dated August 17, 1908 [Private Estate]. In 1910, Leonard Nelson joined the newly formed Progressive People's Party (see FISCHER 1999). Today, the "Friedrich Naumann Foundation for Peace," which was founded in 1958, is associated with the Free Democratic Party.

306 See STEINBACH 2008; DAHMS 1998; WIPF 2005. On the role of women in the popularization of science in the 19th century, see GATES/STEIR 1997, and on their role within the largely anti-feminist *Wandervogel* movement of the early twentieth century, see KLÖNNE 1996.

307 See MARTIN 1999. The Union of Female Students in Germany (*Verband der Studentinnen Deutschlands*) was originally called the Union of Women Studying in Germany (*Verband studierender Frauen Deutschlands*).

308 According to one of their contemporaries, "the Union of Female Students was of course without a tradition [...]. Its leading proponents at the time were the daughters of professors at Göttingen, such as Iris Runge and Elisabeth Klein" ([Büchsel o. J.], pp. 4–5). In a letter to his wife dated July 27, 1909, Carl Runge noted: "Along with Putti, Iris attended a meeting of the *Freibund*" ([STB] 514, p. 12v). According to a document from the [Private Estate], Iris Runge and a group of friends gathered in 1912 to celebrate the fifth anniversary of the Free Student Society.

same movement at the University of Freiburg and at the University of Heidelberg, as is clear from a letter by Anna Goslar:

In recent news, a certain young man has been rallying for me to join this "*Freibund*,"³⁰⁹ and because I am once again deeply committed to politics, and especially for all things liberal, I cannot discount the possibility that I might, at least to some extent, participate in this group's activities. By the way, I noticed in the yearbook that such an organization has also been formed in Göttingen, and that Grelling and Nelson are largely responsible for this. Do you happen to know Reuber, the founder of the *Freibund*? I often met him last winter at the courses for the working class.³¹⁰

Iris Runge was indeed acquainted with Karl Reuber, who died in the First World War. Her former schoolmates Annie Huffelmann and Cora Berliner, who were also friends with him, likewise participated in the courses for the working class.³¹¹

In Göttingen, Leonard Nelson founded a local branch of the *Freibund* in 1908 and served as its leader until 1910. On the relationship between this organization and the objective of workers' education, Iris Runge explained:

It was through the initiative of the *Freibund* that I came to participate in these "student-led courses for the people," a venture that was already underway at many universities and that aimed to make elementary subjects available to the working class. As the students involved, we had the opportunity to interact with ambitious workers, and this was an experience that was just as educational and meaningful for us as it was for them. Those who enrolled in the courses were mostly Social Democrats, as expected, but the courses themselves were politically neutral.³¹²

Organizations devoted to the expansion of public education were already common in the nineteenth century, and at the beginning of the twentieth century the initiative of these groups dovetailed with the efforts of professors to popularize their areas of expertise.³¹³ It was at this time that practitioners of science and engineering were first placed on an equal footing with those of the humanities, and they took this opportunity to create a space for themselves under the common umbrella of "culture." Popular education in the sciences thus came to be regarded as a means of intertwining the humanities and the sciences and of introducing the public to scientific research. The women students of this generation borrowed their orientation in part from that of the intellectual movement of 1848 and 1849, the objectives of which were exemplified by the foundation of Humboldt Societies.³¹⁴ The idea of disseminating scientific awareness across a broad swath of society was tied to the liberal conception of reforming society through education and of alleviating social hardships by providing access to knowledge. This nexus of scientific innovation, social consciousness, and political activity has been analyzed in depth

309 Anna Goslar is here referring to one of her cousins.

310 A letter from Anna Goslar to Iris Runge dated September 6, 1908 (in [STB] 692, p. 88).

311 See [STB] 692, pp. 97–101. On Cora Berliner, see QUACK 2005.

312 [FES] 1/LNAA000513, p. 3.

313 See DAUM 2002.

314 On the objectives of Humboldt Societies in Germany, see *ibid.*, pp. 138–167.

by Matthias Steinbach, whose study focuses on the socialist tendencies of professors at Jena before the First World War.³¹⁵ Such a world view also thrived outside of Jena, of course, but there and elsewhere it was temporary and ultimately incapable of eliminating the boundaries between the social classes.

In 1911, Iris Runge severed her ties with Nelson's intellectual circle, as she noted, in order to preserve her "independence and intellectual vigor."³¹⁶ Nevertheless, her letters from the following years indicate that she had adopted his notion of liberalism,³¹⁷ and her later support for the Social Democratic Party, which she began to champion during the First World War, also bears his stamp (see Section 2.6.5). She joined this proletarian organization in 1918, and she was not the only member of the educated middle class to move in this new political direction. Although its numbers were far from paltry,³¹⁸ this group has apparently been easy to overlook. In his recent biography of Walther Rathenau, for instance, Lothar Gall has even argued that the desire for isolation from the working class was a salient and universal feature of the "new bourgeoisie."³¹⁹

2.6.3 "I wanted a Madame Récamier, not an Ebner-Eschenbach"³²⁰

It is with this line that Wolfgang Kroug, to whom Iris Runge was engaged from 1914 to 1915, expressed his opposition to her social activism. Her exchange of ideas with Kroug, a student two years her junior, reveals her desire to find a partner with whom she could share a loving relationship. At the same time, however,

315 STEINBACH 2008.

316 See her remarks in [FES] 1/LNAA000513, p. 2: "It terrified me to notice something empty in the faces of Nelson's younger followers. I wouldn't go as far as to call them to call them mindless impersonators, but they are certainly lacking in independence and intellectual vigor. Of course, I would not put Courant and Born into this category, who have always been on the same intellectual level as Nelson. But when I considered my own case, I felt as though I was not fully swayed by what he had to say. I began to have misgivings – despite the great respect I have for him – about having surrendered myself to his influence." In the brief curriculum vitae appended to her dissertation, Iris Runge does not mention any of her coursework with Leonard Nelson; she does, however, mention Edmund Husserl.

317 On Leonard Nelson's place in the development of social democracy, see FISCHER 1999.

318 See STEINBACH 2008, and Sections 4.1.3 and 4.1.4 below.

319 See GALL 2009, pp. 13–23, and especially p. 17.

320 A letter from Wolfgang Kroug to Iris Runge dated February 15, 1915 ([STB] 709, p. 175). Written between 1914 and 1917, ninety-one letters from Wolfgang Kroug to Iris Runge – not to mention one postcard, one telegram, and several poems – are archived in [STB] 709. Jean Françoise Julie Adélaïde Bernard, known as Julie Récamier, had married a wealthy Parisian banker at the age of fifteen and hosted a salon that was attended by high society and sundry critics of Napoleon. At the age of eighteen, Marie von Ebner-Eschenbach married her cousin, who was a staunch supporter of her literary ambitions. Their marriage was childless. She was trained as a clockmaker in Vienna and became a well-known author whose works are distinguished by their optimism, engagement with social issues, political consciousness, and by the active roles of their female characters.

their correspondence also reveals that her devotion to social causes was something that no partner could suppress.

Iris Runge's decision to pursue a husband from the ranks of the student movement was a consequence of her experience with Wilhelm Deimler. In 1913, she became friends with Erwin Marquardt in Göttingen. Marquardt had joined the Social Democratic Party in 1912, while still a student; he had been a leading organizer of the student-taught courses for the working class in both Göttingen and Tübingen; and he had sat on the board, also in Göttingen, of the Social Democratic committee for workers' education. Even before the war, Marquardt was forced to go into hiding for political reasons, and thus one day he disappeared unannounced from Iris Runge's life.³²¹ Along with Marquardt and his friend Wolfgang Kroug, Iris Runge participated in the First Free German Youth Day (*Erster Freideutscher Jugendtag*), which took place on the Hoher Meißner Mountain, near Kassel, over a weekend in October of 1913. Invited by way of youth groups from Jena and Göttingen, more than two thousand young men and women gathered to celebrate, nearly one hundred years after the Wartburg Festival of 1817. The participants, who represented a variety of youth movements, came together in the name of protesting and preventing the chauvinistic and patriotic ceremonies that had been scheduled to commemorate the hundredth anniversary of the Battle of Leipzig.³²² Not only did the First Free German Youth Day fail to accomplish this goal, but many of its participants would go on to contribute to the nationalistic delirium that was precipitated by the First World War. Few of them, in fact, followed the likes of Leonard Nelson by adhering to their former pacifism: "Leonard Nelson has been abandoned by nearly all of his students. Arrayed like field marshals, they have bid him farewell to join the army. He alone has been detained by the authorities for refusing to perform any military service."³²³

Wolfgang Kroug, who studied for several years in Marburg before studying under Nelson in Göttingen, was exempt from fighting in the war on account of being a Baltic German with Russian citizenship.³²⁴ In order to understand why Iris Runge had chosen and ultimately rejected him as a partner in life, it will be necessary to provide a brief sketch of his views and opinions. Not only was his disposition as intellectual, enthusiastic, and poetic as hers, but he also shared her fundamental philosophical positions, so that she mused in a poem:

321 Iris Runge first mentions her relationship with Marquardt in a letter dated August 1, 1913 [Private Estate]. Marquardt enlisted as a volunteer soldier during the war. In 1919, he passed his teaching examinations in the fields of German, history, and philosophy ([BBF] Personal Profile). Iris Runge met him later in Berlin where he lost his position for political reasons in 1933 (see Section 4.3.1; KORTHAASE 1933; OLBRICH 2001).

322 At this battle, which took place on October 6–19, 1813 and is also known as the Battle of Nations, allied forces from Austria, Prussia, Russia, and Sweden defeated the army of the French emperor Napoleon I, who had occupied a large part of Germany.

323 KROUG 1955, p. 59. See also BUSSE 2008.

324 See a letter from Aimée Runge to her husband dated August 7, 1914 (in [STB] 523, p. 268). Wolfgang Kroug was born in Narva-Jõesuu, Estonia.

Ein Tag wird sein ...³²⁵
Iris Runge

Ein Tag wird sein, da wird die Sonne
 scheinen,
 und Du wirst mit mir durch die Lande
 gehn.
 Dann lachen Deine Augen in den
 meinen,
 zum Wunder wird uns alles, was wir
 sehn.

There Will Be a Day ...
by Iris Runge

There will be a day on which the sun
 will shine,
 and together we will traipse across the
 land.
 That day your eyes will laugh,
 reflecting in mine,
 as we look in wonder at all that is at
 hand.

Born in Estonia on March 30, 1890 – Wolfgang Kroug’s father was a medical doctor, and his mother ran a small private school for the children of German families – he developed a scientific world view at an early age. Like Iris Runge, he was also a member of the Protestant Church. Even as a boy in St. Petersburg, where he attended a school of this denomination, he had founded a society for the promotion of the arts and sciences. The ten members of this society came together to discuss scientific questions – Darwinism, the formation of the earth’s crust, magnetism, among others – as well as political and religious issues, including anti-Semitism. From the records of this group’s activity, it is clear that social and cultural prejudices were consciously avoided.³²⁶ Kroug’s family, which immigrated to Germany in 1905 and settled in Weimar, had brought with them both a “positive bias” toward Germany and a privately “socialist” mindset.³²⁷ Wolfgang Kroug was active in several organizations in his new homeland; in 1907, for instance, he founded a local branch of the so-called *Wandervogel* movement, and in May of 1912 he established a student group known as the “Academic Association of Marburg.”³²⁸ In his philosophical diary, which he began in 1907, Kroug outlined a theory of politics that he later defined as being “essentially socialist and communist in its orientation.”³²⁹

In the relationship between Kroug and Iris Runge, words acquired an almost magical power, their meaning depending more on their simple presence than on logic alone. Just as, even today, such words as “socialism” or “atheism” can be discredited by some circles and embraced by others, the two of them found a com-

325 [STB] 371.

326 See Wolfgang Kroug’s autobiography, which is archived at the [Osteuropa-Institut], and also his philosophical diary, ninety-one pages of which (from the years 1907 to 1911) are preserved in [STB] 808.

327 See Kroug’s autobiography [Osteuropa-Institut], p. 44.

328 Ibid, p. 47. Tracing its roots to a group of German students that began to meet in 1895, the *Wandervogel* movement was formed in 1901 as back-to-nature youth organization that emphasized freedom, self-reliance, and the spirit of adventure. Incidentally, the word *Wandervogel* means ‘migratory bird’.

329 Ibid, p. 46. Kroug continues: “That I never became a communist despite my very radical political theory can be explained by the deep distrust that I harbored toward all institutions.”

mon language of their own. Even if it was later discovered, after long discussions, that their understanding of the terms “liberalism” and “social activism” were somewhat divergent, for some time they had nevertheless enjoyed a common sense of immediacy and a mutual perception of the world. Kroug discussed social issues with Iris Runge in his letters, and from these it is apparent that, in her opinion, the only way to recognize and measure one’s relationship to society is by participating in immediate, hands-on activism. Thus he wrote:

You always say that you are attempting to grasp what needs to be done by means of your own social activity and thus to forge an awareness of social issues on the basis of your experience in these particular situations. To some extent, perhaps, you tend to elevate these singular insights into a general impression without first subjecting the issues to what might be called scientific and theoretical analysis [...]³³⁰

This provides a good idea of Iris Runge’s practical and hands-on approach to political change, an approach influenced by that of Leonard Nelson. Kroug’s orientation, however, was far more theoretical. He attempted to formulate theses and antitheses, and his pronouncements were often remarkably egocentric:

It is my work that will supposedly bring me to maturity, but fundamentally I do not work for the sake of knowledge itself but rather to become more clever, attractive, and manly. Thus, in its truest sense, social engagement is inaccessible to me, for in this matter too I am fundamentally more concerned with my own personal refinement than with any given social issue.³³¹

Although Kroug’s later autobiographical writings display a more sophisticated manner of thinking, his letters to Iris Runge and his early philosophical diary often betray his vanity and immaturity. A sense of overbearing possessiveness also comes through in his correspondence: “You absolutely have to get some rest, for you have been too tired lately. It upsets me that, after teaching for five hours, you still find it necessary to sing in the choir.”³³² Their relationship ultimately failed, it can be imagined, on account of Kroug’s patently anti-feminist opinion of women:

Some notes on womankind. Their nature should be respected but evaded – their nature! Not their intellect, which is paltry compared to their nature. [...] One searches in vain for intellect and a sense of justice in women, but to expect a sense of justice in women would itself be unjust. They are children or are like children, but they should be treated as dangerous children. [...] As it seems to me, a man can only be understood, fulfilled, and satisfied by an exceptionally great woman; for men are their own lords and can survey the landscape from great heights, but women are not their own lords, bound as they are by the unyielding strength of their nature.³³³

It is obvious that, in Iris Runge, Kroug had met just such an “exceptionally great woman,” but it is also clear that, feeling somewhat inferior to her, he had at-

330 [STB] 709, pp. 125v–126 (written between September 24 and October 14, 1914).

331 A letter to Iris Runge dated January 27, 1915 (in [STB] 709, p. 152).

332 *Ibid.*, p. 73 (written in April of 1914).

333 A diary entry recorded on February 27, 1911 (in [STB] 808, p. 79).

tempted to adopt a controlling role in their relationship.³³⁴ Soon after their engagement, in fact, a number of differences surfaced between them, including a misunderstanding concerning mathematics:

Iris and I disagreed over a small matter today. She professed to see something wonderful in a mathematical relation, but I could not understand her in the least. Finally she said, in utter despair, "Oh, so now there are intellectual misunderstandings as well." It was terrible.³³⁵

Like the majority of men who were active in the student movement, moreover, Wolfgang Kroug held fast to the conventional gender hierarchy that still prevailed among the middle class. To Iris Runge he wrote:

Today I realized how things went wrong between us. I have always been pursued by a single desire: From a woman I want feminine qualities and feminine charms, things that I cannot experience with my fellow men. And yet, having met you, my initial attraction was to the clever, quick, and witty Iris. After I had enjoyed these aspects of your character to my fill, I then wanted a more moral version of yourself, and yet I still desired something of your artistic side. I became sullen because you did not possess the qualities that I desired to the extent that I desired them, and thus I began to imagine myself with someone else. [...] I wanted a Madame Récamier, not an Ebner-Eschenbach.³³⁶

Marie Ebner-Eschenbach, an Austrian writer, was able to enjoy a marriage in which she was free to participate in social and political activism. In this time of Iris Runge's life, few men in Germany were inclined to choose a wife who was professionally ambitious and politically engaged.³³⁷ As far as women were concerned, the conditions were in fact more favorable for an independent author than for a school teacher, for the German government required its female employees to be unmarried. Marriage, that is, meant the end of a woman's career.³³⁸ In one matter in particular, Carl Runge concretely disapproved of his potential son-in-law, namely he felt that Kroug's unfocused and unpromising approach to his studies did not accord with the expectations of the Runge family. As it turned out, Kroug never did complete the dissertation that he began in 1914, which bore the long and

334 See, for instance, his letter to her dated April 29, 1914 (in [STB] 709, p. 83): "Another nice thing came to mind. At the gathering of Husserl's discussion group, you were sitting in the hallway, and Dr. Bulle and I were standing at the door. I said to him: 'She accepts no man. Whoever can impress her will not find in her what he needs, and everyone else is simply too stupid *for her!*' Having said that, I was seized by a sudden agitation, a sensation that attracted me to you all the more. Yours, Wolfgang."

335 From a diary entry by Wolfgang Kroug dated August 28, 1914 [Kroug Private Estate].

336 A letter dated February 15, 1915 (in [STB] 709, pp. 173v, 175). For additional discussion on the role and status of women in the student movement, see KLÖNNE 1996.

337 The following comment about the mathematicians Adelheid and Marie Torhorst has been preserved in [BBF] Torhorst Estate, No. 25: "Both of the sisters were firm in their determination not to marry. [...] Most men at that time were not ready to excuse their wives from household duties for the sake of engaging in professional, social, or political activity."

338 Even after 1919, new stipulations were enacted, according to which married female lecturers could lawfully be dismissed from their positions (see DEUTSCHER JURISTINNENBUND 1984, pp. 76–77).

tentative title “Über die faktische Bedeutung der Philosophie im akademischen Leben und die Grenzen ihrer praktischen Auswertungsmöglichkeiten im Rahmen des heutigen Seminarbetriebes” [On the Factual Significance of Philosophy in Academic Life and the Limitations of its Potential Evaluation within the Context of Contemporary University Seminars].³³⁹ All in all, the relationship between Kroug and Iris Runge reveals that, regarding the liberation of her generation of women, more would be required than simply access to higher education. It would also require the basic recognition that a life lived under the old conventions would be unworthy.

2.6.4 The Kippenberg School in Bremen

After passing her examinations, Iris Runge began her teaching practicum in Leipzig, where she taught under the supervision of Hugo Gaudig,³⁴⁰ and she completed her required training in Göttingen. Max Heinrich, the director of the girls’ secondary school in Göttingen where she finished this probationary period, was also the director of a private institution that was founded in 1908 to prepare young women for university entrance examinations.³⁴¹ In the fall of 1913, Heinrich transferred Iris Runge to this private school, where she would teach both mathematics and physics. At the onset of the First World War, she returned as a full-time teacher to the public secondary school in Göttingen,³⁴² and in August of 1915 she accepted a position at the Kippenberg School, a private institution in the Free Hanseatic City of Bremen, which then had a population of approximately 250,000.

Founded by August Kippenberg in 1859, the Kippenberg School was the first German private institution dedicated to educating women to become teachers. It was recognized as an official secondary school for girls in 1873, and in 1903 its directorship was passed from the founder’s widow, Johanne Kippenberg, to Dr. August Kippenberg, their son. The latter was awarded an honorary professorial title by the senate of Bremen in 1909 for the fact that his school was regularly

339 See [STB] 709, pp. 112, 142. In July of 1917, Kroug passed the teaching examination in the fields of German, religion, and philosophy. Later, in December of 1918, he would also become qualified to teach physics and mathematics. In 1919 he was granted citizenship in Thuringia, where he was a tenured secondary school teacher as of 1928 (see KUNZE, vol. 48 [1941/42]). He moved back Göttingen after the Second World War.

340 As of 1907, Hugo Gaudig was the director of a municipal secondary school for girls in Leipzig. A proponent of vocational pedagogy, he opposed coeducation and held, in general, conservative views regarding the education of women (see GAUDIG 1906; TOBIES 2008d; and, most recently, Sebastian Prüfer, *Hugo Gaudig: Beiträge zum 150. Geburtstag des Leipziger Reformpädagogen* [Halle: Projekte-Verlag, 2010]).

341 Max Heinrich, who was licensed to teach religion, Hebrew, German, and history in 1892, became the director of the municipal secondary school for girls in Göttingen on April 1, 1909 (see [BBF] Personal Profile).

342 See the *Zehnter Jahresbericht über das Städtische Lyzeum Göttingen, Schuljahr 1914–1915* (Göttingen, 1915), p. 6; and Iris Runge’s curriculum vitae in [UAB] R 387, vol. 2, p. 13.

attended by nearly 750 young women, a number that represented more than a quarter of all the daughters of the educated middle class.³⁴³ Although the independent city of Bremen was not part of Prussia, it followed the latter's educational reforms with respect to women's education. In order to prepare young women for university admission, the spectrum of subjects taught at girls secondary schools was expanded, in 1912, to include mathematics and French, and their instruction in the sciences was brought to a higher level.

Even if Iris Runge's chief motivation for moving from Göttingen to Bremen might have been her separation from Wolfgang Kroug – as can be assumed – she nevertheless found herself in a new working environment where she was challenged and highly engaged. She rented an unassuming room on a quiet street and, feeling free after her failed engagement, she was pursuing “a thousand new goals with a renewed sense of self-trust and enjoyment in the world.”³⁴⁴ She became close with her female colleagues, with whom she spent her free time hiking, practicing gymnastics, rowing, and ice skating. She also participated in a choir and went to the theater, to concerts, and to art exhibits. Influenced by Leonard Nelson, she frequently ate at a vegetarian restaurant, and she cultivated relationships with her family's old associations in Bremen, which included the Barkhausen household.³⁴⁵

In a letter about her first day of teaching at the Kippenberg School, she compared the experience with her time as a teacher in both Göttingen and Leipzig:

The children are plainly dressed and clearly not from the wealthiest families, but they are wonderfully studious, confident, and interested in the subjects. This much is clear by the way that they come out of their shells to express themselves openly and ask me questions. I attribute this to the positive environment of the school itself. I had noticed the opposite at the schools in Göttingen, where the children were not performing as well. There, however, the poor performance was attributed to the general indocility of the pupils. And then things were different in Leipzig with Gaudig, among the “brilliant Saxons,” as they called themselves. And yet the people of Bremen, whose reputation for being stiff and reserved is somehow proverbial, are nothing of the sort. Where did this reputation come from? My pupils participate energetically and openly in class, and it seems as though they were all raised to behave in such a way.³⁴⁶

Unlike those at most secondary schools for girls, the faculty at the Kippenberg School was predominantly female; there was only one senior male teacher and a few men who worked there part-time in addition to their duties at other local schools. When one of these part-time instructors was recruited to fight in the war,

343 On the history of the Kippenberg School, see BESSEL 1959; FESTSCHRIFT 1984.

344 A letter from Iris Runge to her mother dated December 16, 1915 [Private Estate]. Her room, which she leased from a streetcar driver named Schultze, was located on Margarethenstraße. Bremen was home to one of the first European streetcars with an overhead electrical line, which was installed in 1890.

345 See her letter dated March 12, 1917 [Private Estate]. Carl Georg Barkhausen was then the mayor of Bremen; the aforementioned Heinrich Barkhausen was a member of this family.

346 A letter from Iris Runge to her parents dated April 7, 1915 [Private Estate].

Iris Runge had to take over his physics class and his chemistry class. In February of 1917, the school system was temporarily closed on account of the war, and she took advantage of her time away from teaching by immersing herself in Walther Nernst's textbook on theoretical chemistry, which had seen seven editions since its initial publication in 1893.³⁴⁷

She was allowed a good deal of freedom with respect to her pedagogical methods and the content of her classes. Occasionally she turned to her father for advice in this regard, though her decisions to teach such subjects as probability theory and statistics were made independently:

Everything is going very well at school. Last Friday I calculated the area of the Bremen moat with the youngest class. We went with a measuring tape and a diopter on a tripod and measured a baseline and two angles. The process took a whole hour and was, of course, very inaccurate. We averaged each of the values from five different positions, and because each of these measurements was made by a different girl, none of whom had ever used a diopter before, the results were pretty shabby, but the children didn't know that. [...] With the senior class I have been doing the calculation exercises that I spoke about with Dad in the spring, namely converting number tables into percentages, for which I've designed a few assignments of my own. [...] Now we are busy with actuarial mathematics and statistics, and in the end we will turn to Dad's hobby horse, demographic statistics, which has become a favorite of my own. For this I have created tables from the statistical yearbook, which I will copy and distribute to the young women on slips of paper.³⁴⁸

Iris Runge quickly established a good relationship with her older pupils, whom she successfully prepared for the university entrance examination, and her colleagues praised the way that she conducted the oral portions of this test. She taught with increasing pleasure at the school, where she earned an annual salary of 3,000 Marks and where her pupils showered her with flowers on her birthday.³⁴⁹ Beginning in the second half of 1917, however, her correspondence indicates that certain differences had arisen between her and the director of the school, Dr. August Kippenberg. She felt as though her efforts were underappreciated and, beyond that, her pupils from the senior class had complained about her for unknown reasons. From this point on, the director conducted repeated observations of her teaching and, on account of her blatant disapproval of these new circumstances, he threatened to terminate her employment. Encouraged by her parents, she decided to study chemistry, to which she had been devoting so much of her free time, in an official capacity. Although Kippenberg retracted his threat to dis-

347 See her letters from 1917 written on May 8, June 30, July 9, and February 25 [Private Estate]. The textbook in question is Walther Nernst, *Theoretische Chemie vom Standpunkt der Avogadroschen Regel und der Thermodynamik*, 7th ed. (Stuttgart: F. Enke, 1913) [the title of the English translation, which can also be found in the bibliography, is *Theoretical Chemistry from the Standpoint of Avogadro's Rule and Thermodynamics*].

348 A letter from Iris Runge to her mother dated November 14, 1916 [Private Estate].

349 See the letters to her mother dated April 25, 1915; September 11, 1915; March 6, 1916; April 14, 1916; June 3, 1917; and June 20, 1917 [Private Estate].

miss her, she nevertheless held fast to her decision and resigned from the school in the spring of 1918.³⁵⁰

2.6.5 Shifting Opinions During the First World War

Iris Runge's position toward the First World War changed throughout its course. In order to demonstrate the shifts in her thinking, it will be enough to examine the concrete experiences of individuals without going into great detail about the well-known and overarching political developments of the time.³⁵¹ While in Bremen, Iris Runge subscribed to a number of newspapers that supported the war, including the *Bremer Tageblatt*, the *Weserzeitung*, and *Die Glocke*, which was a mouthpiece for the right wing of the Social Democratic Party.³⁵²

There were few Germans during these years who were not consumed by the nationalistic reporting about the war, who did not celebrate the news of victorious battles, and who did not adopt a patriotic stance toward their country. Carl Runge, for one, preferred that his sons serve in the fields and not on the front, but he nevertheless permitted their early graduation from secondary school in order that they could enlist as soldiers. Though he had not been one of the signatories of the infamous "Appeal to the Civilized World,"³⁵³ he still upbraided his daughter's fiancé for not contributing to the war effort as a Baltic-German.³⁵⁴ Even though her friend Elisabeth Klein (Mrs. Staiger) had already lost her husband to the war in 1914, and even though her own brother Bernhard had also fallen in this year, Iris Runge could still speak, in May of 1915, about the "tremendously interesting accounts of battle" from her brother Wilhelm, about Paul von Hindenburg's "magnificent" exploits in Latvia, and about August von Mackensen's triumphs. "The enemies," she went on, "seem all too eager to realize how hopeless everything is for them!"³⁵⁵ Such pronouncements not only reflect the sentiments of the Runge family; they are indicative of the bellicose delirium that had begun to pervade all of Germany. It was to his parents alone, however, that Wilhelm Runge reported about success on the battlefield, a fact that gave his sister pause: "I am

350 See the last letter cited in the previous note, as well as those dated November 2 and December 2, 1917 [Private Estate].

351 On the social history of Germany during the First World War, see WEHLER 2003.

352 Founded in 1915, *Die Glocke* [The Bell] was a socialist weekly edited by Alexander Parvus.

353 The so-called "Appeal to the Civilized World" (*Anruf an die Kulturwelt*) bore the signatures of ninety-three German scientists, artists, and authors, including those of Felix Klein, Walther Nernst, Wilhelm Ostwald, Max Planck, and Ulrich von Wilamowitz-Moellendorff. Among other things, the appeal denied the accusations made by critics of the war who claimed that German soldiers had committed atrocities (see UNGERN-STERNBERG 1996).

354 See [STB] 515, p. 282v.

355 A letter from Iris Runge written in Bremen on May 3, 1915 [Private Estate].

somewhat taken aback, on another note, that he never really expresses any joy about the forward march of the German troops.”³⁵⁶

During the summer vacation of 1915, Iris Runge traveled to Berlin-Potsdam, where she met Hedi and Max Born, who was working as a physicist for the military,³⁵⁷ and also Reinhold Rüdenberg, whose position was indispensable at Siemens-Schuckert.³⁵⁸ Carl Runge spent some of this same summer vacation working at Alard du Bois-Reymond’s factory in Kiel. Together with the physicist Max Wien, his goal there was to build a wireless telegraphy device for the army that he had designed in Göttingen with Richard Courant, Peter Debye, and Paul Scherrer.³⁵⁹ Numerous scientists in Kiel were also employed to military ends, including Heinrich Barkhausen, whose research on electron tubes had its beginnings at this time. Max Laue, too, was given leave from his university position to work with Wilhelm Wien at the Physics Institute in Würzburg, where radio telegraphy and amplifier tubes were being developed for the front. All of this activity confirms the historical trend that, at times of “severe national duress,” extra resources are allocated to scientists, and this concentrated effort results in accelerated technological progress.

In October of 1915, Iris Runge was still greeting news of military success with enthusiasm – “Belgrade is indeed excellent, and today Semendria!”³⁶⁰ – but by February of 1916 she decidedly opposed the widespread sentiments of “nationalism” and “chauvinism,” rejecting in particular the positions of Lorenz Morsbach.³⁶¹ At the University of Göttingen, the professors Lorenz Morsbach and Edward Schröder were not only opponents of women’s education, but they were also proponents of the German-National movement. This movement, which was initiated in 1891 and gained strength during the war, advanced a nationalist and expansionist agenda with roots in anti-Semitism, anti-Slavism, and notions of

356 Ibid.

357 Max Born worked for a scientific division of the army, the Artillery Testing Commission, which employed a number of physicists under the direction of Rudolf Ladenburg. Along with Alfred Landé, Born conducted experiments in sound measurement. In addition to that, he also began to investigate the cohesive forces and compressibility of crystal, work that would ultimately yield the unexpected realization that not all of the electrons orbiting a nucleus do so along a single plane (see FORMAN 1970).

358 Iris Runge discusses the nature of Reinhold Rüdenberg’s employment in a letter dated August 21, 1915 [Private Estate]. Between 1914 and 1919, Rüdenberg directed the “Bureau of Calculation R II” for alternating current machines in Siemen-Schuckert’s dynamo factory (see FELDTKELLER/GOETZELER 1994, p. 54).

359 See [STB] 515. Courant took a leave of absence to work on this device in 1915, and well before the end of that year they had produced a device that could transmit electric signals within a range of one to two kilometers (see Courant’s report – dated September 13, 1915 – in [STB] 585, p. 10; and also SCHLÜPMANN 2009). It is because of Courant’s influence that Wilhelm Runge would be transferred to the military division for telecommunications (see Iris Runge’s letter dated July 16, 1917 [Private Estate]).

360 Noted by Iris Runge on October 12, 1915 [Private Estate].

361 See her personal account from February 4, 1916 [Private Estate].

racial purity.³⁶² In such matters, the position of the Runge family accorded with that of Richard Courant, who wrote the following words to David Hilbert on October 12, 1918: “I am already looking forward to the moment when I can take off the ‘king’s uniform’ and return to the Germany of Hilbert and Einstein – not to the Germany of Morsbach and Schröder.”³⁶³

It should be noted that, well before the Runge family, David Hilbert had recognized the causes and momentousness of the First World War. Hilbert subscribed to *Das Forum*,³⁶⁴ a magazine published in Munich, and in 1915 he told Aimée Runge that the periodical “had already been banned on account of its peace-propaganda [...]. It had been alone, he said, in its attempt to reveal the true state of things to the public, to reveal the fact that we know *nothing*, absolutely *nothing*, about what is happening in the war etc. etc.” This letter, written by Aimée Runge to her husband on September 27, 1915, illustrates the extent to which Hilbert’s oppositional stance on the war differed from the position of the Runge family, which was still rather patriotic at that stage. She continues:

Hilbert got on my nerves by claiming – in his typically triumphant and apodictic manner – that the war would last for many more years and that the English were more than capable of outlasting us economically. According to him, only people like me who blindly trust what appears in the newspapers could possibly believe the laughable untruth that England would soon find itself in financial or economic straits. In fact, he said that the conditions in England are ten times more favorable than they are here, given that, among other things, they have lost only 70,000 troops compared to our 600,000 casualties. In his view, the only way that the war could come to a quick end would be if famine and plague were to break out among the people here. This would make the full effects of the war, which the majority of people has not truly felt, a dire reality to civilians at home. In Jena, he went on, it is already the case that two hundred people are dying every day of typhus, but such an epidemic would have to break out at several places simultaneously etc. etc. I know that I shouldn’t put too much stock in what he says, but it truly troubles me to hear the war spoken about in such a tone, especially because I have to struggle with all my energy not to fear for Wilhelm’s safety. This war is not being waged *entirely* because of the narrow-mindedness of the nationalists, and it can’t be brought to an easy end at any time of the day – if only, as Hilbert suggests, some rationality would simply revisit the German people.³⁶⁵

The euphoria of German civilians waned as the war prolonged, and many began to wish for its end. As is clear from her correspondence, however, Iris Runge continued to have greater faith in the German media than in the reports that had begun to circulate from England.³⁶⁶ She was a regular reader of so-called war literature, including the political journalism of Anton Fendrich, whose advocacy for social democracy persisted throughout the fighting,³⁶⁷ and the book *Des Deutschen*

362 See HERING 2004.

363 [UBG] Hilbert Estate, p. 61a. See also MCLARTY 2001.

364 On this magazine, see MÜLLER-FEYEN 1996; MÜLLER-STRATMANN 1997.

365 A letter from Aimée Runge to Carl Runge dated September 27, 1915 (in [STB] 523, p. 279).

366 See the letter to her mother dated May 28, 1916 [Private Estate].

367 See, for instance, Anton Fendrich, *Der Krieg und die Sozialdemokratie* (Berlin: Deutsche Verlags-Anstalt, 1915).

Reiches Schicksalsstunde [The Fatal Hour of the German Empire] by the lieutenant colonel Hermann Frobenius. Although she grew more and more skeptical of the groundless proclamations that were being made about the “enemy,” she nevertheless continued to heed the gushing news reports of military (especially naval) victories.³⁶⁸ With her mother she exchanged several notable books about European cultural developments.³⁶⁹

The idea that the war was a needless undertaking was slow to ripen. Iris Runge spent the summer vacation of 1916 with Clara Ewald in Holzhausen, where she met Thomas Theodor Heine, an illustrator for *Simplicissimus*, a critical and satirical weekly publication³⁷⁰; she learned that her cousin Roland Trefftz had died in battle; and she read letters by her brother that painted the war “in all its atrocity.”³⁷¹ She also began to feel the effects of the war on civilian life: As of February 8, the schools had been closed because there was not enough coal to heat them; on February 17, 1917, the German army ordered all public and private secondary schools to be shut down, as well as all theaters, cafés, and cinemas³⁷²; because of a general lack of food, she and her pupils volunteered for the National Emergency Services, for which they grew and even foraged for vegetables. Despite these hardships she would nevertheless write, in April of 1917: “The feats of our soldiers at Arras and Champagne fill me with grateful pride – so long as they can sustain their efforts, we shall do the same on the home front.”³⁷³

During the abbreviated summer vacation of 1917, Iris Runge met with Richard Courant and her sister Nina in Potsdam, with Walter Kroug in Jena, with her parents in Göttingen, and with Elisabeth Staiger in Bremen. These visits, which were ripe with political discussion, helped to sharpen her perspective. Although somewhat distraught by the resignation of Theobald von Bethmann Hollweg, who had endeavored to mediate between the Social Democrats and the conservatives, she was nevertheless persuaded by Courant’s opinion on the matter, namely that Bethmann Hollweg was “certainly not the right man to achieve peace for us through diplomatic means.”³⁷⁴

Iris Runge’s mixed reaction to the demonstrations of the Bremen merchant class against a “peace of renunciation,” which she read about in the *Weserzeitung*, is further evidence that she had become uncertain about which information could

368 See her letter dated June 6, 1916 [Private Estate].

369 According to a letter from June 3, 1917 [Private Estate], she and her mother read, among other works, Gustaf F. Steffen’s *Die Demokratie in England: Einige Beobachtungen im neuen Jahrhundert und ein Renaissanceepilog* (Jena: Dietrichs, 1911).

370 She mentions this meeting in a letter dated August 8, 1916 [Private Estate].

371 Quoted from a letter dated February 4, 1917 [Private Estate].

372 See her letter dated February 16, 1917 [Private Estate]. While it was closed, the teachers at the Kippenberg School still distributed assignments to their pupils, which they also managed to collect and correct.

373 Quoted from a personal account recorded on April 29, 1917 [Private Estate].

374 Iris Runge made this same remark in a letter written in Potsdam on July 16, 1917, and in a letter written in Bremen on August 28 of the same year [Private Estate].

be trusted.³⁷⁵ She attended political speeches by Social Democrats and military leaders alike,³⁷⁶ and she began to express some support for the newly formed Independent Social Democratic Party (*Unabhängige Sozialdemokratische Partei*): “Mom, what do you have to say about politics? I think it’s awful that Michaelis refuses to acknowledge the legitimacy of the Independents, but otherwise his speech was good [...]. How horrible, too, are the latest revelations about those sailors!”³⁷⁷ News of the anti-war movement and of the naval uprising at Wilhelmshaven, which took place in the summer of 1917, did not reach the public until of October of that year.³⁷⁸ The commotion caused within the navy led to the arrest of ten sailors, two of whom – the socialists Albin Köbis and Max Reichpietsch – were sentenced to death and executed by a firing squad on September 5, 1917.

The Independent Social Democratic Party was formed by delegates of the Social Democratic Party who had begun to voice their opposition to the First World War as early as August 4, 1914. This group of fourteen politicians initially voted against funding the war but later, following party lines, supported the measure in a decisive vote that was held later that year. After this vote, however, they refused to endorse any subsequent military spending, and for this resistance they were expelled from their political party. Together they formed a party of their own, the Social Democratic Working Group (*Sozialdemokratische Arbeitsgemeinschaft*), and it is from this faction that the Independent Social Democratic Party emerged in April of 1917, its chief goal being to bring the war to a swift close.

These efforts were countered by the newly formed Fatherland Party, which was established in September of 1917 on a nationalist, pan-Germanic, and pro-war platform.³⁷⁹ While at the Kippenberg School, Iris Runge came across a list containing the names of her colleagues who were affiliated with the Fatherland Party – Kippenberg himself was a member – and her reaction to this discovery demonstrates her minority position: “A heated discussion ensued, and it happened that Lene Thimme and I were alone in our opposition.”³⁸⁰ From their correspondence it

375 See her letter dated August 28, 1917 [Private Estate].

376 Iris Runge attended speeches by Ernst Heilmann, Friedrich Ebert, and Hermann Molkenbuhr, three Social Democrats who had voted in favor of funding the war and who had advocated for national defense and for the cessation of class conflict during wartime.

377 A letter from Iris Runge to her mother dated October 10, 1917 [Private Estate]. Georg Michaelis served as the Imperial Chancellor and the Prime Minister of Prussia between July 7 and October 31, 1917. He opposed democratic reforms and was soon opposed by the majority of the parliament.

378 For a timeline of these events, see:

<http://www.klausdede.de/index.php?content=weserundjade&sub=48>.

379 The Fatherland Party dissolved on December 10, 1918. Its leaders, including Paul von Hindenburg, disseminated the so-called “stab-in-the-back myth” (*Dolchstoßlegende*), according to which Germany’s defeat was caused by treason on the home front (see HAGEN-LÜCKE 1997).

380 A letter from Iris Runge to her mother dated August 24, 1917 [Private Estate]. One of Iris Runge’s close friends at the time, Magdalene Thimme was certified to teach religion,

is clear that Iris and Aimée argued over matters of politics, but in November of 1917 they expressed their mutual support for the politician Friedrich Ebert, who advocated for sustaining the war “until the enemy is prepared to accept reasonable terms of peace.” The idea that “Germany was to blame for the war,” which was maintained by representatives of the Independent Social Democratic Party, was rejected by Iris Runge as being “appallingly recalcitrant and narrow-minded.”³⁸¹

The influence of the Independents grew considerably, however, in the wake of the Russian Revolution; its membership escalated to a high of 500,000, which was nearly that of its Social Democratic counterpart. Germany’s first peace treaty was ratified with the Ukraine on February 9, 1918, and Iris Runge greeted this news with some skepticism: “Trotsky can hardly be trusted.”³⁸² Elsewhere she declaimed:

It does *indeed* seem as though this Russian revolution might be a historical event that is no less consequential than the French Revolution, however different the two may be. I am, however, rather disappointed with the Leninists, and I think that they are a discredit to socialism. From now on, all the reactionaries will be quick to say: Now you see how everything will look in that future state that you so desire! [...] It is apparent that these Leninists truly imagine themselves as being more closely aligned with the German proletariat than with, say, the Ukrainian bourgeoisie. Of course, I have always believed and I continue to believe that, insofar as it is beyond the stage of revolution, our brand of socialism is a step ahead of theirs.³⁸³

The German schools were closed to honor the signing of this peace treaty. Iris Runge celebrated the occasion with her friend Magdalene Thimme, with whom she would join the People’s Association for Freedom and Fatherland (*Volksbund für Freiheit und Vaterland*). This organization, a response to the Fatherland Party, had been formed in 1917 by a group of politically moderate university professors, and its members included Gustav Bauer, the Social Democrat and future Chancellor of Germany. The labor unions joined as well, the common goal being the establishment of a parliamentary republic.

German, and English on November 1, 1908. She taught at the Kippenberg School until 1939 (for details on her career, see KUNZE 31–39 [1924/25–1939/40]).

381 Quoted from a letter dated November 21, 1917 [Private Estate].

382 Quoted from a letter dated February 9, 1918 [Private Estate]. Leon Trotsky, the Commissar for Foreign Affairs in Soviet Russia, pursued peace with the Central Powers, called for an armistice, and represented the Russian delegation during the negotiations at Brest-Litovsk. Because of the weakness of the Russian army and the favorable position of German forces with respect to the annexation of the Ukraine, he had attempted to delay the question of the latter country’s sovereignty. On February 18, 1918, German forces broke the ceasefire that had been in effect with Russia and occupied the Ukraine, which had declared its independence from Russia the month before. Because of the superiority of the German army, the Soviets signed the Treaty of Brest-Litovsk, which was detrimental to the Ukraine and Russia itself.

383 Quoted from a letter dated February 9, 1918 [Private Estate].

2.6.6 An Interlude at the Haubinda Boarding School

In the early twentieth century, many private boarding schools were opened in Germany as an alternative to the traditional “cram and drill” form of education that prevailed. These schools, which were located in the country, offered a holistic approach to learning that focused on the body as well as the mind, and several of them were also coeducational, which was then a novelty.³⁸⁴ Hermann Lietz, who is regarded as the founder of this educational movement, designed a pedagogical model that aimed to impart intellectual flexibility, tolerance, confidence, and respect to his pupils. At first he accepted mostly boys, to whom he championed truthfulness and patriotism as virtues, and he stressed that there were fundamental differences between the sexes.³⁸⁵ Lietz had been a student of theology, philosophy, history, and German literature, and he was a proponent of Paul de Lagarde, a biblical scholar known for his nationalism and anti-Semitism. Instruction in mathematics and the sciences was another important component at Lietz’s boarding schools, which he had established in the rural areas of Ilsenburg in the Harz Mountains (1898), Haubinda in Thuringia (1901), and in the Bieberstein Castle in Hesse (1904).

By way of her aunt Lily du Bois-Reymond (née Hensel) and Minna Specht, who was Leonard Nelson’s life partner, Iris Runge learned that the Haubinda Country School was in need of a female teacher of science and mathematics. She decided to participate in this educational (and coeducational) experiment for half a year and to postpone the beginning of her graduate studies in chemistry. The position that she accepted had an annual salary of 2,000 Marks, and it included room and board.³⁸⁶ From her first letter about her experience in Haubinda, we learn that she began to teach there at the same time as Minna Specht, who had been studying mathematics at Göttingen since 1914 and who had already passed teaching examinations in several subjects. The two of them were called upon to take over the classes of a retiring teacher, a Swiss man named Dr. Brugmann, who reserved the right to observe and evaluate their work in the classroom. “I have been assigned to teach mathematics to the senior class,” she wrote, “and mathematics and physics to the younger students, totaling eighteen hours in all; Miss Specht has been called upon to teach somewhat less.” The class sizes at the school were extremely small – one of her senior classes consisted of just five pupils, one of them female – and she was clearly looking forward to it: “Even the curriculum is interesting to me; it is like that of a traditional preparatory school but with modern additions such as differential and integral calculus.”³⁸⁷ Iris Runge’s predecessor, however, had conducted his courses as lectures and was, in her opinion, “one of

384 See HANSEN-SCHABERG 1999; HANSEN-SCHABERG/SCHONIG 2002.

385 See KOERRENZ 1994, 2005; and also LIETZ 1935.

386 See a letter from Aimée to Carl Runge dated April 17, 1918 (in [STB] 523, p. 328). On Minna Specht, see HANSEN-SCHABERG 1992.

387 This and the previous quotation are from a letter dated April 23, 1918 [Private Estate].

those teachers who shied away from graphical methods and who discussed the difference quotient of a function without mentioning the concept of slope.”³⁸⁸ While at the Haubinda School she was able to introduce her own approaches with the students; she also tutored two boys in elementary English, gave scientific presentations (on radioactivity, for instance), and was generally content with her performance in the classroom.

At Haubinda, too, there was no lack of food – a significant circumstance during the later stages of the war. In addition to there being a bakery, the grounds of the boarding school included gardens, crop fields, paddocks, and some forest. Lietz tended to the husbandry himself, raising pigs, cows, sheep, and horses. Iris Runge, who resided in a sunny room in one of outbuildings, was enthusiastic about the daily routines at the school and held Lietz, or at least certain aspects of his character, in high esteem:

The most wonderful person here is undoubtedly Lietz himself; I don't think anyone even comes close. Of course he has his downsides (a few of which are entirely disagreeable), but he is nevertheless an amazing figure. Though he never seems to go about things consciously or systematically, everything that he touches somehow comes to life. [...] He takes such naïve pleasure in nobility and propriety. The maxims, proverbs, and quotations that he recites before meals and in the chapel, which would sound like dull regurgitations coming from anyone else, are both stimulating and entirely natural coming from him.³⁸⁹

What upset Iris Runge about Lietz was that, like August Kippenberg, he was a supporter of the Fatherland Party and he received the *Deutsche Zeitung*, which was the organ of the far-right Pan-German League (*Alldeutscher Verband*). Given Lietz's admiration of Paul de Lagarde, this might not come as such a shock. Along with Minna Specht, who was her fellow member of the People's Association for Freedom and Fatherland, Iris Runge lamented the political influence that Lietz exercised over the school children. Minna Specht would later recall “our time shared in Haubinda, where both of us were filled with anger over the nationalistic impact of Hermann Lietz, whom we otherwise admired so highly.”³⁹⁰

In 1917, Minna Specht and Leonard Nelson founded the International Youth Federation (*Internationaler Jugendbund*), the intentions of which were to educate a new generation to govern prudently and to prevent war. The members of this

388 Quoted from a letter dated May 5, 1918 [Private Estate].

389 Quoted from a letter dated April 23, 1918 [Private Estate]. About the chapel and what took place there, Iris Runge wrote the following in the same letter: “The chapel is like a small assembly hall, very pretty and light with west-facing windows. The walls are decorated with wreaths to commemorate victories and with bronze plaques in honor of fallen soldiers. In the middle there is a small table and a chair, where Lietz sits with his wife beneath him to his right. First we sing a folksong. Then he reads aloud while the girls engage in needlework and the boys either draw, make models, or do something of the sort. He always begins his readings with a serious reflection from the likes of De Lagarde, Schopenhauer, or Goethe; then he'll read an appropriate passage from a story [...]”

390 See *ibid.* and a letter from Minna Specht to Iris Runge dated March 3, 1950 (in [FES] Minna Specht 1/MSAE000064).

group were expected to adopt Nelson's theoretical and philosophical positions, to live ascetically (no alcohol, tobacco, meat, etc.), and to be engaged in the causes of the Social Democrats and the labor unions. In the end however, Nelson's Youth Federation attracted few members – in part because of his anti-clerical, anti-Marxist, and even anti-democratic positions – and the few people who did join were expelled from the ranks of the Social Democratic Party in 1925.

By late May of 1918, peace treaties had been signed with Russia and Rumania but the war persisted. Chief among the birthday wishes that Iris Runge sent to her mother that month was the wish for peace. She also posed the question anew: "Why do you insist on polemicizing against socialism?"³⁹¹ At the time, Iris Runge was immersing herself in the correspondence between Marx and Engels, which she had her mother send to her from Göttingen,³⁹² and following the articles in *Die Glocke*, a socialist publication. Here she was especially exuberant about the transcript of a political speech that was delivered by Konrad Haenisch, who, in November of 1918, would be appointed Cultural Minister by the first Prussian government to be led by the Social Democratic Party.³⁹³

Leonard Nelson and Minna Specht endorsed Lietz's idea of country boarding schools despite their disapproval of his political positions. In January of 1919 they negotiated with Haenisch, who was then the Cultural Minister, for state financing to establish additional experimental schools. However, their idea of radically changing the nature of education never came to fruition. Lietz died in 1919, after which Nelson and Specht assumed the directorship of a country school in Walkemühle and shaped its curriculum, with the support of a private foundation, according to their designs. Whereas a good number of youth groups inclined toward conservative politics after the First World War and were opportunistically lured into National Socialism,³⁹⁴ no one with close ties to Nelson ever moved in that direction. This was true even after 1933, when a number of Nelson's acolytes participated in the resistance against the Nazi agenda.³⁹⁵

2.6.7 Women's Suffrage and the Campaign for Social Democracy

Iris Runge returned to Göttingen for her doctoral studies in the fall of 1918, just as the war was coming to a frenetic close and the German Revolution (the so-called November Revolution) was coming to life. According to her own account, she

391 A letter written in Haubinda from Iris Runge to her mother dated May 28, 1918 [Private Estate].

392 See the letter from Iris Runge to her mother dated July 2, 1918 [Private Estate].

393 On Iris Runge's enthusiasm regarding this speech, see her letter dated July 2, 1918 [Private Estate]. Although Konrad Haenisch had voted against funding the war in 1914, he nevertheless remained a member of the Social Democratic Party (see JOHN 2003).

394 See NIEMEYER 2005.

395 See LEMKE-MÜLLER 1997, and Wolfgang Kroug's account (in [BBF] REICH 356) of Adolf Reichwein, who was executed as a resistance fighter in 1944. Nelson himself died in 1927.

learned about the German surrender suddenly and unexpectedly. Like her father, she was concerned about the threat of revolutionary unrest and embittered by the blockade that was imposed by the Allied Powers until the ratification of the peace treaty, an act of hostility that resulted in needless civilian deaths.³⁹⁶

By the end of September, the German high command had recognized the futility of its campaign, sought to arrange an armistice, and made efforts to fulfill the stipulation of establishing a parliamentary democracy. Shortly thereafter, on October 3, Kaiser Wilhelm II appointed the liberal Prince Maximilian von Baden as the next Imperial Chancellor, and the latter's transitional cabinet for the first time included two Social Democrats, namely Gustav Bauer and Philipp Scheidemann.³⁹⁷ The government was converted from a constitutional to a parliamentary monarchy, and with this change the Social Democratic Party at last witnessed the realization of its legitimacy. Unwilling to surrender, the navy command in Kiel ordered a final offensive against England, an order which led to the Wilhelmshaven mutiny, to strikes across all of Germany, and to the formation of workers and soldiers unions and even new political parties. The emperor had no choice but to abdicate. That calamitous rifts and tensions prevailed among the labor force is reflected by the fact that Scheidemann, the Social Democratic secretary of state, and Karl Liebknecht, the co-founder of the communist Spartacus League,³⁹⁸ issued divergent proclamations of a German republic on November 9, 1918.

After the first armistice had been signed on November 11, 1918, the German Council of the People's Deputies – a coalition between the Social Democrats and Independent Social Democrats – made the following proposal:

396 The Treaty of Versailles, which was signed on June 28, 1919, stated that Germany was solely responsible for the war. It was rejected by all of the political parties in Germany and was thought by some to contain the seed of an imminent war to come (see Iris RUNGE 1949, pp. 169–170).

397 On account of a 1912 speech that he delivered in Paris, Philipp Scheidemann had been accused of high treason in Germany. The speech included the following lines: "Against those who are attempting to embroil us in the beastliness of a European war, we shall defend ourselves with a desperate courage. The German workers and socialists respect and love the French workers and socialists as brothers. [...] Our enemy is elsewhere, and it is the same as yours. This enemy is capitalism. Comrades, let us struggle in solidarity for human progress, for the freedom of the worker, and for world peace" (quoted from SCHULZ 1981, pp. 368–369). An effective mediator during the war between the left and right wings of his party, Scheidemann had voted in favor of military funding but later supported a peace settlement that did not involve further annexations.

398 Karl Liebknecht, who in 1914 had been the only delegate of the Social Democratic Party to vote against funding the war, was imprisoned for high treason and not granted amnesty until October 23, 1918. He numbered among the founders of the German Communist Party, which was established on January 1, 1919, and he was assassinated shortly thereafter on January 15.

All elections for public office will henceforth be undertaken according to a system of immediate, confidential, and egalitarian democracy that is based on proportional representation and that is open to all men and women who are at least twenty years of age.³⁹⁹

This new electoral process was passed into law by the German National Assembly on November 30, 1918, and its enactment allowed German women to participate in their first election on January 19, 1919. It was a significant law for Prussian men as well, for it abolished the three-class franchise system that had been in place there since the middle of the nineteenth century. Beginning with the founding of the German Empire in 1871, the only election in which each man's vote was counted equally had been that of the National Parliament (*Reichstag*), and men had to be at least twenty-five years old to cast a ballot. In the year 1919, under the new system of voting, 82.4 percent of eligible men and 82.3 percent of eligible women turned out to vote.

Many German academics became politically active during this time, and by joining parties they contributed to the changing face of the German political landscape. Political fragmentation was characteristic of the era. Regarding labor parties, the Social Democratic Party and the Independent Social Democratic Party were joined by the newly established German Communist Party. The middle class was no less divided. In November of 1918, the German Democratic Party emerged from the defunct Progressive People's Party. The German Democrats integrated liberal, national, and social platforms while rejecting the annexation policy of the former National Liberals. There was also the conservative and anti-republican German People's Party, which temporarily reconciled itself to the idea of democracy through the efforts of its chairman, Gustav Stresemann, who later served as the Minister of Foreign Affairs. Further to the right was the German National People's Party (*Deutschnationale Volkspartei*), the objectives of which included nationalism, national liberalism, anti-Semitism, imperial-monarchical conservatism, and racial purity. As of 1930, the latter party cooperated with Hitler's National Socialist German Workers' Party, which its members were coerced to join in 1933. The National Socialist German Workers' Party was formed, on February 24, 1920, from the short-lived German Workers' Party. Their agenda, which was characterized by radical anti-Semitism, nationalism, and the rejection of democracy and Marxism, ultimately resulted in the catastrophes that were the National Socialist dictatorship and the Second World War. During the Imperial and Weimar years there was also the German Center Party (*Deutsche Zentrumspartei*), which had been founded by German Catholics in 1870.

For the most part, academics aligned with one of the bourgeois parties, some more to the left and others more to right in accordance with their background. Toward the right side of the spectrum, for instance, was the Göttingen historian Karl Brandi, a member of the German People's Party who served as the vice president of Hanover's provincial parliament. Max Planck, who came from a conserva-

399 See BAB et al. 2006.

tive family of judges, belonged to this same party until its dissolution in 1933, as did Friedrich Goeppert, a Göttingen professor of pediatrics.⁴⁰⁰

The German Democratic Party, which with the Social Democratic Party was strongly in favor of the Weimar Republic, attracted a significant number of members from the educated middle class – professionals, teachers, upper-level managers and bureaucrats, employees in the electrical and chemical industries, businessmen, and liberal Jews. In the elections held between January and March of 1919, the German Democratic Party won the second largest number of seats in the German National Assembly and in the Prussian Provincial Assembly (behind only the Social Democrats), and third largest number of seats on the Göttingen City Parliament (*Bürgervorsteher-Kollegium*).⁴⁰¹ In Göttingen, such academics as David Hilbert, Carl Runge, and Felix Bernstein joined the German Democratic Party,⁴⁰² and Albert Einstein had been one of the signatories – on November 16, 1918 in Berlin – of the party's founding proclamation. During the war, Einstein had worked with Hilbert on formulating the equation of gravity, and in 1920 he was appointed by Felix Klein to the editorial board of the journal *Mathematische Annalen*.⁴⁰³

Several university-educated women were also active in the German Democratic Party, among them Elisabeth Staiger, as Klein's daughter was called after her marriage. While working as a lecturer in Essen, she helped to initiate a local branch of this party, and she explained its objectives as follows to her father:

The party associates itself with 1848, and something of that spirit can genuinely be felt, especially in its emphasis on national unity above all. I belong to a board of twenty-five people (including three women) [...]. As far as I see it, our task will be to garner the support of all the left-leaning citizens who are not members of the Social Democratic Party.⁴⁰⁴

In 1930, some representatives of the German Democratic Party joined with members of the Young German Order (*Jungdeutscher Orden*) to form the short-lived German State Party (*Deutsche Staatspartei*), which was dissolved on June 28, 1933.

During the years of the German Empire, membership in the Social Democratic Party would have meant the end of an academic's career,⁴⁰⁵ but this was of course no longer the case once the Social Democrats were installed as the governing party after the November Revolution. Because the positions of the right-leaning

400 Friedrich Goeppert was the father of Maria Goeppert-Mayer, who won the Nobel Prize in physics in 1963.

401 In this local election, the Social Democratic Party won 33.2 percent of the votes and the German Democratic Party 14.7 percent. Between these, the regional German-Hanover Party won 17.6 percent (see DAHMS/HALFMANN 1988, p. 77; and also Adelheid von Saldern's contribution in GÖTTINGEN 2002).

402 See DAHMS/HALFMANN 1988, pp. 70–71.

403 See TOBIES 1994b.

404 A letter dated December 9, 1918 (in [UBG] Cod. Ms. Klein X, No. 432).

405 An example of this is the case of the mathematician Kurt Grelling (see DAHMS/HALFMANN 1988, p. 62).

branch of the Social Democratic Party hardly differed from those of the German Democratic Party, the Weimar Republic was more or less governed by a coalition between the two parties. Iris Runge, who like many young academics in Göttingen supported the Social Democrats, described the similarity of these positions in terms of her father's political temperament:

He had never been one of those people who regarded all Social Democrats as traitors and revolutionaries. Even before the war, on the contrary, he had recognized the legitimacy of some of their opinions. At the same time he did not find it necessary – as so many others did – suddenly to discover his socialist side immediately after the revolution. He thought and felt like the bourgeois man he was, and I mean this in a good sense. He even became a member of the Göttingen branch of the German Democratic Party, in which he hoped to find himself among other progressive members of the middle class.⁴⁰⁶

Iris Runge joined the Social Democratic Party in 1918. She attended party meetings and she participated as an instructor and administrator at the school for workers in Göttingen (the *Arbeiterbildungsschule*, which was founded in April of 1919), about which she also wrote newspaper articles.⁴⁰⁷ Her decision to join the party, which at this time was still promoting a socialist agenda, was made independently of Leonard Nelson, who had criticized Marx's idea of a new social order. Later she attributed her decision to her experience of the First World War:

Years later, after the experience of the First World War had refined my judgment, Nelson's criticism of Marx did nothing to deter me from becoming a member of the Social Democratic Party. And later I learned that Nelson had taken this same step himself. My decision was all the easier because it accorded with the views of my old university friends, who were very accepting when I visited them after my return to Göttingen. They wholeheartedly welcomed me back into their circle; I was close to them throughout my Göttingen years and I remain so even now in Berlin.⁴⁰⁸

Along with Richard Courant, her future brother-in-law, Iris Runge was active in the 1919 election campaign. On the eleventh, fourteenth, and fifteenth of January, the *Göttinger Zeitung* reported about a gathering of students and academics at which Iris Runge and Courant endeavored to familiarize their audience with the "principles and objectives of socialism."⁴⁰⁹

406 Iris RUNGE 1949, p. 171.

407 See her curriculum vitae in [STB] 747, p. 3; and also her letter dated September 16, 1919 [Private Estate]: "Among other such things, I have had to write newspaper articles about the workers' education classes."

408 [FES] Nelson Estate, 1/LNAA=000513, p. 3.

409 The campaign poster is printed in the *Göttinger Zeitung* (January 11, 1919), p. 4. For discussion of this event, see DAHMS/HALFMANN 1988, pp. 67–68; MCLARTY 2001.



Figure 4: Campaign Poster, 1919

The National Assembly was elected on January 19, 1919, and the Göttingen City Parliament on March 2. In the latter, the Social Democratic Party won the most seats with fifteen, two of which were held by Richard Courant and Kurt Grelling. Iris Runge was also considered a potential city councilor, but in the meantime she had taken a teaching position at the Salem Castle School in Baden.⁴¹⁰ As early as October 12, 1918, Courant had written to David Hilbert: “I can’t be upset about the change that has taken place in the world.” Within his army unit, Courant had served as the chairman of the workers and soldiers union, and in November of 1918 he attended a meeting in Berlin of the New Fatherland League (*Bund Neues Vaterland*),⁴¹¹ one of the initiators of which had been Albert Einstein. This pacifist organization, which was established in 1914 and has been known since 1922 as the German League of Human Rights, described itself as follows in the 1918 con-

410 See Section 2.6.8 below. In a letter dated November 20, 1920 [Private Estate], Iris Runge wrote the following to her mother: “It’s unbelievable that I could have become a city councilor! But I thank my lucky stars that this opportunity has passed me by, for I doubt that I could have benefitted much from it, and it would have been a rather demanding and dissatisfying position.”

411 A letter from Richard Courant to David Hilbert dated November 23, 1918 (in [UBG] Cod. Ms Hilbert 61a).

vention program: "The New Fatherland League, which is not affiliated with any political party, is a collaborative organization devoted to developing the German socialist republic on democratic grounds and to promoting international good will."⁴¹²

Courant and Iris Runge stood in favor of these grand ambitions. They condemned the violent quelling of uprisings decreed by the Defense Minister Gustav Noske.⁴¹³ In the letter to Hilbert cited above, Courant lamented the fragmentary political landscape: "The Spartacus League, the Independents, and the Social Democrats are all on unfriendly terms, and the latter two are especially divided by their respective tactics and temperament, by personal feuds, and by the recent past."⁴¹⁴ He was also active in winning support for the university reforms proposed by Hilbert, Felix Klein, and Leonard Nelson. In general, the evidence supports Eberhard Kolb's thesis that the workers and soldiers unions did nothing to stand in the way of the establishment of a parliamentary government.⁴¹⁵ Their predominant goal was the institution of a soviet democracy, not a dictatorship of the proletariat.

The governing Social Democrats had ordered a military deployment against unruly naval troops and striking workers and had sanctioned the assassinations of left-wing politicians, and these actions only deepened their rift with the Independents, whose representatives had begun to play an active role in the government. In the first election of 1919, the Independents were able to win only a small percentage of the votes; things changed, however, by the June election of the next year, in which their stake grew to 17.9 percent while that of the Social Democrats fell to 21.3 percent. Leonard Nelson had belonged to the Independent Social Democratic Party since 1918. That a number of female mathematicians also became members of this party illustrates the extent to which the November Revolution had awakened German academics to political life. The renowned Emmy Noether, for instance, joined the Independents in 1919, as did the pastor's daughter Adelheid Torhorst, who in 1915 had earned a doctorate in mathematics at the University of Bonn.⁴¹⁶ When the Independent party disassembled in 1922, the allegiance of its former members was split between the German Communist Party and the Social Democratic Party, the latter securing the membership of Noether, Torhorst, and Leonard Nelson as well.⁴¹⁷

412 See FRICKE, vol. 1, pp. 351–360.

413 See DAHMS/HALFMANN 1988, pp. 67–68, 80. On Gustav Noske, see WETTE 1987; BUNTEN-SCHÖN/SPOO 1997.

414 The Spartacus League was a left-wing Marxist revolutionary movement organized in Germany during the First World War. Founded by Karl Liebknecht, Rosa Luxemburg, and others, it was named after the leader of the largest slave rebellion of the Roman Republic.

415 See KOLB 1978, 2005 (2nd ed.).

416 In 1931, Adelheid Torhorst changed her allegiance – in spectacular fashion, we are told – to the German Communist Party (see TORHORST 1982).

417 Iris Runge had remained faithful to the Social Democratic Party all along, even despite her strong disapproval of the sanctioned political assassinations. In an undated letter to her par-

Iris Runge was aware that, as an avowed socialist, she would have little chance of finding employment at a state or city school.⁴¹⁸ Despite the Social Democratic government, the public school system remained conservative.⁴¹⁹ This fact explains the growing number of reform-oriented private schools and country boarding schools that were largely attended – it should be said – by children of privilege. Having visited the Salem Castle School as a new potential workplace, she clarified her intentions as follows:

To work with so few children and under such exceptionally beautiful and fortunate circumstances must indeed be a great pleasure, but then one would have to think about the many, many children in the cities who are stuck with nationalistic and pedantic teachers. If placed in such an environment, I would at least be able to do my part to change it. But in the end I have to take whatever I am given, especially now that there is a surplus of teachers. I can hardly complain, after all, about having to work in a castle. Then again, maybe it would be a bad idea for the Catholics to hire me. Being a Social Democrat in these circumstances is hardly favorable, of course, and will only serve to agitate the opposition. For they are probably incapable of imagining a Social Democrat who reads Thomas à Kempis for pleasure. Granted, I probably read him in a light entirely different from that to which they are accustomed.⁴²⁰

Iris Runge accepted this teaching position after passing her supplementary teaching examination in chemistry at the University of Göttingen and after completing the groundwork of her doctoral dissertation (see Section 2.7). She began to work at the Salem Castle School in September of 1920, even though it did not correspond with what she hoped to be doing. Her decision cannot really be understood

ents about the reform-minded pedagogue Kurt Hahn – preserved in the [Private Estate] – she wrote: “Kurt expressed his great indignation about the prevailing tolerant attitude toward the assassinations of Liebknecht and R. Luxemburg, and now Erzberger. He is a defender of the true ‘revolution’, which, he pointed out, had not been made a bloody affair until these murders were carried out by the right. I had not expected this from him.” Her condemnation of Walther Rathenau’s assassination, moreover, is reflected in a letter dated June 20, 1922 [Private Estate].

418 See the letter written in Salem from Iris Runge to her mother dated May 28, 1920 [Private Estate].

419 Marie Torhorst, Adelheid Torhorst’s younger sister, had earned a doctoral degree in mathematics in 1919 (Bonn), passed the state teaching examination, and joined a group of war protestors and religious socialists during the November Revolution. Because no state or city school would hire her, she accepted a position at a private Catholic school for girls. The school director who hired her is reported to have said the following about Torhorst’s political beliefs: “It doesn’t matter. As far as mathematics is concerned, the same laws apply on the moon as they do here with us on the earth” (TORHORST 1982, p. 25).

420 A letter from Iris Runge to her mother dated May 28, 1920 [Private Estate]. Born Thomas Hemerken (“little hammer”) in the year 1380, Thomas à Kempis was an Augustinian monk who died in 1471 at the Agnietenberg Monastery near Zwolle (Netherlands). He is agreed to be the author of *The Imitation of Christ* (*De imitatione Christi*), which was one of the most widely-read books of the Middle Ages. For a complete edition of his works, see Michael Josephus Pohl, ed., *Thomas Hemerken a Kempis...*, 7 vols. (Freiburg: Herder, 1902–1922); for an English translation of his most popular work, see Thomas à Kempis, *The Imitation of Christ*, trans. Leo Shirley Price (London: Penguin, 2005).

in terms of her desire to implement pedagogical reform; it is much more the case that this was the only job available to her at a time when she rather urgently needed to work – her father had recently turned sixty-three years old, and her younger siblings were not yet finished with their (costly) education. She had to support herself with income of her own.

2.6.8 The Salem Castle School

The castle belonged to Prince Maximilian von Baden. In 1917, this liberal aristocrat opposed the renewal of unrestricted submarine warfare, the offensive that enticed the United States to enter the war. As mentioned above, he was appointed Imperial Chancellor and Prime Minister of Prussia on October 3, 1918, and his appointment was made so that Germany could be represented at the peace negotiations by a leader who was considered to be trustworthy by the Allied Powers. After the proclamation of the republic on November 9, 1918, Maximilian von Baden ceded the chancellorship to the Social Democrat Friedrich Ebert, retreated into private life, and founded the Salem Castle School with the help of Karl Reinhardt and Kurt Hahn.⁴²¹

Born in 1849, Reinhardt had studied classical philology and had long served as a director of reformed secondary schools in Prussia. Between 1904 and 1919 he was the Director and High Privy Councilor of the Prussian Ministry of Culture. Personally acquainted with Maximilian von Baden, he was named the first director of the Salem Castle School in April of 1920, a position that he held until his death in 1923.

Kurt Hahn had studied modern philology at Göttingen and Oxford, and in 1914 he was appointed head of the division concerned with English relations at the Department of Foreign Affairs in Berlin. Later he was transferred to the Chancellor's Office, where he worked as Maximilian von Baden's private secretary. Having participated in the negotiations leading to the Treaty of Versailles, he traveled to Baden-Baden to assist with the establishment of the Prince's new educational project.⁴²² Both Hahn and Marina Ewald, who were ultimately in charge of the Salem Castle School's operations, had ties to the large Du Bois-Reymond

421 In a letter to her parents dated September 9, 1920 [Private Estate], Iris Runge described her first encounter with Prince Maximilian von Baden: "Yesterday I met the prince [...]. He seems to be looking after everything [...]. He was very friendly and lively, and when he heard that I came from Göttingen he asked me about Nelson and Mühlestein, about whom he had heard a great deal in Switzerland. Everyone here calls him 'Your Highness,' but I have avoided doing so on account of my republican principles."

422 See RICHTER 1952.

extended family, which is why Iris Runge was so quick to learn about the position there.⁴²³

The school was based on Hahn's principle of creating a new generation of strong-minded and self-determined men and women. According to his educational philosophy, which he also applied in Scotland after his forced emigration in 1933, children should be given the opportunity to discover things on their own, to undertake their own projects, and to challenge themselves physically in athletic competitions.⁴²⁴ Just as Johann Gottlieb Fichte, after Prussia's defeat at the hands of Napoleon, had sought to restore the health of the nation with a new educational agenda, Hahn strove to overcome such "flaws of the German character" as the "inability of intellectuals to act resolutely, the lack of intellectual restraint on the part of those who do act resolutely, and the general atmosphere of discord and dissension that reigns among the people."⁴²⁵ Although scientific and mathematical education did not play a major role in this agenda, Kurt Hahn and Maria Ewald warmly welcomed and increasingly appreciated Iris Runge's contributions as a "science teacher" at their school.

During her preliminary visit to Salem Castle in 1920, Iris Runge was asked to teach two classes to pupils in their fourth year. Her approach reveals her preference for conducting scientific experiments in the classroom: "It was great fun; the boys were as charming as could be, and there were a few girls, too [...]. I introduced the topic of air pressure, and to this end I brought along a bucket of water and a hose, which lent themselves to a number of fine experiments." She described her initial impressions of the school as follows:

Kurt Hahn acts like a character from a knightly romance, which is a little much to handle, but he nevertheless has a good understanding of things and he seems to be entirely convinced of the value and necessity of scientific education. Marina is absolutely fabulous: She manages all matters of husbandry with vim and vigor [...]. The elderly Reinhardt comports himself like a true headmaster – in general, there was something remarkable about the fact that all of the teachers here dressed like lords, with long trousers and neatly cropped beards. This is something that would have rubbed me the wrong way at the country schools in Hau-

423 Kurt Hahn, who was from Berlin-Wannsee, was related to Edmund Landau (see [STB] 523, p. 82); and his aunt Gertrud Hahn was married to the mathematician Kurt Hensel. Marina Ewald was a cousin of Paul Ewald.

424 For the latest research on Kurt Hahn's idea of "experiential education," see LAUSBERG 2007. In English, an informative book about Hahn's life and achievements is RÖHRS/TUNSTALL-BEHRENS 1970. Of Jewish origin, Hahn was imprisoned by National Socialists in 1933 but set free thanks to the direct intervention of the British Prime Minister (Ramsay MacDonald) and the Margrave of Baden. In the fall of 2007, the Kurt Hahn Expeditionary Learning School was opened in Brooklyn, New York. The mission of the school is to prepare informed, skilled, and courageous civic leaders, and it is named after Kurt Hahn because of his embodiment of those values.

425 Quoted from L. Richter, "Kurt Hahn: Politiker und Erzieher," *Die Zeit* (May 5, 1956); HAHN 1931. The philosopher Edmund Husserl evoked similar thoughts in a series of lectures that he delivered on Fichte in 1917 and 1918; see Edmund Husserl, "Fichte's Ideal of Humanity (Three Lectures)," trans. James G. Hart, *Husserl Studies* 12 (1995), pp. 111–133.

binda, Bieberstein, and Wickersdorf. Reinhard really is prodigiously kind – a vivacious and amicable old gentleman. I did, however, sit in on one of his Latin classes, which was somewhat less than thrilling [...].⁴²⁶

When she began teaching at the Salem Castle School in September of 1920, there were only three classes, each with eighteen children – one of whom was the Prince's son – who either boarded on the premises or lived in the local village.⁴²⁷ As enrollment increased, Iris Runge would go on to teach science courses to pupils in their third and fourth years and also to the combined group of pupils in their fifth and sixth years; in addition, she also taught mathematics to pupils in their final two years. The facilities for teaching laboratory courses, however, were notably insufficient throughout her tenure there:

The most necessary instruments are lacking, and so every experiment that I want to prepare is hindered in one way or another. There is no burner, and therefore no possibility of bending glass; no hoses, and therefore no way to connect glass tubes. There is a great deal of cork, but no cork borer; test tubes of every sort, but no test tube stands; plenty of weights, but no scales. There are no chemicals to speak of, nor are any drills or tongs to be found. Moreover, whoever opens the utility chest sees only an insane surplus of supplies, and Kurt and Marina and Mrs. Richter are all of the feeling that, because 2,000 Marks were spent on the equipment, everything I need should simply be there.⁴²⁸

She continued to raise the issue, for it was taking a considerable time to prepare her daily labs, and in October she once again expressed her discontent over the hopeless conditions for teaching chemistry and physics: “[...] and yet whenever I make any inquiries into the matter, they simply stare at me *like the fool who tried to hustle the East*.”⁴²⁹ She helped around the castle as a makeshift electrician, earning a reputation for her expertise in physics and technology, and she was overjoyed by the interest of the older pupils in the sciences. For them, she developed a physics laboratory that was fit for independent or group experiments.⁴³⁰ She also managed to overcome the initial difficulties that she had faced with the behavior of her younger classes: “At their former schools they were accustomed to draconian discipline, and because such punishment does not exist here, they are rather difficult to keep in line.”⁴³¹

426 A letter dated May 28, 1920 [Private Estate]. Bieberstein and Haubinda were country schools founded by Herman Lietz (see above). Wickersdorf was founded by the educational reformer Gustav Wynecken in 1906.

427 This information is taken from a letter dated September 19, 1920 [Private Estate]. The many letters written by Iris Runge during her time at the Salem Castle School contain extensive and interesting descriptions of school's environment and faculty, its buildings, accommodations, rooms, facilities, day-to-day life, etc.

428 A letter dated September 19, 1920 [Private Estate].

429 A letter dated October 10, 1920. The italicized portion of the quotation was originally written in English; it is an allusion to “The Naulahka,” a poem by Rudyard Kipling.

430 See *ibid.* and also a letter dated March 4, 1922 [Private Estate].

431 A letter to her parents dated September 19, 1920 [Private Estate].

In the end, she experienced alternating phases of enthusiasm and self-doubt, the former brought about by her classroom successes, the latter by what she felt to be her “insignificant accomplishments” as a teacher.⁴³² At the same time she was not in full agreement with Kurt Hahn’s philosophy of education, which seemed to emphasize playing hockey over learning about science and mathematics.⁴³³ During 1921 and 1922, the introduction of a new curriculum left her with nothing to do for months at a time. She began to write stories and to give lectures to adults as well as pupils. For this, Arnold Sommerfeld’s latest book (sent to her as a gift by the author) was especially useful.⁴³⁴ She also arranged multiple opportunities for teachers to voice their complaints to Kurt Hahn, noting: “The realization has finally dawned upon everyone here that, given the poor performance of the pupils, it will be impossible to prepare them for the university entrance examination in the mere year and a half that remains.”⁴³⁵

While she was quite content participating in the athletic activities at the school (hiking, hockey), working in the garden, and attending the theatrical and musical performances of the pupils, and she was even mildly amused to eat cakes and chocolates at some of Prince Maximilian von Baden’s parties, she nevertheless wrote: “[...] I can no longer stand to be a prince’s servant, and I sorely miss the presence of working people here.”⁴³⁶ She read book after book, including the four-volume novel *Lienhard und Gertrud* by the Swiss educational reformer Johann Heinrich Pestalozzi – “it is realistically and magnificently written from the

432 A letter to her parents dated March 6, 1921 [Private Estate].

433 In a letter to her parents written in November of 1922 [Private Estate], she wrote: “I have become convinced, by rather many things that have taken place here, that much of Kurt Hahn’s educational philosophy is fundamentally untenable, and I don’t think that I could be convinced otherwise.”

434 Arnold Sommerfeld, *Atombau und Spektrallinien* (Braunschweig: F. Vieweg, 1919) [in English: *Atomic Structure and Spectral Lines*, 3rd ed., trans. Henry L. Brose (New York: Dutton, 1931)]. She discusses this book in a letter dated February 12, 1922 [Private Estate]. Beginning in November of 1922, Iris Runge held lectures to prepare senior pupils for the university entrance examination: “During the first evening devoted to preparing pupils for the entrance examination, I delivered a lecture on atoms and molecules in which I outlined the chemical principles of the atom hypothesis, the kinetic theory of gases, and the X-ray images of crystals in terms that could be understood. I find that I am much better at this than I expected: Everyone in attendance, even complete laymen [...], were captivated, and the boys were especially interested. In short, it was a success. But it is somewhat strange that the children only feel obliged to learn and be kind and attentive during such extracurricular events, whereas they act entirely differently in their regular classes. It is exactly for reasons such as this that I will not regret giving up teaching; after all, there will be plenty of opportunities to give popular lectures in the continuing education courses for adults” (quoted from a letter dated November 22, 1922 [Private Estate]).

435 A letter dated October 12, 1922 [Private Estate].

436 Ibid.

perspective of the poor,” as she noted to her mother.⁴³⁷ She visited relatives in nearby Freiburg and received visitors at the castle itself, including Richard Courant and her sister Nina.⁴³⁸ In the end, however, her daily dealings with the children of ministers and other dignitaries, from Germany and abroad, left her unsatisfied.

While her fellow teachers were preparing for the upcoming celebrations of Corpus Christi, Iris Runge was reading Max Born’s recent book on Einstein’s theory of relativity.⁴³⁹ Her attention was focused on the final stages of her doctoral studies.

2.7 GUSTAV TAMMANN – PHYSICAL CHEMISTRY

Physical chemistry, a more recent field than inorganic and organic chemistry, has always been characterized by its heavy reliance on mathematical methods. These methods were first summarized in Walther Nernst und Arthur Schönflies’s *Einführung in die mathematische Behandlung der Naturwissenschaften* (1895), which was quick to acquire an international audience.⁴⁴⁰ As Hans Jahn noted in his 1905 work on electrochemistry, the field of physical chemistry can hardly be grasped without an intimate knowledge of higher calculus.⁴⁴¹ A detailed treatment of the mathematical methods used in the most important branches of this field – thermodynamics, electrochemistry, kinetics – was provided in the fifth volume of the *Encyklopädie der mathematischen Wissenschaften*.⁴⁴²

437 A complete English translation of this long novel does not exist; for an abridged version of the story, see *Pestalozzi’s Leonard and Gertrude*, trans. Eva Channing (Boston: Ginn, Heath & Co., 1885).

438 See her letter dated December 29, 1920 [Private Estate]. Along with her sisters Ella and Aimée (Bins), she spent the Christmas of 1920 at the home of her aunt Fanny Schröder (née Runge) in Freiburg, where they met Tilly and Fritz Nelson and the Husserl family. A brother of Leonard Nelson, Fritz Nelson earned a doctoral degree in medicine at the University of Kiel in 1917. Like that of Felix du Bois-Reymond, his research was supervised by Ernst Siemerling.

439 See her letter dated May 28, 1921 [Private Estate]. The book in question is Max Born, *Die Relativitätstheorie Einsteins* (Berlin: J. Springer, 1920) [in English: *Einstein’s Theory of Relativity*, trans. Henry L. Brose, rev. ed. (New York: Dover, 1965)]. About the colorful Corpus Christi processions that take place in Germany, Iris Runge remarked: “I can’t believe there are people who seriously consider such hocus-pocus to be holy” (quoted from a letter dated May 8, 1921 [Private Estate]).

440 NERNST/SCHÖNFLIES 1895. This book was soon translated into English as *The Elements of the Differential and Integral Calculus* (YOUNG/LINEBARGER 1900), see also Section 2.3.

441 See Hans Jahn, *Grundriss der Elektrochemie*, 2nd ed. (Vienna: A. Hölder, 1905). The same is essentially said in the prefaces to NERNST/SCHÖNFLIES 1895.

442 The international contributors to this volume of the *ENCYCLOPEDIA* included the British scientist George Hartley Bryan, who submitted an article on the general foundation of thermodynamics; the British mathematician Ernest William Hobson, who co-authored an article on the subject of heat conduction; the Austrians Ludwig Boltzmann and Karl Ferdinand

Table 5: Courses Attended by Iris Runge, 1918–1919⁴⁴³**University of Göttingen***Winter Semester 1918/19*

Physical Chemistry Lab
Chemistry Lab (*Vollpraktikum*)

Professor Gustav Tammann
Professors Adolf Windaus⁴⁴⁴
Walther Borsche
Professor Adolf Windaus

General Chemistry I

Summer Semester 1919

Chemistry Lab (*Halbpraktikum*)
Seminar for Teaching Candidates
Chemistry Seminar (*Konservatorium*)
An Overview of Organic Chemistry
General Mineralogy and Crystallography
Select Topics in the Kinetic Theory of Gases

Professor Adolf Windaus/Dr. Arthur Kötz
Professor Adolf Windaus/Dr. Arthur Kötz
Dr. Arthur Kötz
Dr. Johannes Sielisch (Lecturer)⁴⁴⁵
Professor Otto Mügge
Professor Peter Debye

Interim Semester (Fall 1919)

General Chemistry II
Chemical Technology
Chemistry Seminar (*Konservatorium*)
Seminar for Teaching Candidates
Mineralogy Lab

Professor Adolf Windaus
Dr. Arthur Kötz
Dr. Arthur Kötz
Professor Adolf Windaus/Dr. Arthur Kötz
Professor Otto Mügge

One of the earliest professorships of physical chemistry, preceded only by those at Heidelberg and Leipzig, was established at the University of Göttingen, where it was first held by Walther Nernst and then, as of 1907, by Gustav Tammann.⁴⁴⁶ The majority of Tammann's academic activity was conducted in the field of materials research (the study of metals, glass, and heterogeneous systems), and numerous equations, laws, instruments, and methods continue to bear his name. He was the author of the *Lehrbuch der Metallographie*, which went through multiple German editions and appeared in English as *A Text Book of Metallography*.⁴⁴⁷ For

Herzfeld, who contributed to the entries on kinetics and electrochemistry; and the Dutch physicists Heike Kamerlingh Onnes and Willem Hendrik Keesom, who together wrote the article on constitutive equations. The latter contribution was published in 1911, two years before Kamerlingh Onnes would win the Nobel Prize in Physics.

443 Iris Runge submitted this list as part of her supplementary teaching examination in chemistry, which she passed *with distinction* on January 1, 1920 (see [STB] 747, pp. 24, 28).

444 Adolf Windaus succeeded Otto Wallach at the University of Göttingen in 1915. In 1928 he was awarded the Nobel Prize in Chemistry for his pioneering work on cholesterol and other sterols.

445 On Johannes Sielisch, see BEER 1983, pp. 66–67.

446 See Section 2.3, and Table 2. On Tammann's life and work, see BEER 2004, 2005; PALM 2004.

447 TAMMANN 1914–32. A full citation of the English translation, which is based on the third edition, reads: *A Text Book of Metallography: Chemistry and Physics of the Metals and Their Alloys*, trans. Reginald S. Dean and Leslie Gerald Swenson (New York: The Chemical

many years Tammann served as the editor of the *Zeitschrift für anorganische und allgemeine Chemie* [Journal of Inorganic and General Chemistry], and he was an active member of the Society for Metals Research (*Gesellschaft für Metallkunde*) since its founding in 1919.

An outspoken supporter of women's education, Gustav Tammann first voted in favor of allowing women to hold postdoctoral appointments in 1907 (see Section 2.1.1). The following discussion will concentrate on Iris Runge's admission into Tammann's circle, the role of mathematical methods in her dissertation, and the factors that led to her new career as an industrial researcher.

2.7.1 A Member of Tammann's Circle

Gustav Tammann's father was an Estonian physician who, having died prematurely, left his widow and three children with very little means. In poor material conditions, Tammann studied in Tartu under Wilhelm Ostwald, among others, and completed his first university degree (*Diplom*) in 1882. He earned his doctoral degree in 1890 and, having already achieved an international reputation, was granted a professorship only two years later. Discontent with the Tsarist system of higher education, however, he soon accepted a position at the University of Göttingen. There, at least until the outbreak of the First World War, he was able to attract a great number of students from Russia, the rest of Europe, and even from overseas to complement his already large group of German followers.⁴⁴⁸ Thus he created what would become a renowned international center for the study of physical chemistry, and especially of metals research. Between the years 1904 and 1931, nearly one hundred students from Germany, including three women, completed graduate degrees under his direction in Göttingen, and ten students from Russia and the Baltic states, five from the United States, three from Great Britain, two from South Africa, one from the Netherlands, and one student from Hungary did the same. Additional students from Japan and Sweden, among other places, either came to Göttingen to conduct research or were advised by Tammann while completing dissertations at their home institutions.

Tammann's students went on to hold positions as professors at universities and technical universities, as directors and researchers at the Imperial Institute of Technical Chemistry (*Chemisch-Technische-Reichsanstalt*) and the so-called Kaiser Wilhelm Institutes,⁴⁴⁹ and as schoolteachers. It can be verified that a num-

Catalog Co., 1925). On terminological matters, see TAMMANN 2005; on the history of metals research in Germany and Great Britain, see MARSCH 2000; on metals research as a "techno-science" and on Tammann's influence in particular, see MAIER 2007, pp. 191–196, 208–212.

448 On this and the following information, see BEER 2004, 2005; and Tammann's *Festschrift* (1926).

449 Tammann's former students were especially active at the Kaiser Wilhelm Institutes for iron research and metals research (see MAIER 2007).

ber of his students, too, found positions as directors, heads of laboratories, or plant managers in the metal processing, electrical, and communications industries.

Nicole Chezeau has identified two important dates regarding the birth of metal physics, namely 1886, when the French scientist Henry le Chatelier first turned his attention to the thermocouple, which would allow for the measurement of extremely high temperatures, and the year 1900, when the laws of thermodynamics were shown to confirm the experimental hypotheses of the iron-carbon diagram.⁴⁵⁰ There were other important developments, however, that should not be overlooked, including the breakthroughs in the field of crystallography, made after the discovery of X-ray interference, as well as the increased application of mathematical methods. In the figure of Tammann, physical, chemical, and mathematical methods converged with practical and industrial applicability. He combined the methods of various scientific disciplines and employed them in an interdisciplinary and *industrial*-scientific manner that would later be applied by his former students, both at the Kaiser Wilhelm Institutes and in areas of industrial research.⁴⁵¹

The overview of intermetallic behavior developed by Tammann and his students provided the foundation for a modern and systematic study of alloys. His methods of thermal analysis, in conjunction with the microscopic examination of solidified alloys, allowed far-reaching conclusions to be drawn about the state diagrams of binary systems. It is to his credit, in general, that state diagrams came to be deployed as widely as they did in the study of alloys.⁴⁵²

Tammann's research culminated in his aforementioned textbook on metallography, which he kept up to date in each successive edition. In the preface to the second edition, he noted that results in the atomism of crystalline substances cannot be ignored by a field that, until then, had been exclusively based on equilibrium thermodynamics. For this reason, he wrote, "the chapter on recrystallization has been rewritten in accordance with a new atomistic principle, and the chapter on the chemical and electrochemical characteristics of alloys has been reconfigured to account for the distribution of two types of atoms in a space lattice."⁴⁵³ In the preface to the fourth edition of the book, which appeared under the new title *Lehrbuch der Metallkunde* [Textbook of Metals Research], Tammann stressed that X-ray analyses of metallic substances contributed essential information to our understanding of the fundamental processes of rolling and stretching, "because, in the current state of things, only a small branch of metals research can be said to concern itself with the microscopic structure of metallic compounds."⁴⁵⁴

Beginning with the third edition of Tammann's textbook, its section entitled "The Diffusion of Two Metals into Each Other" would incorporate the most sig-

450 See CHEZEAU 2004; LETTÉ 2004.

451 On the concept of industrial research, which is also referred to as "techno-science," see the discussion in MAIER 2007, pp. 191–196.

452 See SAMSON-HIMMELSTJERNA 1939.

453 TAMMANN 1921, Preface.

454 TAMMANN 1932, Preface.

nificant result of Iris Runge's dissertation, namely her definition of the diffusion coefficient of carbon into iron.⁴⁵⁵ Tammann referred to an article by Iris Runge that appeared in the *Zeitschrift für anorganische und allgemeine Chemie* in 1921, written before the completion of her thesis. During the lean years after the First World War, the majority of doctoral dissertations remained unpublished.

2.7.2 Calculating the Diffusion Coefficient of Binary Solid-Solid Systems

It had been known since 1890, if not slightly before, that solids can diffuse into one another. To determine the rate of this diffusion, however, required knowledge that would only be gained later on, namely an understanding of the differences between mixed crystals and amorphous (non-crystalline) solids, as well as an understanding of equilibrium ratios in binary systems. It was not until these processes had been shown to have practical value (to case-hardening and cementation, in particular), and until new analytic instruments had been made available, that scientists in Italy, France, and Germany conducted the first investigations into the matter. Each of these initial experiments, it turns out, rested on the presupposition that the concentration of the diffusing substance could be determined by chemical means – in defined locations, after a specific amount time – or by measuring chemical activity.

Iris Runge's approach to the problem drew upon Italian experiments – conducted in 1910 and unconcerned with determining diffusion coefficients – on gold-silver, gold-copper, and copper-nickel binary systems. The novelty of her efforts consisted in the continuous measurement of a physical property, such as electrical resistance, that alters in accordance with changes of concentration, and thus to track the process of diffusion temporally instead of spatially. "If the dependence of this property [electrical resistance] on the compounding is known," she concluded, "the diffusion coefficient of this compound can be calculated under these conditions."⁴⁵⁶

Iris Runge investigated the migration of carbon – or rather carbonaceous gases, to be specific – into iron wires by measuring electrical resistance and recognized that both her own series of experiments and those of the Italian scientists before her,⁴⁵⁷ each of which was concerned with cylindrical structures, yielded a general formula (a diffusion equation). She used the results of her experiments to formulate the initial and boundary conditions for this differential equation. Finally, she

455 TAMMANN 1923, p. 242; TAMMANN 1932, p. 307.

456 Iris Runge, Dissertation (*Über Diffusion im festen Zustande [On Diffusion in the Solid State]*), 50-page typescript, p. 3 [UBG]. Another copy of her dissertation is archived in [UAB] Habilitationsakte MNF 1947.

457 G. Bruni and D. Meneghini, in *Atti della Reale Accademia dei Lincei* 20.1; F. Giolitti and F. Carnevali, in *Atti della Reale Accademia delle scienze di Torino* 45. Giolitti exposed a cylindrical iron rod, for several hours and at high temperatures, to a carbonaceous gas and analyzed the carbon content, at various stages, as a function of case-hardened zones.

succeeded in calculating the diffusion coefficient not only of the carbon-iron binary system but also of other such systems already described in scholarly literature, and she compared her findings with those that had been reached by other means.

Quickly convinced by her results, Tammann requested a written summary of her conclusions. This he further abridged and then published under her name in a 1921 issue of the *Zeitschrift für anorganische und allgemeine Chemie*, which was under his editorial control. The article appeared with the title “Über die Diffusionsgeschwindigkeit von Kohlenstoff in Eisen” [On the Diffusion Rate of Carbon into Iron], and it was printed under the rubric “Metallographische Mitteilung aus dem physikalisch-chemischen Institut der Universität Göttingen” [A Metallographic Note from the Institute of Physical Chemistry at the University of Göttingen]. About the publication process and related matters, Iris Runge remarked:

It does not bother me very much that Tammann saw fit, yet again, to slash my work with his pen. After all, I wrote up this project for his eyes only, and I never considered it to be anything conclusive. That would have required at least another six months of experiments, and then there is the theory on top of that. As far as I am concerned, he is free to do with it as he likes. I was much more disturbed by what Inge had written to me about Kyropoulos,⁴⁵⁸ who supposedly said that Tammann had to go out of his way to finish the manuscript, and that if the project had been undertaken by some run-of-the-mill doctoral student – and not by a “saintly personality” such as myself – then the old man would have lost his cool more than once! I had honestly never thought about that.⁴⁵⁹

The journal article provided an overview of her experimental and mathematical procedures. Her mathematical method was described as follows:

The differential equation of diffusion is known; if the coordinates of the cylinder, corresponding to the shape of the wire, are introduced, and it is taken into consideration that the concentration to be determined is the same at equal distances from the axis of the cylinder, the following partial differential equation obtains for the concentration u as a function of time t and the distance from the axis r , where μ represents the diffusion coefficient

$$\frac{\partial u}{\partial t} = \mu \left[\frac{\partial^2 u}{\partial r^2} + \frac{1}{r} \cdot \frac{\partial u}{\partial r} \right].$$

In the present case, the general solution of this equation is restricted by the following conditions: At the beginning of the experiment at $t = 0$, u is equal to zero inside the wire (initial condition). On the surface of the wire, where $r = R$, u is equal to the saturation concentration S (boundary condition) throughout the duration of the process. This allows for the establish-

458 Inge is the first name of one of Tammann's research assistants who could not be identified. Spiro Kyropoulos earned his doctorate at the University of Leipzig. In 1912 he began working as an assistant in Göttingen, where he completed his *Habilitation* in 1931. He is known for his technique of growing artificial crystals. Released from his position on account of his anti-Nazi sentiments, he emigrated to the United States, where he was given a research position at the California Institute of Technology in Pasadena (see C. Tollmien's article in GÖTTINGEN 2002, p. 241).

459 A letter written in Freiburg from Iris Runge to her mother and dated December 12, 1920 [Private Estate].

ment of an Ansatz and for the attainment of a formula for $u(r, t)$ that yields the concentration prevailing at every given time and place.⁴⁶⁰

The formula that Iris Runge developed is as follows:

$$u(r, t) = S \left[1 + \frac{2}{R} \sum_{k=1}^{\infty} \frac{v_k(r)}{\left(\frac{dv_k}{dr} \right)_{r=R}} e^{-\frac{4\mu}{R^2} x_k^2 t} \right]$$

where x_k are the roots of a transcendental equation, and the $v_k(r)$ are functions, defined by infinite series, which were not used later on during the calculation of electrical resistance. She also examined additional cases that could be mathematically solved with the same differential equation and the same initial condition but that required different boundary conditions.

Today there are many analytical methods and numerical algorithms for solving differential equations, which are highly dependent on the necessary initial and boundary conditions. After Adolf Fick had recognized, as early as 1855, that the laws of diffusion behave like those of heat conduction, Albert Einstein provided this observation with a theoretical foundation by deducing the value of diffusion coefficients from the laws of thermodynamics and from the Stokes-Einstein equation.⁴⁶¹ Runge did not rely on this deduction, which was primarily applicable in the case of liquids. Rather, she stressed that her method of calculation could already be found in the German translation of Joseph Fourier's 1822 textbook *Theorie analytique de la chaleur*,⁴⁶² which addresses the related problem of heat conduction within a cylinder. She derived additional formulas for complicated cases – such as when carbonaceous gas did not yield enough carbon during an allotted unit of time – and she demonstrated how the change in electrical resistance during the diffusion process could be determined mathematically and, finally, how the diffusion coefficient could be calculated.

Beginning in October of 1920, Iris Runge had found sufficient time at the Salem Castle School to devote to reading scholarly literature, and her plan (as stated in March of 1921) proved itself to be realistic, namely to work on her dissertation

⁴⁶⁰ Iris RUNGE 1921, pp. 300–301.

⁴⁶¹ See EINSTEIN 1905, pp. 555–556: “Thus, apart from universal constants and the absolute temperature, the diffusion coefficient of the suspended substance depends only on the friction coefficient of the liquid and the size of the suspended particles.” For an English translation of this article, see Albert Einstein, “On the Movement of Small Particles Suspended in Stationary Liquids Required by the Molecular-Kinetic Theory of Heat,” in *The Collected Papers of Albert Einstein*, 8 vols. (Princeton: Princeton University Press, 1987–1989), vol. 2, pp. 123–134.

⁴⁶² Jean Baptiste Joseph Fourier, *Analytische Theorie der Wärme*, trans. Bernhard Weinstein (Berlin: Julius Springer, 1884), pp. 235–237; in English: *The Analytic Theory of Heat*, trans. Alexander Freemann (Cambridge: Cambridge University Press, 1878; repr. 2009).

during the Easter and summer breaks, to submit the work in the fall, and to take her oral doctoral examinations during the winter vacation.⁴⁶³ On August 1, 1921, she began a six week period of intensive work toward the completion of the project; still busy with her dissertation, she returned to Salem in the middle of September and, in order to submit the work in October and defend it in December, she employed a copyist to prepare five copies.⁴⁶⁴ From a letter to her father, we can gather that she had discussed her mathematical methods with him, that she recognized the novelty of her approach, and that she was somewhat less than enthusiastic about her experimental results:

Dear Dad,

Last week I finally managed to submit my thesis [...]. Now I'm only anxious because things have unfolded so quickly that I might have to conduct my oral doctoral examination before Christmas. [...] By the way, I should also tell you that, in the end, I decided against incorporating your integral into the project. I was able to integrate for a few values of t and u , but realized that this approach hardly altered the results achieved by Fraenkel's raw methods and, according to my own formulas, did not yield anything more approximate to Bruni's values.⁴⁶⁵ Since, at this stage, all of the trials have been experimentally crude, it seems to me that there would be little use in subjecting the results to more intricate calculations. In general, as soon as I've double-checked and reviewed everything, I'd like to label the project with the motto "I dunno, don't like it" (*weess nich, mir gefällt se nich*), but at least there are the actual numerical results. These calculations, I think, are quite tidy, and I also think that my conclusion is of some value, namely that the rate of diffusion is tied to miscibility. But the experiments are flimsy, and the sad thing is that they could have been conducted much better if everything done thus far could have been regarded simply as preliminary and then built upon in a systematic and orderly way. Bruni's experiments could have been repeated as well and, so long as a conductivity curve for high temperatures were incorporated, put to good use. Of course, Roberts-Austen would also have to be tested again, but Tammann will have to send another doctoral student down that path.⁴⁶⁶

Iris Runge was the first person to adopt a mathematical approach to the diffusion problems of binary solid-solid systems. Later she would employ this and other methods in an article, published in 1925, on the electrical conductivity of metallic binary systems, a contribution that continues to be cited in recent scholarship.⁴⁶⁷

In the first part of her dissertation (the theoretical section, pp. 4–15), she derived formulas for determining concentration in general, for determining concen-

463 See her letters dated October 10, 1920; March 6, 1921; and June 6, 1921 [Private Estate].

464 She mentioned this in two letters, those dated July 23, 1921 and September 9, 1921 [Private Estate].

465 The reference is to W. Fraenkel and H. Houben, "Studien über die Diffusionsgeschwindigkeit in festen Gold-Silbermischkristallen und Messung des Diffusionskoeffizienten von Gold in Silber bei 870° C," *Zeitschrift für anorganische und allgemeine Chemie* 116 (1921), pp. 1–15.

466 A letter written at the Salem Castle School dated October 21, 1921 [Private Estate]. Iris Runge's analysis of Robert-Austen's work on the diffusion of gold into solid lead shows that those experiments could not have been concerned with pure diffusion; see her Dissertation, p. 50 [UBG].

467 See CRANK 2004, pp. 272, 405; Iris RUNGE 1925; and Section 3.4.1.2.

tration in the case of a diffusing substance, and for determining concentration in the case of the reciprocal diffusion of two substances, and she demonstrated how the chronological sequence of a physical property that changes along with concentration could be calculated (integration over a given function of concentration). In the second section, she described her experiments and their results, making use of her own general formulas to calculate diffusion coefficients. At the end of the dissertation she presented all of the previously known diffusion constants of the different binary solid-solid systems in a tabular form and drew the following conclusion: “From this emerges the structurally and theoretically sound observation that diffusion coefficients in conditions of restricted miscibility are generally greater than those in conditions of unrestricted miscibility.”⁴⁶⁸

Tammann encouraged another of his doctoral students, Karl Schönert, to pursue this topic further.⁴⁶⁹ In an essay prepared for the Association of the German Iron and Steel Industry (*Verein deutscher Eisenhüttenleute*) – “Über die Diffusion des Kohlenstoffs in Metalle und die Mischkristalle des Eisens” [On the Diffusion of Carbon into Metals and the Mixed Crystals of Iron] – Tammann took note of Schönert’s and Runge’s conclusions. A table in this essay contains the coefficient data in various iron compounds and at various temperatures; beside the data, the names of the relevant scholars are provided. The table includes the diffusion coefficient of electrolytic iron, which Runge had initially presented – in the aforementioned article from 1921 – as 2.0×10^{-7} cm²/sec at 930° but would later revise in her dissertation, after additional experiments, to 1.15×10^{-7} cm²/sec or 0.010 cm²/day at 925°.⁴⁷⁰ The result presented in her dissertation would prove lasting; indeed it was this figure that found its way, as the diffusion coefficient of the carbon-iron binary system, into the third and subsequent editions of Tammann’s textbook.

In his brief evaluation of her dissertation, Tammann went out of his way to underscore Iris Runge’s independence as a scientist: “The candidate solved the problem set before her, and she demonstrated great independence both in her experiments and in her treatment of her calculations and those of others. Her work has earned the grade *very good*. On account of the scientific maturity of the candidate, she can be granted permission to move along to the oral examination without further deliberation.”⁴⁷¹

468 Iris Runge, Dissertation, p. 50 [UBG].

469 The result was Schönert’s 1922 dissertation, “Über die Diffusion von Kohlenstoff, Phosphor und Arsen in feste Metalle” [On the Diffusion of Carbon, Phosphorous, and Arsenic into Solid Metals]; see also BEER 2005, p. 26.

470 TAMMANN 1922, p. 2.

471 [UAG] Phil. Fak. Prom. Spec. R. Vol. IV, 1915–1922, No. 22.

Table 6: The Topics of Iris Runge's Oral Examination (December 16, 1921)⁴⁷²*Main Subject:*

1. Examination in physical chemistry (Tammann, 5–6 PM)

Topics: theory of diluted solutions, hydrolytic dissociation, electrolytes, energy balance in a galvanic cell, crystallization in binary systems.

Her responses and her knowledge of these topics were evaluated as *good to very good*.

Minor Subject:

2. Examination in applied mathematics (Carl Runge, 6–6:30 PM)

Topics: descriptive geometry, two-plane method, constructions with points, straight lines, and planes. – Numerical solution of equations, Newton's approximation procedure, the application of Graeffe's method,⁴⁷³ Sturmian theory, interpolation, graphical and numerical integration.

The candidate's knowledge proved to be good and secure.

*Minor Subject:*3. Examination in physics (James Franck,⁴⁷⁴ 6:30–7 PM)

Topics: thermodynamics, kinetic theory of gases, fundamentals of electricity, measuring resistances, radiation, etc.

It is obvious that Iris Runge would be examined in physical chemistry by her doctoral supervisor. The examination in applied mathematics, however, could be conducted only by the one full professor in that field, and therefore she had to be tested by her own father. This was not entirely unusual at the time, and nothing in the sources indicates that there had been any concern over the matter. It was only in the field of physics that Iris Runge had the opportunity to choose her examiner. While at Göttingen for her earlier degree, she had studied under the experimental physicist Eduard Riecke and under the theoretical physicist Woldemar Voigt, but both of them had died in the meantime. Peter Debye, with whom she had become acquainted in Munich and who was active at the University of Göttingen during her doctoral studies, accepted a professorship at the University of Zurich in 1920 and was therefore not available. At the time of her examination, the professors of physics at Göttingen included Max Born, James Franck, Robert Pohl, and Max Reich. Her close friendship with Born and his wife Hedi probably discouraged her from choosing him as an examiner. James Franck, who would win a Nobel Prize in 1925 and leave for a position in the United States in 1933, was known to judge the merit of scientists regardless of their gender. The same could not be said of Robert Pohl. Whereas Franck, for instance, supported the post-doctoral research of

472 Ibid.

473 See C. H. Graeffe, *Die Auflösung der höhern numerischen Gleichungen, als Beantwortung einer vor der königlichen Akademie der Wissenschaften zu Berlin aufgestellten Preisfrage* (Zurich, 1837). Carl Runge explicated Graeffe's method in RUNGE 1898–1904.

474 In 1920, the Jewish physicist James Franck became professor of experimental physics and the director of the second institute of experimental physics at the University of Göttingen.

his assistant Hertha Sponer, who completed her *Habilitation* in 1925 and became a senior research assistant, Pohl is known to have opposed Sponer's research activity after the Nazis came to power and to have done so for solely antifeminist reasons (she ultimately accepted a professorship at Duke University in North Carolina).⁴⁷⁵ Iris Runge was of course well aware of the opinions and traits of the individual professors. Although she had not attended any of Franck's lectures, she nevertheless sent a written statement to the dean – dated October 18, 1921 – in which she requested that James Franck conduct her examination in physics.⁴⁷⁶



Figure 5: Iris Runge's Doctoral Certificate

While working in the industrial sector, Iris Runge would employ the mathematical methods used in her dissertation to solve problems of materials research (see Section 3.4.3), and this she did well before the first international professorship of theoretical chemistry would be established, in 1932, at Cambridge University.⁴⁷⁷

475 TOBIES 1996a. See also the online biography of Hertha Sponer, written by Marie-Ann Maushart and updated by Brenda Winnewisser: <http://news.phy.duke.edu/2011/04/duke-physics-to-publish-hertha-sponer-biography-online/>

476 The letter and the doctoral certificate are archived in [UAG] Phil. Fak. Prom. Spec. R Vol. IV, 1915-1922, No. 22.

477 See Marika Blondel-Mégrelis, "Between Disciplines: Jean Barriol and the Theoretical Chemistry Laboratory in Nancy," in REINHARDT 2001, p. 105.

2.7.3 The Decision to Become an Industrial Researcher

In the 1920s, women educated in mathematics and physics seldom elected to work in industry, and even in the 1930s this path was often taken unwillingly. It should be said that this was not only true of women researchers in Germany but was rather an international phenomenon.⁴⁷⁸ In general, female chemists entered industry both in greater numbers and earlier on than did their counterparts in physics and mathematics. As Jeffrey Johnson has shown, however, their activity in the chemical industry was typically restricted to bibliographical or, less frequently, patent-related work.⁴⁷⁹ The upstart enterprises of the electrical and communications industries changed this trend by creating opportunities for women scientists that had never been known before.

The physical chemist Franz Hahn – a relative of Kurt Hahn and an employee of the Hahn'sche Werke Corporation in Düsseldorf – visited the Salem Castle School, where he delivered a lecture on wireless telegraphy and inspired the students to construct a receiver station. While there, he also expressed his interest in the industrial applications of Iris Runge's doctoral project and gave her the idea that, with her profile, she would be able to find a position as an industrial researcher.⁴⁸⁰

Her reasons for considering another career, however, were far from one-dimensional. She also wished to leave the elite Salem Castle School, for instance, on account of feeling increasingly cut off from the world and politics of any sort. Thus, during the summer of 1922, she planned to spend two or three weeks as a social worker under Friedrich Siegmund-Schultze in Berlin, as she explained, “in order to be reminded of what a member of the working class even looks like.”⁴⁸¹

It was this experience in Berlin that finalized her decision to seek employment there in the industrial sector, and her network of acquaintances from Göttingen proved to facilitate this transition. Thus, in September of 1922, she expressed her intention to “speak in person with Courant, Tammann, and Franck about my search for a job” some time during the upcoming winter break.⁴⁸² Before she could do so, however, she acted on an earlier suggestion by Richard Courant to send an application to Erich Thürmel, who directed a laboratory in the Communications

478 See especially PIEPER-SEIER 2008; VOSS 2008; OGILVIE/HARVEY 2000.

479 See JOHNSON 1998, a revised version of which was published in TOBIES 2008a, pp. 283–305.

480 She mentions this in a letter written in December of 1921 [Private Estate]. Hahn'sche Werke was a subsidiary of the Mannesmann Corporation, a conglomerate based in Düsseldorf (see HANDBUCH FÜR WIRTSCHAFTSARCHIVE 2005, p. 45).

481 A letter dated May 28, 1922 [Private Estate]. On Friedrich Siegmund-Schultze and his social movement, see Section 4.2.1 below.

482 A letter from Iris Runge to her mother dated September 10, 1922 [Private Estate]. The school's winter vacation, which consisted of five and a half weeks (December 12, 1922 to January 24, 1923), was combined with the Easter vacation to reduce travel expenses during the period of inflation.

Equipment Factory of the Siemens & Halske Corporation in Berlin. It was under Thürmel's leadership, at the so-called Pupin Laboratory, that the first electron tubes were designed for serial production.⁴⁸³ On November 9, 1922, Iris Runge sent another application to the Osram Corporation, where Max Born had put in a good word for her:

This is how things currently stand with respect to my applications: I have sent everything that Dr. Thürmel requested – the questionnaires, recommendations, photographs, etc. – and yesterday I received an official letter from the human resources department at Siemens notifying me that they would forward everything along to the appropriate division, and that they would remain in contact with me regarding further developments. In addition, I received a letter yesterday from a certain Dr. Gehlhoff in Berlin⁴⁸⁴ – with whom Dr. Born seems to have interceded on my behalf – in which I am advised yet again to apply to Siemens (this time to Professor Gerdien) and also to the Osram Company. Thus I mailed off an application to Osram without delay. [...] Of course, I think that Siemens would be nicer than Osram, but two options are always better than one. It's all very exciting.⁴⁸⁵

By now, a number of people who had been educated in Göttingen were working for businesses in the German capital. Hans Gerdien, for instance, who during the war had run his own tube laboratory for Siemens & Halske in Berlin, had also been awarded an honorary professorship at Göttingen in 1916. By that time he had already overseen the construction of a large central laboratory for the same company.⁴⁸⁶

483 See PICHLER 2008. In 1910, Thürmel was awarded a doctoral degree for a dissertation entitled “Das Lummer-Pringsheimsche Spektral-Flickerphotometer als optisches Pyrometer” [The Lummer-Pringsheim Spectro-Flicker Photometer as an Optic Pyrometer]; see the JAHRESVERZEICHNIS 25 (1911), p. 107. The Pupin Laboratory was named after M. I. Pupin, a Serbian physicist who studied in the United States, obtained his doctorate in Berlin under Hermann von Helmholtz (1889), and became a lecturer and professor of mathematical physics at Columbia University (1901–31), where today there is a “Pupin Laboratory” within the Institute of Electrical Engineering. Pupin is best known for his numerous patents, including a means of greatly extending the range of long-distance telephone communication by placing loading coils at predetermined intervals along the transmitting wire (known as “pupinization”). See M. I. Pupin's autobiography, *From Immigrant to Inventor* (New York: Charles Scribner's Sons, 1924).

484 In 1907, Georg Gehlhoff earned his doctoral degree at the University of Berlin under the supervision of Emil Warburg. Gehlhoff completed his *Habilitation* in 1912 (under Jonathan Ze-neck) at the Technical University in Danzig. After working for several years at the C. P. Goerz Corporation, where he served as the director of both a headlight and a glass manufacturing plant, he joined the Osram Corporation in July of 1922 as the head of industrial glass research. He was one of the founding members of the German Society for Technical Physics (*Deutsche Gesellschaft für Technische Physik*), and in 1923 he accepted an associate professorship in industrial physics at the Technical University in Berlin-Charlottenburg, where he taught part-time in addition to his full-time industrial position (see Section 3.3 and HOFFMANN/SWINNE 1994).

485 A letter from Iris Runge to her mother dated November 12, 1922 [Private Estate].

486 See FELDTKELLER/GOETZELER 1994, p. 37.

Osram replied to Iris Runge's application immediately.⁴⁸⁷ Regarding Siemens & Halske, in contrast, she heard from a third party that one of Thürmel's colleagues had expressed no knowledge of her interest in working there. Detecting a degree of "disorderliness" on the part of Siemens & Halske, she left for Berlin at the beginning of her winter vacation to meet with the executives at Osram and to establish the terms of her employment.⁴⁸⁸

2.8 SUMMARY

Iris Runge's choice of embarking on a new career was based on a complex web of social and professional factors. On the one hand, she no longer wished to expend her efforts for the exclusive benefit of the elite; on the other hand, she wanted to find a venue in which her scientific knowledge would be both challenged and valued to a greater extent.

Rooted in a Huguenot family tradition, she became a tolerant and independent thinker at an early age whose scientific approach to the world and general mindset opposed the widespread clichés concerning the roles of women in society. From her early childhood, Iris Runge's thinking accommodated philosophical conviction alongside mathematics, the natural sciences, and their application. Influenced by her family and other associations, these two sides of her theoretical disposition developed into two intertwined sides of practical engagement. She came to realize that, in addition to putting her mathematical gifts to good use, she could not be content in life without involving herself in politics.

Even as a schoolgirl she was known to hold debates about ideological and social affairs, both with the fellow members of her "Plato Society" and with a circle of classmates at secondary school. The philosopher Leonard Nelson, who was closely associated with the extended Du Bois-Reymond family, proved to be the greatest early influence on her social activism. Through Nelson she came to the conviction that it was necessary to engage in politics. She joined student organizations, including the Union of Female Students in Germany and the *Freibund* [Free Union]. While still a student, she gave instructional courses for workers in evening classes, and as a teacher she became a member of the People's Association for Freedom and Fatherland and campaigned on behalf of the Social Democratic Party. Political activity was rampant after the First World War, and Iris Runge belonged to a group of young, middle-class intellectuals who became engaged in the socialist workers' parties. Her brother-in-law Richard Courant and other doctoral students of David Hilbert also belonged to this group, whereas the older generation of Göttingen mathematicians – such as Carl Runge, Felix Bernstein, and Hilbert himself – became members of the liberal-bourgeois German Democratic Party.

487 See below, Section 3.2.2.

488 A letter dated December 8, 1922 [Private Estate].

Both generations were pursuing the common goal of a new democratic society with rather utopian ideals.

Iris Runge was recognized in her school days as a mathematical genius, and her education benefited most notably from the careful instruction and thought collective of her father. Carl Runge's graphical and numerical methods provided her with the mathematical foundation that would prove useful as she moved from one field to the next. As a student she devoted herself to enhancing her expertise and experience in the mathematical methods of her father and in those of others. Exhibiting an array of interests, she was not only involved with the broad circle of scholars who gathered to discuss applied mathematics and mechanics at the so-called "tea party of applied mechanics," but she was also appreciated as a pure mathematician by the number theorist Edmund Landau. Among others, the following factors constitute decisive evidence of her escalating commitment to higher mathematics:

1. Her participation in the Runge family's translation project of F. W. Lanchester's *Aerial Flight*, in which graphical solutions to differential equations played a dominant role.
2. Her involvement in Arnold Sommerfeld's circle of theoretical physicists, in which she applied numerical methods to problems in the field of theoretical optics.
3. Her written university examination for the theoretical physicist Woldemar Voigt, in which she applied the novel numerical method of Walter Ritz – the Ritzian integration method – to the problem of measuring parabolic membrane oscillations.
4. Her dissertation, supervised by the physical chemist Gustav Tammann, in which she was the first to employ a partial differential equation to determine the rate of diffusion of *solid* binary systems and to calculate their diffusion coefficients.

The practical application of mathematical methods also requires a broad knowledge of physics and chemistry. Iris Runge acquired such knowledge as a university student and supplemented it both by studying on her own and by involving herself in the intellectual circles of her father Carl Runge, and those of Arnold Sommerfeld, Woldemar Voigt, and Gustav Tammann. In fact, her wide-ranging participation in various academic groups proved to be an important and defining characteristic of her professional development. Though it is true that all students of mathematics, physics, and chemistry were necessarily trained in a broad number of fields, few of them had the chance to prove themselves in such a variety of contexts.

As one of the few doctoral students of her pioneering generation of women, Iris Runge had come to terms with the fact that, sooner than later, women pursuing advanced degrees would have to face an either/or dilemma: They would either

have to find a suitable partner in life and abandon their career, or they would, like men, have to attain a suitable professional position.

After the successful defense of her dissertation, Iris Runge made a conscious decision, against the wishes of her headmaster,⁴⁸⁹ to forfeit her (traditional) career as a schoolteacher. Her time teaching at elite secondary schools represented a transitional and necessary solution, all the more so because her socialist beliefs prevented her from being employed by the state or city school systems. At the same time, the political and pedagogical conventions of reform-oriented schools – such as nationalistic tendencies and the subordination of mathematics and science – similarly clashed with her intentions. Thus she exchanged the prestigious Salem Castle School for a metropolitan industrial laboratory.

Iris Runge's participation in different intellectual circles, networks, or thought collectives was instrumental to this professional transition, a transition that had been smoothed or perhaps even enabled by the written recommendations of her colleagues and friends in Göttingen. Her new career path, which also created space for her political activism (see Chapter 4), reflected the urgent need of the industrial sector for more and more mathematicians and scientists. The aim of the next chapter will be to demonstrate, in detail, the extent to which Iris Runge's skill as a mathematician would define her success as an industrial researcher. In doing so, more general insight will also be provided into the development and early applications of mathematics at the Osram and Telefunken Corporations.

489 Kurt Hahn was taken aback by her announcement, as Iris Runge noted to her mother in a letter dated December 12, 1922 [Private Estate]: "Kurt is indignant over the fact that I want to leave, but I have begun to realize more and more that it is the right thing to do. For now I am only amazed that it took me so long to come to this realization."

3 MATHEMATICS AT OSRAM AND TELEFUNKEN

It is important to note at the beginning of this chapter that readers without expertise in mathematics should not be deterred. As far as mathematics and engineering are concerned, only Section 3.4 can be considered complex. The first order of business will be to provide an overview of who it was that worked as mathematical experts within the electrical industry (3.1). Because the specific focus below will be on light bulb and electron tube research at Osram and Telefunken, it will be appropriate to describe the organizational structures of their research divisions (3.2). The next section, concerned with scientific communication, will elucidate the extent to which these businesses encouraged their researchers to be involved in broader scientific communities (3.3). Section 3.4, already mentioned, will clarify particular problems of light bulb and electron tube research and the mathematical methods that were used to solve them. Finally, the general characteristics and methods of mathematical consultants in industrial research will be summarized and compared with those of mathematicians in other fields.

In Germany, three parent companies were largely responsible for developments in the areas of electrical and communications engineering: the Siemens & Halske Corporation, which was established in 1847 by Werner von Siemens and Johann Georg Halske as a telegraph construction company; the General Electric Power Company known as AEG (*Allgemeine Elektrizitätsgesellschaft*), which was founded in 1887 by Emil Rathenau; and the German Gas Lighting Corporation (*Deutsche Gasglühlicht Gesellschaft*) or Auer Company, which was founded in 1892 by Carl Auer von Welsbach, an Austrian who invented the incandescent gas mantle and the filament light bulb, and who developed the flint that is still used in lighters today. Each of these businesses owned several distinct factories for their various branches, many of which were eventually divested and operated as daughter companies. Together with Schuckert & Co., for instance, Siemens & Halske created the independent company Siemens-Schuckertwerke from their respective high voltage divisions. Together with AEG, Siemens & Halske likewise formed a wireless telegraphy business, in 1903, called the Company for Wireless Telegraphy Ltd. – Telefunken System (*Gesellschaft für drahtlose Telegraphie m.b.H. System Telefunken*).¹ After the First World War, the incandescent light

1 The wireless telegraphy of Siemens & Halske was based on a system developed by Karl Ferdinand Braun, whereas the system used by AEG had been developed by Adolf Slaby and Georg Graf von Arco. Pressured by Kaiser Wilhelm II, the two telegraphy businesses were united on November 11, 1903, and in April of 1923 the name of this daughter company was changed to the Telefunken Company for Wireless Telegraphy (*Telefunken Gesellschaft für drahtlose Telegraphie*).

bulb factories of all three of these parent companies were ultimately combined to form Osram (see Section 3.2). Both parent and daughter companies were headquartered in Berlin, where they quickly developed into international conglomerates, and thus Berlin came to be a creative hub of what might be called the “knowledge industry.”²

Whereas pragmatic experiments and a basic knowledge of physics had been enough to produce the earliest achievements of electrical and communications engineering – in such areas as telegraphy, wireless telephony, wireless radio, and vacuum electronics – the increasing mass production of such goods as light bulbs and electron tubes required an ever more accurate scientific understanding of production and assembly processes. Just before and all throughout the First World War, these companies expanded their research laboratories from what had been one-man operations into larger divisions. After the German defeat, when science was recognized to be a powerful factor in its own right, they placed an even greater emphasis on their research programs, which now included the application of mathematical methods.

At the University of Berlin, the first professorship in applied mathematics was established in 1920 and held by Richard von Mises.³ This position, after that of Carl Runge at the University of Göttingen, was the second university full professorship in applied mathematics in all of Germany (such professorships already existed at several *technical* universities). In the year 1922, Richard von Mises wrote the following words to the Ministry of Science in Berlin:

Just as the industrial sector must necessarily rely on the services of engineers educated at our technical universities, it is just as true that they also require the talents of a few theoreticians whose professional training is based on a comprehensive education in physics and pure mathematics, an education that only our universities can offer. The demand for these abilities, as I know from personal experience, currently exceeds their supply. Universities, which have hitherto served industries by producing chemists and, to a lesser degree, physicists, must now prove their industrial utility in another field, namely that of applied mathematics.⁴

Richard von Mises consciously prepared his mathematics students for future employment in the industrial sector, and many of the latter indeed went on to work as aeronautical researchers for the aviation industry. His comments are no less valid, of course, with respect to the electrical industry, which is our main concern below. Iris Runge numbered among those “few theoreticians” who were employed as industrial researchers in Berlin.

2 See HEBLER 2007; ZIMMERMANN 2006; LUXBACHER 2003.

3 On the hiring process for this position, during which Max Planck had attempted to lure Carl Runge to Berlin before opting for the “more affordable” Richard von Mises, see the introduction to HENTSCHEL/TOBIES 2003.

4 A letter from Richard von Mises to the Ministry of Science, Art, and General Education in Berlin – dated June 28, 1922 – in [STA] REM, No. 1447, p. 65.

3.1 TRAINED MATHEMATICIANS IN THE ELECTRICAL INDUSTRY

According to the sociologist Anthony Giddens, modern society is governed by so-called expert systems.⁵ All types of expertise are determined by demand, and experts function as custodians of knowledge that may or may not be closely associated with a given profession or scientific discipline.⁶ The status and trustworthiness of an expert are decisive factors in the perceived quality of his or her area of expertise, and this applies to the past as well as the present. In the electrical industry of the 1920s, there was certainly no lack of appreciation for mathematical expertise; what was typically lacking in these businesses, as Thornton Carl Fry noted of the time, were the mathematical experts themselves.⁷

Trained mathematicians, who could expertly oversee or determine the processes of industrial research, were relatively rare during the period in question. In the United States, Thornton Carl Fry directed the first mathematics research department within a greater industrial laboratory. Over the course of his career, he worked as a mathematician for the American Telephone & Telegraphy Company, for the Western Electric Company, and as of 1925 for the Bell Telephone Laboratories (Bell Labs), which had been founded as an independent unit of research and development by the Western Electric Manufacturing Co.⁸ In 1941, Fry analyzed the activity of industrial mathematicians in the United States, and here he commented upon the “fewness of the mathematicians,” that is, of the “men of this type.”⁹ “The practical engineer,” he would later stress, “got his mathematics where he could – often through self-education, sometimes by seeking the help of his long-haired colleagues.”¹⁰ Although he mentioned no women, we know from Claude Shannon’s biography that Fry had met his wife, Elizabeth (Betty) Moore, while she was a numerical analyst at Bell Labs.¹¹

Mathematical experts in the electrical and communications industries could come from a variety of backgrounds. Some held doctoral degrees in mathematics, others were licensed to teach physics and mathematics in secondary schools, and others still were simply mathematically talented electrical engineers, physicists, or physical chemists. Recognition as such an expert depended on a researcher’s academic achievements and on the reputation that he or she developed on the job.

5 GIDDENS 1990.

6 See ENGSTROM et al. 2005; REIHNHARDT 2003, 2006.

7 FRY 1964, p. 936.

8 Thornton Carl Fry earned a PhD in mathematics at the University of Wisconsin-Madison with a dissertation entitled “The Application of Modern Theories of Integration to the Solution of Differential Equations.” For more on his life and accomplishments, see G. Baley Price, “Award for Distinguished Service to Dr. Thornton Carl Fry,” *American Mathematical Monthly* 89 (1982), pp. 81–83; and his obituary, by John Firor and Virginia Trimble, in the *Bulletin of the American Astronomical Society* 29 (1997), pp. 1470–1471.

9 FRY 1941, p. 255 (all quotations of Fry were originally written in English).

10 FRY 1964, p. 936.

11 For Claude E. Shannon’s collected writings, see SHANNON 2003; on his life and work, see ROCH 2009.

Fry observed that there was a trend in industrial laboratories to charge good mathematicians with the tasks of engineers, a trend that was necessarily squandering the mathematical talents that were available. To counter it, he established the Mathematical Research Department at Bell Labs, which was the first of its kind. Here, up to fourteen people worked as mathematical consultants for the other departments, and the staff included such outstanding researchers as John R. Carson (see Section 1.2.2), Sergei A. Schelkunoff, George Stibitz, Hendrik W. Bode, Claude E. Shannon, and Walter A. Shewhart. The mathematical activity of the department encompassed electromagnetic propagation and antenna theory (Carson, Schelkunoff), statistical quality control (Shewhart), automated computing (Stibitz), the mathematical theory of feedback control (Bode), and information theory (Shannon).¹²

Most of the mathematicians in the communications industry were employed by companies that produced electron tubes and electrical networks, and only at the Bell Labs was there a special department devoted to mathematical research.¹³ Fry contrasted the approach of this novel organization with that of Thomas Edison, the prolific inventor who founded General Electric in 1892: “As the scientific method replaced Edisonian cut-and-try, the engineer’s methods of design became more and more analytical.”¹⁴

It is noteworthy that even Edison had surrounded himself with an international team of experts, to which belonged a number of highly competent mathematicians.¹⁵ Nicola Tesla, whose talents were unappreciated by Edison and who ultimately went on to develop the alternating current system for Westinghouse Electric, described Edison’s methods as inefficient.¹⁶ With Edison, as was later the case at most companies in the electrical and communications industries worldwide, experts in mathematics engaged in experimental activity and worked directly with the objects being researched, developed, and produced. About electrical manufacturing in the United States, Fry claimed: “The number of mathematicians in the industry is smaller than in communications, and is not easy to estimate because their work is less segregated from other activities.”¹⁷ In 1941, he estimated this

12 See FRY 1941, p. 282; FRY 1964, p. 936.

13 FRY 1941, pp. 281–282.

14 FRY 1964, p. 936.

15 Edison’s team of experts included the Germans Sigmund Bergmann and Ludwig Karl Böhm (a glassblower who had already collaborated with Heinrich Geissler, the inventor of the eponymous Geissler tube); the mathematician and physicist Francis Robins Upton, who had studied at Princeton and in Berlin (under Hermann von Helmholtz) and who is known for his mathematical analysis of the multiple arc feeder and of the three-wire system of electric lighting; and the electrical engineer Harry Ward Leonard, who had studied at the Massachusetts Institute of Technology (see NEAR 1989).

16 See the bluntly titled article published in the *New York Times*: “Tesla says Edison was an Empiricist. Electrical Technician Declares Persistent Trials Attested Inventor’s Vigor. His Methods – Inefficient. A Little Theory Would Have Saved Him 90% of Labor, Ex-Aide Assests. Praises His Great Genius” (October 29, 1931, p. 25).

17 FRY 1941, p. 283.

number to be around twenty, and it is clear that in the German electrical industry this number was even smaller (precise data are unfortunately lacking).

As expected, the electrical engineering companies in Germany preferred to hire electrical engineers. Theoretically inclined physicists and mathematicians remained in the minority. The first person with a doctoral degree in physics to be hired by Siemens & Halske – the year was 1873 – was Oskar Fröhlich, who developed new approaches to the calculation of dynamo-electric machines.¹⁸ Under the leadership of Hans Gerdien, a central research laboratory, with approximately two hundred employees, was established at Siemens in 1929, but even here there were remarkably few researchers who dealt exclusively with mathematical problems.¹⁹ One of the latter was the Walter Schottky, a former doctoral student of Max Planck. Known for his pioneering contributions to solid-state physics and the development of electron tubes and semiconductors, the mathematically talented Schottky struggled to make himself understood at Siemens & Halske. According to Reinhard W. Serchinger, “translators” had to be called upon to clarify Schottky’s ideas in terms that were intelligible to engineers. In this context, the notion of a translator originated with Eberhard Spenke, who worked as Schottky’s mathematical assistant from 1928 to 1939. Schottky functioned as the in-house theoretical consultant for the entire Siemens conglomerate, for which he was simultaneously engaged in a variety of research endeavors.²⁰

Even before the First World War, the Siemens-Schuckertwerke company contained a few calculating offices (*Rechnungsbureaus*), which were predominantly housed by electrical engineers. At these offices, for instance, the graphical method of the “circle diagram” was used for the calculation of three-phase asynchronous machines, a method developed in 1894 by the electrical engineer Alexander Heyland and later refined by Charles Steinmetz.²¹ Reinhold Rüdenberg, an electrical engineer educated in Göttingen and Hanover, worked from 1908 to 1911 in one of the calculating offices at Siemens-Schuckertwerke. He completed his *Habilitation* at the Technical University in Berlin, where he also worked on a part-time basis as an honorary professor of high-voltage and high-tension engineering. In 1914 he was appointed director of the “Calculating Office II” at Siemens-Schuckert, in 1919 he became the head of all the calculating offices devoted to electric ma-

18 See SCHULTRICH 1985, p. 86. Oskar Fröhlich earned his doctoral degree in 1868 at the University of Königsberg and became a chief electrical engineer at Siemens & Halske in 1873 (see NDB, vol. 5, p. 131).

19 For a description of the central research laboratory at Siemens, see ECKERT/SCHUBERT 1986, p. 131.

20 Eberhard Spenke augmented Schottky’s theory of frequency modulation noise in amplifier tubes and also participated in the latter’s semiconductor research (see HANDEL 1999, pp. 30–31, 110–112). After working in Siemens & Halske’s low voltage cable laboratory (1915–1919) and at the universities in Würzburg (*Habilitation*) and Rostock (professor), Schottky worked again at the Siemens Corporation between the years 1927 and 1951 (see GOETZELER/FELDTKELLER 1994, pp. 70–77; SERCHINGER 2008).

21 See HEILBRONNER 1999.

chines, and in 1923 he assumed the directorship of a newly established department concerned with the fundamental problems of high-voltage transmission. Not only is this department credited with more than three hundred patents, but it was also here that some of the first methods of statistical quality control were applied. Despite all of this, Max Steenbeck, who in 1927 was the first theoretical physicist to join the department, could still detect differences between the methodological approaches adopted by the theoreticians and those adopted by the engineers:

In order to make a problem more “vivid” to my mind, I would often, at least initially, simplify and abstract matters to a far greater extent than most engineers would ever do. It was their practice to pay much closer attention to the whole technical side of things, and in doing so they accepted, on account of empirical observation, a number of things as simply given. Through my unbiased lines of questioning, it was not uncommon for them to discover novel and unexpected points of view.²²

No mathematicians were ever employed in this research department at Siemens-Schuckertwerke, and the entire department was closed down after Rüdenberg’s emigration in 1936.²³

At other companies, too, there is evidence of fruitful collaborations between practical engineers and theoretical experts. Beginning in 1937, Ernst Ruska and Bodo von Borries were in charge of the industrial development of electron microscopy for Siemens & Halske (this was after Reinhold Rüdenberg had patented the principle of electron-microscope imaging in 1931). Ruska is credited with building the first electron microscope, for which he was awarded the 1986 Nobel Prize in physics. Together with Max Knoll he had succeeded in demonstrating, also in 1931, that a magnetic coil could function as an electron lens, an observation that would serve as the fundamental principle behind the electron microscope.²⁴ Ruska stressed that the technical implementation of his idea was facilitated by his cooperation with a theoretical scientist, Walter Glaser, who had advanced a theory of the electron microscope that allowed for the calculation of magnetic lenses.²⁵

In the year 1928, AEG founded a comprehensive and independent research institute in Berlin-Reinickendorf with twenty-three scientists and departments of general physics, general chemistry, and electrical engineering, among others.²⁶ Although there was not a special division for mathematical research at this specific institute, it is nevertheless possible to identify a number of mathematicians who were active at AEG’s other factories and calculation offices. Thus Herbert Buchholz, a doctor of engineering from the Technical University in Berlin (1928), held a mathematical consulting position at AEG and ultimately directed a mathe-

22 STEENBECK 1977, p. 51.

23 See *ibid.*, pp. 46–62; FELDTKELLER/GOETZELER 1994, pp. 53–59.

24 See MÜLLER 2009.

25 See Ernst Ruska’s article on Walter Glaser in NDB, vol. 6, pp. 432–433.

26 By 1938, the staff at AEG’s research institute had grown to 365, and by 1944 to 863 (including non-scientific personnel). Approximately forty percent of these employees were women (see LORENZ 2004, pp. 10–17).

mathematical research department devoted to remote control technology. Among other methods, this department is known to have applied the theory of cylindrical waveguides that had been developed by the Bell Labs.²⁷ Cäcilie Fröhlich (later Cecilie Froehlich), who held a doctorate in mathematics, worked as a scientific assistant at the AEG machine factory in Berlin (Brunnenstraße) as of 1929, and in 1933 she was promoted to serve as a consultant to the company's executive board. A competent securer of patents, her mathematical efforts concerned, among other things, Foucault (eddy) currents, switching operations, rectifiers, mechanical oscillations, and gyroscopes. Her mathematical modeling and calculations of eddy current losses in iron plates and in the support rings of electric machines aroused international attention, and this acclaim would facilitate her (forced) emigration from Nazi Germany in 1937.²⁸

At Telefunken, which was founded in 1903, there were few employees with graduate degrees. By 1919, only three of the company's seventy-five senior engineers and technicians (those who had worked there for longer than ten years) held a doctoral degree.²⁹ When Wilhelm Runge joined Telefunken's developmental laboratory for radio receivers, on November 1, 1923,³⁰ he found only one person in this work environment with whom "he could discuss the application of differential equations and trigonometric functions to the problems of high frequency." His theoretical approach was distrusted and unappreciated by the senior engineers who directed developmental laboratories and yet lacked his academic training. Wilhelm Runge offered the following sketch of his first supervisor, August Leib:

Like many of Telefunken's other officials at that time, he had worked his way up the company ranks, from the position of a mechanic to that of a laboratory director, by means of his energy and hard work, his organizational talents, and the precision and reliability of his experimental methods. He possessed only an elementary education, and he could not speak any foreign languages, but he was a strong personality who could assert his will without being imperious. His knowledge and notion of engineering may have been primitive, but the observations and measurements of his experiments were highly precise.³¹

Wilhelm Runge was one of the first researchers to apply mathematical methods, with success, to problems of high frequency engineering. His university education

27 See J. R. Carson et al., "Hyper-Frequency Waveguides: Mathematical Theory," *Bell System Technical Journal* 15 (1936), pp. 310–333. For an evaluation of Buchholz's scientific contributions, see Paul Jacottet, "Das transversale Feld im kreiszylindrischen Hohlleiter," *Archiv für Elektrotechnik* 39 (1948), pp. 108–115, at 108.

28 See Cäcilie Fröhlich, "Wirbelstromverluste in massiven schmiedeeisernen Platten und Ringen," *Archiv für Elektrotechnik* 26 (1932), pp. 321–329. For biographical information about Fröhlich, see STRAUSS/RÖDER, vol. 2, p. 344. She became the first female professor of electrical engineering at the City College of New York.

29 See *Telefunken* 3 (1919), pp. 106–107.

30 Wilhelm Runge was recommended for this position at Telefunken by Reinhold Rüdenberg, who had been a frequent guest at his parents' house in Göttingen (see Wilhelm Runge's autobiography in [DTMB] 4413, p. 2).

31 [DTMB] 4413.

had begun in 1920 at Göttingen, where he studied science and mathematics for four semesters, after which he transferred to the Technical University in Darmstadt to pursue electrical engineering. There he was able to take his preliminary examinations after only one semester, and he passed the final examination for his *Diplom*, with distinction, in May of 1923. The elective topics of this examination included not only high frequency engineering, telegraphy, and telephony, but also vector calculus and partial differential equations.³² Just half a year after completing his *Diplom*, which had involved experimental work under the direction of Karl Wirtz, Wilhelm Runge submitted a more theoretically oriented dissertation with the title “Über die stabilen Amplituden angefachter Koppelschwingungen” [On the Stable Amplitudes of Induced Coupled Oscillations]. Wirtz evaluated this thesis as follows:

In the wake of a study by Max Wien,³³ the phenomena that occur in transmitter tubes with feedback have been addressed in a number of publications and with a variety of methodologies. In large part, however, comprehensive mathematical approaches have been lacking in comparison with physical approaches, and a number of specific phenomena remain unexplained. The author of the present study has based his approach to the subject on the introduction of a current-voltage curve and on the stability conditions of the power system. His mathematical presentation thereby yields not only an essential simplification of matters but also clear and comprehensive insight into somewhat intricate phenomena. His experimental tests, moreover, confirm his mathematical results quite well. The presentation is fluent and clear. I recommend this study to be accepted as a dissertation.³⁴

The first academic to join Telefunken’s radio receiver laboratory, Wilhelm Runge was quickly promoted, in the fall of 1924, to be the head of the department. Because he could now make personnel decisions of his own, he specifically sought mathematical talent in his new colleagues:

When I asked him (Zepler) during his interview about the process of a circuit board that I showed him, he said: “That can certainly be calculated.” Though he immediately offered an incorrect calculation, his approach to this matter of high frequency engineering appealed to me. In fact, it was exactly what I was looking for.³⁵

Wilhelm Runge patented approximately one hundred technological innovations with relevance to radio receivers, radar equipment, directional radio, and return beam detectors. At Telefunken he was assigned to oversee the transition from a

32 The certificate for this examination, which was taken on May 15, 1923, is archived in [UAD] TH 12/01, No. 203–213.

33 Max Wien was a professor at the University of Jena and a pioneer in the field of high frequency engineering. He invented a generator, known as a *Löschfunkensender*, of slightly weakened electromagnetic oscillations.

34 This evaluation by Karl Wirtz, which was written on October 23, 1923, is archived in [UBD]. For a published excerpt of Wilhelm Runge’s dissertation, see *Archiv für Elektrotechnik* 13 (1924), pp. 34–48.

35 [DTMB] 4413, p. 4. Erich Zepler became an expert in electronics and an internationally renowned composer of chess problems. In 1935 he went into exile to England, where he worked for the Marconi Wireless Telegraph Company.

haphazard, trial-and-error research process to one that was systematic. This new and desired approach to research involved precise calculations with measuring devices and discouraged the development of new technology by randomly experimenting on whatever antennas might be at hand.³⁶ As of December 1, 1935, Wilhelm Runge was put in charge of the development of all non-radio equipment at Telefunken, and in this capacity he managed the rapid increase in personnel that was instigated by the rearmament of the German military.³⁷ He was thus left with little time for any mathematical work of his own.

Unlike her brother Wilhelm, Iris Runge was free, while working at Osram, to devote her energies to mathematical and theoretical problems, and her freedom to concentrate on mathematics was not restricted by her later transfer to Telefunken. In order to determine the precise role that Iris Runge played at these two corporations, the next section will concern the organizational structure of their research facilities.

3.2 THE ORGANIZATION OF LIGHT BULB AND ELECTRON TUBE RESEARCH

Even before the First World War, the production of incandescent light bulbs had been one of the fastest growing sectors of the electrical industry. In Germany, the manufacturing of this product was largely undertaken by the three large corporations mentioned above, namely Siemens & Halske, AEG, and the Auer Company. These three businesses cooperated before the war and together created Osram as a subsidiary operation to run their light bulb factories.

On April 17, 1906, the name Osram was registered as number 86,924 in the index of trademarks at the Imperial Patent Office, and its submission was credited to the Auer Company. The word Osram, which was formed from the element names *osmium* (OS) and *wolfram* (RAM), refers to the two metals that were used, on account of their high melting points (3,000 and 3,400° C, respectively), to make filaments. The recognition, first made in 1913, that gas-filled filament bulbs produced an unexpectedly stronger light intensity resulted in the gradual obsoles-

36 See FRÄNZ 1986, pp. 7–8

37 About these years, Wilhelm Runge wrote the following in his autobiography ([DTMB] 4413, p. 53): “An essential component of my managerial position at the laboratory was the vetting and hiring of the growing personnel that was needed to contribute to the rearmament. Over the course of those years I hired many hundreds of engineers and physicists, and the growth rate of the operation nearly doubled every year. In 1933, the developmental laboratory housed approximately 250 employees working as engineers or scientists, and by 1943 their number had increased to 1500.” Under his boss Dr. Karl Rottgardt, Wilhelm Runge was also required to undertake certain sales and marketing assignments, which left him with even less time for long-term research projects. Increasingly discontent, he voluntarily left Telefunken on November 1, 1944 to direct the Institute for Electrophysics at the German Center for Aeronautical Research in Berlin-Adlershof (*Deutsche Versuchsanstalt für Luftfahrt*). He returned to Telefunken, however, in July of 1945 (see *ibid.*, pp. 57–58).

cence of the once dominant arc light. In November of 1918, the Auer Company finally established Osram G.m.b.H, a limited liability company, with which Siemens & Halske and AEG would merge their own light bulb factories in 1920.³⁸ After the fact, the official date of Osram's founding was proclaimed to be July 1, 1919. The three light bulb operations of the parent firms, each with its own production plants and research laboratories, occupied a considerable amount of property in Berlin and were given the following simple designations by Osram: Factory A (originally part of AEG), Factory D (originally part of the Auer Company), and Factory S (originally part of Siemens & Halske).³⁹ It should be noted that, from its inception, Factory A was responsible for the production of both incandescent light bulbs and electron tubes.

The three parent companies developed and manufactured a variety of products, of course, and thus possessed production and research facilities beyond those that were run by Osram. All of these institutions cooperated to some extent, but they were also in competition. An especially close bond existed between Osram and Telefunken because they happened to share the same parent companies, AEG and Siemens & Halske.

3.2.1 The Experimental Culture at Osram

From its beginning, the Osram Corporation employed outstanding scientists to head its research departments. These research directors, most of whom held doctoral degrees in physics or chemistry, were responsible for numerous patents and generally distinguished themselves with their groundbreaking creative ideas. The organizational structure of their research operations was partly novel and partly modeled after that of the parent companies. As was formerly the case, the product-oriented research laboratories were located on site at the individual factories. A main research department was created in order to coordinate the efforts of the separate laboratories. In addition to this main department at Osram, there was the so-called Research Society for Electric Lighting (*Studiengesellschaft für elektrische Beleuchtung*), which functioned as a central research institute for the study

38 The shares of Osram were divided such that Siemens & Halske and AEG each held forty percent, the remaining twenty percent being allotted to Leopold Koppel, the owner of the Auer Company.

39 Factory A (AEG), which was built in 1905 and 1906 on a 7,587 square meter plot of land, consisted of a complex of buildings on Sickingenstraße that contained a combined 41,738 square meters of work space. Built in 1899 on a 6,735 square meter lot on Helmholtzstraße, Factory S (Siemens & Halske) was augmented to include five buildings with a total of 37,850 square meters of work space. Factory D (Auer Company), which was constructed between 1906 and 1911, consisted of three large buildings on Rotherstraße. The buildings occupied 14,793 square meters of land and contained 61,812 square meters of work space. All told, the work space of the three factories amounted to more than 150,000 square meters (see [LAB] 448). Between 1946 and 1990, Factory D was owned by Narva, a manufacturer of light bulbs (see LIEWALD 2003, p. 39).

of the applied and long-range problems that faced the industry. This research society was housed in Factory D and its organization and operations were independent of the production plants.⁴⁰

A designated seat on Osram's executive board was allotted to a representative from the field of research. This was the highest research position at the corporation, and it was held by the Austrian chemist Fritz Blau from the very beginning until his death in 1929.⁴¹ Within the corporate structure, he was the head of "Management Branch III: Scientific Management and the Protection of Intellectual Property," to which belonged the corporation's patent department (directed by Martin Schwab), main research department (directed by Marcello Pirani), department of glass research (directed by Georg Gehlhoff), and the Research Society for Electric Lighting (co-directed by Karl Finckh and Franz Skaupy).

Fritz Blau completed his doctoral degree in 1886 at the University of Vienna; he worked as a laboratory assistant to Robert von Lieben, who is famous for developing a telephone amplifier by means of an electron tube; and in 1902 Blau was hired by the Auer Company in Berlin. In 1916, while working for the latter company, he founded a forerunner to Osram's Research Society for Electric Lighting, which would itself become an organization of more than one hundred employees.⁴² Blau's many ideas led to 185 patents with relevance to organic chemistry, the manufacturing of tungsten filaments, gas discharge, incandescent light bulbs, radiation technology, wireless telegraphy, electric furnaces, and X-ray technology. He remained enthusiastic about Osram's experimental culture throughout his tenure there and, according to Marcello Pirani, he inspired his colleagues with countless ideas.⁴³ It was Blau, too, who instigated the innovative application of mathematical statistics to problems of mass production, an area of industrial research to which Iris Runge is known to have contributed (see Section 3.4.2).

Blau's successor was the physicist Karl Mey, who had become a deputy member of Osram's executive board in 1931 (responsible for "research and development") and a full board member in 1934 (responsible for "science"). Mey had formerly been employed at the carbon filament bulb factory of AEG in Berlin, and he was made the director of this factory after only five years on the job. Having transferred to Osram, he directed Factory A from 1920 to 1931. It is noteworthy that Mey – like other research directors at Osram (Marcello Pirani and Georg

40 Analogous in structure were the Bell Telephone Laboratories in Murray Hill, New Jersey, which were established in 1925 as an independent research institution by the Western Electric Manufacturing Company.

41 In 1923, the executive board at Osram consisted of five full board members, five deputy board members, and the research advisor (Fritz Blau). See [LAB] 445 for an overview of Osram's corporate structure in 1923.

42 By 1931, the Research Society for Electric Lighting had 158 staff members; only fourteen of whom, however, held advanced degrees (see LUXBACHER 2003, p. 298).

43 See PIRANI 1930a. It is likely – though unconfirmed – that Fritz Blau was related to Marietta Blau, the famous Austrian-Jewish physicist (see ROSNER/STROHMAIER 2003).

Gehlhoff, for example) – had studied under the physicist Emil Warburg, many of whose students became prominent researchers.⁴⁴

Since the founding of Osram, Marcello Pirani worked as the director of its main research department, and as of 1921 he was also appointed deputy director of the Research Society for Electric Lighting, over which he assumed full control in 1928. Having studied physics, mathematics, chemistry, and philosophy, and having earned a doctoral degree in physics from the University of Berlin (1903), Pirani worked briefly as a research assistant at the Technical University in Aachen before joining Siemens & Halske in October of 1904. There he had worked for one year as an assistant in a laboratory run by the chemist Werner von Bolton before being entrusted with the directorship of his own physics laboratory. Pirani attained numerous patents, such as that for the Pirani manometer; he was promoted to senior engineer by Siemens & Halske in 1910; and in 1911 he managed to complete his *Habilitation* at the Technical University in Berlin with a study entitled “Die Messung der wahren Temperaturen von Metallen” [Measuring the True Temperatures of Metals]. As was the case with Georg Gehlhoff, this is just another example of the close ties that were developing in Berlin between academic and industrial research. Though Pirani’s main professional position was in industry, he also worked part-time as a professor at the Technical University in Berlin (1918), as an associate professor of physics and lighting technology at the same institution (1922), and later as the director of that university’s Institute for Lighting Technology (1932), a position that he was forced to abandon the following year after the enactment of racial laws under Hitler. His university courses were primarily concerned with the production, application, and measurement of high temperatures, as well as with the application of graphical methods in the fields of physics, chemistry, and engineering. When Karl Mey became a full member of Osram’s executive board in 1934, Pirani occupied a newly established position as a deputy board member. He emigrated two years later.⁴⁵

44 Karl Mey earned a doctoral degree at the University of Berlin with a dissertation entitled “Kathodenfall an Alkalimetallen” [Cathode Fall in Alkali Metals]. His doctoral supervisor Emil Warburg, a son of Jewish parents who converted to Protestantism, was one of the last physicists with expertise in both theoretical and experimental physics. In his own dissertation – “De systematis corporum vibrantium” [On the System of Oscillating Bodies] (1867) – Warburg explained a certain oscillation system with a fourth order differential equation, and in 1880 he discovered the phenomenon of magnetic hysteresis, which he also treated theoretically. After completing his *Habilitation* in 1870, Warburg held professorships at the University of Strassburg (1872), the University of Freiburg (1876), and the University of Berlin (1894), and he served as the director of the Imperial Institute of Technical Physics (*Physikalisch-Technische Reichsanstalt*) from 1905 to 1922. For an overview of Osram’s corporate structure during the years 1931 and 1934, see [LAB] 445. A comprehensive book on Karl Mey is currently being prepared by Dieter Hoffmann and Günther Luxbacher.

45 Born in Berlin, Marcello Pirani was the son of the Italian composer and author Eugenio von Pirani and his German-Jewish wife Clara (née Schönlink). He was classified by the Nazi regime as “half-Jewish,” even though he had stressed in the curriculum vitae appended to his dissertation – “Über Dielectricitätsconstanten fester Körper” [On the Dielectric Constants of

As the director of Osram's main research department, Pirani was responsible for coordinating the research that was conducted at the three individual factories and at the Research Society for Electric Lighting, for attending to the scientific or technical problems faced by other departments, and for distributing reports about the scientific and technical breakthroughs that were being made both within the corporation and outside of it. In 1930, to this latter end, Pirani initiated the book series *Technisch-wissenschaftliche Abhandlungen aus dem Osram-Konzern* [Technical and Scientific Publications of the Osram Corporation], which was published by the Julius Springer Press. In addition to original scientific contributions, these volumes also collected abridged reports of articles that Osram employees had published beforehand in different journals. The main research department had the authority to delegate special tasks to whatever experts seemed most fit to accomplish them. Although the corporate bylaws stipulated that these experts only be employed as *experimental* assistants,⁴⁶ under Pirani's leadership it was also common for Iris Runge, Osram's mathematical expert, to assist in finding solutions to wide-ranging problems.

The research agenda initiated by Pirani is known from numerous publications, including some that he co-authored with Iris Runge or with his other female colleagues. Just as he had collaborated with the physicist Hildegard Miething,⁴⁷ a co-worker from his days at Siemens & Halske, he later encouraged Iris Runge in her mathematical research.⁴⁸ As his "general secretary," moreover, he chose to appoint the female physicist Ellen Lax.⁴⁹

Solids] – that he was an avowed Protestant (see [UAB] Phil. Fak., Prom.-Akten, No. 380, p. 618). Among his inventions is the Pirani gauge, a thermal conductivity gauge used for measuring the pressures in vacuum systems (see Section 3.4.3.1 below). Pirani's achievements as a researcher earned him an international reputation that later served to facilitate his emigration (see CLAYTON/ALGAR 1989, p. 121). Dr. Werner von Bolton developed a process for manufacturing tantalum filaments. Through the efforts of the German-trained American physicist William David Coolidge, who was working for General Electric in New York, the tantalum filament bulb was ultimately replaced by the tungsten filament bulb (see LUXBACHER 2003, pp. 103–106). For additional biographical notes on Marcello Pirani, see the eulogy – delivered by his former colleague Oskar Herrmann on January 22, 1968 – that is archived in the [Geiger Private Estate]; and [LAB] 282, vol. 2. For information on Pirani's lectures, see the *Zeitschrift für technische Physik* 30 (1929), p. 242.

46 For an outline of Osram's corporate structure and research assignments, see [LAB] 445.

47 See Hildegard Miething and Marcello Pirani, "Strahlungsenergie, Temperatur und Helligkeit des schwarzen Körpers," *Verhandlungen der Deutschen Physikalischen Gesellschaft* 17 (1915), pp. 219–239; PIRANI/RUNGE 1924, 1931; LAX/PIRANI 1929. For additional publications by Miething, Lax, and Iris Runge, see the lists in POGG., vols. VI, VIIa, VIII.

48 See Iris Runge's letter to her mother dated October 8, 1924 [Private Estate], in which she refers to Pirani as her "unmitigated benefactor."

49 Beginning in 1925, Ellen Lax – known as "Pirani's right-hand woman" – appeared in Osram's corporate reports as "Miss Dr. Lax, Senior Officer" beside Pirani's name (see [LAB] 445). Lax completed her doctoral degree under Walther Nernst at the University of Berlin, after which she conducted experimental research on lighting technology and authored comprehensive chapters for a variety of textbooks. Her position at Osram involved

To some extent, the laboratories at each of Osram's three factories were applying different research methods to the same technological problems. Displeased with the lack of communication among the research facilities, the board of directors created a new organizational system that was based on product-oriented committees of experts. Each of these committees consisted of a member of the executive board, a representative from the relevant factory, and a representative from the Research Society. Eight of such committees were formed in January of 1924, and their respective concentrations reflect the areas of research with which Osram was chiefly concerned, namely: 1) new light sources, excluding tungsten filament bulbs (chaired by Franz Skaupy); 2) materials testing (chaired by Hermann Pohl); 3) methods of physical and chemical measurement (chaired by Marcello Pirani); 4) matters of lighting technology and propaganda, with several subcommittees (chaired by Karl Finckh); 5) filament research (chaired by Fritz Blau); 6) glass research (chaired by Georg Gehlhoff); 7) problems particular to the production of normal filament bulbs (chaired by Karl Finckh); and 8) specialty filament bulbs (chaired by a certain director named Krause).⁵⁰

The research was oriented toward the development and production of Osram's main products: electric light sources, particularly the numerous manifestations of electric filament bulbs (these already existed in approximately 6,000 types by the year 1930, each for a distinct use). Whereas all three of the factories conducted research on lighting, bulbs, materials, and measurement methods, only Factory A (formerly of AEG) conducted research on electron tubes, that is, on such things as X-ray tubes, amplifier and transmitter tubes, rectifiers, and the resistivity of iron and constantan. Iris Runge was hired to work in the laboratory of Factory A, where she began as a light bulb researcher but was later reassigned, in May of 1929, to investigate electron tubes.

3.2.2 The Research Laboratories for Incandescent Light Bulbs at Factory A (Osram)

Today I gave Jacoby yet another lesson in mathematics [...]. I am always amazed by the great extent to which my modest mathematical knowledge is appreciated here.⁵¹

On March 1, 1923, Iris Runge began working as a "physicist" at Osram's Factory A, which was located on Sickingenstraße 71 in Berlin-Moabit.⁵² Her position was part of the department of experimental laboratories, which was directed by Dr.

the coordination of assignments within the main research department itself. After Pirani's emigration in 1936, she took a new position at the Julius Springer Publishing House (see LORENZ 1975; TOBIES 2008a, pp. 325–326).

50 See [LAB] A Rep. 231, No. 281, vol. 1 (a seven-page document dated January 3, 1924).

51 A letter from Iris Runge to her parents dated May 28, 1928 [Private Estate].

52 The date of Iris Runge's first day of employment was made known to me in a personal letter – dated March 3, 1995 – from AEG's current office on Sickingenstraße in Berlin.

Richard Jacoby and which was closely associated with the manufacturing side of things.

Jacoby, who was born in Berlin to the Jewish merchant Leopold Jacoby, had studied chemistry, mineralogy, physics, and mathematics in Freiburg, Würzburg, and Berlin, in which city he completed a doctoral degree in chemistry – *magna cum laude* – in the year 1901 and began what would be a long career as an industrial researcher.⁵³ While working at AEG's light bulb factory in 1913, Jacoby and his colleagues Ernst Friederich and Karl Mey determined the conditions that an incandescent bulb had to fulfill in order to keep heat conduction at a minimum.⁵⁴ This finding, which is one of the most significant in the history of incandescent light bulb research, was discovered nearly simultaneously by Irving Langmuir – a former student, as mentioned above, of Walther Nernst – at General Electric in New York.

Responsible for hiring Iris Runge, Jacoby had recognized the scientific promise of his future colleague as early as November of 1922. In response to her letter of application (dated November 9, 1922), he explained, as follows, the interdisciplinary research project with which she would be engaged (see Figure 6):

We also believe that you would be quite content with the field of research to which your efforts would be assigned, and that you possess all the necessary qualifications for such work. The project itself involves conducting chemical and physical experiments on tungsten filaments, an endeavor for which you would have the opportunity to apply your expertise in chemistry, metallography, physical chemistry, and mathematics.⁵⁵

She was asked to consider “whether she felt up to the demanding task of working in the experimental laboratories of a factory for more than eight and a half hours per day.” A probationary period of three months was agreed upon.

53 Richard Jacoby's dissertation – “Die Doppelnitrate des vierwertigen Caesiums und Thoriums” [The Twin Nitrates of Tetravalent Cesium and Thorium] – was inspired by the work of the then lecturer Dr. Richard Josef Meyer. Hans Heinrich Landolt, the famous Swiss chemist, conducted Jacoby's oral examination, about which he wrote: “The candidate has demonstrated an outstanding knowledge of all relevant fields, including the most difficult among them.” The mineralogist Carl Klein evaluated Jacoby's performance as “excellent,” the physicist Max Planck as “*magna cum laude*.” On April 18, 1939, the University of Berlin revoked Jacoby's doctoral degree on account of his Jewishness (see [UAB] Phil. Fak., Prom.-Akten, No. 362, pp. 388–397). On March 21, 1941, he was murdered in the Sachsenhausen concentration camp (see GEDENKBUCH 1995, p. 574).

54 At the University of Heidelberg, Ernst Friederich completed his doctoral thesis in 1905 under the supervision of Theodor Curtius, “Beitrag zum Benzolproblem” [A Contribution on the Benzene Problem]. He came to work at AEG in 1909, and later he was the director of various chemistry laboratories at Osram. In 1939 he became the director of all of Osram's laboratories concerned with incandescent light bulbs, and in 1942 he was made the executive director of the Research Society for Electric Lighting (see [LAB] 445). Friederich moved to California in 1945 (see LUXBACHER 2003, p. 299).

55 November 16, 1922 (in [STB] 746, pp. 1–2; reproduced in Figure 5).

Dr. J/Ka.

OSRAM

G. m. b. H. Kommanditgesellschaft
 Vereinigte Glühlampenfabriken
 ALLGEM. ELEKTRICITÄTS-GESELLSCHAFT
 SIEMENS & HALSKE A.-G.
 OSRAMWERKE

Fabrik A

Geldverkehr:
 Reichsbank Berlin
 Postcheckamt Berlin Nr. 115228

Abt. Dr. J.
 Angabe des vorstehenden Vermerkes in der Antwort erbeten.
 Betrifft: **Bewerbung.**
 Antwort auf Ihr Schreiben v.

Berlin NW.87, 16. November 1922
 Sickingenstr. 71
 Fernanschrift: Elektronlampe Berlin
 Fernsprecher: Amt Moabit 3007-3010, 8790-91

Fräulein

Dr. Iris Runge,

Schloss Salem
 ---.---.---.---.---.
 (Baden)

Im Besitz Ihres gefl. Schreibens vom 9. d. Mts. sind wir gern bereit, Ihrer Bewerbung näherzutreten. Wir glauben auch, dass das Arbeitsfeld, auf dem Sie sich zu betätigen hätten, Ihnen Befriedigung bringen würde, und dass Sie für dasselbe die nötigen Kenntnisse mitbringen würden. Es handelt sich um chemische und physikalische Untersuchungen an Wolframdrähten, bei denen Sie Ihr physikalisches, metallographisches, physikalisch-chemisches und mathematisches Wissen zu verwenden Gelegenheit hätten. Spezialkenntnisse auf dem Gebiet des Wolframs setzen wir natürlich nicht voraus.

Wir möchten Sie aber bitten, sich zu überlegen, ob Sie den Anstrengungen einer Tätigkeit in den Versuchs-Laboratorien einer Fabrik mit einer von 1/2 8 bis nach 4 Uhr dauernden Arbeitszeit sich gewachsen fühlen.

Die Gehaltsfrage wird sich zweifellos in Ihrem Sinne regeln lassen, wenn uns auch augenblicklich die genauen Zahlen für die Besoldung wissenschaftlicher Assistentinnen an

./.

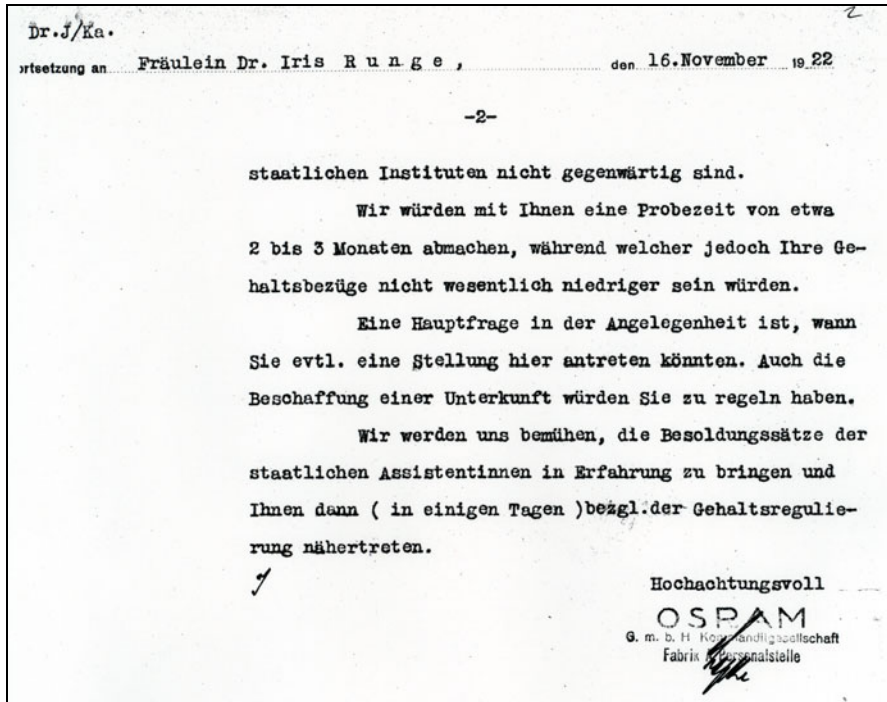


Figure 6: A Letter from Richard Jacoby to Iris Runge (dated November 16, 1922)

Iris Runge stated that her desired salary would be equivalent to the compensation of a university research assistant, and these terms were accepted by Osram in a letter dated November 22, 1922. In this letter she was also asked to come to Berlin as soon as possible for a personal interview, for which her travel expenses would be remunerated. The letter made it clear, too, that “Dr. Jacoby is more than willing to meet with you outside of the factory, either in the evening or on Sunday.”⁵⁶

Jacoby served as the representative of Factory A on the special Osram committee – mentioned above – for filament research. Tungsten filaments were not only essential to the production of tungsten filament bulbs, but thoriated tungsten filaments were also just beginning to be used as cathodes in electron tubes. At the time, new realizations about the crystal structure of metals led to development of spiral filaments of this sort, which form small crystallites when heated to 1,200–

⁵⁶ [STB] 746, pp. 3–4. The information in the letter was very detailed: “Dr. Jacoby’s apartment is located in Berlin W. 15, Bayerische Straße 6, telephone: Pfalzburg Office 1682. The factory is located near the train station on Beusselstraße and can be reached by taking the 17 streetcar from the Anhalter Station (telephone: Moabit Office 3007). Dr. Jacoby’s apartment is near Olivaer Platz, which can be reached from the Anhalter Station by taking line 62.” On salary increases during the period of inflation, see Section 4.1.1 below.

2000°C. Jacoby and Fritz Koref discovered the conditions in which drawn tungsten filaments, when recrystallizing, will maintain a consistent microstructural form at even higher temperatures, and they attained a patent for their discovery.⁵⁷ Iris Runge recognized relatively quickly how to anticipate possible solutions for technical problems and her first publication as an employee appeared after only her fifth month on the job.⁵⁸ The collaborative research on tungsten filaments that was conducted throughout Osram resulted in many findings that would be summarized by Ellen Lax and Marcello Pirani in volume three of Georg Gehlhoff's *Lehrbuch der technischen Physik* [Textbook on Technical Physics], which was devoted to tungsten (*Wolfram*).⁵⁹

Iris Runge worked closely on this tungsten filament project and even appeared holding the *Wolfram* volume in the photo album that was presented to Karl Mey, the director of Osram's Factory A, on the occasion of his twenty-fifth anniversary in the industry in 1929.⁶⁰ There were sixty-one senior officers on staff, including two directors, a university professor, and twenty-five with doctoral degrees. Three of the latter were women with doctoral degrees in chemistry, namely Iris Runge, Magdalene Hüniger, and Ilse Müller. At least in principle, these senior positions were permanent, and this fact allowed for the formation of stabile research teams to work together on long-term projects.⁶¹

Jacoby oversaw the work of physicists, chemists, electrical engineers, general engineers, factory foremen, laboratory assistants, and librarians. In her very first letter to her parents about her new job at the laboratory, Iris Runge raved about the inspiring and motivational atmosphere that prevailed there. Jacoby, for instance, was known by his employees as "the kindest boss at all of Osram."⁶² Though somewhat awkward and less than urbane, Jacoby was a highly organized supervisor who could manage many tasks at once while delegating ancillary assignments to others. The work day ran according to a rigid schedule and was appreciated by

57 The patent can be seen online at <http://www.freepatentsonline.com/1739234.html>. See also LAX/PIRANI 1929, p. 323. Fritz Koref had earned a doctoral degree in 1920 under the supervision of Walther Nernst.

58 IRIS RUNGE 1923. On this study, see Section 3.4.3.1 below.

59 See LAX/PIRANI 1929.

60 [DTMB] Photo Album for Karl Mey. The photograph of Iris Runge holding the *Wolfram* volume is reproduced in Plate 5 at the end of the book. Other photographs from this same album are reproduced in Plates 11, 12, 13, and 14. According to a letter that she wrote to Hendrik de Man on October 23, 1931 [IISH], Iris Runge had been promoted to the position of senior officer (*Oberbeamte*) two years earlier, and from this it can be concluded that her promotion coincided with her 1929 transfer to the field of electron tube research. For additional personnel with this title, see the book *25 Jahre Telefunken* (1928), which contains a list of more than six hundred employees, including all of the senior officers (p. 295).

61 A similar research organization existed in the central laboratory of Siemens-Wernerwerke F, as Siemens's telephone equipment factory had been called since 1905 (see SCHULTRICH 1985, pp. 89–90; and SCHEEL 1930).

62 This quotation and the information that follows are taken from Iris Runge's letter to her parents dated March 4, 1923 [Private Estate].

the employees as being both pleasant and efficient. Writing utensils were laid out on the desks in morning, and the researchers took breakfast (8:15 AM) and lunch (1 PM) in their rooms, for which drinks, silverware, and a cleaning staff were provided.

On Iris Runge's first day of work, Jacoby summoned her at 8:30 in the morning to welcome her personally. He assigned her a working space in an office with five desks and placed three books into her hands with which she was expected to introduce herself to the processes of incandescent bulb production. The walls of her relatively small office were almost entirely made of glass, the bottom halves of which were painted. The work space was also used as a weigh station, and Iris Runge's office mates included a trained physicist named Kühne, another physicist named Walter Heinze, the aforementioned Magdalene Hüniger, and a laboratory assistant known as Miss Bauch.⁶³ About her colleagues, Iris Runge reported:

[...] I should say a few more things about my colleagues. Dr. Kühne and Dr. Heinze from our office do not have the most appealing personalities, but they fool around a bit, and Heinze is a real *gent*. Dr. Hüniger, however, is extremely kind [...]. Miss Bauch is portly, humorous, and resolute [...]. Today she said that she hoped not to be at Osram by this time next year. Laboratory assistants have no room for advancement, and thus they always have to be looking for something better. In another laboratory there is a man named Mr. Lutterbeck who also seems very nice. Above all I would like to associate with a certain Mr. Frenz, who is a foreman here, that is, he comes from the working class. He is still quite young, however, and looks to be rather well educated; he is said to be wonderfully capable and to have learned everything on his own. He will be responsible for carrying out the experiments based on my calculations, and I look forward to working with him. The secretary, Miss Jakobs, also seems to be very nice, and she is the person to whom I will have to dictate my results. And then there are several student employees [...].⁶⁴

63 Like Richard Jacoby, Magdalene Hüniger had conducted her doctoral research, which culminated in a thesis entitled "Die quantitative Bestimmung des Zirkoniums" [The Quantitative Measurement of Zirconium], at Richard Josef Meyer's private chemistry laboratory in Berlin, and she was awarded her degree in 1919. The man referred to as Dr. Kühne plays no further part in the remainder of this book. Walter Heinze, who began to work at Osram on September 1, 1921, obtained his doctorate under Rudolf Seelinger (a former student of Arnold Sommerfeld) at the University of Greifswald with a thesis entitled "Die Lichtemission in den verschiedenen Teilen der Glimmentladung" [Light Emission in the Distinct Parts of Glow Discharges]. To put matters into context, Rudolf Seelinger had just finished a contribution – "Elektronentheorie der Metalle" [The Electron Theory of Metals] – to the fifth volume of the famous *ENCYCLOPEDIA*. On March 20, 1939, Heinze was reassigned to Osram's television department (see [LAB] 444, vol. 1). On Heinze's later activity, see Chapter 5.

64 A letter dated March 4, 1923 [Private Estate]. The word *gent* appears in English in the original letter. For photographs of Walter Heinze and Otto Frenz, see Plates 11 and 12, respectively, at the end of the book. One student employee was assigned to assist Iris Runge in her work: "On Tuesday [...] I was the first person in the laboratory; everyone else arrived later (with the exception of my student assistant, so it was probably a good thing that I was there)" (quoted from a postcard written by Iris Runge on January 3, 1927 [Private Estate]).

Jacoby's broad scientific knowledge is to be thanked for that fact that, from her first day, Iris Runge was able to apply herself to her full potential and develop as a researcher. She expressed her enthusiasm about the interdisciplinary nature of her projects and about the prospect of using mathematical methods:

The beautiful thing about it is that so many different subjects come into play – chemistry, electricity, current theory, metallography, and seemingly everything else of which I have a fundamental understanding. The job is thus extremely enjoyable to me. [...] Things are going splendidly at work, and in the meantime I have survived through the probationary period of my employment. Jacoby is very kind [...]; he has already told me what I need to do next, and I have begun to think about the theoretical aspects of this new assignment. It is all very lovely; he has managed to figure out precisely what I am good at and he applies my talents to such ends. Between assignments he gave me yet another English study to read and summarize to him in person, after which I am to dictate my summary to his secretary. [...] Tomorrow I will begin to make the calculation that Jacoby has requested, and I already have an approximate idea of how it will turn out. I can hardly wait to sit down to it.⁶⁵

It was not long before Iris Runge felt accepted at the laboratory, and her letters to her parents reflect her increasing self-confidence:

Today was yet another good day at the factory. [...] Jacoby is very enthusiastic about me [...]. He treats me very delicately. Today, for instance, he darted in unannounced to ask me in confidence whether I was getting along with my office mates and, if not, to tell him so at once. He has also already offered to give me a personal tour of the factory.⁶⁶

A “scientific boss,” as Carl Runge called him,⁶⁷ Jacoby cultivated personal relationships with his colleagues. Iris Runge was regularly invited to his home, occasionally together with her brother Wilhelm. She was genuinely ebullient about the circumstances: “As always, things are going exceedingly well for me: Work is wonderful, Jacoby is wonderful, my free time is wonderful, sleep is wonderful, my whole life is wonderful.”⁶⁸ She also had the pleasure of introducing her father to Jacoby's circle of acquaintances.⁶⁹

Iris Runge was recognized in this work environment for her skill at applying numerical and graphical methods, for using and developing methods of probability theory and statistics, and for her ability to solve diverse problems in such fields as materials research, optics, and quality control (see Section 3.4). Even in her first years on the job, her knowledge of mathematics was put to use in a number of Osram's departments, and with the growing significance of wireless broadcasting she was later transferred to work as a mathematical expert in the developmental laboratory for radio tubes.

65 A letter from Iris Runge to her parents dated March 4, 1923 [Private Estate].

66 Ibid. This letter was begun on March 4, 1923 and continued on the following Monday.

67 A letter from Carl Runge to his brother Richard dated March 8, 1923 (in [STB] 526).

68 A letter from Iris Runge to her parents dated July 22, 1923 [Private Estate].

69 See Sections 3.3 and 3.4.1.1 below. After Carl Runge's death on January 3, 1927, Mrs. Jacoby – whose husband was ill – visited Iris Runge and said, “Your father might have been the dearest guest that we have ever hosted.” The quotation is from a postcard written by Iris Runge to her mother and dated January 11, 1927 [Private Estate].

3.2.3 The Developmental Laboratories for Radio Tubes at Factory A (Osram)

[...] I have begun to realize more and more that it is undoubtedly valuable for the factory to have someone like me around, for the people here who are dealing with practical problems are often confused by the simplest of theoretical details.⁷⁰

After the First World War, AEG decided to divest and relocate large portions of its electron tube facilities, which had been built for Telefunken in 1914 and directed by Hans Rukop,⁷¹ to Factory A at Osram. As of 1920, Karl Mey was thus not only in charge of overseeing the production of light bulbs but also of electron tubes. Coinciding with the development of radio broadcasting – the first German broadcasting station opened its operations on October 23, 1923 in Berlin – the laboratories on Sickingenstraße were expanded to include divisions for radio tube technology, to be directed by Dr. Hellmut Simon, and the production process was automated in a way analogous to that of light bulbs.⁷² The electron tubes manufactured by Osram were designed to be used in Telefunken's radio receivers.

This development led to a new organizational structure, initiated in 1928, within Osram's research laboratories. Special departments were formed for the purpose of researching metals, filaments, high vacuums, getter materials, electric discharge tubes, etc.⁷³ On November 1, 1928, Professor Adolf Eugen August Güntherschulze assumed the directorship of these radio tube laboratories, and Iris Runge was reassigned to work as a theoretical expert for him in May of 1929.

Güntherschulze completed his doctoral degree in 1902 under the electrical engineer Wilhelm Kohlrausch at the Technical University in Hanover, and later he was named a senior government advisor and was appointed to the executive board of the electrochemical laboratory at the Imperial Institute of Technical Physics (*Physikalisch-Technische Reichsanstalt*). With his rich professional experience and long list of publications,⁷⁴ he was quick to appreciate the contributions made

70 A letter from Iris Runge to her mother dated May 11, 1939 [Private Estate].

71 Hans Rukop completed his doctoral degree in 1912 under Gustav Mie at the University of Greifswald (his oral examination, which he passed *summa cum laude*, was in the subjects of physics, mathematics, and chemistry). In 1914 he joined Telefunken, where his research concerned electron tubes for radio transmitters and amplifiers. On April 1, 1927 he assumed the newly established professorship in technical physics at the University of Cologne, where his salary (14,539.02 Realm Marks in 1928) was funded by a Telefunken foundation. On June 29, 1933 he resigned from the university to become a member of Telefunken's executive board, and in that same year he stressed that he had never been a member of any political party (see [UA Köln] Personnel File, Access 17, No. 4814).

72 See SIMON 1930. For biographical information on Simon, see POGG.

73 See LUXBACHER 2003, p. 298. A *getter* is a chemical substance used for removing residual gases from electron tubes. Once a tube has been evacuated and sealed, the getter substance is heated until it evaporates, leaving a coating on the walls of the tube. Any residual gases left in the tube will then chemically combine with the getter coating; see also Appendix 4.

74 See POGG., vols. IV, V, VI, VIIa, VIII; and SEWIG 1953. Adolf Güntherschulze's most well-known book – *Elektrische Ventile und Gleichrichter* (Berlin: Springer, 1924) – appeared in English as *Electric Rectifiers and Valves* (New York: Wiley, 1928).

by Iris Runge, who by this time had earned a name for herself within the community of mathematicians and physicists. This is how she described a ball, attended by technical physicists, that was held in Berlin during the early summer of 1929:

I truly had an amusing time at this ball; I had many dance partners, including some of the foremost “luminaries” – the university rector, Hamel, and Paschen! The latter told me endearing things about my articles, which he purported to have read, and about my position at Osram, of which he had somehow been informed. My new boss, Güntherschulze, was formerly at the Imperial Institute. [...] I was most *elated*, for I realized that this is how things ought to be. The big shots in the world of science really ought to know me and treat me kindly, and it hardly matters to me whether they regard me as a talented scientist or simply as someone pretty and endearing.⁷⁵

Georg Hamel, whom she mentions here, had earned a doctoral degree under David Hilbert and was a professor at the Technical University in Berlin (and its rector in 1928). The physicist Friedrich Paschen, who served as the president of the Imperial Institute of Technical Physics from 1924 to 1933, is famous for Paschen’s law (1889), which concerned the breakdown voltage of parallel plates in a gas and the distance between the electrodes of gas-filled tubes – the very objects that had become a principle focus of Iris Runge’s research.⁷⁶

In October of 1929, Güntherschulze gave Iris Runge two theoretical-mathematical assignments, whereas the groups working beside her were asked to work on experimental and engineering tasks (Table 7). To her mother she explained how she had to invent her own assignments in her new laboratory:

You already know that, since Pentecost, I have been working at the electron tube factory, a position that pleases me on account of the new, interesting, and greater challenges that it promises. At first I only read and studied in order to comprehend all of the new things I would have to face, which was both interesting and comfortable. Since returning from my vacation, however, I have had to take the initiative to make active contributions, partly by making calculations based on the experiments of my colleagues, and partly by conducting my own experiments on the basis of suggestions made by my boss and by my fellow researchers. This has not at all been easy, especially because I am still barely capable of distinguishing what is easy from what is difficult. [...] For a few days things have been going somewhat better in the laboratory. Admittedly, I can’t yet boast of any great successes, but at least I now know where the mercury and the alcohol are kept, I can use a high-vacuum pump on my own, and I have begun to find my way around the place. In addition, I had a conversation with my boss (and before that with Wilhelm), and I told him that I wanted to defer my work on a certain problem because of its unforeseen difficulty (this problem was not assigned to me, but rather I had chosen it for myself in a moment of ignorance). Now I have a clearer picture of what I will have to do and of how I ought to go about it, and I am quite confident in my abilities to accomplish these tasks.⁷⁷

75 A letter from Iris Runge to her mother dated June 19, 1929 [Private Estate]. The English word *elated* appears in the German original.

76 On Hamel’s conservative sentiments, see MEHRTENS 1985/1989. Friedrich Paschen is also discussed below in Sections 3.4.5.1 and 4.4.2.

77 A letter dated October 4, 1929 [Private Estate]. The Wilhelm mentioned is her brother.

Güntherschulze's research program had a lasting influence at Osram despite the fact that, in 1930, he left the corporation for a professorship at the Technical University in Dresden. To each of his experimental researchers he typically assigned four to twelve individual tasks. For her part, Iris Runge was engaged in her two theoretical assignments on a long-term basis, and in the meantime she also cooperated closely with her colleagues who needed assistance to solve certain theoretical and metrological problems.

Table 7: The Structure of the Laboratory for Receiver and Transmitter Tube Research at Osram's Factory A (October 1929).⁷⁸

Director: Prof. Dr. Adolf Güntherschulze

- I) Dr. Willy Statz and Dr. Herbert Daene⁷⁹ (Indirectly heated electron tubes with low noise output)
- II) Dr. Erich Hoepner⁸⁰ (Water-cooled transmitter tubes)
- III) Dr. Peter Kniepen⁸¹ (100-watt thorium tubes etc.)
- IV) Dr. Rudolf Sewig⁸² (Photocells, measuring instruments)
- IV) Dr. Konrad Meyer⁸³ (Rectifiers)
- V) Dr. Iris Runge (1. Development of the theory of electron emission;
2. The calculation of tube parameters)
- VI) Student employees Keller, Krüger, Fritz Köppen⁸⁴ (types of glass, getter materials, current density and cathode fall in mercury vapor)

When Karl Mey, the director of Factory A, was promoted to Osram's executive board in 1931, the electron tube manufacturing facilities and the radio laboratories

⁷⁸ See [DTMB] 6614. The document is reproduced in its entirety in Appendix 4.3.

⁷⁹ Willy Statz would later become Iris Runge's supervisor (see below). Daene's dissertation – "Prüfung der theoretischen Erklärungen der Sekundärelektronen-Emission von Isolatoren und damit zusammenhängenden Erscheinungen" [An Examination of the Theoretical Explanations of the Secondary Electron Emission of Isolators and Associated Phenomena] – was published in the *Zeitschrift für Physik* 53 (1929), pp. 404–421.

⁸⁰ Erich Hoepner earned a doctoral degree under the supervision of Gustav Mie at the University of Greifswald, and a portion of his thesis – "Experimentelle Ermittlung der Zahl der Elektronen, die eine Metallscheibe bei Bestrahlung mit äusserst schwachen Röntgenstrahlen in der Minute emittiert" [An Experimental Investigation of the Number of Electrons Emitted over the Course of One Minute by a Metal Plate Irradiated with Weak X-Rays] – appeared in *Annalen der Physik* 46 (1915), pp. 577–604. Hoepner was hired by Osram on March 1, 1924, and he went on to direct a transmitter tube laboratory at Telefunken; for a photograph of him, see Plate 12 at the end of the book.

⁸¹ Advised by Max Reich at the University of Göttingen, Peter Kniepen earned his doctorate in 1922 with a dissertation entitled "Über das Radiometer" [On the Radiometer]. He joined Osram on January 2, 1928 (see [DTMB] 199; and [DTMB] 6734, p. 31).

⁸² Rudolf Sewig, who completed his doctoral degree in 1925 at the University of Bonn, had worked at both Siemens & Halske and the Imperial Institute of Technical Physics before accepting a position at Osram in 1929. On an article co-written by Sewig and Iris Runge (RUNGE/SEWIG 1930), see Section 3.4.4 and 3.5 below.

⁸³ In 1938, Iris Runge was placed under Konrad Meyer's supervision at her own request.

⁸⁴ Fritz Köppen, a student of physics, later worked as a researcher for Telefunken.

were put in the hands of Dr. Max Weth, a physicist.⁸⁵ Weth, in turn, entrusted Willy Statz to oversee the development of electron tubes. As a student of the physicist Leonhard Grebe at the University of Bonn, Statz had conducted primarily experimental research, and after joining Osram – on July 17, 1922 – he quickly applied himself to the technical development of oxide cathodes. He became Iris Runge’s immediate supervisor after Güntherschulze’s resignation.⁸⁶

Table 8: The Electron Tube Laboratories at Osram’s Factory A (March 1933).⁸⁷

<i>Department Head:</i>	Dr. Willy Statz (Tel. 143)
	Dr. Iris Runge (Tel. 143)
<i>Glass Development:</i>	Dr. Lisa Honigmann ⁸⁸ (Tel. 356)
<i>Typing Department</i>	(Tel. 147)
<i>Receiver Tube Development:</i>	Dr. Herbert Daene (Tel. 144), with Dr. Hubmann, Knöll, Köppen, A. Schmidt (Calibration Room)
<i>Transmitter Tube Development I:</i>	Dr. Erich Hoepner, with Wundt (Laboratory)
<i>Transmitter Tube Development II:</i>	Dr. Peter Kniepen and Dr. Eberhard Uredat ⁸⁹ (Laboratory)
<i>Rectifier Development:</i>	Dr. Konrad Meyer (Laboratory)
<i>Photocell Development:</i>	Dr. Werner Flechsig ⁹⁰ (Tel. 274), Laboratory (Tel. 277)
	Pump Station and Measurement Room, Laboratory I (Tel. 142)
	Laboratory II (Tel. 141)
	Laboratory Station: Werder
	Electrical Engineering Work Station, Test Bay for Receiver Tubes, Test Bay for X-rays, Test Bay for Transmitter Tubes, Pump Station, Sockets Room, Glass Machining

85 [LAB] 436. Weth began working at Osram on April 1, 1924 (see [DTMB] Photo Album; and Plate 14), and later transferred to Telefunken, where he was active at the electron tube factory as late as 1950 (see [DTMB] 0058). In the years 1949 and 1950, moreover, he served as the treasurer of the Physical Society in Berlin (*Physikalische Gesellschaft*).

86 On the history of the oxide cathode and its applications, see WEHNELT 1925. Representative works by Willy Statz include: “Eine experimentelle Bestimmung des wahren Absorptionskoeffizienten von harten Röntgenstrahlen,” *Zeitschrift für Physik* 11 (1922), pp. 304–325 [doctoral thesis]; and “Die technische Herstellung von Oxydkathoden,” *Technisch-wissenschaftliche Abhandlungen aus dem Osram-Konzern* 1 (1930), pp. 321–326. See also [DTMB] 5724; PD 3471; 0199.

87 [LAB] 446 (Osram’s telephone directory from March 1933). Additional employees were stationed in general laboratory and calibration rooms.

88 Lisa Honigman authored numerous laboratory reports and papers (see [DTMB] 6645, 6646, 6647), several of which she co-wrote with Dr. Werner Hubmann, whom she married in December of 1936. As a married woman she was forced to retire, and her husband was put in charge of the “Department of Glass Development” (see [LAB] 444, vol. 2).

89 Eberhard Uredat submitted his dissertation – “Über den Einfluß der Oberflächeneigenschaften der Glasreflektoren und den integralen Effekt der sekundären Elektronen” [On the Influence of the Surface Characteristics of Glass Reflectors and the Integral Effect of Secondary Electrons] – to the University of Berlin in 1930, while already working at Osram. He would later take a position at Telefunken, where he worked beyond the year 1945 as a technical director of transmitter tube production and quality control (see [DTMB] 6734, p. 27).

90 In July of 1938, Werner Flechsig patented the shadow mask color television.

Iris Runge shared a work space with Willy Statz from as early as 1933 until the June of 1938 (see [Tables 8 and 10](#)).⁹¹ Statz lacked the charisma of her former supervisors, and they did not see eye to eye on everything. He was increasingly busy with administrative matters and frequently absent, and she soon grew weary of having to take his many telephone calls.⁹² Statz, moreover, did not have an adequate understanding of her theoretical and mathematical work.

It was a time during which Iris Runge began to consider professional alternatives, during which Max Weth approved her taking a business trip to the United States, and during which she began to devote her free time to studying the history of science. Although many of her friends, colleagues, and acquaintances were leaving the country, she was able to isolate herself at work from the political turmoil of the day. Her first (and Jewish) supervisor, Richard Jacoby, continued to direct an experimental laboratory at Factory A until his forced retirement in 1938. Because Jacoby's laboratory was concerned with questions of both incandescent light bulbs and electron tubes, its staff ought to be enumerated below.

Table 9: The Experimental Laboratory Directed by Richard Jacoby (1933/1936).⁹³

March 1933

Dr. Düsing, Miss Eisner, Dr. Heinze, Dr. Hüniger, Janke, Lutterbeck (*crossed out and replaced by* Woeckel), Dr. Ilse Müller, Mrs. Ristau, Miss Stahnke, Trinks, Library (Miss Brandenburg, Miss U. Werner), Metallographical Laboratory.

July 1936

Dr. Düsing, Miss Eisner, Miss Gysae, Dr. Heinze, Dr. Hüniger, Janke, Dr. Ilse Müller, Münch, Mrs. Ristau, Miss Stahnke, Stange, Trinks, Dr. Wagener, Woeckel, Library (Miss Brandenburg, Miss U. Werner), Technical Engineering Laboratory, Chemical Laboratory (on the fifth floor), Glass Laboratory (Sickingenstraße 24), Metallographical Laboratory.

In order to process corporate data with Hollerith cards, Osram was restructured to consist of 102 numbered departments or administrative offices on July 1, 1936. The fundamental organization of the electron tube laboratories remained unchanged. What was new, however, was the addition of a department concerned exclusively with the development of electron tubes for the military authorities.

91 See Osram's telephone directories – archived in [LAB] 444, 446 – from March 1933, October 1936, and May 1939.

92 See the letters from Iris Runge to her sister Ella dated February 9 and 10, 1938 (in [STB], pp. 13–14).

93 [LAB] 444, 446. Dr. Düsing, a physical chemist, began working at Osram on June 1, 1927. After 1945 he was active as the director of the department of glass manufacturing at Telefunken (see [DTMB] 6734, p. 26). Brigitte Gysae completed her doctoral studies at the Technical University in Berlin in 1938. Her dissertation – “Über die Temperaturabhängigkeit der Austrittsarbeit bei Oxydkathoden” [On the Temperature Dependence of Electron Emission in Oxide Cathodes] – was written under the direction of August Gehrts (see VOGT 2008a, p. 66). Siegfried Wagener was a student assistant at Osram in 1930 and made a full employee there in 1932. Iris Runge would be one of the external evaluators of Wagener's 1935 dissertation (see Section 3.5 and Appendix 5.5).

Table 10: The Electron Tube Laboratories at Osram's Factory A (July 1936).⁹⁴

General Director: Dr. Willy Statz (Tel. 143)

Iris Runge (Tel. 143)

Departments:

Dept. 58 RF *Glass Development*: Dr. Honigmann and Laboratory (1 staff member)

Dept. 65 RF *Receiver Tube Development*: Dr. Daene, with Bünger, Eberhardt, Günther Herrmann,⁹⁵ Dr. Hubmann, Fritz Köppen, Alexander Schmidt, Dr. Malsch,⁹⁶ Pump Station, Measurement Room, Laboratory (with 8, 3, and 3 staff members, respectively)

Dept. 69 RF *Materials Testing Center*

Dept. 71 RF *Transmitter Tube Development I*: Dr. Hoepner, Dr. Lohmann,⁹⁷ Laboratory (1 staff member)

Dept. 72 RF *Transmitter Tube Development II*: Dr. Kniepen, Dr. Uredat, Dr. Ziegenbein, Laboratory (8 staff members)

Dept. 73 RF *Transmitter Tube Development III*: Dr. Konrad Meyer, Laboratory (5 staff members)

Dept. 75 RF *Experimental Work Station*

Dept. 76 RF *Document Development*: Gassmann, 2 Rooms with 6 staff members each (5 women)

Dept. 102 RF *Tube Development for the Military*: Heinz Beckenbach,⁹⁸ Laboratory (4 staff members)

The development of X-ray tubes, which had been overseen by Adolf Güntherschulze, was assigned to a new department – Dept. 74 RF *X-Ray Tubes* – and placed under the direction of Wilhelm Traub. This department, which was independent of Willy Statz's authority, contained two subordinate laboratories that

94 [LAB] 444, vol. 2 (index of department numbers at Factory A – July 1, 1936); [LAB] 446 (telephone directory).

95 In 1938, Günther Herrmann would submit the following doctoral thesis, directed by August Gehrts, to the Technical University in Berlin: "Einfluß von nichtmetallischen Zusätzen auf die Elektronenemission einer Oxydkathode" [The Influence of Non-Metallic Additives on the Electron Emission of an Oxide Cathode]. He began working at Osram as a student on July 30, 1934 and would later become a laboratory director (1939) and the technical director of the electron tube department (1945–1975) at Telefunken (see [DTMB] 6734, p. 27; POGG). For his collaborative work with Iris Runge see Section 3.4.5.2.

96 In 1924, Johannes Malsch earned a doctoral degree under Max Wien at the University of Jena, where he would also complete his *Habilitation* in 1927. In 1934 he became an untenured associate professor – and in 1939 a tenured associate professor – of technical physics (high frequency engineering) at the University of Cologne (see POGG.). Malsch was discussed as a potential candidate to replace Arnold Sommerfeld at the University of Munich (see ECKERT 2007).

97 Theodor Lohmann was awarded a doctoral degree on August 13, 1932 by the Technical University in Dresden for a dissertation entitled "Der Intensitätsverlauf der K-Strahlung verschiedener Elemente in Abhängigkeit von der Röhrenspannung" [The Intensity Distribution of the K-Radiation of Different Elements as a Function of Tube Voltage] (see JAHRESVERZEICHNIS 48 [1932], p. 710).

98 For a discussion of Heinz Beckenbach's collaboration with Iris Runge (BECKENBACH/RUNGE 1933), see Section 3.4.5.2 below.

were directed by Dr. Anton Eisl and Dr. Paul Lenz. On occasion, Iris Runge was called upon to collaborate with Traub (see Appendix 5.4, No. 2).⁹⁹

The forced resignation of Jewish personnel and the growing demands required by the rearmament resulted in additional organizational changes. Richard Jacoby's laboratory was closed on March 8, 1938, and the employees who had been working there were redistributed to other research departments. Weth decided that those concerned with light bulbs had to transfer to Dr. Ernst Friederich's department, and those concerned with electron tubes were temporarily moved to the department of Dr. Erich Wiegand.¹⁰⁰ Drs. Werner Düsing, Walter Heinze, Anton Weber, and Georg Tschoepe were each given their own laboratory to direct.¹⁰¹

During this period, Iris Runge was feeling increasingly isolated and discontent working under Statz's supervision. She thus took the initiative to arrange for her position to be put under new leadership, which enabled her to use more mathematics and to produce and apply theories of measuring instruments as a research technologist.¹⁰²

In the meantime I have managed to collaborate with a variety of researchers in the laboratory. In a conversation with Dr. Meyer, I expressed my desire to undertake more projects of this sort. He said that he needed someone to attend to the methods of measurement that were being applied by engineers who did not understand them. In response I mentioned to him that I would be willing to do just that. In the morning I simply went down to the laboratory and told the engineers that I would like learn about this or that and I asked them to show me how certain things are done. Then I sat there for hours until I fully understood the matter at

99 Wilhelm Traub wrote the doctoral thesis "Dispersion der Luft im ultravioletten Spektrum" [The Dispersion of Air in the Ultraviolet Spectrum] in 1919 under Friedrich Paschen at the University of Tübingen. He began working at Osram's Factory A on September 1, 1921 (see [DTMB] 444, vol. 2). Anton Eisl's doctoral dissertation, which was written at the Technical University in Munich, was published as "Über die Ionisierung von Luft durch Kathodenstrahlen von 10–60 kV" [On the Ionization of Air by 10–60 Kilovolt Cathode Rays] in *Annalen der Physik* 395 (1929), pp. 277–313. After 1945 he worked at AEG's High Voltage Research Institute in Kassel (see WALOSCHEK 2004). Paul Lenz's dissertation, which was submitted to the Technical University in Berlin in 1932 and entitled "Beitrag zur Technik gittergesteuerter Gasentladungen" [A Contribution to the Engineering of Grid-Controlled Gas Discharge Tubes], was reviewed by Iris Runge for Osram (see [DTMB] 6603, p. 84).

100 See [LAB] 444, vol. 2. Erich Wiegand, who had begun working for AEG/Osram as a student on August 25, 1919, completed his doctoral studies at the Technical University in Berlin in 1923; the title of his dissertation was "Über die Gesamtstrahlung des Leuchtkörpers der Nernstlampe bei verschiedenen Temperaturen" [On the Total Radiation of the Nernst Lamp Illuminant at Various Temperatures]. Wiegand would later become an executive of Osram's electron tube factory, and after 1945 he served as the director of production at Telefunken's tube factory in Berlin (see [DTMB] Photo Album, 6734, p. 22).

101 [LAB] 444, vol. 2; [DTMB] 6734. Anton Weber had been working at Osram since April 16, 1920 (see [DTMB] Photo Album, 6734, p. 21). Accepted by the University of Münster, Georg Tschoepe's dissertation – "Über Herstellung und Ausmessung von Adsorbensoberflächen" [On the Production and Measurement of Adsorbent Surfaces] – was published in the *Zeitschrift für Physik* 100 (1936), pp. 145–165. During the war, he oversaw the production and development of cm-tubes for Telefunken (see [DTMB] 6734, p. 34).

102 On the role of research technologists in industrial laboratories, see SHINN 2002.

hand and a number of improvements came to mind. I have already convinced them to re-design a certain device, and the engineer in question was amazed by how much better it worked. I have to say that I am a little proud of this achievement. With luck, things will continue in this way.¹⁰³

In June of 1938, Iris Runge became an official employee of the “Department of Transmitter Tube Development III,” a laboratory directed by Konrad Meyer. Here she found renewed recognition for her theoretical expertise in mathematics and instrument design. She was invited to participate in solving experimental problems, something that she had ceased to do while working for Statz:

Working in Dr. Meyer’s laboratory is really very nice; he is an extremely endearing person who is full of interests – one of those highly educated southern Germans from whom the old culture still emanates. It is wonderful that, under his direction, I have been able to return to experimental work, for there is nothing truer in life than bringing together theory and practice. That I enjoyed myself so little in Statz’s laboratory and ultimately abandoned it stemmed from the fact that I never really got along with the man, and thus none of the engineers regarded my work as important or would even offer me any assistance when I needed it. Things are completely different with Meyer: He is very happy to see me busy with practical matters, and he always stresses how necessary it is to have someone with a broad understanding of things to work on such projects. He claims that his engineers lack this understanding, although he is quick to acknowledge that they are very skillful at what they do. What is more, his high opinion of my work has already rubbed off on the engineers, with the effect that they hold my investigations in high esteem and are always ready to provide me with whatever I might need. Things are thus going quite well!¹⁰⁴

Konrad Meyer, an electrical engineer, earned his doctorate with distinction under the supervision of Winfried Otto Schumann at the Technical University in Munich. In addition to its experimental component, his dissertation included a formidable theoretical section, the first page of which included a citation of Adolf Güntherschulze, whose employee and collaborator he would become at the Osram Corporation. It was by Güntherschulze that Meyer was encouraged, above all, to devote his energy to the study of rectifiers, an area in which he and Iris Runge had collaborated as early as 1931 (see Appendix 5.4, No. 6, and Section 3.4.5.2). Meyer’s tenure at Osram had begun in the rectifier development laboratory, which was directed by Willy Statz, and he ultimately became the head of the Department of Transmitter Tube Development (III). On account of another corporate restructuring, this taking place in July of 1939, he took a new position at the parent company AEG.¹⁰⁵ Before doing so, however, he had been able to lend new authority to the mathematical methods that Iris Runge was applying at Osram:

103 A letter from Iris Runge to her sister Ella dated April 3, 1938 (in [STB] 663, p. 15).

104 A letter from Iris Runge to her mother dated May 11, 1939 [Private Estate].

105 See [DTMB] PD 2375; for Konrad Meyer’s dissertation – “Untersuchungen über die dielektrische Festigkeit fester Isolatoren” [Studies on the Dielectric Strength of Solid Isolators] – see *Archiv für Elektrotechnik* 24 (1929), pp. 1–25; [HATUM] PromA. and StudA. A photograph of Meyer is reproduced in Plate 13 at the end of the book.

My activity here at the factory has come to include a great many interesting things. Once again I am glad that the engineers and practitioners have great respect for mathematics and for those who know the subject well. And I have begun to realize more and more that it is undoubtedly valuable for the factory to have someone like me around, for the people here who are dealing with practical problems are often confused by the simplest of theoretical details, details that I am able to explain to them in five minutes, so long as I am asked.¹⁰⁶

3.2.4 The Telefunken Electron Tube Factory

On July 1, 1939, the day that Osram's electron tube facilities were handed over to Telefunken, the latter corporation became Europe's largest tube manufacturer, its main and subsidiary factories employing more than eight thousand men and women.¹⁰⁷ These factories produced approximately twelve million electron tubes yearly, which represented three quarters of the entire German market. From its inception, Osram had maintained close ties with Telefunken, for which it manufactured transmitter and receiver tubes by order of AEG, their common parent company. There had long been a close relationship, moreover, between Osram's and Telefunken's research laboratories.¹⁰⁸

In 1939, Telefunken was run by Martin Schwab, a former submarine captain who had been assigned to the Telefunken board of directors by Siemens in 1932. As the only non-Jewish board member at the time, Schwab was made the chief executive officer in 1933. In 1939, Telefunken's board consisted of the following members: Dr. Karl Rottgardt, a physicist who directed the Communications Division (this was the department in which Wilhelm Runge was employed); Dr. Engels, who led the Sales Division; Prof. Dr. Hans Rukop, who was in charge of the Division of Electron Tube Research and Development; and Dr. Karl Mey, who was hired from Osram to head the Division of Electron Tube Manufacturing.¹⁰⁹

The research division directed by Hans Rukop included individual departments for matters of high frequency, low frequency, television research, and electron tube development. Osram's former electron tube researchers were assigned to this latter department, which had been a relatively small operation before their arrival. The director of this research department was Dr. Karl Steimel, who had earned his doctorate in the field of mathematics.

With the help of her brother Wilhelm, Iris Runge was able to assure that she would be assigned to an appropriate research group. She wrote the following remarks to her sister Ella concerning her plans to speak with one of Telefunken's representatives:

106 A letter from Iris Runge to her mother dated May 11, 1939 [Private Estate].

107 See [LAB] 444, vol. 1. For economic details, see LUXBACHER 2003.

108 See RUKOP 1928. For information on the collaboration between these laboratories in the years 1935–1937, see [DTMB] 0088; 6473, pp. 88–110.

109 [DTMB] 00005. The chief responsibility of Dr. Karl Rottgardt's division was to satisfy the needs of the military authorities. He allocated fewer resources to long-term projects, on account of which Wilhelm Runge was especially marginalized ([DTMB] 4413, pp. 67–70).

It is now a reality that our branch will be transferred to Telefunken, and Wilhelm has smoothed the way for me to speak with someone there about my future activity. At this meeting it should be revealed whether my work will continue to take place on Sickingenstraße. Perhaps it will, but it is impossible to predict what will happen. It is well known, for instance, that Telefunken is planning to build a large new factory in Zehlendorf, and it is likely that many different offices will later be united under that roof.¹¹⁰

Having arrived at Telefunken, Iris Runge was made a member of its mathematical research group, which had been established there some years before under the supervision of Karl Steimel. His doctoral thesis, completed in 1928 at the University of Cologne, concerned a new method for integrating an oscillation differential equation and was thus an important contribution to applied mathematics. Having studied mathematics, physics, and philosophy, Steimel shifted his focus to technical physics after completing his doctoral studies and became Hans Rukop's research assistant at the University of Cologne, where Rukop held a professorship from 1927 to 1933.¹¹¹ Steimel had joined the Telefunken electron tube factory in 1932, and by the next year he had already been entrusted to direct his own laboratory. He applied for twelve patents in 1932 and 1933, a number that would reach one hundred by 1943 (approximately sixty of these applications were accepted). Beginning in 1934, Steimel was put in charge of radio tube development, and in 1936 he became the director of all electron tube development at Telefunken. By the time Iris Runge was hired, Steimel had long been engaged in mainly experimental work, but he nevertheless encouraged the promotion of gifted mathematicians. Such a researcher was Dr. Erik Scheel, who directed the laboratory that Iris Runge was to join.

Born in Estonia, Scheel earned his doctorate in 1926 from the Technical University in Karlsruhe. His thesis provided a summary of all of the mathematical and graphical methods that had then been developed for the calculation of electron paths in a triode and it contained a newly formulated graphical method for special types of electron tubes. In their evaluations of this dissertation, August Schleiermacher (a former student of Heinrich Hertz) and the physicist Herbert Hausrath underscored the great importance of Scheel's mathematical contribution. If the distribution of electron potentials is given, Scheel's novel method would enable researchers to calculate the fraction of an electron current that is flowing to the grid of a triode. Hausrath was confident, in his evaluation, that it would be possible with this method to determine the parameters of electron tubes in advance.¹¹²

110 A letter dated January 7, 1939 (in [STB] 663, p. 35). Zehlendorf is a district of Berlin, and the factory was planned to be constructed on Goerzallee.

111 [UA Köln] Philosophical Faculty, No. 478; BOSCH 1991.

112 [UA Karlsruhe] Diplom-Akte 21015, 4011 (*Diplom* awarded with distinction, 1922); Prom-Akte 21013, 484. Scheel's doctoral degree was conferred on November 30, 1926, and his dissertation – "Beitrag zur primären Elektrodenstromverteilung in technischen Dreielektrodenröhren bei positiven Potentialen beider kalten Elektroden gegen die Kathode" – was published in the *Archiv für Elektrotechnik* 23 (1930), pp. 383–412.

While at Telefunken, Scheel led a group in Steimel's division that was responsible for the development of all types of radio broadcasting tubes. His group was charged with evaluating new ideas of electron tube development, a task that involved testing new tube designs for utility and operability, calculating their potential output against desired results, and constructing prototypes that could be put into mass production. Steimel greatly appreciated Scheel's methods of calculation, which he praised in a letter of support to the Technical University in Karlsruhe, where Scheel completed his *Habilitation* in 1937:

In his work on electron tubes with a linear-logarithmic curve and with various boundary conditions and variations, Dr. Scheel was afforded the best of all possible opportunities to test the utility of the calculation methods that he had developed earlier in Karlsruhe. The success of these methods was simply astounding. The practical results agreed with his calculations so closely that we had never seen anything like it, not even in the simplest calculations for electron tubes with constant penetration factors.

Karl Steimel's leadership promoted the trend in industrial laboratories of using mathematical methods. About Scheel's contributions, he continued:

One type of electron tube had been developed to the extent that it was sent over to the factory, where a larger number of samples was produced. The sample created by the factory indicated a deviant result in its characteristic curve. By recalculating this result and comparing it to that of the original curve, it was revealed that the diameter of its grid had to be 3.0 mm instead of 2.7 mm. A subsequent control test confirmed, in fact, that the factory had accidentally used a 2.7 mm grid instead of the 3.0 mm grid that had been prescribed.¹¹³

Enthusiastic about the possible applications of mathematics, Steimel stressed that the utility of theory to industrial research had been demonstrated beyond any doubt. He went on to note that, in several urgent cases, tube designs based exclusively on calculations had been put directly into production without the need for the factory to produce samples, and that such a practice could result in a savings of up to 5,000 Realm Marks.

During Steimel's tenure as the director of the development division, Osram's former electron tube researchers continued to work on Sickingenstraße in Berlin-Moabit, and Telefunken's original researchers remained at their accustomed site on Maxstraße in Berlin-Schöneberg. A division of experimental laboratories, which was led by Willy Statz, was also located on Sickingenstraße.

113 The complete text of this document – “On the Work and Position of Dr. J. E. Scheel in the Electron Tube Laboratory of the Telefunken Corporation” (November 16, 1937) – is reproduced in Appendix 6, which also contains an outline of the organizational structure of Telefunken's electron tube division for the year 1937. Scheel's *Habilitationsschrift*, “Zur Bestimmung der Steuerspannung von Elektronenröhren mit unveränderlichem Durchgriff längs der Systemachse” [On Determining the Control Voltage of Electron Tubes with a Constant Penetration Factor along the Axis], was published in the *Archiv für Elektrotechnik* 29 (1935), pp. 47–69, and was accepted in Karlsruhe on July 10, 1937 (see [UA Karlsruhe] 21011, 389).

Table 11: The Organization of Electron Tube Research at Telefunken
(July 1939).¹¹⁴

11a: Electron Tube Development

Rö/E	<i>Röhrenentwicklung</i> 'tube development'	Dr. Karl Steimel Department Head	Maxstraße
Rö/E-1	Research and Pre-Development	Dr. Erik Scheel	Maxstraße
Rö/E-2	Miniature Tubes for the Military	Dr. Werner Kleen ¹¹⁵	Maxstraße
Rö/E-3	Transmitter Tubes and Applications	Dr. Rudolf Hofer ¹¹⁶	Maxstraße
Rö/E-4	Transmitter Tube Development	Dr. Erich Hoepner	Sickingenstraße 71
Rö/E-5	Magnetic Field Tubes	Dr. Karl Fritz ¹¹⁷	Maxstraße
Rö/E-6	Radio Broadcasting Tubes	Dr. Herbert Daene	Sickingenstraße 71
Rö/E-7	Radio Tube Sales Engineering	Rudolf Schiffel	Maxstraße
Rö/E-8	Television Tubes	Dr. H. Knoblauch	Maxstraße
Rö/E-Z	Central Engineering	Dr. Carl Zickermann ¹¹⁸	Maxstraße
Rö/E-P	Test Facilities for Control Samples and Customer Complaints	Dr. Paul Wolf ¹¹⁹	Sickingenstraße 71
Rö/E-P 1	Test Bay for Radio Tubes	Dr. W. Wehnert ¹²⁰	Sickingenstraße 71
Rö/E-P 2	Test Bay for Miniature Military Tubes	Dr. Helmut Biskamp ¹²¹	Maxstraße

114 [DTMB] 00005 (the Telefunken telephone directory for 1939).

115 Werner Kleen earned his doctorate in 1931 from the University of Heidelberg, where he also completed his *Habilitation* in 1942. He worked at Telefunken's electron tube laboratory from 1931 to 1946 (see [DTMB] 7779; 6734; POGG.).

116 Rudolf Hofer's dissertation – "Leistungsmessung mit Elektronenröhren" [Measuring the Performance of Electron Tubes] – was written under the direction of the electrical engineer Hans Piloty at the Technical University in Munich and accepted on January 1, 1937 (see [HATUM] PromA, HoferR.). On August 1, 1941, he transferred from Telefunken to Siemens, where he directed the test facility for large electron tubes (see [DTMB] 1552).

117 Karl Fritz wrote a mathematically formidable dissertation: "Die Messung der ponderomotorischen Strahlungskraft auf Resonatoren im elektromagnetischen Feld" [Measuring the Ponderomotive Radiation Force upon Electromagnetic Resonators] (*Annalen der Physik* 403 (1931), pp. 987–1016), for which he was passed *magna cum laude* by Karl Försterling and Hans Rukop in Cologne ([UA Köln] Phil. Fak. Prom.-Akte 719).

118 In 1933, Carl (Karl) Zickermann was awarded a doctoral degree by the University of Hamburg for a thesis entitled "Adsorption von Gasen an festen Oberflächen bei niedrigen Drucken" [The Adsorption of Gases on Solid Surfaces at Low Pressures], portions of which were printed in the *Zeitschrift für Physik* 88 (1933), pp. 43–54.

119 Paul Wolf completed his doctorate in technical physics at the University of Cologne.

120 Waldemar Wehnert earned a doctoral degree from the University of Leipzig for a dissertation entitled "Untersuchungen an hochohmigen Siliziumkarbid- und Kohlenstoffwiderständen mit Gleichstrom- und Hochfrequenzbelastung" [Studies in High-Resistance Silicium Carbide and Carbon with Continuous Current and High Frequency Loading] (see JAHRES-VERZEICHNIS 41 [1925], p. 609).

121 Having studied technical physics at the Technical University in Darmstadt (see [UAD] Diplomakte), Helmut Biskamp completed a dissertation titled "Untersuchungen an den Spektren von CO⁺, SH und S₂" [Studies in the Spectra of CO⁺, SH, and S₂], which was published in the *Zeitschrift für Physik* 86 (1933), pp. 33–47.

Rö/E-P 3	Test Bay for Air-Cooled Transmitter Tubes	Dr. Helmut Biskamp	Maxstraße
Rö/E-P 4	Test Bay for Water-Cooled Transmitter Tubes	Erich Doelle	
Rö/E-W	Work Station	Dr. Kurt Richter	Maxstraße

11b: Experimental Laboratories

RöW/Vs	<i>Röhrenwerke/Versuchstellen</i> ‘Tube Factory/Test Stations’	Dr. Willy Statz Department Head	Sickingenstraße
	Large Electron Tubes	Dr. Peter Kniepen	Sickingenstraße
	Miniature and Radio Tubes	Dr. Günther Hermann	Sickingenstraße
	Television Tubes	Dr. Walter Heinze	Sickingenstraße
	Cathode Construction	Alexander Schmidt	Sickingenstraße
	Metallurgy	Ernst Woeckel	Sickingenstraße
	Glass Engineering	Dr. Werner Düsing	Sickingenstraße
	Ceramics, Luting	Dr. Hans Pulfrich ¹²²	Sickingenstraße
	Materials Physics ¹²³	Dr. Anton Weber	Sickingenstraße
	Electrical Measuring Instruments	Fritz Köppen	Sickingenstraße
	Chemical Analyses and Preparations	Dr. Maximilian Schriel ¹²⁴	Sickingenstraße

Iris Runge worked together with colleagues both from the experimental laboratories and from the development department. In 1939 and 1940, her laboratory reports still bore the stamp of her previous office, namely R-10, but as of 1941 they began to appear with the designation Rö/E-1. Her reports were prepared for each of the following supervisors: Dr. Rukop, Dr. Steimel, Dr. Scheel, Dr. Kleen, Dr. Hoepner, Dr. Daene, and Dr. P. Wolf.

The department Rö/E-1 was led by Erik Scheel, and part of its staff comprised an identifiable mathematical research group. In addition to Iris Runge, this group included Johannes Müller and Max Geiger, both of whom had learned the new methods of calculation as students of electrical engineering. Müller’s doctoral research was conducted under Otto Schumann at the Technical University in Munich, and he proceeded to develop, among other things, equations for calculating the parameters of multi-grid electron tubes.¹²⁵ In 1936 and 1937, while still at Osram, Iris Runge had familiarized herself with these equations and expanded their

122 Hans Pulfrich earned his doctoral degree from the University of Jena in 1924 for a dissertation concerned with the hydration processes of cement; later he would develop methods of producing ceramic for electron tubes (see [DTMB] 0005).

123 As of 1943, the “Experimental Laboratory for Material Physics” would be co-directed by Anton Weber, Hildegard Warrentup, and Siegfried Wagener (see [DTMB] 06236).

124 Maximilian Schriel’s dissertation “Über die Einwirkung von Bariummetall auf Bariumoxyd bei höheren Temperaturen” [On the Effect of Barium Metal on Barium Oxide at Higher Temperatures] was accepted in 1936 by the Technical University in Berlin.

125 See J. Müller, “Magnetische Untersuchungen an dünnen Drähten. 1. Widerstandsänderung v. Nickel, Eisen u. Wismut in tonfrequenten Wechselmagnetfeldern, 2. Permeabilität v. Nickel u. Eisen bei sehr kleinen Wellenlänge $\lambda = 4\text{--}10$ Meter,” *Zeitschrift für Physik* 88 (1933), pp. 277–294, 143–160; and [HATUM] PromA., MüllerJ.

applicability.¹²⁶ It is noteworthy that Müller also formulated calculation methods for determining the sensitivity of radio receivers, for which he incorporated a novel theory of hollow conductors that had been developed at the Bell Labs in 1936.¹²⁷ Like Erik Scheel, Max Geiger was a product of the Technical University in Karlsruhe, where he earned his *Diplom* in the field of theoretical electrical engineering (1934). After working briefly for Siemens & Halske, he joined Telefunken in 1935, where he was initially employed in the field of television technology. Such research, however, was soon reduced on account of the increasing demands of the military, and thus he was reassigned to concentrate on decimeter wave technology, which was relevant to transmitters, circuits, and electron tubes.¹²⁸ Devoted to electron tube research since the early months of 1940, Geiger was occupied with problems similar to those assigned to Iris Runge. Among these were problems of electron transit time, a topic on which he wrote his doctoral thesis, which was submitted to the Technical University in Karlsruhe on April 15, 1943.¹²⁹

Telefunken's research division, which was still under the leadership of Hans Rukop, was restructured yet again on July 1, 1943 (Table 12). At that time, the division employed approximately 1,500 academically trained personnel, many of whom were called upon to contribute to military research.¹³⁰ The new position of *laboratory manager* was created, under which at least two laboratory directors were subordinated. The research division was divided into departments for high frequency, low frequency, television technology, and electron tubes, and these were themselves subdivided into various laboratories. Although the focus below will strictly be on the electron tube departments, it should be mentioned that it was possible to identify a mathematical research group among the department of television research. A recorded speech given by Rolf Rigo, who had worked at Telefunken's department of television research from 1939 to 1945, reveals that the sub-department of electron research (known as F6 and led by Max Knoll) consisted of three distinct research groups: The first was concerned with image recording tubes, the second with image display tubes, and the third was a group of mathematicians – "They made calculations."¹³¹ It was common for the different

126 See Iris RUNGE 1937a, p. 127; and Section 3.4.5.1 below.

127 See [DTMB] 5086; and FRÄNZ 1986, p. 8. For the theory in question, see John R. Carson, Sally P. Mead, and S. A. Schelkunoff, "Hyper Frequency Wave Guides – Mathematical Theory," *Bell System Technical Journal* 15 (1936), pp. 310–333.

128 In the summer of 1940, researchers formerly assigned to television technology were transferred to work under Wilhelm Runge (see [DTMB] 4413, p. 46).

129 Max Geiger's doctoral degree was conferred on May 27, 1944 (see [UA Karlsruhe] 21013, 1057), and his dissertation was titled "Allgemeine und spezielle Laufzeitverhältnisse beim Elektronenübergang in der Längsfeldkammer" [General and Special Transit Time Ratios in the Case of Electron Transitions within a Longitudinal Field Chamber].

130 See HANDEL 1999, p. 263.

131 The sources on these research groups are extremely scarce. In 2008, at the [Archiv des Elektromuseums] in Erfurt, I came upon a recorded lecture that Rolf Rigo had delivered to the *Gesellschaft der Freunde der Geschichte des Funkwesens e.V.* [Society of Friends of the History of Broadcasting].

departments to collaborate with one another. For instance, the textbooks on electron tubes written by Werner Kleen and Horst Rothe, the latter of whom directed the high frequency research department, were sure to include Iris Runge's latest findings.¹³²

Table 12: The Structure of Telefunken's Research Division (July 1, 1943)¹³³

Department LH	High Frequency Laboratory	Dr. Horst Rothe ¹³⁴ (Department <i>Head</i>)
LH 1 to LH 4	LH 1 unstaffed	Laboratory Managers
Department LN	Low Frequency Laboratory	Dr. Hugo Lichte ¹³⁵ (Department <i>Head</i>)
LN 1 to LN 4	LN 2 unstaffed	Laboratory Managers, Lab. Directors
Department F	Television and Research	Prof. Dr. Fritz Schröter ¹³⁶
F 1 to F 7	F 1, F 3 unstaffed	(Department <i>Director</i>) Laboratory Managers, Lab. Directors
Department RøE	Electron Tube Development	Dr. Karl Steimel (Department <i>Director</i>)
RøE/Z	Central Engineering	Laboratory Director: Dr. Hans Kraft ¹³⁷
RøE 1	Research and Pre-Development	Laboratory Manager: Dr. Erik Scheel
RøE 1a		Lab. Director: Dr. Johannes Müller
RøE 1b		Laboratory Director: Max Geiger
RøE 2	Miniature Tubes for the Military	Laboratory Manager: Dr. Werner Kleen
RøE 2a		Lab. Director: Dr. Walter Graffunder ¹³⁸
RøE 2b		Laboratory Director: Dr. Harry Huber

132 See ROTHE/KLEIN 1940, 1941, 1955; and Section 3.4.5 below.

133 [DTMB] 3483, pp. 63–65 (announcement of June 6, 1943, No. 4/43); 6236; PD 3114.

134 Advised by Heinrich Barkhausen at the Technical University in Dresden, Horst Rothe was awarded a doctoral degree in 1925. After working under Walter Schottky at the University of Rostock, he joined Telefunken as a laboratory director in 1927, and he continued to work for Telefunken after 1945 (see Chapter 5).

135 Hugo Lichte was another product of the interdisciplinary research center at the University of Göttingen, where he earned his doctorate under Hermann Theodor Simon in 1913. He was employed by Telefunken from 1931 to 1945 (see POGG.).

136 Fritz Schröter, who earned a doctoral degree in applied chemistry in 1909, also had a background in electrical engineering. Hired by Telefunken in 1920, he played an instrumental role in television research, especially in the application of Braun tubes. In 1931, having attained more than 170 patents, he became an honorary professor at the Technical University in Berlin (see POGG.; NDB). Iris Runge, incidentally, conducted mathematical research on Braun tubes for Osram in 1931 and 1932 (see Appendix 5.4, No. 3).

137 In 1941, Hans Kraft's office of central engineering, which was chiefly responsible for overseeing the production of electron tubes for the military, was directly accountable to Karl Steimel, the department director. Kraft's doctoral degree was awarded by the University of Göttingen, and his dissertation – "Die Diffusion des Kristallwassers" [The Diffusion of Water of Hydration] – appeared in *Zeitschrift für Physik* 110 (1938), pp. 303–309.

138 Graffunder had completed his *Habilitation* at the University of Frankfurt (am Main) in 1933, and did not become a lecturer for political reasons. In 1934 he joined Telefunken, where he achieved remarkable results on the flicker effect in receiver tubes. In 1950 he became an associate professor at the University of Fribourg in Switzerland. For further biographical details, see NDB 6 (1964), p. 734.

RöE 3	Design and Application of Transmitter Tubes	Lab. Director: Dr. Fritz Hülster ¹³⁹
RöE 4	Transmitter Tube Development	Laboratory Manager: Dr. Erich Hoepner
RöE 4a		Lab. Director: Dr. Wolfgang Rohde
RöE 5	Magnetron Tubes	Laboratory Director: Dr. Karl Fritz
RöE 6	Radio Broadcasting Tubes	Laboratory Manager: Dr. Herbert Daene
RöE 7	Radio Tube Sales Engineering	Laboratory Director: Rudolf Schiffel
RöE/W	Electron Tube Work Station	Laboratory Director: Dr. Kurt Richter
RöE/P	Test Bays for Control Samples and Customer Complaints	Manager: Dr. Paul Wolf
RöE/P-1		Director: Dr. Waldemar Wehnert
RöE/P-2		Director: Dr. Helmut Biskamp
RöE/P-3		Director: Günther Wolf

1943 saw another organizational change in the field of electron tube research. In addition to his duties as the director of Telefunken's department of electron tube development, Karl Steimel was also appointed by the government to oversee the nationwide production of these devices (see Section 4.3.3).

In 1944, large parts of the Telefunken electron tube factory in Berlin were relocated to areas that were presumably less endangered by the war, and Iris Runge was transferred to the company's ceramics plant in Liegnitz. Most of Telefunken's departments for development, experiments, and assembly were in fact moved to the Lower Silesian – now Polish – cities of Liegnitz and Reichenbach im Eulengebirge (Legnica and Dzierżonów, respectively).¹⁴⁰ Iris Runge's last research report for Telefunken – at least among those that have been preserved – was submitted in Liegnitz on November 7, 1944 (see Appendix 5.2).

When, in 1947, Telefunken wished to reopen its electron tube operations in western Berlin, the British occupying authorities required that a list be submitted containing the names, addresses, and specializations of the firm's former and current employees. Among the sixty-two people who appear on this list, Iris Runge stands as the only female researcher. At the same time, she is also the only person whose earlier activity at Telefunken is designated with the following words: "specialized in treating mathematical valve problems."¹⁴¹

139 Fritz Hülster conducted his doctoral research at the University of Cologne at the time when Hans Rukop was working there as a professor of technical physics. His dissertation, which was entitled "Zeitliche Phänomene, Ausbreitung und Stabilisierung bei großen Magnetisierungsprüngen" [Temporal Phenomena, Propagation, and Stabilization in the Case of Large Magnetization Jumps], appeared in the *Zeitschrift für technische Physik* 13 (1932), pp. 516–531.

140 See [DTMB] 6659, which is a list containing names of researchers, departments, and relocations. It is known that Dr. Werner Kleen had already been transferred to Liegnitz in 1943 to direct a laboratory devoted to decimeter and centimeter tubes (see BOGNER 2002c).

141 [DTMB] 6734, pp. 19–35. Excerpts of this list are reproduced in Appendix 10 and Plate 15; see also Chapter 5.

3.3 SCIENTIFIC COMMUNICATION AT THE LOCAL, NATIONAL, AND INTERNATIONAL LEVEL

On my first day, Jacoby asked me to attend a lecture on X-ray crystallography that was to be held on Friday evening at the Physics Society. At 4:30, as I was about to leave for the day, he dropped by once again to give me a small map with precise directions to the venue.¹⁴²

During the years under consideration, the interwoven relationship between industrial and academic research was showcased especially in Berlin, which was the center of knowledge production in the country. Industrial researchers participated in a tight network of scientific communication,¹⁴³ and corporations placed a high value on their qualifications and on their ability to expand and influence this very network. They also earned postdoctoral degrees at the Technical University in Berlin and accepted part-time appointments as professors, as has already been noted in the cases of Georg Gehlhoff, Marcello Pirani, and Reinhold Rüdberg.

About the scientific presentation mentioned in the quotation above, which was a lecture by Michael Polanyi on “Structural Analyses by Means of X-Rays,” Iris Runge wrote:

It was at the Technical University at 7:30 in the evening. Osram’s other doctors were there – Gerdien, too, and Dr. Masing, Dr. Gehlhoff, and Dr. Mey. The lecture was very good, though the presentation could have been clearer. In any case, Dad, it contained some new things that I didn’t already know: images created with the rotating crystal method and conclusions pertaining to the straight lines that are perpendicular to the rotational axis and upon which diffraction spots are arranged on a cylindrical film. Jacoby, who saw that I had greeted Gerdien, later gave me a cautionary speech in which I was warned not to reveal anything about my work.¹⁴⁴

From this letter it is clear that the exchange of scientific ideas was not without certain restrictions. The latest research findings made in industrial laboratories were not, of course, to be shared with representatives of competing firms. Hans Gerdien, whom Iris Runge names in the letter, knew her from Göttingen. He had been responsible for developing Siemens & Halske’s physical and chemical laboratory, directed by him since 1912, into a central research laboratory that served both Siemens & Halske and Siemens-Schuckertwerke. In 1922, Siemens delegated

142 A letter from Iris Runge to her parents dated March 4, 1923 [Private Estate]. Iris Runge began working at Osram on March 1, which was a Thursday. On the following day she attended a gathering of the German Society of Technical Physics at which Michael Polanyi, who then directed a department at the Kaiser Wilhelm Institute of Fiber Chemistry, gave a lecture. For notes on the latter event, see *Zeitschrift für technische Physik* 4 (1923), p. 135.

143 See GOSCHLER 2000.

144 A letter dated March 4, 1923 [Private Estate]. Michael Polanyi, a Hungarian scientist, was born into a Jewish family but later converted to Christianity. He is known for his significant findings in the areas of kinetics, X-ray diffraction, and the adsorption of gases on solid surfaces. In 1921, Polanyi developed the mathematical foundation for fiber diffraction analysis. Having been working at the Kaiser Wilhelm Institute of Fiber Chemistry in Berlin since 1920, he went into exile in Great Britain in 1933. The rotating crystal method, it should be noted, is used to determine crystalline structures.

all of its unfulfilled research assignments to Gerdien's large-scale industrial facility, which Osram regarded as competition despite the fact that Siemens & Halske was one of its parent companies.

Georg Masing, whom Iris Runge also mentioned, was another former student of Gustav Tammann in Göttingen. After earning his doctorate in 1909, he was hired by the firm Erich & Graetz in Berlin, which produced street lamps, and in 1916 he joined Siemens & Halske's light bulb factory, which would become part of Osram a few years later. In 1922, however, Masing left Osram to run the department of metallography at Siemens's central research laboratory.¹⁴⁵

Despite the obligation for confidentiality with respect to sensitive data, it was nevertheless in the interest of businesses to encourage and enable their researchers to publish most of their findings. The foundation of new scientific journals by industrial researchers was a trend that began in the early 1920s, a time when many periodicals in Germany were struggling to survive, and it is indicative of the degree to which the scientific work undertaken in the private sector had risen to prominence. The quality of these new publication outlets was considered to reflect the economic clout of the businesses that supported them. Such periodicals included the *Zeitschrift für technische Physik* [Journal of Technical Physics], which was founded in 1920 by Georg Gehlhoff (Osram) and Hans Rukop (Telefunken), as well as specialized trade journals such as the *Wissenschaftliche Veröffentlichungen aus dem Siemens-Konzern* [Scientific Publications of the Siemens Corporation], which was likewise established in 1920; the *Jahrbuch des Forschungsinstituts der AEG* [Yearbook of the AEG Research Institute], which first appeared in 1929; the *Technisch-wissenschaftliche Abhandlungen aus dem Osram-Konzern* [Technical and Scientific Publications of the Osram Corporation], which was inaugurated in 1930; and *Die Telefunken Röhre* [Telefunken Tube], the first issue of which was published in 1934. The purpose of these publications was both to keep researchers up to date in the field and to advertise new products, and thus the economic utility of published theoretical findings was made implicit by the fact that such results appeared alongside promotions for the very products that they had helped to create.¹⁴⁶ Businesses also financially supported the publication of books written by their employees (on such topics as graphical methods, the application of statistics, electron tubes, technical physics, and so on).

It was not long before Iris Runge became a recognized member of the scientific community in Berlin. She was invited, for instance, to tour the Hahn-Meitner departments, which were part of the Kaiser Wilhelm Institute for Physical Chemistry, and she received invitations to attend all of the official engagements held

145 For more details of Georg Masing's biography, see FELDTKELLER/GOETZELER 1994, pp. 65–69. Masing, incidentally, wrote a very warm review of BECKER/PLAUT/RUNGE 1927 (see Section 3.4.2.3).

146 See the first article in the inaugural volume of the *Technisch-wissenschaftliche Abhandlungen* (RUNGE 1930); and SCHULTICH 1985, p. 90. For an evaluation of the *Bell System Technical Journal*, which was founded in 1922, see ECKERT/SCHUBERT 1986, p. 131.

by the community of physicists and physical chemists, which had many international connections. The historian Michael Eckert has already discussed the international quality of Arnold Sommerfeld's intellectual circle,¹⁴⁷ and this same quality was no less prevalent in Berlin. A special celebration was held, for instance, when the American scientist Irving Langmuir, the aforementioned student of Walther Nernst, visited the city in 1930, and Iris Runge wrote the following about the event to her mother: "Two weeks ago, moreover, [...] an event was held in Dahlem in honor of Irving Langmuir, and I was invited to attend. There I also had the opportunity to speak to Planck [...]. So now you see that, in the world of physicists here, I finally number among the top 10,000 personalities!"¹⁴⁸

Beyond putting in their normal working hours, industrial researchers in Berlin were also expected to attend scientific conferences. These events were instituted by a variety of organizations, including the *Deutsche Gesellschaft für technische Physik* [German Society for Technical Physics (est. 1919)], the *Deutsche Beleuchtungstechnische Gesellschaft* [German Society for Lighting Technology (est. 1912)], the *Deutsche Glastechnische Gesellschaft* [German Society for Glass Technology (est. 1922)], the *Verband deutscher Elektrotechniker* [Association of German Electrical Engineers (est. 1893)], and the *Berliner Elektrotechnischer Verein* [Berlin Society of Electrical Engineering (est. 1879)]. This aspect of working as a researcher at international corporations has already been analyzed to some extent by Michael Eckert and Helmut Schubert.¹⁴⁹

The German Society for Technical Physics, which was initiated by the Osram director Georg Gehlhoff, was supported not only by Osram but also by its parent companies, AEG and Siemens, as well as by Telefunken, the Optische Anstalt C. P. Goerz and the Carl Zeiss Corporation (both manufacturers of optical instruments), and by a number of businesses in the chemical industry.¹⁵⁰ The majority of Osram's researchers became members of this society, among them the chemist Richard Jacoby and the physicists Walter Heinze and Ellen Lax. Although Iris Runge chose not to join the organization officially, she nevertheless participated regularly in its meetings.¹⁵¹

Beginning in 1926, Iris Runge would give several talks to the Society for Lighting Technology, which had been founded by Emil Warburg, who was then

147 See ECKERT 1996.

148 A letter dated March 23, 1930 [Private Estate]. Two years later, in 1932, Irving Langmuir was awarded the Nobel Prize for his work in the field of surface chemistry (a field to which the autodidact Agnes Pockels had also made significant contributions). Langmuir was later awarded an honorary doctoral degree by the Technical University in Berlin, an honor mentioned on page VIII of that university's course catalogue (*Vorlesungsverzeichnis*) in 1944.

149 See ECKERT/SCHUBERT 1986, pp. 131–132. On working for the Siemens Corporation in particular, see SERCHINGER 2008.

150 See GEHLHOFF 1929, p. 197; HOFFMANN/SWINNE 1994.

151 Iris Runge and Ellen Lax were often the only women to take part in these conferences, and they made a habit of meeting in a restaurant afterwards to discuss the proceedings (see a letter dated July 22, 1923 [Private Estate]). For a list of the Society's members, see [Swinne].

the president of the Imperial Institute of Technical Physics.¹⁵² This she did despite her relatively low estimation of these meetings in Berlin. While in Jena for this society's national conference, which she attended with Marcello Pirani in 1924, she detected qualitative differences among the researchers in the field:

The general meeting of the Society for Lighting Technology was not nearly as boring as the meetings of its Berlin branch always are. Four of the five presentations were given by members of the Society from Jena, the remaining one by a member from Berlin, and the quality of the presentations from Jena was, I noticed, markedly superior.¹⁵³

Jena's reputation for excellence in the field of optics owes much to the efforts of Ernst Abbe, a pioneer in scientific optical technology who had encouraged close collaboration there between academic and industrial researchers. As a professor of mathematics and physics – and concurrently as Carl Zeiss's business partner – Abbe had not only developed the requisite mathematical and physical groundwork for building certain optical instruments (the microscope among them), but he had also promoted, with the help of the Carl Zeiss Foundation, the establishment of additional professorships for physics and mathematics, including one devoted exclusively to microscopy.¹⁵⁴ Iris Runge's own subsequent work in this field – optics and colorimetry, in particular – would coincide with a period during which the Society for Lighting Technology cooperated closely with other organizations, in Berlin and throughout the country, and regularly co-sponsored meetings with the Society for Technical Physics, the *Architektenverein* [Association of Architects], and the *Deutsche photographische Gesellschaft* [German Photographic Society].¹⁵⁵

Osram paid for its researchers to attend national and international congresses and also allocated a number of days – not counted toward their vacation – during which these researchers were free to attend any other scientific affair that might have caught their eye. After only two months at the company, Iris Runge wrote the following enthusiastic note to her father:

Dear Dad,
Just imagine – next week I get to travel to Hanover at Osram's expense to attend the annual meeting of the Bunsen Society. Jacoby made me aware of this only yesterday, and completely out of the blue! He will be going as well. [...] An entire day there will be dedicated exclusively to X-ray crystal structures.¹⁵⁶

New advances in the field of X-ray structure analysis, which were salient to theoretical physics and materials research alike, were quickly incorporated into both academic and industrial research agendas. The Bunsen Society (*Bunsengesell-*

152 See LUXBACHER 2001; and Section 3.4.4 below.

153 A letter to her parents dated October 8, 1924 [Private Estate].

154 See the *Ernst-Abbe-Sonderband* (Jenaer Jahrbuch zur Technik- und Industriegeschichte 7, 2005); and TOBIES 1984.

155 See LUXBACHER 2001, p. 15.

156 A letter dated May 8, 1923 [Private Estate].

schaft), a society for physical chemistry founded in 1894, had declared crystal physics to be the theme of its 1923 convention, an event that attracted a larger crowd than was typical.¹⁵⁷ While in Hanover, Iris Runge reunited with her doctoral supervisor, Gustav Tammann, and also took the opportunity to introduce her father to Richard Jacoby. Jacoby, who had already familiarized himself with Carl Runge's book on vector analysis, promptly responded to meeting its author by inviting him to give a lecture in Berlin (see Section 3.4.1.1).

In September of 1923, Iris Runge attended the annual convention of German mathematicians and physicists, which took place in Bonn.¹⁵⁸ This meeting captivated her theoretical interests and expanded her professional and scientific contacts. It was here and not in Berlin, for instance, that she first met the physicist Richard Becker, who was working for the Research Society for Electric Lighting at Osram's Factory D. Both of them, it turned out, had been inspired to pursue theoretical physics by Arnold Sommerfeld, and they made sure to collaborate in the future.¹⁵⁹ Each researcher, of course, had his or her own specific reasons for joining one professional society or another, and Iris Runge chose to become a member of the German Physical Society (*Deutsche Physikalische Gesellschaft*) on account of the predominantly theoretical nature of her work. Marcello Pirani served as the treasurer of this organization from 1924 to 1929, and Iris Runge's membership to this society, which was officially acknowledged on November 14, 1924, had been sponsored by none other than her colleague Richard Becker.¹⁶⁰

157 See JAENICKE 1994, p. 99.

158 A letter from Iris Runge to her parents dated September 29–30, 1923 [Private Estate]. A combined gathering of German physicists and mathematicians had been introduced in 1921 as a reaction to the 1920 decision of the *Gesellschaft Deutscher Naturforscher und Ärzte* [Society of German Natural Scientists and Physicians] to meet only every other year (see TOBIES 1996b).

159 In a letter to her mother dated February 10, 1924 [Private Estate], Iris Runge remarked: "This week I had a truly pleasant experience. One of Osram's employees, Dr. Becker, a very kind man from Hamburg whom I got to know in Bonn (he is, by the way, eminently clever and will certainly make something of himself – he's more theoretically than experimentally inclined, too) invited me to accompany him and his wife to the 'Blue Bird', which is said to be the most extravagant, brilliant, and stimulating cabaret in all of Berlin." In 1910, Richard Becker earned a doctorate in zoology at the University of Freiburg, where he had been a student of August Weismann. Having been influenced by Arnold Sommerfeld in Munich, he then turned his attention to physics. He joined Osram after having worked at the Kaiser Wilhelm Institute for Physical Chemistry and for the explosives industry, and while at Osram, in 1922, he completed his *Habilitation* in theoretical physics at the University of Berlin (Max Planck was his director). His main field of research became the thermodynamic theory of materials, including the physics of shock waves, plasticity theory, ferromagnetism, superconductivity, nucleation, and crystal growth. His work on the theory of nucleation constituted a significant contribution to the field of statistical physics. For further discussion of his mathematical and statistical collaborations with Iris Runge, see Section 3.4.2.

160 See *Verhandlungen der Deutschen Physikalischen Gesellschaft* (1924), p. 54. I am indebted to Dr. Stefan Wolff for bringing this reference to my attention.

Iris Runge traveled to attend several annual conventions of the Society of German Natural Scientists and Physicians, in addition to special conferences for physicists and mathematicians. Records indicate that she attended the conventions held in Innsbruck (1924), Hamburg (1928), Prague (1929), Nauheim (1932), and Bad Kreuznach (1937). In the latter city and in Hamburg as well, she is known to have presented research of her own.¹⁶¹ As a research director at Osram, Pirani ensured that the attendance of conferences did more than serve the individual interests of the scientists under his charge; he required conference attendees to prepare summaries of new findings for Osram's in-house reports.¹⁶²

Through their membership in professional societies, researchers working in industrial laboratories, at universities, and at government-sponsored research institutions (the Kaiser Wilhelm Society, the Imperial Institute of Technical Physics, etc.) came into close contact, and this contact often resulted in collaborative research projects.¹⁶³ The appointment of outstanding industrial researchers as part-time, honorary, or endowed professors at the Technical University in Berlin, a phenomenon that has already been mentioned, is perhaps the clearest reflection of the extent to which academic and industrial research had become intertwined. Among the industrial researchers who received such professorial appointments were Reinhold Rüdenberg in 1919 (high-frequency and high-voltage engineering), Marcello Pirani in 1922 (physics and lighting technology), Georg Gehlhoff in 1923 (technical physics), August Gehrts in 1927 (applied electronics), Karl Willy Wagner in 1927 (general oscillation theory), Fritz Schröter in 1931 (television technology), Georg Masing in 1935 (metals research), and Wilhelm Cauer in 1939 (applied mathematics).¹⁶⁴ In 1926, Richard Becker left Osram for a permanent position at the Technical University in Berlin, namely a newly established professorship in theoretical physics. Because of their associations with the Technical University, each of these researchers was in an excellent position to recruit talented students to work in industrial laboratories.

To facilitate the dissemination of scientific knowledge from the academy to the private sector, and vice versa, these professors also organized lecture series at the *Außeninstitut* – “Outreach Institute” – of the Technical University in Berlin. Institutes of this sort, which existed at several technical universities in Germany, were centers of advanced studies that served as bridges between the academy and the public. As a researcher at Osram, Iris Runge was once called upon to participate in just such a series. Since the middle of the 1920s, the Technical University in Berlin hosted lectures on the following themes, among others: partial differen-

161 For the published results of these presentations, see Iris RUNGE 1928b and 1937b.

162 See [LAB] 280, vol. 1.

163 Science historians have yet to analyze these collaborations in great depth. For a study of how Robert Rompe (of Osram's Research Society) cooperated both with the Kaiser Wilhelm Society as well as with the faculty at the University of Berlin, see NAGEL 2007b.

164 See the course catalogue of the Technical University of Berlin. August Gehrt's position in applied electronics, incidentally, was the first in this field at a German university.

tial equations and engineering (delivered in 1925 by Rudolf Rothe), the fundamentals of radio receivers (delivered in 1927 by Karl Willy Wagner), quality control based on statistical methods (delivered by Iris Runge and others in 1928 and 1929), electrothermics (by Marcello Pirani in 1930), and the application of operator theory in physics and engineering (by Karl Willy Wagner in 1935).¹⁶⁵

To what extent, it should be asked, was Iris Runge involved in the mathematical circles of her day? It is immediately apparent that a close relationship existed at the time between mathematicians and physicists, given that their respective professional societies held an annual conference together. In her correspondence, Iris Runge customarily mentioned to her parents the various personalities whom she encountered at these meetings. These people included, in addition to physicists,¹⁶⁶ such mathematicians as Otto Blumenthal – David Hilbert’s first doctoral student and a professor in Aachen (where he was an acquaintance of Erich Trefftz) until 1933 – and Friedrich-Adolf Willers, a student of her father with whom she consulted on matters of nomography until well into the 1940s.¹⁶⁷

Iris Runge did not belong to the German Mathematical Society (*Deutsche Mathematiker-Vereinigung*), nor is there evidence that she was a member of the Society for Applied Mathematics and Mechanics (*Gesellschaft für angewandte Mathematik und Mechanik*). Since 1923, however, she had been personally acquainted with Richard von Mises, a co-founder of the latter society and the founder of its journal, the *Zeitschrift für angewandte Mathematik und Mechanik*. It is of some historiographical significance that her first meeting with Richard von Mises took place in the house of Ludwig Bieberbach. With the endorsement of Von Mises, Bieberbach became a professor of mathematics at the University of Berlin in 1921. In April of 1923, Richard Courant brought along his sister-in-law Iris Runge to a gathering at the Bieberbach household, where she received an open invitation to come to their Sunday dinners. She first acted on this invitation on June 17, 1923:

To my surprise, this was an entirely relaxing affair with a proper supper for nine people, the hosts included. The little Bieberbach has a rather sunny disposition and he clearly likes to be in pleasant company. His wife is hospitality itself – plump and portly and highly concerned with the comfort of her guests. Aside from a few people whom I didn’t know, the guests included none other than Laski, and also Erich’s Von Mises [Erich Trefftz’s doctoral supervisor], a rather worldly Austrian who reminded me somewhat of Haar and Kármán, among others. The conversation was remarkably warm; stories were swapped about Koebe and Remak, and the same harmless antics of Trefftz and Renner’s Göttingen years were rehashed yet again.¹⁶⁸

165 See the reports on such professional activity in the *Zeitschrift für technische Physik*; WAGNER 1927; WAGNER 1940; PLAUT 1930; and also KÄNDLER 2009.

166 In Innsbruck in 1924, Iris Runge met the physicist Wolfgang Gaede, a pioneer of vacuum engineering and then a professor in Karlsruhe, with whom she danced and sailed on the Bodensee (see her letters dated October 8, 1924 and August 28, 1925 [Private Estate]).

167 See Section 3.4.1.2.

168 A letter dated June 22–26, 1923 [Private Estate]. With the exception of Von Mises, everyone mentioned in this letter was known to Iris Runge from Göttingen. Gerda Laski, who

Bieberbach had been awarded a doctoral degree in 1910 from the University of Göttingen, and he was a prominent function theorist. During the period of National Socialism he emerged as a vocal anti-Semite and supporter of the Nazi regime,¹⁶⁹ whereas Richard von Mises (like Courant and many other mathematicians and physicists) was forced to emigrate on account of his Jewish background.¹⁷⁰

It is not known whether Iris Runge made any later visits to the Bieberbach household. In her research, she took account of Courant's contributions on the utility of differential equations in physics, Bieberbach's conclusions regarding transformation geometry, as well as Richard von Mises's publications on probability theory. When considering, in July of 1923, to which journal she might submit her recent findings, the *Zeitschrift für angewandte Mathematik und Mechanik* seemed to be out of the question.¹⁷¹ To her father she relayed Marcello Pirani's opinion of the publication – “He seems to have something against Mises's journal” – to which she added: “They seem to be so swamped with manuscripts right now that it would take an eternity for my article to appear.”¹⁷² In her estimation, the article in question, which presented a vector-analytic treatment of certain crystallographical problems,¹⁷³ was better suited to another outlet. It is perhaps safe to surmise that Pirani's attitude toward Von Mises simply reflected the differences that existed between the practical and theoretical researchers of the day.¹⁷⁴

It is difficult to separate Iris Runge's scientific community from her private circle of acquaintances, a circle that, in addition to resulting in collaborative scien-

earned her doctorate in 1917 from the University of Vienna, had worked as Peter Debye's assistant in Göttingen, and was then Heinrich Ruben's research assistant at the University of Berlin. In 1924 she was appointed director of a department at the Kaiser Wilhelm Institute of Fiber Chemistry (see VOGT 2008a, pp. 107–108). On the Göttingen activity of the Hungarians Alfred Haar (who earned his doctorate under David Hilbert in 1909) and Theodore von Kármán (whose doctoral degree was completed there in 1908 under Ludwig Prandtl), and also of Paul Koebe (who finished his *Habilitation* there in 1907), see REID 1976. The mathematician Robert Remak had also spent a few years in Göttingen, as a Jew he was persecuted by the Nazi regime (see SIEGMUND-SCHULTZE 2009).

169 Despite these opinions, Bieberbach associated and published with his Jewish colleagues, and he even attended a costume ball held by the Jewish Reinhold Rüdenberg, an event to which Iris Runge had also been invited (see her letter dated December 26, 1925 [Private Estate]). For a discussion of Bieberbach's racist opinions, see MEHRTENS 1987/1995.

170 See SIEGMUND-SCHULTZE 2009.

171 Edited by Richard von Mises, the *Zeitschrift für angewandte Mathematik und Mechanik* was published by the VDI-Verlag. Its first editorial board consisted of August Föppl, Georg Hamel, Richard Mollier, Heinrich Müller-Breslau, Ludwig Prandtl, and Reinhold Rüdenberg. The journal was considered the successor of the *Zeitschrift für Mathematik und Physik*, which had been edited by Carl Runge and Rudolf Mehmke and which ceased publication during the First World War.

172 A letter dated January 22, 1923 [Private Estate].

173 This particular study never appeared in print. However, she did return to the topic, with new quantitative methods, in 1950 (see Iris RUNGE 1950a, 1950b).

174 On one of Von Mises's critical reviews, see Section 3.4.2.3. I should mention here that Reinhard Siegmund-Schultze is preparing a comprehensive biography of Von Mises; see also SIEGMUND-SCHULTZE 2004.

tific projects, cultivated broader intellectual interests in such things as music, literature, and the fine arts. Beyond her close associations with the extended Du Bois-Reymond family and with her colleagues at Osram, Iris Runge also made frequent visits to the households of Reinhold Rüdenberg and Otto Berg, a physicist.¹⁷⁵ She is known to have gone to the theater with Richard Becker and his wife, at whose home they would also meet to discuss and refine their collaborative work.¹⁷⁶ Such work included their participation in the lecture series at the Technical University in Berlin and also a co-authored book on the application of statistical methods (see Sections 3.4.2.3 and 3.4.2.4).

While enjoying the respect and admiration of her scientific colleagues in general, Iris Runge also made sure to maintain close relationships with her fellow women researchers in Berlin.¹⁷⁷ She was a regular visitor at the homes of Gerda Laski and Lise Meitner,¹⁷⁸ and she took frequent excursions with Charlotte Landé, Cora Berliner, and others. During her first visit to the home of Ellen Lax, who was Pirani's "general secretary," scientific topics stood at the heart of their conversation. There, Lax and the crystallographer Rudolf Groß, who had also been invited, inquired of Iris Runge how a mathematical approach might be formulated to elucidate their work on crystal growth.¹⁷⁹ This type of mathematical consulting – which occupied her free time as well as her work life – exemplifies the nature of her activity throughout the Weimar years; she would later devote her leisure time to pursuing other interests.

Rather than shutting its doors during the period of National Socialism, the German Physical Society continued to operate at a "decelerated" pace, a move that the historian Dieter Hoffmann has attributed to the independent character of the board members Karl Mey (Osram), Jonathan Zenneck, and Peter Debye.¹⁸⁰ Karl Mey was elected to this board in 1933 in an effort to protect the Society from political influences. This appointment was made despite the fact that, since 1931, Mey had also been serving on the board of the German Society for Technical Physics.

Political exigencies also resulted in the need for Osram, during the middle of the 1930s, to create a new means of corporate communication. Written communication at the company suffered dearly on account of Pirani's and Ellen Lax's res-

175 Together with Walter Noddack and Ida Tacke (later Noddack), Otto Berg, who had been working for Siemens & Halske since 1911, discovered the chemical element rhenium (see TILGNER 2000). Iris Runge's relationship with Berg's family is discussed further in Section 4.3.2 below.

176 See a letter from Iris Runge to her mother dated May 28, 1927 [Private Estate].

177 On the interaction that took place among women scientists in Berlin, see Annette Vogt's contribution in LABOUIE 2009, pp. 143–173.

178 See Appendix 7, which reproduces a letter from Iris Runge to Lise Meitner written on November 26, 1938.

179 A letter from Iris Runge to her parents dated July 22, 1923 [Private Estate].

180 See Dieter Hoffmann's article "Die verzögerte Gleichschaltung der DPG" in HOFFMANN/WALKER 2007, pp. 174–184. On Peter Debye, see also REIDING 2010.

ignations in 1936; between that year and 1943, for instance, not a single volume of the series *Technisch-wissenschaftliche Abhandlungen aus dem Osram-Konzern* was published. In September of 1936, the chemist Ernst Friederich, who succeeded Pirani in a number of roles, established a special series of lectures in order to maintain the dissemination of new scientific findings and to keep his employees up to date with respect to national and international conference proceedings (see Table 13). The lectures took place on Friday afternoons at Factory A on Sickingstraße, and it was at such an event that Iris Runge presented a report about her business trip to the United States in 1936.

Even when military research was at its peak in Nazi Germany, industrial scientists remained closely engaged in the international scene. That said, Osram and Telefunken, which cooperated both nationally and internationally in the field of electron tube research, still maintained a strict practice of confidentiality regarding their latest findings, a practice that was also followed during Iris Runge's trip to North America.¹⁸¹ Throughout the 1930s, managers and research directors from these corporations regularly traveled to meet with business partners in Great Britain, the Netherlands, the United States, and elsewhere – trips that also served to facilitate the emigration of exiled or threatened researchers.¹⁸² As late as 1942, Telefunken continued to exchange patents on an official basis with the Radio Corporation of America (RCA),¹⁸³ General Electric, and Westinghouse.¹⁸⁴

The wartime recognition that there was a shortage of German researchers in the field of radio receiver technology, along with the installation of the Telefunken manager Karl Steimel as the nationwide director of electron tube development (see Section 4.3.3), led to a partial cessation of the competitive confidentiality practices that had prevailed among the businesses in this industry. During this time, the research conducted by the military, by private enterprises, and by scientific associations was coordinated in the name of research consortiums with which Iris Runge and other mathematical experts had no choice but to cooperate (see Appendix 5.6). In this light, Helmut Maier's designation of such consortiums as

181 See Section 3.4.5.1, which concerns magnetron research.

182 On the trips made by, among others, Marcello Pirani, Richard Jacoby, Lisa Honigmann, and Iris Runge to the General Electric Company in America, see [LAB] 282, vol. 2; and [DTMB] 6645, pp. 36–41. On February 2, 1931, Osram's executive branch announced, for instance, "that they had agreed to initiate a temporary exchange of young employees with business partners at the General Electric Company in London for the purpose of promoting the international and linguistic experience of these researchers" (quoted from [LAB] 435). For the scientific questions that Osram prepared for a team of Telefunken researchers about to visit America in 1929, see Appendix 4.2.

183 RCA was founded in 1919 as a subsidiary company of General Electric. In 1929, General Electric purchased enough shares of one of Osram's parent companies, AEG, to secure positions on the latter's executive board. On the relationship between these companies, see LUXBACHER 2003, pp. 314–316.

184 See the second volume of SCHARSCHMIDT 2009.

intermediary contributors to advances in military research must undoubtedly be accepted as valid.¹⁸⁵

Table 13: Scientific Lectures at Osram, 1936–1937.¹⁸⁶

- Evening Lecture* (Friday, September 26, 1936): Dr. Walter Heinze, “W. Heinze and S. Wagener, The Activation Process of Oxide Cathodes,” based on a lecture delivered at the physics conference in Bad Salzbrunn.
- Evening Lecture* (Friday, October 9, 1936): Dr. Arved Lompe (Research Society), “The Depletion of Noble Gases in Electric Discharges.”¹⁸⁷
- Evening Lecture* (Friday, November 6, 1936): Iris Runge, “Impressions from my Trip to America.”
- Evening Lectures* (Friday, December 11, 1936): 1) Dr. Waelsch, “The Development of a New Tuning Indicator”; 2) Dr. Walter Heinze, “A Comparison of the Magic Eye Tube with the Glow Indicator Tube.”¹⁸⁸
- Evening Lectures* (Friday, March 12, 1937): 1) Dr. Siegfried Wagener, “On H. Schnitger’s Studies of Spray Discharge in *Zeitschrift für Physik* 102 (1936), pp. 163–182”¹⁸⁹; 2) Günther Herrmann, “On L. Malter: Thin Film Field Emission, in *Physical Review* 50 (1936), pp. 48–58.”¹⁹⁰
- Lecture Series* (Friday, April 6, 1937 to Friday, July 6, 1937): Josef Kammerloher, “High Frequency Engineering.”¹⁹¹
- Evening Lectures* (Friday, October 15, 1937): 1) Dr. Wilfried Meyer, “On the Relationship between the Energy and Emission Constants in the Thermal Conductivity of Semiconductors (W. Meyer and H. Neldel)”; 2) Hans Neldel, “An Adjustable High Ohmic Resistor without Sliding Contact”; 3) Erwin Weise, “Some Examples of Bridge Circuits in Semiconductor Resistors,” based on lectures delivered at the physics conference in Bad Kreuznach.

185 See MAIER 2002, p. 28.

186 [LAB] 444, vol. 2. The lectures held in later years are not documented, but from FRÄNZ (1986, p. 7) it is known that Telefunken held a theoretical colloquium toward the end of the war. The participants included, among others, Karl Willy Wagner – who had studied under Hermann Theodor Simon in Göttingen and became a pioneer in the theory of electronic filters – and the mathematicians Wilhelm Cauer, Helmut Hasse, and Wilhelm Magnus.

187 Arved Lompe, one of the developers of the gas discharge lamp, worked as a professor and as an executive at Osram after 1945. In 1959 he was appointed to the board of the German Physical Society.

188 Osram produced various types of glow indicator tubes for use in radio receivers.

189 Herbert Schnitger worked for the Institute for General Electrical Engineering at the Technical University in Dresden, which was then directed by Adolf Güntherschulze.

190 Louis Malter (discoverer of the Malter Effect), was an employee of the Radio Corporation of America (RCA) in New York City. He earned his Ph.D. from Cornell University in 1936 and was later employed by RCA’s Research and Engineering Department (in Harrison, New Jersey) and for the same company’s Laboratories Division (in Princeton, New Jersey).

191 Josef Kammerloher, a lecturer at the Gauß School of Engineering in Berlin, published a series of textbooks on high frequency engineering. In the preface to KAMMERLOHER 1938, it should be noted, he stressed the importance of mathematical methods to his field.

3.4 MATHEMATICS AS A BRIDGE BETWEEN DISCIPLINES

How it feels to be treated as a mathematical authority!¹⁹²

Within the realm of industrial research, mathematical experts were necessarily called upon to collaborate with colleagues in a great variety of fields, so much so that it can be said with confidence that their main task was to build mathematical bridges, in both an interdisciplinary and transdisciplinary manner, between different areas of expertise.

In terms of collaborative research, *interdisciplinary* refers to the formulation and solution of problems within the confines of two or more scientific fields, though the choice to investigate one matter or another can admittedly be influenced by external, non-scientific factors. Interdisciplinarity across the fields of physics, physical chemistry, mechanics, and mathematics has recently been called the “Oxford model,”¹⁹³ but at the University of Göttingen, as we have seen, Felix Klein had also created research seminars that fostered a similar interdisciplinary approach to scientific problems (see Sections 2.3 and 2.4.2). In general, such an approach was more common at British and American universities at the time than it was in Germany, where the institutional structure of professorships did much to discourage collaboration among academics in different fields.¹⁹⁴ German industrial laboratories, however, did not suffer from such organizational restrictions, and therefore interdisciplinary research was conducted in this setting from rather early on. At Osram and Telefunken, the highly focused research on incandescent light bulbs and electron tubes required teamwork among a variety of specialists.

Scholars have used the term *transdisciplinarity* in a variety of senses.¹⁹⁵ Here it will be employed to designate an integrative approach to the formulation and solution of problems that involves both scientific and extra-scientific knowledge. Industrial laboratories were predominantly (but not exclusively) concerned with solving problems that required various sorts of practical knowledge – knowledge, for instance, of manufacturing and distribution processes, as well as of quality control and the marketing of certain products. To determine how a particular problem ought to be mathematically modeled, that is, mathematicians typically had to take into account these many extra-scientific factors, and thus technicians and factory foremen could be closely involved with the act of problem solving. It was often on account of their input, for instance, that certain problems could be recognized and properly formulated in the first place, and in this way they could be instrumental both to the process and the end result of a given mathematical research project.

192 A letter from Iris Runge to her parents dated July 22, 1923 [Private Estate].

193 HOFFMANN 2007, p. 233. See also FOX/GOODAY 2005.

194 For an analysis of interdisciplinarity in the United States, see ECKERT 2000.

195 For more on the use of the term, see G. Hirsch Hadorn, C. Pohl, and G. Bammer, “Solving Problems Through Transdisciplinary Research,” in *The Oxford Handbook of Interdisciplinarity*, ed. R. Frodeman et al. (Oxford: Oxford University Press, 2010), pp. 431–452.

By the time Iris Runge began to work as an industrial researcher, her contemporary mathematicians and physicists had already written comprehensive books about the mathematical methods that could be applied to solving physical and technical problems. Beyond the books written by Carl Runge and his students on numerical and graphical methods, there was also, for instance, Wilhelm Hort's important textbook on the application of differential equations to the field of engineering, *Die Differentialgleichungen des Ingenieurs*.¹⁹⁶ Iris Runge enjoyed a close professional relationship with Hort, who had earned his doctorate at the University of Göttingen in 1904 and who, as the editor of the *Zeitschrift für technische Physik*, was responsible for publishing a number of her articles. Her private library also included the seven-volume *Handbuch der physikalischen und technischen Mechanik* [Manual of Physical and Technical Mechanics], which was co-edited by Wilhelm Hort and Felix Auerbach, a professor at the University of Jena, and which was published from 1925 to 1931. In 1928, a volume entitled *Mathematische Hilfsmittel in der Physik* [Mathematical Resources in Physics] appeared as the third volume of the series *Handbuch der Physik* [Manual of Physics]. In addition to surveying the mathematical fields that were most relevant to physical research, it also addressed probability theory, statistics, and graphical and numerical methods.¹⁹⁷ Subsequent volumes of this series also concerned the latest methods of quantum statistics and their application to the electron theory of metals, subjects that were of great value to understanding the physical processes of electron tubes. In the section devoted to physics in Philipp Frank and Richard von Mises's two-volume *Die Differential- und Integralgleichungen der Mechanik und Physik* [The Differential and Integral Equations of Mechanics and Physics], attention was given to such technical areas as amplifier tubes, but this book largely failed to take into account the approximation methods that were so important to practical success in the industrial setting.¹⁹⁸ Richard Courant and David Hilbert's *Methods of Mathematical Physics*, as its English edition was titled, was also a significant contribution with which Iris Runge was well acquainted.¹⁹⁹ As Courant's sister-in-law, she knew all of his work closely, and later she would even translate his popular book *What is Mathematics?* into German.²⁰⁰

In what follows, it will not be possible to provide a detailed description of the development and significance of each of the methods mentioned in these text-

196 The first edition of *Die Differentialgleichungen des Ingenieurs* appeared in 1914, and it was subsequently reissued in 1925 and 1939. Wilhelm Hort had conducted doctoral research under the supervision of Eduard Riecke, Hans Lorenz, and Felix Klein. After his earning his degree, he took a position in the industrial sector. While a researcher at AEG, he also worked part-time as a professor at the Technical University in Berlin, where he became the first German professor of mechanical vibration theory in 1931.

197 See THIRRING 1928.

198 See the preface to FRANK 1927.

199 For a comparison of FRANK/MISES 1935 and COURANT/HILBERT 1924, see SIEGMUND-SCHULTZE 2007.

200 See COURANT/ROBBINS 1941, which saw many English and German editions.

books. The focus below will rather be on how mathematicians worked in industrial laboratories, on how the mathematical methods in question were tailored to be applied to specific technical and physical problems, and on how the process of interdisciplinary and transdisciplinary collaboration actually functioned.

The first concern of this section will be the use of graphical methods as a foundational tool of applied mathematics. The remainder of the section will be organized according to the various fields to which graphical and other methods were applied, namely quality control, materials research, optics/colorimetry, and electron tube research. The overarching goal will be to demonstrate how the methods of probability theory, statistics, numerical analysis – among others – were both employed and (in part) refined at the Osram and Telefunken Corporations.

3.4.1 Graphical Methods

Even though graphical methods were in wide use at the time, the engineers of the 1920s hardly exhausted their potential. It was still common then for some engineers and industrial physicists to lack an adequate understanding of the latest methodologies. In Section 2.4 it was mentioned that engineers had been using special graphical methods since the nineteenth century, that Carl Runge had made graphical and numerical methods the focus of his research and the focus of the applied mathematics curriculum at the University of Göttingen, and that Iris Runge was educated in this style of thinking. Here the discussion will concentrate on 1) how new mathematical methods developed by academic mathematicians found their way into industrial research, 2) how industrial researchers at Osram systematized graphical methods for practical use, and 3) which graphical methods were adopted for specific problems of incandescent light bulb and electron tube research.

3.4.1.1 The Influence of a Lecture by Carl Runge on Graphical Integration Methods

The German Society for Technical Physics invited Carl Runge to give a lecture in Berlin, the purpose of which was to familiarize those attending with the latest advances in graphical methods. Richard Jacoby, who instigated the invitation, had been made aware of the importance of these methods by Iris Runge, and he intended to exploit Carl Runge's authority in order to popularize them among the engineers and physicists who were working for him.

Carl Runge delivered this invited lecture on June 15, 1923, and in it he focused on graphical integration methods. In general, integration methods were both easier and more broadly applicable than methods of differentiation.²⁰¹ Moreover, graphical solutions of differential equations, which were especially useful for

201 See Carl RUNGE 1919, p. 87.

solving practical problems, were based on the graphical integration of given functions. In an earlier study, Carl Runge had stressed: “The method is nothing more than a graphical translation of Picard’s approach to solving differential equations.”²⁰² In his book *Graphical Methods*, Carl Runge underscored that the functions used to solve problems in science and engineering were, more often than not, only given graphically. Although it was possible, he noted, to formulate an approximation by means of analytical expressions, such calculations were typically eschewed on account of their difficulty and inconvenience.

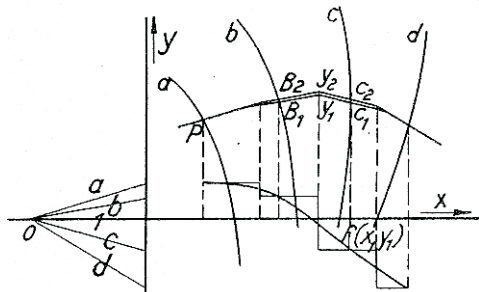


Figure 7: *The Graphical Integration of a Differential Equation* (Carl RUNGE 1924, p. 164).

One result of Carl Runge’s lecture was that more and more researchers at Osram began to seek Iris Runge for mathematical advice, as she mentioned in a letter written in July of 1923:

Consider this, Dad: First of all, my colleague Dr. Heinze recently came to me and wanted to know about graphical interpolations of the second order. Having attended your lecture, he recalled that you had said something about it that he had since forgotten, and he was eager to put it to use. I, too, had only a vague notion of the matter, and so I consulted your *Graphical Methods* but couldn’t find what I was looking for there. Slowly it all began to come back to me, and after much thinking I was able to derive the graphical solution for him on a piece of paper while he stood by my side. Among other things, I’m not sure that I organized the lines in the simplest of ways – the solution didn’t turn out exactly as I had remembered it – but it nevertheless accomplished its goal. In any case, Heinze was no less satisfied than I was by the result. Second, Pirani recently came to see us here again. A few weeks ago he had sent us a paper by one of his young researchers that contained the same differential equation that I had shown you at the time, and since then I have been able to calculate two quadratures based on it. It was clear that this young researcher didn’t even know where to begin; all he managed to do was to simplify the physical problem by making some rather daring assumptions, and in doing so he quietly eliminated the inconvenient term with T^5 . Pirani sent the work to Jacoby in the hope that I could perhaps come up with a graphical solution for it. Well, I was able to do just that, and I had to explain the process to Pirani. This was a joy because he was so clearly pleased by my explanation.²⁰³

202 Carl RUNGE 1907, p. 272; see also TOURNÈS 2003 and 2009.

203 A letter from Iris Runge to her parents dated July 23, 1923 [Private Estate].

Carl Runge's lecture was published under his name in the *Zeitschrift für technische Physik*, though the manuscript had been prepared by his daughter. Her involvement in the publication, which is not mentioned in the journal, is known from letters to her parents. In January of 1924, somewhat later than would be expected, the director of the electron tube factory Karl Mey had requested a written version of the lecture. Iris Runge was somewhat irritated at first by the tardiness of this request, for she and her father had already requested permission to publish his presentation in June of the previous year. It must have been realized at Osram that the business could profit from the application of these methods. Iris Runge ultimately regarded the task as something of an honor, and so she reproduced the text of her father's lecture – largely from memory – and she furnished the draft with illustrations from her own hand. The manuscript became such a high priority at Osram that a secretary was sent after hours to assist Iris Runge at her apartment (to this secretary she was able to dictate the text while lying on the couch). "I have had special difficulties with the introduction and conclusion," she wrote to her father, adding: "Perhaps you could improve them with a sentence or two."²⁰⁴

In comparison with his book *Graphical Methods*, Carl Runge's essay focused even more closely on specific examples. The essay closes with the wish that "engineers might direct their attention more than ever before to this thoroughly promising field. The identification of new and practical problems that will doubtless arise from their efforts, moreover, can be nothing but a benefit to pure science as well."²⁰⁵ Iris Runge would come to adopt her father's wish as a maxim. This lecture, in addition to a later presentation that Carl Runge made to the German Society for Technical Physics in Berlin,²⁰⁶ served to familiarize a group of industrial researchers with the latest mathematical methods and also increased Iris Runge's visibility, throughout all of Osram, as an expert in mathematics.

3.4.1.2 New Editions of Marcello Pirani's Graphische Darstellung

In 1914, while working as a chief engineer for Siemens & Halske, Marcello Pirani published his *Graphische Darstellung in Wissenschaft und Technik* [Graphical Representation in Science and Engineering], a book that appeared as volume 728 of the encyclopedic series known as "Sammlung Göschchen" [The Göschchen Collection].²⁰⁷ The purpose of this short work, in contrast to that of Carl Runge's textbook, was to provide industrial engineers and physicists with a resource for creating, on their own, graphical tables that could be employed in solving concrete

204 A letter from Iris Runge to her parents dated January 25, 1924 [Private Estate].

205 Carl RUNGE 1924, p. 165.

206 Entitled "Über die Ausgleichung von Beobachtungen" [On the Equalization of Observations], Carl Runge's second lecture to the German Society for Technical Physics was delivered on March 6, 1925; see *Zeitschrift für technische Physik* 6 (1925), p. 40.

207 The Göschchen Collection, begun in 1889, was a book series published by the G. J. Göschchen publishing house (later by Walter de Gruyter).

problems. The book aimed, in Pirani's words, "to offer a summary of the rules and laws that are relevant to graphical representation and to describe the simplest methods, with the help of examples, of creating graphical nomograms."²⁰⁸ The demand for this book was such that it was twice reprinted without revisions.

Numerous researchers in the 1920s contributed to developments in the methods of transformation geometry and nomography (the study of creating nomograms, which are two-dimensional diagrams for the approximate graphical computation of a function). Regarding the future of applied mathematics, Richard von Mises offered the following prognostication:

Far more comprehensive and ripe for further development are undoubtedly the methods of graphical calculation, which is capable of accomplishing everything that numerical calculation is able to accomplish. [...] The second approach to geometry that we would like to see expanded falls in the area of approximation theory, in Felix Klein's sense of the term.²⁰⁹ This, too, will involve a methodical development of the principles and resources of graphical calculation [...]. It is well known that, not long ago, Maurice d'Ocagne made essential advances in this regard by establishing the field of nomography.²¹⁰ We are now in a position, by means of planar figures, to calculate functional correlations between more than two variables. Almost all of the fundamental problems of nomography still remain unsolved, and it is reasonable to expect that their solution will also bring to light unforeseen areas of application. Here we encounter mapping problems that can be categorized under a broad conception of descriptive geometry. There are other problems of graphical calculation – the problem of constructability with the aid a fixed curve (analogous to Steiner constructions with a fixed circle),²¹¹ for example, as well as the questions of infinitesimal geometry concerning the integration of ordinary and partial differential equations – that are more than casually associated with the terminology and methodology of a generic mapping geometry.²¹²

A look through the contents of the first volumes of Richard von Mises's journal reveals that nearly every issue included articles, reports, or discussions on the latest results and applications of nomograms. Together with his former student Hans Schwerdt, Pirani himself contributed an article on novel graphical tables.²¹³ Thus it became necessary to bring his book up to date in a new edition, and for this Pirani secured Iris Runge as its editor. As early as 1926, she wrote to her parents that she had been working assiduously on *her* nomography book. The project was undertaken largely in her free time, and the final set of proofs was not made available for her review until April of 1930.²¹⁴

208 PIRANI 1914, p. 5 (reprinted in 1919 and 1922).

209 Felix Klein's notion of approximation theory is discussed above in Section 2.3.1.

210 See Maurice d'Ocagne, *Traité de nomographie* (Paris: Gauthier-Villars, 1899); and Friedrich Schilling, *Über die Nomographie von M. d'Ocagne* (Leipzig: B. G. Teubner, 1900); Schilling's book was inspired by Felix Klein (see p. 3).

211 See Jacob Steiner, *Die geometrischen Constructionen, ausgeführt mittelst der geraden Linie und eines festen Kreises, als Lehrgegenstand auf höheren Unterrichts-Anstalten und zur praktischen Benutzung*, 2nd ed., rev. A. J. v. Oettingen (Leipzig: W. Engelmann, 1913).

212 MISES 1921, pp. 4 and 9.

213 M. Pirani and H. Schwerdt, "Über zwei neue Rechentafeln für Multiplikation und Division," *Zeitschrift für angewandte Mathematik und Mechanik* 3 (1923), pp. 315–319.

214 See her letters dated January 24, 1926 and April 25, 1930 [Private Estate].

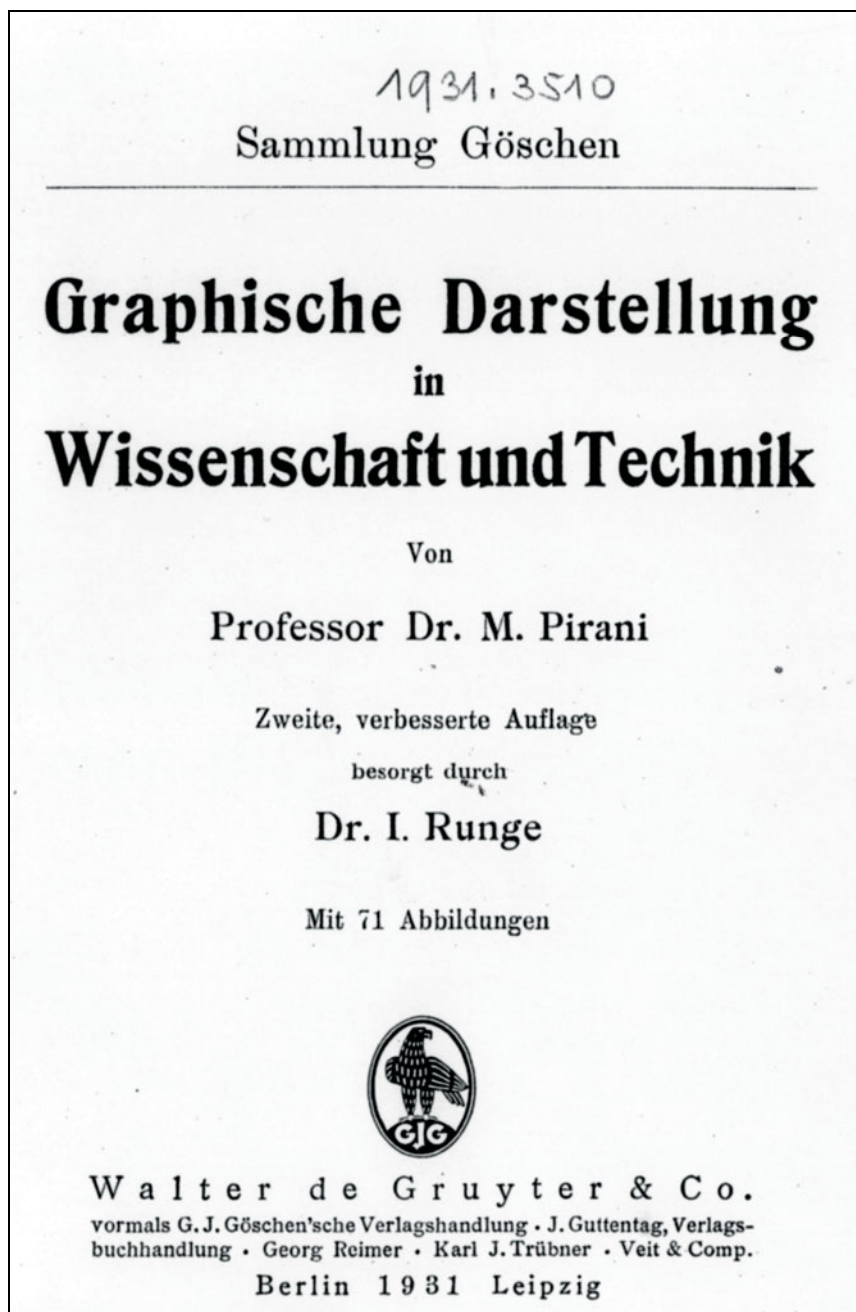


Figure 8: The Title Page of Iris Runge's Revision of Marcello Pirani's *Graphische Darstellung in Wissenschaft und Technik* (1931)

A comparison with Pirani's first edition reveals that Iris Runge expanded the book from its original 126 pages to 149 and that she added fifteen new illustrations to the original fifty-six. The bibliography, moreover, was augmented from sixteen to thirty-one titles.²¹⁵ She also contributed discussions of the new avenues of research suggested by Richard von Mises, and she supported her claims by citing the works on nomography and transformation geometry by Ludwig Bieberbach, Paul Schreiber, B. M. Konorski, and H. Schwerdt. She also made reference to Friedrich A. Willers's volume on graphical integration and to the latest works concerned with the construction of nomograms and other calculating tables.²¹⁶ Just as Pirani, in his first edition, made sure to cite books by American, French, and British authors, Iris Runge expanded his list of international titles by citing books by the Americans Alan Cecil Haskell and Harry Manley Goodwin and an article by the Danish engineer Jørgen Ryber.²¹⁷

Iris Runge's edition distinguished itself by a special feature that would recur in much of her later work, namely the clear and systematic representation of knowledge in a tabular form. Whereas the first edition of Pirani's book contained no such tables, Iris Runge's revision included an appendix containing a tabular summary of all the discussed graphical charts alongside the general form of the corresponding function (divided into sections for "three variables" and "more than three variables"), the corresponding type of chart (net charts, alignment charts, proportional charts, Z-scores, floating curve charts), and the specific formulas used in the practical examples. This overview of the book's material was singled out by reviewers as being especially useful.

215 Carl Runge's *Graphical Methods* did not contain a bibliography. He referred instead to the comprehensive references in MEHMKE 1902 and RUNGE/WILLERS 1915.

216 The works in question are Ludwig Bieberbach, "Über die mathematischen Grundlagen der Nomographie," *Zeitschrift des Vereins Deutscher Ingenieure* 68 (1924), pp. 495–498; idem, "Über Nomographie," *Die Naturwissenschaften* 10 (1922), pp. 775–782; Paul Schreiber, *Grundzüge einer Flächen-Nomographie*, 2 vols. (Braunschweig: Vieweg, 1921–1922); Boleslaw Konorski, *Die Grundlagen der Nomographie* (Berlin: J. Springer, 1923); Hans Schwerdt, *Lehrbuch der Nomographie auf abbildungsgeometrischer Grundlage* (Berlin: J. Springer, 1924); idem, *Die Anwendung der Nomographie in der Mathematik, für Mathematiker und Ingenieure* (Berlin: J. Springer, 1931); Friedrich A. Willers, *Graphische Integration*, Sammlung Göschen 801 (Berlin: Walter de Gruyter, 1920); Otto Lacmann, *Die Herstellung gezeichneter Rechentafeln. Ein Lehrbuch der Nomographie* (Berlin: J. Springer, 1923); Fritz Krauss, *Die Nomographie oder Fluchtlinienkunst. Ein technischer Leitfaden* (Berlin: J. Springer, 1922); O. Heck and A. Walther, "Nomogramme für die komplexen Wurzeln charakteristischer (insbesondere quadratischer und kubischer) Gleichungen von Schwingungsproblemen," *Ingenieur-Archiv* 1 (1930), pp. 611–618.

217 She cites Alan Cecil Haskell, *How to Make and Use Graphical Charts* (New York: Codex, 1920); Harry Manley Goodwin, *Elements of the Precision of Measurements and Graphical Methods*, 2nd ed. (New York: McGraw-Hill, 1913); and Jørgen Rybner, "Nomograms," *General Electric Review* 33 (1930), pp. 164–178. Rybner, who had been educated in the United States, was also the author of *Nomograms of Complex Hyperbolic Functions*, 2nd ed. (Copenhagen: J. Gjellerups, 1955).

All of the reviewers, in fact, praised the new edition. Only Hans Schwerdt, who nevertheless dubbed the volume an “excellent introduction,” felt that it could have benefited from the inclusion of one more type of table, “a ladder chart with a curve net.”²¹⁸ In this regard, Iris Runge had consciously limited herself to including only those ladder charts that had a curvilinear base. Overall, she altered the contents of the book to include discussions of “interpolation in net charts” (*Interpolation in Netztafeln*), “floating curves” (*Wanderkurvenblätter*), and “graphical representation with glide curves” (*Gleitkurvendarstellung*), and she also replaced outdated terms with modern equivalents.²¹⁹ The basic format of the book, however, remained unchanged, including the considerable space that Pirani had originally devoted to explaining alignment charts. Charts of this sort, which were used for solving problems with more than two variables, had first been developed by Maurice d’Ocagne, and in the meantime they had come to be used internationally. In his treatment, Pirani relied especially on John B. Peddle’s *The Construction of Graphical Charts*, a book that discussed alignment charts at length.²²⁰ Each of Pirani’s charts had to be recalculated to accommodate new examples, a task to which Iris Runge contributed.

Over the subsequent decades, nomography steadily came to be applied to ever more areas of research.²²¹ Germany, at least, saw the development of “more and more first-rate and elaborate nomograms, designed with integrated ladder charts and the occasional curve chart,”²²² and also a remarkable surge in the diversity of their application. Even before the end of the Second World War, Iris Runge entertained the idea of producing a third edition of Pirani’s book. In 1944, Friedrich A. Willers, who had lectured on nomography as a professor at the Technical University in Dresden, complied with her request to send her a survey of all the latest German and international scholarship on the subject.²²³ Shortly after the war, Pirani held a discussion with Iris Runge about the possible outline of this new edi-

218 Hans Schwerdt’s review appeared in volume 24 of *Maschinenbau – Der Betrieb* (1931). A collection of all the reviews are archived in Iris Runge’s [Private Estate]; they were published in the following journals: *Physikalische Zeitschrift*, *Zeitschrift für technische Physik*, *Maschinenbau – Der Betrieb* (as mentioned), *Monatshefte für Mathematik und Physik* (Vienna), *Zeitschrift des österreichischen Ingenieur- und Architekten-Vereins*, *Chemische Novitäten*, *Zeitschrift für mathematischen und naturwissenschaftlichen Unterricht*, and *Zeitschrift für Instrumentenkunde*.

219 Pirani made these remarks himself in a notice for the book that was published in the journal *Der Deutsche Techniker* on May 1, 1932.

220 John B. Peddle, *The Construction of Graphical Charts* (New York: McGraw-Hill, 1910). A second edition of this book was published in 1919. Peddle, incidentally, was an American professor of machine design.

221 See, for instance, ADAMS 1964.

222 WALTHER/KRON 1948, p. 119.

223 See [UA Dresden] Willers Estate, No. 22; and a letter from Willers to Iris Runge dated December 10, 1944 [Private Estate]. See also Willers’s main work on the subject, in which he summarized his methods: Friedrich A. Willers, *Practical Analysis: Graphical and Numerical Methods*, trans. Robert T. Beyer (New York: Dover, 1948).

tion; he also sent her references to the latest scholarship in English and made several suggestions about additional citations and about the new chapters and areas of application – especially chemistry and statistics – that ought to be included.²²⁴

That a third edition, based on Iris Runge's preparatory work and completed by the engineer Johannes Fischer, was indeed finally published in 1957 can be taken as a sign that graphical methods, even at the beginning of the computer age, were still widely being used by industrial researchers. As the physicist Sidney Millman has underscored, graphical methods were still being applied well into the 1980s at the Bell Telephone Laboratories, where they were considered useful in the area of quality control.²²⁵

3.4.1.3 *The Use of Graphical Methods in Light Bulb and Electron Tube Research*

A summary of the foundational graphical methods of the period in question can be gleaned from reading the three editions – published, to repeat, in 1914, 1931, and 1957 – of Pirani's *Graphische Darstellung in Wissenschaft und Technik*. In what follows, closer attention will be paid, above all, to the graphs that were used and developed by the researchers at Osram and Telefunken. These can be separated into groups according to their two main areas of application. Charts were designed, first of all, for the monitoring of production processes and quality control of mass-produced commodities (light bulbs, electron tubes), and these were based on the methods of statistics and probability theory. Such charts included those for determining sample sizes to achieve a desired level of confidence, alignment charts for determining the sizes of preliminary samples, and Gaussian curves for tracking production processes (see Section 3.4.2). Second, charts were developed, namely compound nomograms, for designing electron tubes according to predetermined specifications and parameters (see Section 3.4.5.2).²²⁶

The focus of the next section will be the standard and novel approaches to quality control that were used at Osram – comparisons will be made to the international state of the field – and the graphical methods that these approaches required.

224 In a letter to Iris Runge dated October 6, 1946 [Private Estate], Pirani mentions the following books by name: Dale S. Davis, *Nomography and Empirical Equations* (New York: Hill, 1943); and Egon Sharpe Pearson, *The Application of Statistical Methods to Industrial Standardization and Quality Control* (London: British Standards Institution, 1935). See also Iris RUNGE 1936b. For additional research on graphical methods by one of Iris Runge's contemporaries, see Dorothea Starke, "Ein graphisches Verfahren zur Auflösung eines linearen Gleichungssystems mit komplexen Koeffizienten," *Zeitschrift für angewandte Mathematik und Mechanik* 11 (1931), pp. 245–247. Starke, a doctoral student of Max Winkelmann at the University of Jena, was one of the few research assistants working in applied mathematics at the time. Winkelmann, it should be noted, had completed his own doctoral research as a student of Felix Klein at the University of Göttingen.

225 MILLMANN 1984, p. 74.

226 See Iris RUNGE 1940.

3.4.2 Quality Control on the Basis of Mathematical Statistics

The application of mathematical statistics to mass production leads, if critically applied, to a more deliberate form of quality control. By viewing individual phenomena as a totality, outlying phenomena and deviations caused by changes in the production process can be recognized. By means of applying statistical methods, it can be shown which conditions need to be fulfilled in order to make sound comparisons between products made with different production schedules, at different factories, and by different means. In this way, too, the basic principles for evaluating products in a reasonable and realistic manner are provided.²²⁷

These are the words with which Iris Runge began “Prüfung eines Massenartikels als statistisches Problem” [Testing of a Mass-Produced Good as a Statistical Problem], which appeared as the leading article in the inaugural issue of Osram’s book series, *Technisch-wissenschaftliche Abhandlungen aus dem Osram-Konzern*, which was published by the renowned Julius Springer publishing house. Here she elucidated the fundamental problems of statistical quality control and opposed the common belief that “assertions based strictly on probability could be too inaccurate to serve as a foundation for making important decisions.”²²⁸

In his summary of the history of statistics, Hermann Witting outlines the most important developments that took place on the Continent and in England, among which he numbered the application of statistical methods to the process of mass production. To illustrate the emergence of this specific development, he cites the first book ever to be devoted to statistical quality control, namely *Anwendungen der mathematischen Statistik auf Probleme der Massenproduktion* [The Application of Mathematical Statistics to Problems of Mass Production], a book that was co-authored by Iris Runge and two of her Osram colleagues.²²⁹ As we will see, the field of quality control was characterized by international communication both at an earlier stage and to a greater extent than has previously been thought.²³⁰ Since the 1920s, statistical methods were used for purposes of quality control by businesses in Germany and abroad, even despite Egon S. Pearson’s observation that there is a paucity of sources on specific methods, especially as they were applied by British firms, because of the desire of businesses to keep their scientific practices confidential from each other:

A difficulty in dealing accurately with this subject is that we do not know, at any rate in earlier years, what use of statistics was being made within individual firms. This was inevitably the case because progressive firms which might have had something to say, hesitated to display to their competitors their uses of scientific methods.²³¹

Contrary to what Pearson asserts, the evidence from corporate publications, books, and articles by industrial researchers in the United States (Bell Labs, ceramics

227 Iris RUNGE 1930a, p. 1.

228 Ibid.

229 WITTING 1990, p. 79; BECKER/PLAUT/RUNGE 1927. See also BAYART/CRÉPEL 1994.

230 See BAYART 2000, pp. 157–158.

231 PEARSON 1973, p. 165 (this is an original English quotation).

industry) and Germany (iron industry, electrical and communications industries) indicate that these methods were quickly and consciously made public in order to convince even competing researchers of their utility.

Up until the beginning of the 1920s, methods of quality control had been tested in certain countries without the explicit application of probability theory. Among such initiatives can be numbered the efforts of Henry Le Chatelier, who worked in the French chemical industry, and the use of the so-called routing slip device both in the United States and, beginning in 1915, at Siemens & Halske's light bulb facilities, which were then led by Marcello Pirani.²³² Walter Masing has contended that, as early as 1917, Siemens began to make use of statistical methods "in order to come to terms with business problems presented by the ever growing demand for telephone connections, on the one hand, and the fact that, on the other hand, so many telephone conversations were taking place at the same time."²³³ Masing's assessment must be considered with caution, however, in light of the fact that Ragnar Holm, a Swedish physicist at Siemens & Halske, would stress in 1920 that it still remained urgently necessary to address the problem of simultaneous telephone conversations with the methods of probability theory.²³⁴ In 1919, Bernhard P. Dudding of the General Electric Company in England began to apply statistical methods to the design and production processes of light bulbs, metals, and glass.²³⁵ This company was associated with the light bulb production and research branches of Osram not only by their common connection to the International General Electric Company; their researchers regularly took each other's findings into account, as is evidenced, for instance, by a report that Marcello Pirani prepared on Dudding's work.²³⁶ Despite Dudding's observation that, in the 1920s, aspects of quality control still had to overcome certain inefficiencies,²³⁷ and despite Ragnar Holm's judgment that statistical quality control was more often praised than put into practice, statistical methods nevertheless infiltrated many business sectors. Statistical advances in communications, glass technology, machine design, the ceramics industry, the steel and iron industries, and even in the cotton industry can be seen as components of a *probability revolution* that was unfolding on the international stage.²³⁸ Methods of mathematical statistics, which

232 See BAYERT 2000, p. 156; LUXBACHER 2003, pp. 270–271.

233 MASING 2003, p. 4.

234 Ragnar Holm, "Über die Benutzung der Wahrscheinlichkeitstheorie für Telefonverkehrsprobleme," *Archiv für Elektrotechnik* 8 (1920), pp. 413–440; see also the pioneering work in this field of the Norwegian mathematician and engineer Tore Olaus ENGSET 1918.

235 See DUDDING 1952, pp. 3–4.

236 This report – dated July 2, 1926 – is archived in [LAB] 282, vol. 1.

237 See DUDDING 1950, p. 5.

238 See KRÜGER et al. 1987. On the term "control revolution," which is used in connection to the growing application of statistical methods to the problems of mass production, see BENIGER 1986, pp. 308–310. On the development of these methods in different branches of industry, see DAEVES 1924; CZOCHRALSKI 1924; SCHMIZ 1927; and WESTMAN 1927. On the British cotton industry, for which L. H. C. Tippett began to use statistical methods, in 1925, as part of his experimental work on spinning and weaving, see PEARSON 1973, p. 170.

had already been applied in the fields of economics, demography, and biometrics, now found a steady footing in the area of quality control, and this phenomenon, in turn, contributed to the development of new statistical methods.²³⁹

At nearly the same time, such methods also caught the attention of international businesses that were concerned with increasing their productivity.²⁴⁰ On the one hand, these businesses had to identify purely random processes (the rather predictable simultaneous use by anonymous clients, for instance, of telephone networks with limited capacities), and on the other hand they had to deal with random processes that could not be foreseen as such in advance. The latter difficulty was typical of efforts to control the quality of mass-produced goods; that is, product deficiencies and deviations could just as well be caused by defective tools or inattentive employees, and the consequences of such singular and contained errors could easily be misinterpreted as random processes. Controlling for such events involves a degree of risk, for it is difficult to determine whether certain contingencies are truly of a statistical nature. The development of appropriate models for such scenarios requires a keen grasp of production processes and can be understood as concrete and individual case studies of business mathematics.

Mindful of an international context, the following sections will discuss instances of quality and production control at Osram in which Iris Runge played a prominent role, namely 1) the introduction of control charts to the process of mass production, 2) the development of special formulas and charts for the determination of sample sizes, and 3) the scholarly publications and international communication that characterized the work.

3.4.2.1 Control Charts

In the United States, the term *control chart* is associated with Walter Andrew Shewhart, a researcher at the Western Electric Company who introduced the use of such charts in 1924 as a means of inspecting mass production processes.²⁴¹ Shewhart's quality control chart, which graphically represents individual points of data in relation to the control limits of a given process, is one of the oldest and simplest tools of statistical process control.²⁴² Today we distinguish between

239 See MILLMANN 1984; PEARSON 1973; HALD 1998, 2007.

240 In addition to mathematical statistics, the process of optimizing productivity also involved industrial psychology, personnel assessment, and technical matters such as assembly line productivity (see MEHRTENS/SOHN 1999; POKORNY 2003; and, as regards Osram in particular, LUXBACHER 2003, pp. 242–277).

241 Trained as a physicist, Shewhart is known in the United States as the father of statistical quality control (see EISENHART 1992; BAYART 2001; FAGEN 1975, ch. 9; and MILLMAN 1984, pp. 70–74).

242 See PEARSON 1973, p. 173: "His first control chart showing the monthly number of percent defective items in some unspecified piece of apparatus, with an upper control limit drawn in, was presented to his chief in 1924, with the remark that if approval was given he could

various types of control charts, the basic purpose of which is to provide graphical representations of sample values – the value of the sample mean, for instance, and the standard deviations of the samples – in order to identify, as quickly as possible, any non-standard variation occurring in a given production process.

Graphical methods, which were being developed in many industrial laboratories, were especially easy to manage by engineers on the ground. Sidney Millman, a physicist, opined:

As is evident [...], a common theme running through much of the work of Bell Labs statisticians has been an emphasis on graphical methods of display and analysis of data. Indeed much of the power of Shewhart's control-chart methodology derives from the fact that it is a graphical technique, readily understood by workers on the shop floor.²⁴³

Whereas Egon S. Pearson, who conducted statistical research at General Electric from 1924 to 1928, could remark that “no use is made of the normal curve nor of the idea of correlation,”²⁴⁴ it was precisely these tools of statistics that lay at the center of German industrial research during this same time. In the steel industry along the Rhine and in the electrical and communications industries in Berlin, statistical work was characterized, beginning in the 1920s, by what was known as *Großzahlforschung*, that is, “large scale” or “wide coverage research.” In the words of Hubert Curt Plaut, a trained mathematician working at Osram, the goal of this type of research was “to control and improve the quality of manufactured products by subjecting all production data to painstaking statistical analysis.”²⁴⁵

Dr. Karl Daeves, who directed the research laboratory for the United Steelworks Corporation in Düsseldorf (*Vereinigte Stahlwerke A.G.*), was concerned with one of the most persistent problems of the steel industry, namely identifying the proper alloy specifications of cast iron. He arrived at a solution to this problem by graphically representing and statistically evaluating the frequency distribution of a large sample batch. In response to his success, the Association of the German Iron and Steel Industry (*Verein deutscher Eisenhüttenleute*) created a department

prepare similar charts dealing with other quality characteristics” (an original English quotation). For Shewhart's original study, see Walter A. Shewhart, “Some Applications of Statistical Methods to the Analysis of Physical and Engineering Data,” *Bell System Technical Journal* 13 (1924), pp. 43–87. Along with the histogram, Pareto chart, check sheet, cause-and-effect diagram, and scatter diagram, the control chart is one of the seven basic tools of quality control (see DIETRICH/SCHULZE 2005).

243 MILLMAN 1984, p. 74 (an original English quotation).

244 PEARSON 1973, p. 173. Here he also notes that his statistical work was largely restricted to the use of “survivor curves to estimate the median life of a class of lamps.”

245 PLAUT 1930, p. 6. Hubert C. Plaut had studied in Freiburg, Munich, Berlin, and Göttingen. His doctoral research, which was instigated by Alfred Loewy at the University of Freiburg and supervised by Wilhelm Franz Meyer at the University of Königsberg, culminated in a dissertation entitled “Über gemeinsame Teiler von n Formen einer Variablen, von n linearen homogenen Differential- oder Differenzen-Ausdrücken” [On Common Factors of the n Forms of a Variable, of n Linear Homogeneous Differential or Differentiation Expressions]. In the curriculum vitae appended to his dissertation, Plaut openly wrote: “I am Jewish.”

for technical statistics.²⁴⁶ Daeves's extensive commentary on how to construct distribution curves in a way that is expedient for solving practical problems was both known and put to use by researchers at Osram.²⁴⁷ Moreover, by means of "normal probability paper," which Daeves later helped to develop, an (integrated) normal distribution could also be represented linearly.²⁴⁸ On such graph paper, data are plotted according to ordered response values (the vertical axis) and expected mean values (the horizontal axis), and in such a way it can be determined whether a given value pair accords with or deviates from the patterns of normal distribution. In 1946, Pirani wrote to Iris Runge that Daeves's probability paper should be included among the new graphical methods of applied statistics to be discussed in the third edition of his *Graphische Darstellung in Wissenschaft und Technik*.²⁴⁹

Hubert Plaut directed a department of technical statistics at Osram for several years,²⁵⁰ and the nature of his work there is reflected by a lecture that he delivered in 1925 to the German Society for Technical Physics: "Über eine neue Methode der Großzahlforschung und ihre Anwendung auf die Betriebskontrolle" [On a New Method of Large Number Research and its Application to the Monitoring of Production Processes].²⁵¹ As Plaut himself mentions, he had first formulated this "new" method in the summer of 1923. It was based on the determination of means, on the mean of Gaussian quadratures, on quadratic variance measurements, and on the comparison of variance measurements, whereby – inspired by the work Richard Becker – he could represent geometrically the relation between three different variance measurements (total variance, series variance, single variance). Plaut stressed that his approach was comprehensive and could accommodate, as special cases, both the ballistic methods for comparing successive values with median variation as well as Bernoulli's process of sampling random variables.²⁵²

Plaut, Iris Runge, Ellen Lax, and other researchers at Osram were engaged in designing graphical charts to represent data in the clearest possible fashion. A so-called step curve, for instance, could serve to communicate the linear dispersion of such things as the expected lifespan of an incandescent light bulb. When drawn out on graphing paper, this step curve could make a logarithmic dispersion measurement (or uniformity factor) easily discernable, something that the researcher W. Geiß had deemed especially important to the production of light bulbs.²⁵³ For the comparison of two product lots on the basis of two samples – to

246 DAEVES 1924, p. 16. See also MASING 2003, p. 3; and LUXBACHER 2003, p. 272.

247 See BECKER/PLAUT/RUNGE 1927, p. 19.

248 See DAEVES/BECKEL 1941; SCHULZ 1948, p. 189.

249 See a letter from Marcello Pirani to Iris Runge dated October 6, 1946 [Private Estate].

250 See [LAB] 446. It is not documented in what year Plaut was given this position, but he is still named as the head of technical statistics in October of 1936. This department was part of a larger corporate division called "plant management – research/development."

251 PLAUT 1925.

252 Ibid., p. 227. Plaut's conclusions are summarized in BECKER/PLAUT/RUNGE 1927, p. 51.

253 See the illustration and explanation in *ibid.*, p. 8.

test, for instance, the difference in quality between two types of bulbs – a graphical table was developed that enabled engineers to determine the value of Gaussian error integrals (probability distribution functions) without having to make numerical calculations. From this graph it was possible to ascertain, with some ease, the probability of one type of lamp being superior to another.²⁵⁴ To determine, moreover, whether a statistical correlation existed between two product characteristics – the respective lifespans, for instance, of highly or minimally contaminated bulbs from the same production series – a special correlation chart was developed that rendered correlation coefficients immediately recognizable.²⁵⁵

The methods of quality control that were applied at Osram to the production of light bulbs were also used later to regulate the mass production of electron tubes. For this purpose, it was necessary to determine which concrete properties would have to be regularly measured in order ascertain the statistical properties of different electron tube types.²⁵⁶

Iris Runge's laboratory reports from the years 1934 and 1935 contain examples of the use of distribution curves as a means of the monitoring of production processes. Below, the graph reproduced in [Figure 9](#) demonstrates how, by measuring the parameters of a given electron tube (here the RENS 1284), the data of an initial production run could be compared with results based on various changes in the tube's design. When, in her laboratory report on variance research and statistical analysis, Iris Runge could write that she "intended to provide information about the statistical properties of certain important types of electron tubes and to outline the considerations that might inform an ongoing statistical analysis for the supervision of the production processes," it is clear that, by April of 1935, the tube testing facilities had not been making use of any statistical controls on a regular basis.²⁵⁷

There did exist, however, certain "measurement protocols" upon which statistical analyses could be based, and it is with these data that Iris Runge performed quality control measures, in September and October of 1934, on somewhere between 1,100 and 1,200 samples from five different types of electron tube.²⁵⁸

254 For an explanation of this graphical table, see BECKER/PLAUT/RUNGE 1927, p. 51.

255 Ibid., p. 60. For an additional graphical method for comparing test results from different production series, see PLAUT 1930a.

256 As late as April of 1928, it had not yet been conclusively decided at Osram how electron tubes ought to be tested at the factory (see Appendix 4.2, especially questions 12 and 13).

257 See [DTMB] 6603, pp. 39–42. The pentode tube referred to as RENS 1284 (R stands for *Röhre* 'tube', E for *Empfänger* 'receiver', and NS for *Netzstrom* 'mains power') was an indirectly heated four-volt tube designed for high and low-frequency amplification, and it was used in radio receivers produced by several companies. The success of its design is reflected in the fact that, among other things, a variant of it was produced (the RENS 1294) with a modified control grid that was able to regulate different field strengths. For a discussion of the basic parameters of electron tubes (transconductance, penetration factor, anode resistance), see Section 3.4.5.2 below.

258 See [DTMB] 6603, Report No. 23 (see Appendix 5.1).

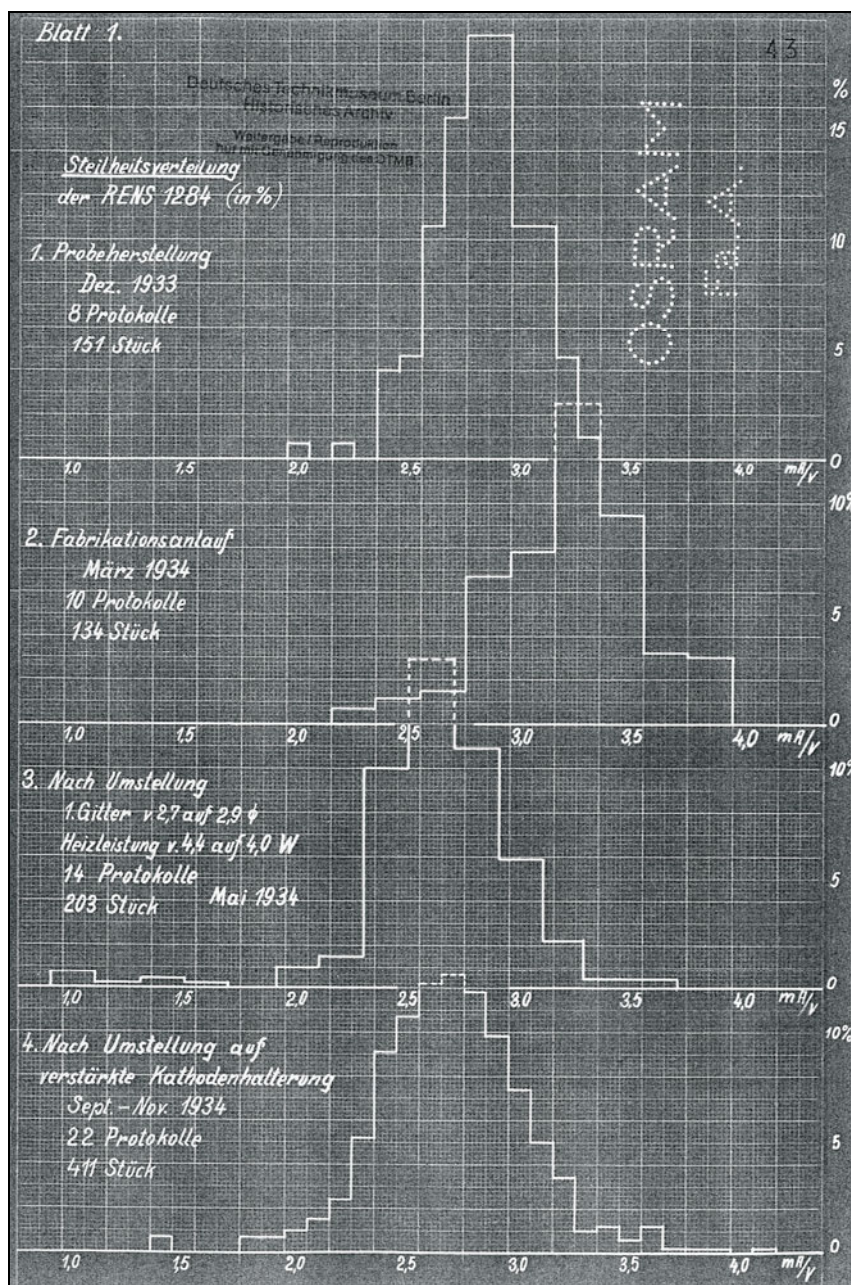


Figure 9: Iris Runge, *A Graphical Representation of the Distribution Curves of the Transconductance of an Electron Tube During Four Stages of Development (1934)*, ([DTMB] 6603, p. 43).

Within this report (No. 23), Iris Runge also introduced a standardized evaluation procedure that involved the following five steps: 1) drawing distribution curves for the relevant parameters of a given electron tube (transconductance, penetration factor), 2) calculating the means and the value of quadratic variance (quadratic deviation), 3) examining wildly deviant data, 4) comparing the results with the production dates of the tubes, and 5) drawing conclusions about the uniformity of the production process based on the extent to which, from one day to the next, the observed control measures deviated from the mean.

It had to be freshly determined, with each new product, which data should be checked during the testing process, and different businesses tended to look at different things. In a 1936 report on the electron tube factory of the Tung-Sol Corporation in the United States, for instance, Iris Runge remarked: “The data concerned with heat are not checked at all,” but rather those concerned with vacuum, grid current, filament film isolation, bias current, transconductance (dynamically), and emission.²⁵⁹ With the help of such observations, the department of technical statistics was able to make headway with its various investigations. The data collected with process control charts provided the foundation for examining process capabilities in such a way that the frequency distribution of a monitored parameter could be compared to statistical tolerance limits.

3.4.2.2 Determining the Size of a Random Sample

It can be shown that Iris Runge created not only new graphical tables to determine the size of samples, but new formulas as well. Her work in this field also demonstrates the close cooperation between the research laboratories of Osram and Telefunken, especially because the latter did not yet have its own expert in mathematics. A letter dated October 19, 1934 from Osram’s electron tube laboratory to Telefunken offers the following description of Iris Runge’s activity:

From a September conversation among Dr. Runge, Dr. Jobst, and Mr. Hasenberg, it emerged that the certainty with which conclusions can be drawn, from the current test results, about the properties of our entire line of electron tubes seems too slim, and thus the question has been raised, as it has already been at Telefunken, about whether we have been testing a sufficiently large sample size. In response to this matter, Dr. Runge has designed a graphical table on the basis of probability theory, from which the requisite sample sizes can be determined for given defect rates. Satisfying our pursuit of certainty, these sample sizes will now enable us to recognize such defect rates with a desired degree of accuracy, assuming that the sample lot is chosen strictly at random. For your benefit we have taken the liberty of enclosing three copies of this table, each with its own page of explanation.²⁶⁰

259 [DTMB] 6616, pp. 15–28.

260 [DTMB] 6603, p. 46. Werner Hasenberg and Günther Jobst were employees at Telefunken. Jobst, who had earned a doctoral degree under Arnold Sommerfeld in 1923, created the groundwork for the design of the pentode tube in 1926, which was further refined in the same year by Bernard Tellegen, a researcher at the Philips Corporation in Eindhoven. Bet-

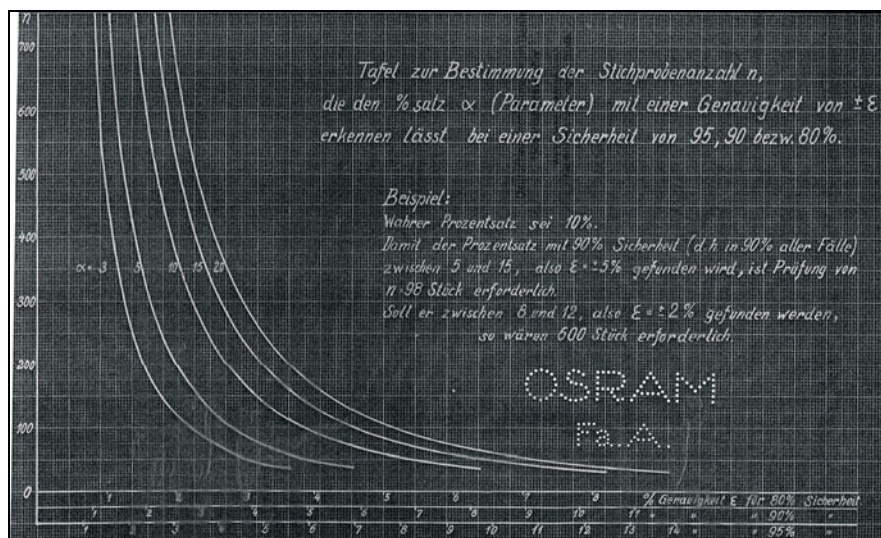


Figure 10: Iris Runge, A Table for Determining Sample Sizes (1934), ([DTMB], 6603, p. 47).

Iris Runge explained the table that she developed as follows:

Because it is often unclear, while evaluating defect rates, what sort of variation can be expected on account of chance when dealing with a limited sample size, the present table has been formulated on the basis of probability theory in order to serve as a guide during such evaluation. The table will yield the desired sample size n as a coordinate if a percentage α has been discovered with a given accuracy $\pm \varepsilon$. Depending on whether the result is needed to lie within 80, 90, or 95%, three different abscissa scales will obtain accordingly. *Practical Example:* Let percentage α be 10%. How many items will have to be tested for the discovered percentage, in 90% of the cases, to fall between 5 and 15%? Because the result is supposed to be valid in 90% of all cases, the middle abscissa scale will be valid. The accuracy of the limits 5 and 15 amounts to $\pm 5\%$. If one follows scale mark 5 on the middle abscissa scale up to the curve $\alpha = 10$, this will yield the coordinate 98. Therefore, 98 items will have to be tested. *An Inverse Example:* In a test of $n = 50$ items, 6% of the products were found to be defective. Normally, however, only a percentage of $\alpha = 3\%$ is acceptable. Can this result be attributed to chance, or does it reflect a decline in the quality of the production process? As far as accuracy is concerned, the discovered percentage exceeds what is normal by $\varepsilon = 3$. If one follows from the coordinate $n = 50$ on the curve $\alpha = 3$ down to the scale for 80%, one finds $\varepsilon = 3$. Thus there will always be a 20% chance of finding even more than 6%. There is nothing abnormal, then, in this result in itself, and therefore it cannot yet be concluded that the product is defective. – Runge.²⁶¹

ween 1939 and 1945, after some years of self-employment, Jobst directed a company known as the Research Society for Electronic Devices (*Studiengesellschaft für Elektronengeräte GmbH*) in Hamburg, which had been founded as a developmental laboratory by Valvo and Philips (see THIELE 2003, p. 133; BOGNER 2002a).

261 [DTMB] 6603, p. 48.

While at Osram, Iris Runge and her colleagues Ellen Lax and Hubert Plaut developed charts for determining appropriate sample sizes.²⁶² At Telefunken, meanwhile, Karl Steimel began to encourage a more rigorous application of mathematical methods and a closer cooperation with researchers at Osram.

At least two of Iris Runge's reports – those entitled “The Evaluation of Defect Rates on the Basis of Random Sampling” (July 1935, Appendix 5.1, No. 26) and “An Alignment Chart for Determining Sample Sizes on the Basis of a Small Preliminary Sample” (February 1936, Appendix 5.1, No. 28) – contain novel findings and were published. In report No. 26, for instance, she developed a new formula, which she presented along with its proof. She noted, as her point of departure, “that most of the formulas based on probability theory, on account of their cumbersome numerical analysis, are presented in such a way as to be impractical in many areas of industrial application.”²⁶³ The areas in question are those for which the binomial function, which is most applicable to small sample sizes, is inconvenient, and for which the exponential function, which is only sensible in the case of large samples, is not quite practicable. In other words, an appropriate formula was lacking that could be applied to the mid-range sample sizes that industry had come to prefer. She made it her task “to fill this gap.” “First,” she continued, “the binomial formula will be reconfigured into something numerically convenient; second, continuous approximations will be provided, for which it will be possible to estimate the range of values within which each of them can be applied with an acceptable degree of accuracy.”²⁶⁴ The point was to reveal something about the relationship between the defect rate of an entire product run to the defect rate and size of a tested sample. It should either be possible to predetermine the necessary sample size required to reach a sound conclusion or, if nothing else, to pronounce something about this conclusion and its certainty based on the deficiencies of the test in question. Iris Runge summarized her results as follows:

In a sample of n items, the probability that a property, with probability p , will be encountered in a fraction q of the entire product run can be expressed:

$$W_q dq = \binom{n}{nq} (1-p)^{n-nq} p^{nq}, \quad (1)$$

where dq designates that change in q whereby the factor nq , assumed to be an integer, is increased by 1, that is, $dq = 1/n$. To be distinguished from this is the probability that a property, encountered in a sample of n items as a fraction q of the entire product run, will have a frequency p . This yields the formula:

$$W_p dp = (n+1) \binom{n}{nq} (1-p)^{n-nq} p^{nq} dp. \quad (2)$$

Finally, for the probability that the overall frequency of the property might be more than p_1 , if a frequency q is found in a sample of n items, one arrives at the formula:

262 See for example LAX/PLAUT 1930.

263 [DTMB] 6603, p. 6 (the proof is given on pp. 18–20); Iris RUNGE 1936a, p. 134.

264 Iris RUNGE 1936a (*Zeitschrift für technische Physik*), p. 135.

$$W_{p > p_1} = \binom{n}{nq} (1 - p_1)^{n-nq+1} p_1^{nq} \left[1 + \frac{nq}{nq_1} \left(1 + \frac{nq-1}{(n-1)p_1} \left(1 + \frac{nq-2}{(n-2)p_1} (1 + \dots) \right) \right) \right]^{265}$$

From this latter formula, Iris Runge constructed a graph with which the important correlation of p_1 , q , and n could easily be derived:

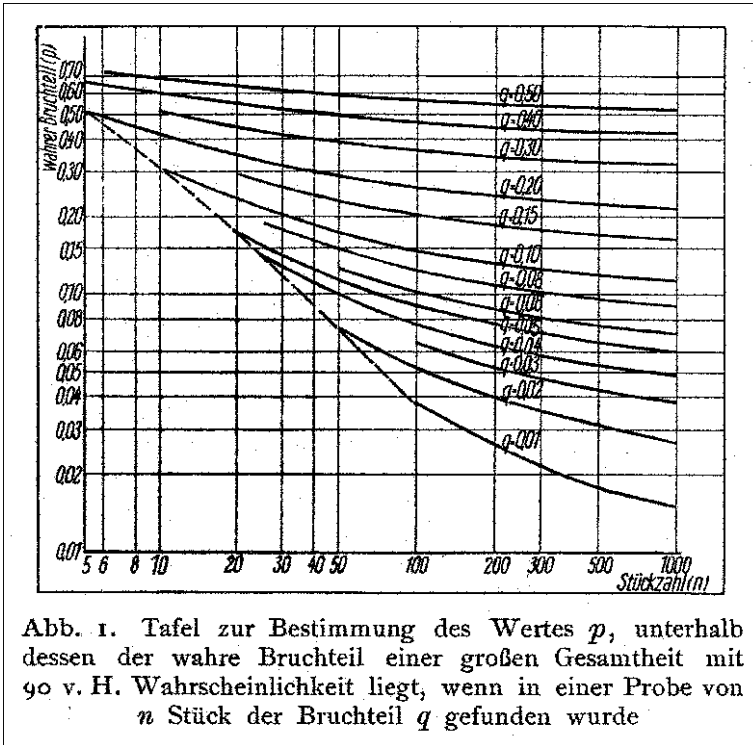


Figure 11: A Double Logarithmic Nomogram (Iris RUNGE 1936a, p. 138).

The graph was drawn on a double logarithmic nomogram in order to maintain the relative accuracy of even small values. To this end, all of the curves extend leftward only to the point where $nq = 1$ or to the point that represents the smallest possible whole number, for nq must at least equal 1 in all cases where q differs from 0. The ends of the curves, thus determined by $nq = 1$, are plotted along a dotted line. She explained the chart with the following example:

265 Iris RUNGE 1936a (*Technisch-wissenschaftliche Abhandlungen aus dem Osram-Konzern*), p. 150.

Within a sample of 80 items, for instance, let there be 12 items that exhibit the property under consideration, and thus $q = 0.15$. If the curve $q = 0.15$ is followed to the point where $n = 80$, this corresponds on the diagram with $p = 0.21$. It may then be concluded with a probability of 90% that the true defect rate is less than 20%. A probability of 90% means that, if similar results are often observed, a production error should continue to be detected in 1 of every 10 cases.²⁶⁶

A different graph had to be drawn for each probability, for if a probability of, say, 90 percent was insufficient (if 95 percent were needed), then the relation of p , q , and n would be different. Each of these different graphs could be drawn according to Iris Runge's formula, as she herself emphasized: "As to which relations need to be graphically illustrated on the basis of the general formula, this depends on the particular question faced by the engineer."²⁶⁷

It can be gathered from laboratory records that Iris Runge developed additional nomograms and that her article was frequently consulted by her colleagues and by the military authorities as well. On September 10, 1938, for instance, the document office of Osram's Factory A sent a letter to the Army Technical Office D, in which it reads: "In accordance with your wishes we have enclosed an off-print of Dr. Runge's study 'The Evaluation of Defect Rates on the Basis of Random Sampling' along with two of her graphs that concern the same matter."²⁶⁸ On March 20, 1940, Iris Runge sent a solicited copy of the same study to Dr. F. Löhle, a government advisor,²⁶⁹ and on April 1 of the same year she fulfilled a request of the Army Weapons Agency by supplying that office with a survey report on her article. To be precise, the report had been requested by a research group concerned with "the measurement of large sample sizes," which was part of the Association of German Engineers' consortium devoted to industrial metrology.²⁷⁰ An article written to serve the needs of civilian mass production was, at the same time, of great relevance to the mass production of military ware.

The second study mentioned above, No. 28, contained a special alignment chart for ascertaining sample sizes by means of testing a preliminary sample, a problem of significant practical importance. Iris Runge explained the general problem in the following terms:

If a property has been detected in a small number n_1 of observations, and the mean and statistical variance have been calculated from this data, this variance allows a claim to be made about the accuracy with which the mean can be expected to be correct. For if the discovered dispersion s_1 is divided by

$$\sqrt{n_1},$$

then it will be known that, with a probability of 68.2%, the true statistical mean of an entire large production run will lie within the range

266 Iris RUNGE 1936a (*Zeitschrift für technische Physik*), p. 138.

267 [DTMB] 6603, p. 17.

268 [DTMB] 6604, p. 52.

269 [DTMB] 6604, p. 9.

270 [DTMB] 6604, pp. 5–8. This survey report is reproduced in Appendix 5.6.

$$\frac{s_1}{\sqrt{n_1}}$$

on either side of the mean found in the small sample, and that this probability will increase to 90% if the tested sample were 1.65 times as large, and to 95% if the sample were 1.96 times larger.²⁷¹

Because production quality often depended on establishing the statistical mean with greater precision, some indication was needed to know how many additional exemplars had to be tested to ensure that the mean calculated from the sample batch would correspond, with a likelihood of 90% or 95%, to that of the production run as a whole. To this end she developed an alignment chart that consisted of three parallel scales:

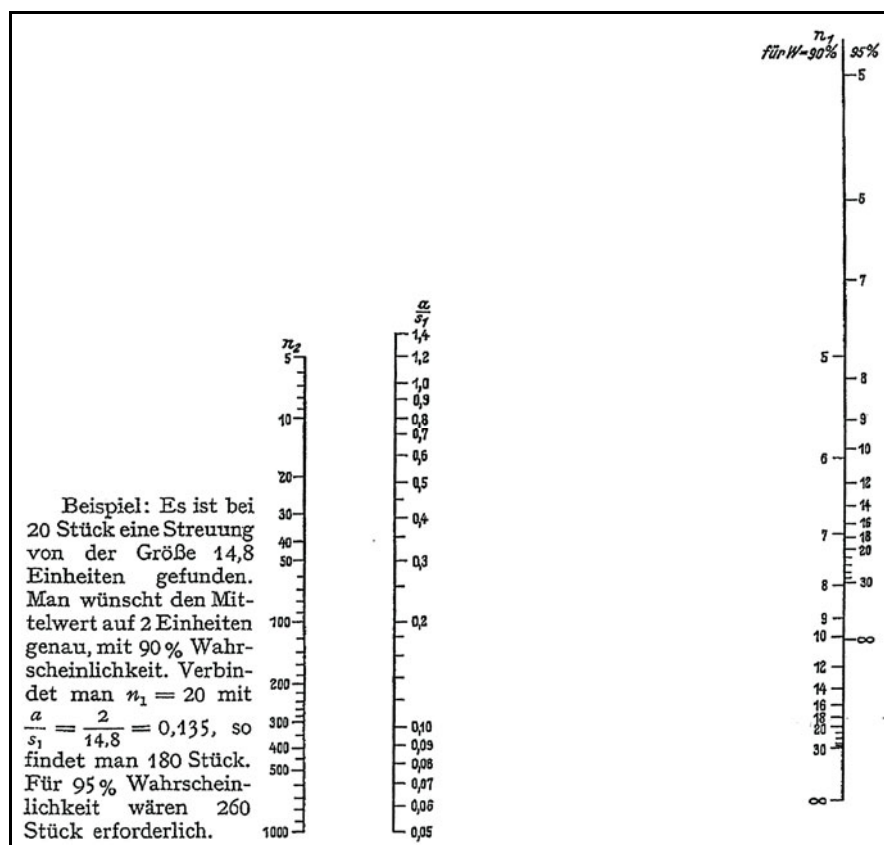


Figure 12: An Alignment Chart (Iris RUNGE 1936b, p. 152).

271 Iris RUNGE 1936b, p. 151.

The scale on the right is for n_1 = the number of observations tested in a preliminary sample (with indications for both 90% and 95% probabilities); the middle scale is for a/s_1 , where s_1 stands for the discovered statistical variance and a for the desired range within which the true statistical mean should correspond to the mean of n_2 exemplars (the increased number of items that should be tested); the left-hand scale is for n_2 , the expanded sample size.

To use the chart, an engineer would proceed to locate the value of a/s_1 on the middle scale (e.g., $a = 2$, if the desired mean is needed to fall within two units, divided by the determined statistical variance, e.g., 14.8 in the case of $n_1 = 20$ items). This point – $2/14.8 = 0.135$ – is then connected to the coordinate $n_1 = 20$ on the right-hand scale. By extending this line leftward with a straightedge, the desired number n_2 is then revealed (in her example, 180 items need to be tested for a confidence level of 90%, 260 items for 95%).

Behind the simple coordination of data points between the different scales, which an engineer could accomplish without any training in higher mathematics, lay Iris Runge's knowledge of probability theory. Pirani held this chart in such high esteem that he recommended it be included in the third edition of his book on graphical methods.²⁷² In general, Iris Runge's articles and laboratory reports can be regarded as contributions to the history of small-sample statistics. The origins of this subfield can be traced to a 1908 article by William Sealy Gosset, though it would be fifteen years after the appearance of this publication before another statistician directed his attention to the topic.²⁷³

3.4.2.3 The First Textbook of Its Kind

In 1927, the first edition of *Anwendung der mathematischen Statistik auf Probleme der Massenfabrikation* [The Application of Mathematical Statistics to Problems of Mass Production] was published by Verlag Julius Springer. Written under the aegis of Osram's main research department, the book was initiated by the research director Fritz Blau.²⁷⁴ The authors Richard Becker, Hubert C. Plaut, and Iris Runge stressed, in their preface, "that leading figures in certain branches of engineering have begun to recognize that their manufactured products can be treated as 'collective objects', in the mathematical sense, and that the principles of collectives (*Kollektivmaßlehre*) can consequently be applied to understand variations in the properties of these products."²⁷⁵

272 See a letter from Marcello Pirani to Iris Runge dated October 6, 1946 [Private Estate]; and PIRANI/FISCHER 1957.

273 See WIMMER/DOMINICK 2005, pp. 293–294.

274 See PIRANI 1930a, p. 97.

275 BECKER/PLAUT/RUNGE 1927, p. III. The term *Kollektivmaßlehre*, which is rendered here as 'principles of collectives', was introduced by Theodor Fechner in a book of that name; his thinking had a longstanding influence in the field of statistics (see WITTING 1990).

This book, the first of its kind in any language, should be discussed alongside contemporary works of a similar sort, especially Walter A. Shewhart's *Economic Control of Quality of Manufactured Product* (1931), which was informed by German sources and which is repeatedly acknowledged for its great influence.²⁷⁶ Denis Bayart, for one, has written the following with respect to Shewhart's methods: "In other countries [...], the methods that were developed remained fragmentary or limited to certain firms and have been definitely superseded by the method of Bell Labs."²⁷⁷ Egon S. Pearson's assessment of Shewhart's contribution was likewise positive, if in a more roundabout way:

I think the theoretical side of the book was less happily presented than the broad outline of principles. [...] Few British engineers in industry would have been prepared to tackle a 500-page book in which it was only at about page 300 that the writer got down to describing his five criteria for detecting lack of control. But if the book itself did not have much influence, Shewhart's visit to England in 1932 set going a train of events of very great importance.²⁷⁸

Of course, Becker, Plaut, and Runge could not have known about Shewhart's book because it appeared after the publication of their own, but they did fail to cite his published articles, which would have been available to them. That said, the authors did explicitly mention the "early experiments with large measuring units," which had been conducted by Karl Daeves for the iron industry, by Jan Czochralski in the field of metals research, and by the American chemist Albert E. R. Westman for purposes of improving the production of ceramics.²⁷⁹ In his article, Westman discussed fundamental concepts of statistics such as arithmetic mean, standard deviation, frequency distribution, as well as matters pertaining to random sampling, correlations, and statistical significance.²⁸⁰ He provided practical examples and based much of his presentation on the work of such British statisticians as Karl Pearson, R. A. Fisher, and William Sealy Gosset.²⁸¹

The book by Becker, Plaut, and Runge consists of 119 pages, including its bibliography and appendix, the latter containing a table for using the Gaussian error integral. The authors discuss, by way of introduction, the central question of testing the quality of mass-produced goods, which manifests itself in a factory setting as the ability to "consistently repeat the task of mass production," a task

276 See BAYART/CRÉPEL 1994; BAYART 2000; GASCA 2004, p. 41. In a survey of his work written for the American Statistical Association, Shewhart mentions German contributions to this field with the following short remark: "[...] the researches of Becker, Plaut, Runge and Daeves in the production of steel in Germany" (SHEWHART 1931a, p. 214).

277 BAYART 2000, p. 158 (an original English quotation).

278 PEARSON 1973, p. 172 (an original English quotation).

279 BECKER/PLAUT/RUNGE 1927, p. III. Westman's methods are mentioned once more in their introduction (p. 4) and alluded to later on in their discussion of SCHIMZ 1927 (p. 31).

280 WESTMAN 1927. A histogram, incidentally, is a graphical representation of distribution data.

281 Ibid. Analyses by Karl Pearson, who had attended lectures in Berlin by Emile du Bois-Reymond (Iris Runge's grandfather), were well known in Germany. The bibliography of BECKER/PLAUT/RUNGE 1927 lists, for instance: "Works by Pearson, K. in Phil. Trans. Roy. Soc. and Proc. Roy. Soc. London (1895–1926)."

that typically cannot be monitored without recourse to testing restricted product samples. Furthermore, the question of probability is paramount in explaining whether a certain testing process will yield, on the basis of a sample, results that can confidently be accepted as valid for a product run as a whole. The introduction concludes with a plea for every engineer concerned with quality control to familiarize him- or herself with the laws of statistics.

In order to motivate these very engineers, the authors decided to begin their book with a practical section. Here they explain the concrete problems of light bulb production that can be addressed by way of statistics, such as evaluating a mass production line on the basis of a sample, comparing two production runs on the basis of different tests, drawing correlations between two properties, and discerning risk and acceptable test specifications. At the same time, graphical and calculation methods are elucidated with concrete examples.

The second, mathematical section presents the derivations and laws that were applied in the first part of the book. The contents of this section read as follows: I. General Properties of Collectives: The Quadratic Dispersion Approximation; II. The Properties of Collectives with Gaussian Distribution²⁸²; III. Comparing Two Collectives (1. The Probability of there Being a Given Difference Between Particular Values, 2. The Probability of there Being a Difference Between Statistical Means, 3. The Probability of Positive Differences); IV. The Distribution of the Mean in Arbitrarily Distributed Collectives. The latter chapter contains the uniqueness theorem for characteristic functions in the special case of a normal distribution as well as the addition theorem for characteristic functions. This theoretical section of the book is essentially based on the works of Emanuel Czuber. In the section on correlations, for instance, the finer details and possible applications of correlation coefficients, as discussed in Czuber's *Die statistischen Forschungsmethoden* (1921), are explicitly cited, and their discussion of the additional theorem for characteristic functions includes a reference to the second edition of Henri Poincaré's *Calcul des probabilités*. According to Ivo Schneider, it was in this latter book that the term "characteristic function" was first used (Paris 1912, pp. 206–209), though the concept had already been implicit in work of Laplace.²⁸³

It is to the credit of Becker, Plaut, and Iris Runge that, on account of their textbook, the methods of statistics and probability theory were introduced to industrial circles, and the publisher decided to print a second edition in 1930. The majority of the reviews, which appeared mostly in 1928, wholeheartedly praised the book, both for the utility of its organization and the clarity of its presentation.²⁸⁴ The most comprehensive review was written by Georg Masing, a former doctoral student of Gustav Tammann; he asserted:

282 Gaussian distribution is also known as normal distribution. BECKER/PLAUT/RUNGE (1927, p. 35) also refers to practical examples for which the Gaussian curve would be inapplicable.

283 SCHNEIDER 1989, p. 420.

284 On December 12, 1928, Marcello Pirani sent a collection of reviews to Dr. Alfred Meyer, a director at Osram (see [LAB] 282, vol. 1). The collection contained reviews that were pub-

[...] It can therefore be stated that the book under review fulfills a strongly felt need. It concerns the practical application of statistics to matters of production, an application that is supported throughout by a detailed and correct understanding of mathematics. Simply by leafing through the book, readers will be struck by the extraordinary usefulness of the manner in which the material has been presented for industrial use. [...] It is *the one* book that should be required reading for all engineers dealing with matters of large number research, especially in light of what little has been said about the subject in the majority of technical publications that have appeared in recent years.²⁸⁵

Of all the reviewers, only Richard von Mises, writing in the *Zeitschrift für angewandte Mathematik und Mechanik*, expressed a degree of criticism:

As far as theory is concerned, the authors' reflections hardly go beyond a discussion of Laplace's solution of the Bernoulli problem. The few words that are said about correlation, too, are not very illuminating. The division of the book into 'practical' and 'mathematical' sections does not seem fully justified. Regarding the last section, on 'Poincaré's characteristic functions', it ought to be noted that what is dealt with here is really nothing more than the adjoint or 'generating function' introduced by Laplace. All in all, however, this fluently written and highly readable book should enjoy a wide audience, for it offers the engineer a very useful introduction to a field that is, for him, still novel and presumably very important.²⁸⁶

From atop his theoretical perch, it is clear that Richard von Mises was not in the best position to evaluate what was both realistic and necessary with respect to the quality control of contemporary production processes.

From a historiographical perspective – and also from the perspective of Iris Runge's biography – it is of some interest to know which of the three authors was responsible for the various sections of this "highly readable" textbook. Günther Luxbacher has written: "In 1927, Plaut, this time together with his colleague Iris Runge and under the aegis of Richard Becker, published one of the first works on the application of statistical methods to the mass production of complex goods."²⁸⁷ In response it should be clarified that Iris Runge was not Hubert Plaut's immediate colleague. It would be much more accurate to say that three trained mathematicians from different departments of the Osram Corporation – Becker, during the course of the project, accepted a professorship at the Technical University in Berlin – had been brought together for the sake of writing the book. In a later curriculum vitae, Iris Runge wrote:

In addition, I have edited a series of contributions on quality control – written by myself, Prof. R. Becker, and Dr. H. Plaut – into a uniform book: *Anwendung der mathematischen Statistik auf Probleme der Massenfabrikation*.²⁸⁸

lished in the journals *Weltwirtschaftliches Archiv*, *Werkstattstechnik*, *Zeitschrift für Metallkunde*, *Zeitschrift des Vereins deutscher Ingenieure*, and the *Zeitschrift für angewandte Mathematik und Mechanik*.

²⁸⁵ Georg Masing, writing in volume 20 of the *Zeitschrift für Metallkunde* (1928).

²⁸⁶ R. von Mises, in *Zeitschrift für angewandte Mathematik und Mechanik* 8 (1928), p. 336.

²⁸⁷ LUXBACHER 2003, p. 273.

²⁸⁸ [UAB] R 387, vol. I, p. 14.

If this account can be trusted, then Iris Runge was the author responsible for creating the systematic presentation of the work. Her expertise in the area of quality control was further demonstrated by a number of her other writings. As already mentioned, the book series *Technische-wissenschaftliche Abhandlungen aus dem Osram-Konzern* opened its inaugural volume, in 1930, with one of her articles on statistical quality control – a sure sign of the recognition that she had come to achieve.²⁸⁹ Walter Ernst Masing, a student of Werner Heisenberg and an expert in quality management, has even gone out of his way in recent years to praise the book by Becker, Plaut, and Iris Runge.²⁹⁰

In the wake of studies published in Germany, the publication of Shewhart's book in the United States (1931), and a project of the British Standards Institution that culminated in *The Application of Statistical Methods to Industrial Standardisation and Quality Control* (1935),²⁹¹ what emerged internationally was a more closely-knit collaboration between academic and industrial researchers in the field of statistical quality control.

3.4.2.4 *The Collaborative Effort of Industrial and Academic Researchers to Propagate the Application of Statistical Methods*

Walter Ernst Masing's remark that German engineers had been averse to "thinking about probabilities," and Egon Pearson's statement that there were, in the Great Britain of 1933, "practically no young men in industry with a knowledge of statistical method," encourage a deeper inquiry into how the statistical advances made at Osram, described above, ought to be evaluated.²⁹² In my search for answers to this question, I encountered both German and British efforts to spread an awareness of statistical methods, and these efforts resembled one another to the extent that they both involved lecture series aimed at disseminating this knowledge. It also came to light that Walter A. Shewhart's contributions to the field had served as a research catalyst not only in England, but in Germany as well.

Shewhart, who lectured at London University in 1932, initiated a series of lectures at the Royal Statistical Society on the application of statistical methods, and this has long been recognized as an important event.²⁹³ In 1933, inspired by Shewhart, Bernard P. Dudding established an Industrial and Agriculture Research Section within the Royal Statistical Society "to encourage the use of statistical methods in the manufacturing industries."²⁹⁴ As far as British industry was concerned, however, what was theoretically desirable seemed incompatible with what was

289 Iris RUNGE 1930a, p. 1.

290 See MASING 2003 (unpaginated online text).

291 The author of this book was Egon S. Pearson (see PEARSON 1973, pp. 175–176).

292 MASING 2003 (unpaginated); PEARSON 1973, p. 176 (this is an original English quotation).

293 See PEARSON 1973, pp. 176–177.

294 DUDDING 1942, p. 64 (an original English quotation).

practically feasible. According to Dr. R. H. Pickard, the director of the British Cotton Industry Research Association, British engineers simply did not understand the language of theoretical statistics, and both Dudding and Pearson have lamented how difficult it had been to introduce new concepts to the industrial setting. It was only around 1942, with the founding of an Industrial Applications Group within the Royal Statistical Society, that successful headway began to be made, and even then it was largely the interests of the military that enabled this success.²⁹⁵ Such “national efforts” during wartime were also characteristic of German military institutions, as is indicated by the request, mentioned above, of the Army Weapons Agency to see the results of Iris Runge’s research.

It has hardly received any attention that Shewhart, during his visit to Europe in 1932, was also in touch with German researchers. On June 3, 1932, from a hotel in Berlin, he wrote to Richard von Mises that “committees have now been organized in Germany, England, and America to further the application of statistical and probability theory in attaining economic control of manufactured product from raw material to finished article and in establishing economic standards and sampling methods.”²⁹⁶ Even though Shewhart and Von Mises never did manage to get together in person, the former did indeed meet with certain industrial researchers in Berlin. It is thanks to Shewhart’s influence, for example, that the German Standards Committee (*Normenausschuss*) began to standardize statistical methods. As the director of Osram’s department of technical statistics, Hubert Plaut participated in the first conference held by the Royal Statistical Society’s newly established Industrial and Agriculture Research Section, which took place in London on November 22, 1933. There Plaut reported about Shewhart’s influence on the German Standards Committee:

Lately, after a visit of Mr. Shewhart to Berlin, the work was also taken up by the *Deutsche Normenausschuss*. Here a questionnaire was circularized, and a proposal for the standardization of frequency curves worked out, which on one hand was to make results achieved on the same subject at different places immediately comparable, on the other hand was to prevent advertisers from publishing frequency curves founded on little fact.²⁹⁷

295 See DUDDING 1943; DUDDING 1952, p. 4; PEARSON 1973, p. 177. On the statistically-based production control of weapons manufacturing that was undertaken in France during the late nineteenth century, see HENRY 1894. On the relationship between the descriptive and mathematical traditions of statistics, see DESROSIÈRES 2005.

296 From the Central-Hotel in Berlin, Shewhart wrote to Von Mises that he had arranged to meet with him about the German Association of Engineers. Although this meeting never came about, Shewhart bought a copy of Von Mises’s book on probability theory (MISES 1928) with the anticipation of meeting him later; see [HUG] 4574.5, Correspondence (1903–1953), Box 2, Folder 1932 (I am indebted to Reinhard Siegmund-Schultze for bringing this source to my attention). Shewhart would make reference to Von Mises’s findings in his book *Statistical Method from the Viewpoint of Quality Control* (1939, p. 13).

297 Quoted from Hubert Plaut’s contribution to PICKARD 1934, p. 21 (an original English quotation). My thanks are due to Denis Bayart for making this reference known to me.

The prominent statisticians Egon Pearson and William Gosset also attended this conference. Plaut went on to express his amazement about the British advancements in mathematical statistics, stressing that German industrial employees would have recoiled at the prospect of having to make use of higher mathematics:

As compared with the admirable results attained in England in the theory of statistical research, little mathematics have been applied in the *Grosszahlforschung* in Germany. This was not mere chance, but was because it was strongly felt from the beginning that it would be difficult to get men inside the industry to use higher mathematics. Besides, there was a difficulty in interesting purely theoretical statisticians in the problems of industry. A book published lately by K. Daeves, Düsseldorf, in application of statistics in industrial research, is based almost entirely on graphical methods and avoids nearly all mathematical formulas.²⁹⁸

Here Plaut was referring to Karl Daeves's recently published *Praktische Großzahlforschung* (1933), which the physicist Marianus Czerny relegated to the "less mathematical branch" of this type of scholarly literature. Even though his name appears on its title page, Plaut oddly failed to mention BECKER/PLAUT/RUNGE 1927/1930, a work that Czerny assigned to the "strongly mathematical branch" of this same literature.²⁹⁹ Perhaps this is some indication that Plaut had nothing at all to do with the theoretical component of that book.³⁰⁰ When he mentions that it has been difficult in Germany to interest purely theoretical statisticians in the problems of industrial research, he is perhaps alluding to the same atmosphere that inhibited Shewhart from developing closer relations with Richard von Mises.

In Berlin, however, a close collaboration did indeed materialize between industrial and academic researchers, as is demonstrated by two lecture series that were held on the application of statistics and probability theory (see Table 14 and Section 3.3). Organized and hosted by the Technical University in Berlin, these lectures were later edited and published as anthologies.³⁰¹ They were held before anything comparable would take place in Great Britain, but they also came to an earlier end. Whereas British industries would not welcome statistical methods until the war had broken out, even the first set of German lectures, which took place in 1928 and 1929, was planned and organized by representatives of the industrial sector. Not only were the editors of the proceedings industrial researchers – Plaut and Fritz Lubberger – but so too were several of the lecturers themselves:

298 Ibid.

299 Quoted from Marianus Czerny's contribution to LUBBERGER 1937, p. 1.

300 Additional studies by Plaut and Pirani reveal their reliance, when it comes to purely mathematical matters, either on Iris Runge's detailed derivations or on the book BECKER/PLAUT/RUNGE 1927, e.g., "Greater detail on the theory of the measurements used here can be found, for instance, in Becker-Plaut-Runge [...]" (PIRANI/PLAUT 1930, p. 7). In PIRANI/PLAUT 1931, p. 8, reference is made to the theoretical considerations in RUNGE 1930b and BECKER/PLAUT/RUNGE 1927. See also PLAUT 1931a, p. 17; and PLAUT 1934, pp. 143–144, where the author remarks: "Mr. W. Schwietzke helped me to carry out the truly arduous numerical calculations that were necessary for assembling the graphs and tables."

301 PLAUT 1930b; LUBBERGER 1937.

Marcello Pirani, Iris Runge, Reinhold Rüdenberg, Ragnar Holm, and K. Franz. Two speakers from the Technical University in Berlin, namely the professors Richard Becker (the former Osram researcher) and Georg Schlesinger, had also once been active on the business side of things. In the lecture by Lubberger, who had worked for years on designing telephone systems in the United States, commentary was provided on the latest technological advances from North America and Europe. He supported his claims by, among other things, referring to a book that addressed the mathematical principles required for dealing with problems of telephone installation.³⁰²

Table 14: Two Series of Lectures on the Application of Statistical Methods

a) Quality Control on the Basis of Statistical Methods (Winter Semester 1928/29).

- IV. Randomness and Regularity in the Case of Large Data Sets. – Demonstrating the Emergence of Statistical Regularities in a Mechanical Model. – Frequency Curves as a Fundamental of Technical Statistics. (Prof. Marcello Pirani, TU Berlin, and Dr. Hubert C. Plaut, Osram)
- V. The Fundamentals of Mathematical Statistics. (Prof. Rudolf Rothe, TU Berlin)
- VI. The Normal Frequency Curve and Its Meaning. (Dr. Iris Runge, Osram)
- VII. The Methodology of Technical *Großzahlforschung*. (Dr. Hubert C. Plaut, Osram)
- VIII. Warranty and Acceptance Terms. (Prof. Richard Becker, TU Berlin)
- IX. Statistical Methods for Evaluating Electrical Machines and Devices by Means of Tolerances. (Prof. Reinhold Rüdenberg, Siemens-Schuckert)
- X. The Evaluation of DIN Adaptors in Light of Statistics. (Prof. Georg Schlesinger, TU Berlin)
- XI. On a Fundamental Task of Statistics in the Field of Telephony: Calculating the Losses Caused by Busy Lines in an Automated Network. (Dr. Ragnar Holm, Research Laboratory of the Siemens Corporations)
- XII. Performance Statistics. (Prof. Walther Moede, TU Berlin)

b) The Latest Advances in Probabilities and Fluctuations (January 13–February 24, 1936, organized by the German Association of Electrical Engineers and the Technical University in Berlin).

- I. The Fundamental Terms and Laws of Probabilities and Fluctuations. (Prof. Marianus Czerny, University of Berlin)
- II. Probability in the Monitoring of Production Processes. (K. Franz, Siemens)
- III. Observations, Provisions, and Theories of Fluctuations in the Case of Telephone Traffic. (Dr. Fritz Lubberger, Chief Engineer at Siemens & Halske and Associate Professor at the TU Berlin)
- IV. Hidden Periodic Phenomena. (Prof. Julius Bartels, College of Forestry in Eberswalde)
- V. The Occurrence of Probability Laws and Fluctuation Phenomena in Physics. (Prof. Richard Becker, University of Göttingen, prepared by Werner Döring³⁰³)

³⁰² LUBBERGER 1937, p. 50. The book in question is WINKELMANN 1936.

³⁰³ Supervised by Becker, Döring earned his doctoral degree in theoretical physics in 1936.

In the lectures on statistics and probability theory, the spectrum of applications encompassed not only issues of quality control in various industries, but also matters pertaining to experimental sciences (advanced metrology, physics, geophysics), business economics, and psychology.

Plaut deliberately referred to the production monitoring as a new area for statisticians to explore: “If statisticians come to realize from these lectures that a new field has emerged that can benefit from their services, then the goal of this book has been achieved. It is hoped that such practitioners will come to feel that this new field warrants a justifiably high place among the other fields to which theoretical statistics has been applied.”³⁰⁴ In addition to matters of quality control, Becker’s contributions also addressed the three main areas of physics that had been illuminated by the laws of probability in the preceding decades, namely error theory, (classical) statistical mechanics, and quantum theory.³⁰⁵

Those who spoke and wrote about business economics and industrial psychology were representing new disciplines that had arisen out of the efforts of businesses to economize their operations and were thus, almost by nature, reliant on statistical methods. Georg Schlesinger is regarded as the founder of industrial management (*Betriebswissenschaft*), a branch of science and engineering that is concerned with the interaction of product engineering, organization, and human labor, and that ultimately seeks to extract the maximum potential, in terms of efficiency and quality, from the activity of individual workers.³⁰⁶ He had been the chief designer at the machine factory of the Ludwig Loewe Company until 1904, when he accepted a newly established professorship in machine tools, factory design, and factory operations at the Technical University in Berlin. There, in 1918, he co-founded an institute for industrial psychology with his colleague Walther Moede, a development that was in step with the trend of researching human performance capacities in order to maximize the efficiency of businesses (the same type of research, that is, that had led to the assembly line in the United States).³⁰⁷ Moede, who had already conducted character assessments of military personnel during the First World War, taught from 1921 to 1945 as an associate professor of occupational and industrial psychology at the Technical University in

304 PLAUT 1930b, p. IV.

305 At a time when “pure” mathematics and theoretical physics were being criticized by the National Socialist regime, Becker stressed that the new tool of probability theory allowed for a great deal of atomic phenomena to be calculated quantitatively and unambiguously, and he distanced himself from the practice of “German” physics in general: “Let us not be impeded in this work by the passion with which older generations of worthy physicists have exerted themselves in the name of perpetuating the tradition of classical physics” (Becker’s contribution to LUBBERGER 1937, p. 98). With this remark he was reacting to attacks made by the so-called “German” physicists, whose most notable representatives were the Nobel laureates Philipp Lenard and Johannes Stark (for further discussion and the latest scholarship on this topic, see ECKERT 2007).

306 For more on the achievements of Georg Schlesinger, see SPUR/FISCHER 2000.

307 See BOBERG et al. 1984, pp. 310–312.

Berlin, where his research concentrated on the application of psychology to production operations. In addition to this position, he also directed a new institute for industrial psychology that had been founded in 1920 at Berlin's College of Business (*Handelshochschule*).³⁰⁸

In the 1930s, important figures in the collaboration between industrial and academic research were forced to flee from the city and the country. Although the mathematician Rudolf Rothe and the psychologist Walther Moede, for instance, were able to keep their positions, many important participants in these lectures were driven into exile. In 1936, Richard Becker was forcefully transferred to Göttingen³⁰⁹ – a “small” sacrifice – but others were less fortunate: Schlesinger, Jewish by birth and accused of treason, lost his professorship and emigrated in 1934; Pirani, who was classified as “half-Jewish” by the National Socialist authorities, fled to Great Britain in 1936; Plaut, the son of a Jewish physician, similarly left for London³¹⁰; like Pirani, Reinhold Rüdénberg held lectures in London and went on to work for the General Electric Company as an advisory engineer. In 1938 he accepted an invitation to teach at Harvard University.³¹¹

Even despite this drain of talent, a 1937 report by the German Mathematical Society (*Deutsche Mathematiker-Vereinigung*) revealed that, by that time, the methods of mathematical statistics had begun to exert unprecedented influence in a wide variety of fields: economic monitoring and research, business economics, laboratory development, civilian and military materials testing, animal husbandry, highway and railroad design, industrial psychology, medical statistics, and genetics research.³¹² Plaut had already mentioned in 1933 that statistical methods were being used by several industries – steel, electrical, light bulb, mining, charcoal, and glass – as well as by scientists conducting chemical analyses of food.³¹³ Although the DMV report of the year 1937 had argued that Germany was lagging behind Great Britain and the Scandinavian countries in the practical application of statistical methods to business and engineering, this was perhaps nothing but an intentional contradiction of the facts. In reality, this rhetoric served only to fuel the supposition of Germany's inferiority in this aspect of science, which in turn led to the result that the field received even greater attention and financial resources than it already enjoyed. Additional articles from the time indicate, moreover, that statistics had been appropriated by even more types of businesses than have been mentioned here.³¹⁴

When German scientists were called upon to present summary reports to the occupying powers concerning any advances in probability theory that might have

308 See SPUR 2009; and Gundlach's biographical entry on Moede in NDB, vol. 17, p. 611.

309 See RAMMER 2004.

310 Dr. Max Plaut, a relative of Hubert Plaut and the chairman of the Jewish Religious Federation in Hamburg, documented the deportations of his family members (ROSENBERG 1992).

311 STRAUSS/RÖDER 1999, vol. 2, p. 1003.

312 BÖHM 1937, p. 239.

313 See Plaut's contribution to PICKARD 1934, p. 21.

314 On the use of quality control in the food industry, for instance, see HENGST 1941.

been made during the years 1939 to 1945, they limited their responses to cursory assessments of the progress that had been made exclusively within different areas of mathematics.³¹⁵ Not a single word was written about the use of statistical methods in the industrial sector. At only one point was the name Karl Daeves mentioned, but no context was given. Wilhelm Lorey referred briefly to the first journal of business mathematics – the *Archiv für mathematische Wirtschafts- und Sozialforschung* – but he seems to have mentioned the journal for the sole reason of announcing its discontinuation:

Begun in 1936, the *Archiv für mathematische Wirtschafts- und Sozialforschung*, which was edited by Timpe and Riebesell with the cooperation of Burkhardt, Peter, and v. Stackelberg, developed into a successful publication outlet for scientists who, like those in other countries, endeavored to apply effective mathematical methods to the study of business and society. Pressured by the authorities, however, the journal was shut down in 1941 after the publication of its seventh volume.³¹⁶

Even though “industrial mathematics” had become a fashionable term in the 1930s,³¹⁷ the specific statistical methods that were applied and developed by German industries nevertheless remained little-known – if known at all – to broader circles throughout the country. Because so many authorities in the field were either exiled or forcibly transferred away from Berlin, fruitful collaboration between industrial and academic researchers ceased to exist during the period of National Socialism. Because of the political isolation of Germany, because of the war, and because of the dissolution of German businesses in 1945, most of the advances that had been made in applied statistics were consigned to oblivion.

The following sections will concentrate on Iris Runge’s contributions to materials research, optics/colorimetry, and electron tube research.

3.4.3 Solving Problems of Materials Research

[...] It is absolutely imperative that I get enough sleep tonight, for tomorrow I would like to make yet another hundred glorious calculations, something that I will be unable to do so well otherwise. (It is somewhat like awaking early on Christmas morning in anticipation of playing with new toys for the entire day.)³¹⁸

Iris Runge wrote these words after working for just three months at the experimental laboratory directed by Richard Jacoby, where the focus of research was incandescent light bulbs. Having recently completed a dissertation in physical

315 See GEPPERT 1948; LOREY 1948; SCHULZ 1948.

316 LOREY 1948, p. 201. Aloys Timpe, Paul Riebesell, and Felix Burkhardt were professors of applied mathematics, statistics, and actuarial science, respectively. Hans Peter, Erich Schneider, and Heinrich Freiherr von Stackelberg were economic theorists who had studied mathematics alongside economics.

317 See MEHRTENS 1996, p. 104.

318 A letter from Iris Runge to her father dated June 6, 1923 [Private Estate].

chemistry (see Section 2.7.2), she was eager to employ her knowledge of mathematical methods in the field of materials research. In fact, she would go on to make advances in applied mathematics that have remained relevant up to the present day.³¹⁹

3.4.3.1 Practical Analysis

Iris Runge succeeded in finding new mathematical approaches to solving practical problems of metal physics, and it would not be inappropriate to regard these new approaches as contributions to the general field of practical mathematical analysis. It should be noted right away, however, that no laboratory reports have come down to us from the six years that she was active in incandescent light bulb research, which is nevertheless the period that is presently under consideration. The analysis in this section is based on three published articles and on the personal letters in which Iris Runge discussed their progress and aims.

A New Method of Integrating the Heat Equation for Electrically Heated Filaments

The heat equation is a partial differential equation that describes the distribution of heat (or variations in temperature) in a given region over time. In her doctoral thesis, Iris Runge had addressed the diffusion in binary heterogeneous systems formed by two solids using the partial differential equation that described physical distribution processes (diffusion, heat conduction). Her familiarity with partial differential equations was such that she recognized in them a pattern of order (*Ordnungsmuster*) that could be used to elucidate a variety of distribution processes.³²⁰ Thus she applied them, while working on her first research assignment at Osram, to determine the heat conduction of the filaments that were used in incandescent light bulbs, and in doing so she developed a new method of integrating the heat equation for electrically heated filaments.

The same physical principle had already been applied experimentally in the development of the so-called Pirani gauge, an instrument for measuring vacuum pressure in which the radiation and dissipation of heat from a metal filament play an essential role. From monitoring the temperature variations and resistance variations of a heated filament, that is, conclusions can be drawn about the vacuum that surrounds the filament in question. Iris Runge realized that a mathematical understanding of these phenomena would facilitate the design of suitable filaments.

319 This estimation of Iris Runge's contributions to this field is that of the mathematician Helmut Neunzert, who kindly shared this opinion with me in our personal correspondence.

320 On the term *Ordnungsmuster*, which is difficult to capture in English, see Section 1.2.2 in the introductory chapter. On the history of metal physics as well as the calculation of the "diffusion of metals in metals," see CHALMERS 1949; CRANK 1956/2004.

The task before her was to create a mathematical model for the problem of electrically heated filaments that dissipate heat as radiation. For this she developed a one-dimensional heat equation in which the heat sources are expressed in terms of Joule heating and radiation³²¹:

$$\frac{d}{dx} \left(\lambda(T) q \frac{dT}{dx} \right) = - \frac{i^2 w(T)}{q} + 2 \sqrt{\pi q} s(T),$$

where x is the distance from the end of the filament, T the temperature, q the diameter of the filament, i the electric current, λ the conductivity, w the specific resistance, and s the radiated energy.

In her article, which was published in the *Zeitschrift für Physik*, Iris Runge noted that, until then, no one had managed to integrate this equation in a general form. Her novel contributions were to replace T with the negative heat flow

$$u = \lambda \frac{\partial T}{\partial x},$$

and to replace x with the new independent variable

$$v = \frac{du}{dx}.$$

Therefore, she had to postulate certain monotonicity criteria, especially an “equilibrium temperature” in the center of the filament, to ensure that the flux at that point could be assumed to be zero. This enabled her to integrate the above differential equation analytically, and the resulting integrals could be integrated graphically. It is typically the case that a general solution cannot be found, and that numerical methods are thus needed to arrive at approximate solutions. Iris Runge demonstrated that, under appropriate conditions, the first integral could indeed be solved conclusively, whereas the integration of the second integral necessarily required the use of known graphical or numerical methods.³²² Graphical methods, of course, were far more manageable in the hands of engineers.

Calculating the Electrical Conductivity of Alloys

Iris Runge solved another problem during her first year at Osram, namely that of the conductivity of homogeneous bodies. This problem, too, involved diffusion processes in binary systems (tungsten alloyed with thorium for use as filaments and cathodes, for example). Following a suggestion by Pirani, she refined a mathematical formula that had been developed thirty years earlier by Lord Rayleigh, a renowned British physicist.³²³ She published her results in two versions, a short

321 Also known as ohmic or resistive heating, Joule heating is the process by which an electric current, when passing through a conductor, releases heat. This heat is proportional to the square of a current multiplied by the electrical resistance of a given wire.

322 Iris RUNGE 1923, p. 231.

323 RAYLEIGH 1892.

summary written with Pirani in the *Zeitschrift für Metallkunde* and a longer exposition that appeared in the *Zeitschrift für technische Physik*. Iris Runge explained to her father:

I insisted to Pirani that he ought to be designated as a co-author because all of the ideas, aside from Rayleigh's, came directly from him. He ultimately agreed to publish something with me, but only in the form of a short, qualitative study for *Metallkunde*. With this article he wanted to relate what was essential for metals researchers and to do so in such a way that they could reproduce the calculations and achieve some approximate results. Then he suggested that I should prepare a separate publication on the mathematical component of the research [...].³²⁴

By the middle of the 1920s, Rayleigh's article had been largely forgotten; bearing the title "On the Influence of Obstacles Arranged in Rectangular Order upon the Properties of a Medium," its theoretical complexity had deterred most scientists from testing or applying its results. The article concerned what still remains a central problem of homogenization, namely the study of partial differential equations with rapidly oscillating coefficients. Rayleigh's contribution remains important to physicists and engineers because it is equations of this type that govern the physics of non-homogeneous materials.

Iris Runge took it upon herself to address the following problem of homogenization: Cylinders or spheres with a conductivity ν are periodically embedded into a material with a conductivity of one. What is the intermediate conductivity of this aggregate? In today's theory, a length ε is assumed for a periodicity cell such that the number of cells t is of the order $1/\varepsilon$, and the intermediate conductivity is defined as the limit when ε approaches zero.

These limiting processes were not available to Iris Runge as she thought about these things more than about 75 years ago. But she found another way. Having first solved the averaging problem for one periodicity cell, she then solved a Laplace equation in which, at the inner boundary of the cylinder or sphere, there were jump interface conditions for normal derivatives. She approached this problem, which even today remains an "auxiliary problem" of homogenization, by expanding two- and three-dimensional spherical functions. In addition to calculating the first expansion terms, she improved Lord Rayleigh's publication by correcting an error and she demonstrated the applicability of her method to arrays composed of cylindrical shells. To her father she remarked:

By applying the same principle that Rayleigh had used in his calculations of arrayed cylinders, it is possible, as I have now come to realize, to make calculations about arrayed cylinder shells whose core is identical to the surrounding medium. The formulas are only somewhat more complicated, and they are actually supported by empirical results.³²⁵

324 An undated letter from Iris Runge to her father written some time in 1923 [Private Estate].

325 Ibid. For her correction of Rayleigh's error, see Iris RUNGE 1925, p. 65; on the next page she discusses the applicability of the formulas to cylindrical shells.

Although only a few experiments had been conducted that addressed this problem, Iris Runge was able to confirm that the existing experimental data accorded with her calculations. Her results for one cell, moreover, hardly deviated from the calculation made for very many cells, so long as the conductivity ν was not too far from 1. She could therefore conclude her article by stressing that, with the formulas that she had developed, the conductivity of binary systems could now be approximated in advance and, conversely, the structure of such systems could now be determined on the basis of known conductivities:

Even though there is a paucity of experimental data with which to compare the results of the formulas developed here, this says nothing against their utility. To be sure, it would still be interesting to examine whether, in accordance with the formulas, the influence of microscopically observable structural differences – the longitudinal elongation of particles, for instance – might really be detectable in the conductivity being measured. If this is indeed so, then the formulas afford us the possibility of predicting the approximate conductivity of binary mixtures on the basis of the conductivities determined by the structural particularities of its individual components. Conversely, the formulas enable us to draw conclusions about the structure of binary mixtures on the basis of their observed conductivity. It is worth stressing that, as Rayleigh already remarked, the same formulas are generally applicable to all of the scalar material properties of mixed media for which the boundary conditions can be given in the form $k_1 (\delta V / \delta n)_1 = k_2 (\delta V / \delta n)_2$, where k_1 and k_2 designate the values of the respective scalar properties on both sides of the boundary and V designates a solution to the equation $\Delta V = 0$. Thus, for example, the dielectric and magnetization constants, as well as the heat conductivity, can also be calculated in this way from the corresponding properties of the materials in question.³²⁶

Published in 1925, Iris Runge's article acquired an international audience and continued to be cited after 1945. In the book *The Mathematics of Diffusion*, John Crank acknowledged her contribution as follows: "Starting from solutions of Laplace's equation expressed in Legendre functions, Rayleigh (1892) obtained an improved approximation for identical spheres arrayed on a single cubic lattice. His work was developed further by Runge (1925) and de Vries (1952a,b) to include both body-centred and face-centred cubic lattices and cylinders."³²⁷ Her work was also cited in a piece from 1977 – "Exact Modelling of Cubic Lattice Permittivity and Conductivity" – that was published in the journal *Nature*.³²⁸

3.4.3.2 Similarity Solutions

In 1930 or 1931, Iris Runge began to investigate whether the flow processes of molten glass inside a melting tank could be understood more accurately by means of a model experiment,³²⁹ and the results of her investigation were presented in the

326 Iris RUNGE 1925, p. 68.

327 CRANK 1956/2004, p. 272.

328 D. R. McKenzie and R. C. McPhedran, "Exact Modelling of Cubic Lattice Permittivity and Conductivity," *Nature* 265 (1977), pp. 128–129.

329 See also Appendix 5.3, No. 9.

article “Über die exakten Voraussetzungen der Untersuchungen von Glasströmungen in Modellwannen” [On the Precise Conditions for Testing Glass Flow in Model Tanks], which was published in 1934. Here she theoretically deduced the conditions under which a material would be suitable for tank flow experiments. The article begins by considering similarity laws:

The question of the possibility of conducting model experiments is really one of knowing the particular form of the similarity laws that pertain to the matter under investigation. Such laws are significant to a great variety of physical and technological disciplines. They are probably best known for their application to ship and aircraft design and to studies concerned with electrical discharges in gases. The laws of similarity are based on the fact that the different physical quantities that determine a given process have accordingly different units or “dimensions,” and between these there exist very specific relationships. These relationships entail that a change in one dimension – in the linear scale, for example – will result in certain other changes that can be detected from the form of the equation.³³⁰

Thus, Iris Runge concerned herself with problems that remain current today, namely those of dimensional analysis and similarity. Typically one seeks, by dimensional analysis, a compound parameter, whose values characterize a flow situation, for example. The quotation above mentions the applicability of similarity theory to ship and aircraft design. She had been familiar with this area of research from her days at the University of Göttingen, where she attended courses taught by one of the foremost experts in the field, Ludwig Prandtl. If, for example, one wants to study the behavior of a small-scale aircraft model inside a wind tunnel, the value of a specific dimensionless number (the so-called Reynolds number) must be the same for both the original aircraft and the model in order to achieve an acceptably similar flow field.³³¹ It was numbers of this sort that Iris Runge sought in her study of glass flow in melting tanks.

She began her article by explaining a classical example of the problem – one that Reynolds and others had already treated – without mentioning her predecessors by name (her summary was simply meant to clarify matters for the members of the German Society for Glass Technology). She then turned to the complicated case that arises because there are high, location-dependent temperatures within a melting tank, and that such physical parameters as viscosity, density, and thermal conductivity are strongly dependent on temperature. In order to approach the model in mathematical terms, Iris Runge developed a simplified model that did not take the forces of inertia into consideration. With this she was able to draw sound conclusions about the material properties of a glass melting tank that was operating within the temperature ranges prevailing in practice. It was not possible, however, for her to establish with any certainty whether the glass within the tank might in fact meet these criteria. Because experiments were lacking, it had not yet

330 Iris RUNGE 1934/1936, p. 137.

331 Named after the British physicist Osborne Reynolds, the Reynolds number is a dimensionless number that provides a measure of the ratio of internal forces to viscous forces. On the history of fluid dynamics, see ECKERT 2006.

been clarified “whether a material exists with which a practical model could be built that satisfies these conditions.”³³² Thus it cannot be ascertained whether her findings could have been put to practical use. There were no simple models for glass melting tanks, and this remains the case today.³³³

3.4.4 Optics, Colorimetry

I’ll probably bring some work along with me, for I’m flooded with interesting problems right now. I haven’t had any time for these at Osram because I’ve been filling in for Dr. Heinze and I have twenty other urgent matters on my plate. My schedule is so scrambled, in fact, that my days seem to unfold in little three-minute chunks of time.³³⁴

The “interesting problems” mentioned in this quotation, which was written in 1927, concerned the field of theoretical optics, a discipline to which Iris Runge had been introduced while studying under Arnold Sommerfeld in Munich (see Section 2.5.2). She had also studied optics at the University of Göttingen, where she attended lectures on the topic by Woldemar Voigt and by the experimental psychologist David Katz, whose post-doctoral research had contributed to the understanding of color perception.³³⁵ At Osram, where lighting technology was the chief concern, theoretical optics and colorimetry were essential components of the research agenda. With a foundational study published in 1920, the physicist and future Nobel laureate Erwin Schrödinger had managed to elevate colorimetry into a central scientific issue. Hotly discussed internationally, colorimetry was also a common topic at the gatherings of the German Society for Lighting Technology and the German Society for Technical Physics in Berlin.³³⁶ In addition to advances in colorimetry, the 1920s and 1930s also witnessed great progress in photometry (the measurement of visible light) and radiometry (the measurement of invisible light). Having attended the 1923 congress of mathematicians and physicists in Bonn, Iris Runge was inspired to return to the research that she had begun under

332 Iris RUNGE 1934/1936, p. 140.

333 See, for instance, Daniel Schippan, *Untersuchung des reaktionstechnischen Verhaltens in Behälterglaswannen mit Tracerversuchen* (PhD, Technische Hochschule in Aachen, 2003).

334 A letter from Iris Runge to her mother dated August 24, 1927 [Private Estate]. Here she is discussing a vacation to Langeoog that she and her mother were planning to take together (Carl Runge had died on January 3, 1927).

335 Iris Runge referred to David Katz’s work in a presentation that she gave on color vision (see RUNGE 1927a). From the curriculum vitae appended to her dissertation, it is known that she attended his lectures. Katz became a professor at the University of Rostock in 1919. Having been expelled from Germany in 1933 on account of his Jewish heritage, he spent his exile in Sweden, where he worked as a professor in Stockholm. One of his most renowned works, *Der Aufbau der Farbwelt* (Leipzig: Barth, 1930), appeared in English as *The World of Colour*, trans. R. B. MacLeod and C. W. Fox (London: Kegan Paul, 1935). This work continues to be cited in contemporary tube research; see, for example, Lothar Spillman et al., “Brightness Enhancement Seen Through a Tube,” *Perception* 39 (2010), pp. 1504–1513.

336 See JOHNSTON 2001.

Sommerfeld's supervision, namely that concerned with the application of vector analysis to problems of optics.³³⁷ The results of her continued efforts attracted attention far beyond her industrial context; several theoretical physicists, for instance, are known to have acknowledged the relevance of her findings.

Calculating the Light Output of Coiled Filaments

Together with Ellen Lax, who was responsible for the experimental side of things, Iris Runge wrote an article on the influence of radiation absorption on the light output of coiled filaments ("Einfluß der Strahlungsschwärzung auf die Lichtausbeute bei Leuchtkörpern aus Wendeldraht"). This study, which the authors dedicated to the research director Fritz Blau, was published in 1925 in the *Zeitschrift für technische Physik*. Iris Runge contributed to the work by developing a theoretical model for the practically important problem of light output in the case of coiled filaments, which had only just begun to be used. Her model was based on the following observation: "In the case of illuminants whose individual components are capable of irradiating one another mutually – as is the case, for instance, with coiled filaments – there will be a degree of internal radiation alongside pure surface radiation, i.e., in addition to radiation without surface reflection, other radiation will be emitted from the interior of the illuminant that has indeed been altered by reflection."³³⁸ She explained that in light bulbs with coiled filaments, which are selective emitters, the ratio between light radiation and total radiation is altered by internal radiation, and that this is so because internal reflections cause such illuminants to approximate the nature of a blackbody emitter. Behind all of this is the problem, still relevant today, that pure tungsten was and remains the preferred material for electron emitters.³³⁹ It is preferred because, at constant temperatures, the temperature dependence of its spectral emission coefficient allows it to yield approximately forty percent more light than a blackbody emitter. Some of the gains of this selective emission, however, are offset by the effects of coiling the filament, which is done for the sake of other efficiencies.

As a mathematical model, Iris Runge introduced a geometric series for the absorption capacity of a body, and she demonstrated that, under the effects of reflection, the total radiation of a coiled filament increases at a faster rate than that of its light radiation alone, and thus its light output is somewhat reduced.³⁴⁰ She estimated this reduction to be approximately ten percent, and she based this calculation on additional models of the surface area of coiled filaments. In the end, no

337 She discussed this inspiration in a letter to her parents written in 1923 [Private Estate].

338 LAX/RUNGE 1925, p. 317. By means of electrical resistance, a coiled filament transforms an electrical current into radiant and thermal energy.

339 See, for instance, two recent patent applications: DE19843852A1 (an electric light bulb patented by Osram on March 30, 2000), and DE102007015243A1 (a light bulb with a structured illuminant patented on October 2, 2008).

340 Light output was measured in watts per Hefner candle.

practical conclusions could be drawn regarding the performance of light bulbs with coiled filaments, and this is because the coiled form allowed for certain benefits – fewer support wires, thicker filaments, etc. – that counteracted the effects of reduced light output. It was not yet possible at the time to describe these beneficial factors in mathematical terms.

Determining the Cross Section of Thin Filaments

Various methods were developed at Osram for determining the cross section of thin filaments. In an article on optical micrometry that was published in 1928, Iris Runge wrote: “Thin filaments, those with a diameter of approximately $10\ \mu$, play an especially significant role in the engineering of incandescent light bulbs and electron tubes. An accurate measurement of their diameters is an important factor in controlling the uniformity of the production process, among other special applications.”³⁴¹ In an effort to solve this problem, she developed a measuring device – an optical micrometer – that would later be produced and marketed by the Carl Leiss Corporation (see [Figure 13](#)). She showcased this device in 1928 at the annual convention of the Society of German Natural Scientists and Physicians, which was held in Hamburg, and she did the same in 1929 before the Society for Lighting Technology in Berlin. Her commentary on the latter event offers an interesting look into how such scientific presentations were executed:

On the tenth of January I made yet another presentation, this one to the Society for Lighting Technology. It went pretty well, but it involved a great deal of preparation, and the day itself could not have been more hectic. Some of the items needed for my demonstration had to be gathered from Pirani’s laboratory, others from one of Osram’s daughter companies – “Agelindus” – and the rest from our laboratory here. I had requested that everything be sent by two o’clock to the technical university, where the presentation was to take place and where I was already waiting. Pirani had sent two technicians, but all of the items from Agelindus were missing. Moreover, two of the apparatuses that the men delivered were wrong, and therefore I had to call to have the correct ones sent – I waited around and lost an endless amount of time. Whereas I had hoped to be able to finish my preparations by four, drink a peaceful cup of coffee at home, rest, and change clothes, in reality I had to do everything in a mad rush. I was very tired by the time six o’clock came around, but I discovered that it didn’t really matter. In the end, the presentation turned out to be very warmly received, and Miss Hüniger told me the following day that it had been both good and interesting.³⁴²

In her article, Iris Runge explained to what extent it was possible, with her micrometer, to draw conclusions about the cross section of a non-circular filament on the basis of diameter measurements.

341 Iris RUNGE 1928b, p. 484 (reprinted in 1930).

342 A letter from Iris Runge to her mother dated January 19, 1929 [Private Estate]. Founded in 1922, the Agelindus Corporation was a subsidiary of Osram.

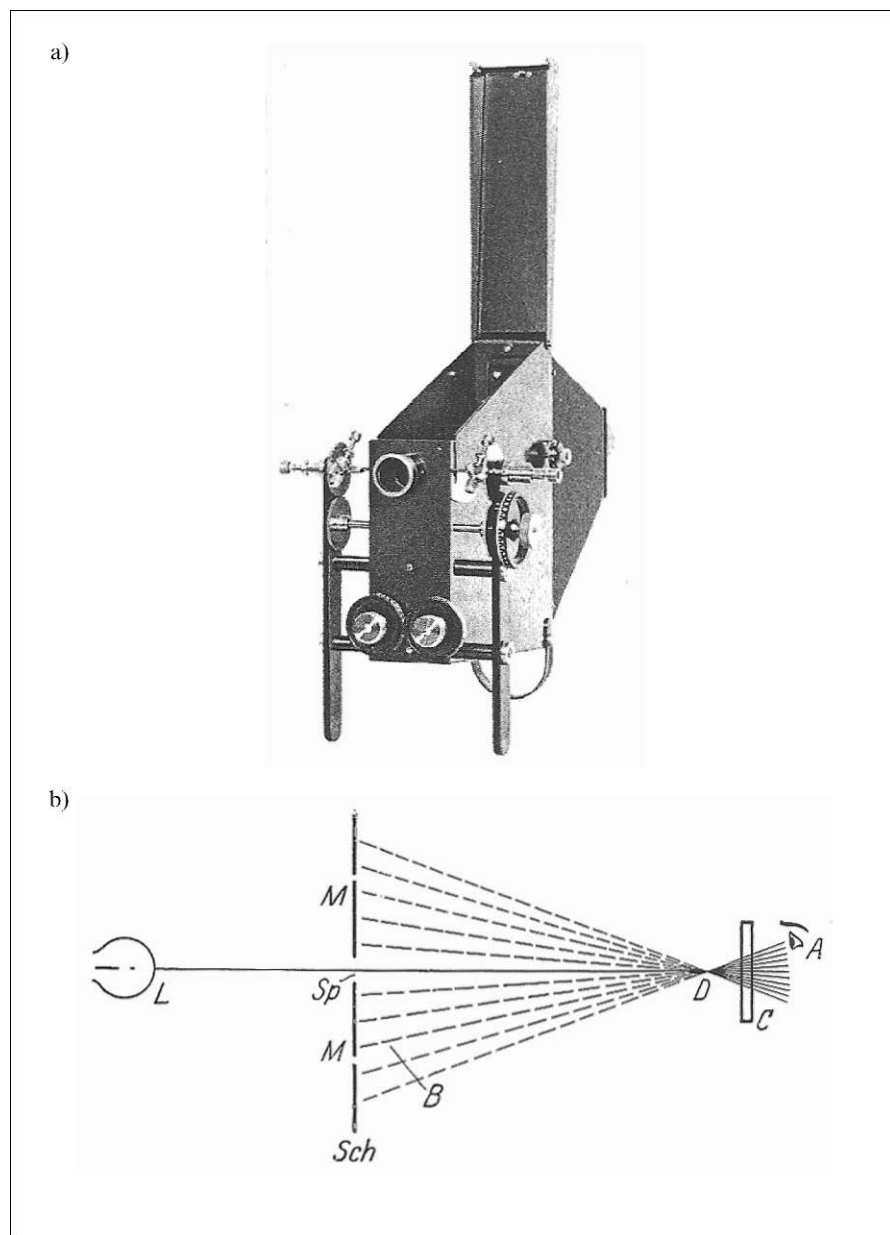


Figure 13: Optical Micrometer, a) General View, b) Optical Path
(Iris RUNGE 1928b/1930, p. 166).

A=eye (*Auge*); *B*=diffraction image (*Beugungserscheinung*); *C*=cylindrical lens; *D*= filament (*Draht*); *L*=light; *M*=a movable element (*Marke*); *Sch*=screen (*Schirm*); *SP*=slit (*Spalt*).

First Iris Runge demonstrated the necessary steps for determining the shape of a cross section, which is done by utilizing the refraction effect of a given wire – that is, the interference of parallel rays of light that pass by both sides of the wire – and by measuring the distances between the parallel tangents. She continued by explaining how the surface area of a cross section could be calculated; here she set aside the idea of central symmetry, assuming rather that there would be minor deviations from a truly circular shape. She also took into account the fact that parts of the filament with more pronounced curvatures (certain sharp edges, for instance) could yield inaccurate measurements of a cross section, and it was therefore necessary to estimate the margin of error. As she demonstrated with a Fourier expansion for a number of measured cross sections, this turned out to be negligibly small (up to 1.2%), and thus she was able to conclude that, by using the formula that she had developed, the surface area of a cross section could be calculated from the average of the observed values (half the average distance between the tangents).

It is noteworthy that, as early as 1899, Arnold Sommerfeld had already concerned himself with the theory of single wires. In a later chapter on “wire waves” included in Richard von Mises and Philipp Frank’s *Die Differential- und Integralgleichungen der Mechanik und Physik* [The Differential and Integral Equations of Mechanics and Physics], Sommerfeld also addressed the special topic of very thin wires.³⁴³

Color Vision and Colorimetry

At the request of the research director Marcello Pirani, Iris Runge gave a lecture to the German Society for Lighting Technology in which she provided an overview on the topic of color vision. Pirani was aware of her qualifications in the field of theoretical optics, and he thought that at least some knowledge of this subject should be disseminated to the broader community of industrial researchers. In addition to this lecture, Iris Runge also produced research results pertaining to colorimetry; her efforts drew upon the scholarship of Erwin Schrödinger and the findings of other internationally established scientists. To clarify, the basic task of colorimetry, or color measurement, is to provide numerical descriptions of the results obtained through visual color inspections and color comparisons.

Iris Runge’s first lecture on this topic to the Society for Lighting Technology took place on December 9, 1926 and was titled “Grundlagen des Farbensehens” [The Principles of Color Vision]. To her mother she described the event as follows:

I gave the talk at Pirani’s request, and it concerned Helmholtz’s color theory and Arthur König’s fundamental color sensations (*Grundempfindungen*). [...] All in all it was a joy and a success. [...] The old measurements and theories are clearly not known to enough people,

343 See Arnold Sommerfeld, “Sehr dünner Draht,” in FRANK/MISES 1927 [1935], pp. 908–910. On the history of this book and its several editions, see SIEGMUND-SCHULTZE 2007.

even though they are of considerable significance to today's lighting technology, so much so that they deserve to be showcased and explained as thoroughly as possible. These older studies are somewhat difficult to get hold of and generally make for difficult reading; only a few specialists understand them well, but with some knowledge of physics and mathematics – not to mention a knack for pedagogy – it is possible to do the good deed of sharing this information in an intelligible manner. This truly needs to be done, moreover, because most of the people here are still enamored by Ostwald's pseudo-science.³⁴⁴

Iris Runge began her lecture by posing a set of simple practical questions, among them: "How do I create artificial light whose effect on the eye is the same as that of natural light?" She went on to underscore the interrelations between physics, physiology, and psychology and the close connection between objective and subjective phenomena in the case of color vision.³⁴⁵ She explained this latter correlation by discussing the wave length of light, the spectral colors, the notion of color as a three-dimensional multiplicity, and the possibility of representing all colors as mass points on a plane. In turn she explained the mathematical principles of the color triangle – a theory of additive color proposed by Thomas Young and further developed by James Clerk Maxwell and Hermann von Helmholtz – and demonstrated how the brightness of a color could be determined from its spectral distribution or color coordinates. The lecture concluded with an appeal for researchers to devote more attention to the subject, just as scholars in England and America had been doing throughout the previous decade. Here she also stressed the necessity of reevaluating existing measurements with the help of the latest technologies.

After delivering this lecture, Iris Runge was asked to prepare a survey article on the fundamentals of color theory – "Zur Farbenlehre" – for the *Zeitschrift für technische Physik*. The article, which appeared in 1927, presented an overview of the foundational research in the field, most notably the work of Hermann von Helmholtz and Erwin Schrödinger. Here she also voiced her opposition to Wilhelm Ostwald's color theory, as others had done before her, and outlined the mathematical principles of colorimetry.³⁴⁶ Beyond her theoretical exposition, she also discussed a variety of experimental issues, including the colorimeter invented by the Polish scientist Jan Szczepanik and one of her own methods for calibrating a

344 A letter dated December 26, 1926 [Private Estate]. Arthur König was a student of Hermann von Helmholtz.

345 On this matter and the ensuing discussion, see Iris RUNGE 1927a, p. 3.

346 Iris RUNGE 1927b. Wilhelm Ostwald's color theory, which was popularized by his 1916 book *Die Farbenfibel* [The Color Primer], was soon rejected by most physicists as unscientific. For an early detraction of Ostwald's work, see K. W. F. Kohlrausch, "Bemerkungen zur Ostwald'schen sogenannten Farbentheorie," *Physikalische Zeitschrift* 22 (1921), p. 402. Later, Ostwald's taxonomy of pigment colors was deemed to be a valuable contribution that did not contradict the classical trichromatic theory of color perception. In this regard, see Helmut Hönl, "Die Ostwaldsche Systematik der Pigmentfarben in ihrem Verhältnis zur Young-Helmholtzschen Dreikomponententheorie," *Die Naturwissenschaften* 41 (1954), pp. 487–494; and the work of Jan J. Koenderink at the University of Utrecht.

tristimulus colorimeter.³⁴⁷ Her survey also included various diagrams and examples for their application, and these were meant to supersede other, more time-consuming methods of solving colorimetric problems.

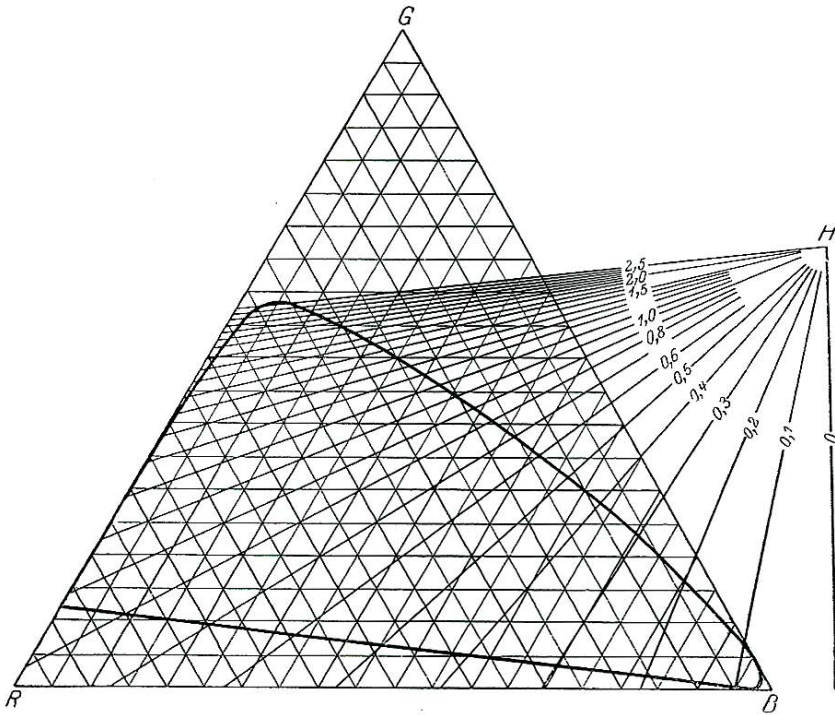


Figure 14: A Diagram for Determining the Brightness of a Color
(Iris RUNGE 1928a/1931, p. 328).

In a paper published in the *Zeitschrift für Instrumentenkunde* [Journal for the Study of Technical Instruments], Iris Runge treated the experimental aspects of colorimetry in greater detail. Here she described how color measurements could be made by means of a colorimeter and how this instrument could be applied to

347 See RUNGE 1928a, 1928b. Today, of course, there are various methods of calibrating tristimulus colorimeters and there are many new types of colorimeters. Iris Runge developed and described her own calibration before the establishment of the so-called *CIE 1931 Standard (Colorimetric) Observer*. See János Schanda, George Eppeldauer, and Georg Sauter, “Tristimulus Color Measurement of Self-Luminous Sources,” in *Colorimetry: Understanding the CIE System*, ed. János Schanda (Hoboken: Wiley-Interscience, 2007), pp. 135–158; and *Methods for Characterising Tristimulus Colorimeters for Measuring the Colour of Light*, a technical report released by the Commission Internationale de L’Eclairage (CIE) in 2007.

the practical problems faced by industrial researchers. In particular, the article sought to increase the ease of using a so-called trichromatic colorimeter: “Because it is the case that, when measuring a given color with a trichromatic colorimeter, one must rely on the mere three colors filtered by this device, the true color coordinates, as they apply to the system of fundamental sensations, have to be determined by means of calculation.”³⁴⁸ To perform the necessary calibration of this colorimeter, she made use of transformation equations that had been formulated in Great Britain (a relatively simple algebraic equation system with three equations and three variables).³⁴⁹ Her diagram enabled the values of color coordinates and brightness to be read immediately from the data produced by the colorimeter. By comparing Iris Runge’s results to color coordinates achieved spectroscopically, one of her colleagues had tested the accuracy of her procedure and determined that a good deal of time and effort could be saved by using her colorimeter and diagrams as opposed to the methods of spectroscopic or planimetric analysis.

In yet another study concerned with color theory – “Die Unterschiedsschwelle des Auges bei kleinen Schwinkeln” [The Differential Threshold of the Eye at Small Angles of Vision] – Iris Runge used a photometer to investigate the differences in brightness illuminated by an incandescent bulb and, in doing so, confirmed Fechner’s law in the case of small visual angles.³⁵⁰ The theoretical questions of whether and how the difference in brightness between two colors can be quantitatively determined, which were significant to the field of lighting engineering, had not been fully explained by 1929; this is true despite the existence of Erwin Schrödinger’s foundational article on the matter, “Outline of a Theory of Color Measurement for Daylight Vision” (as it is known in English).³⁵¹ Iris Runge evaluated the problem as follows:

In his research on colorimetry, Schrödinger makes the assumption that the difference in brightness between two colors can be measured by the smallest number of barely distinguishable steps that can be detected between the colors in question. On the basis of certain

348 Iris RUNGE 1928a/1931, p. 325.

349 The British work in question is J. Guild, “The Transformation of Trichromatic Mixture Data: Algebraic Methods,” *Transactions of the Optical Society* 26 (1924), pp. 95–108.

350 Iris RUNGE 1929/31b. The German physicist Gustav Theodor Fechner, who is mentioned above in Section 3.4.2.3 regarding his theory of collectives (*Kollektivmaßlehre*), was one of the founders of the field of psychophysics, a science concerned with the qualitative relations between physical sensations and the stimuli that evoke them. In 1860 he postulated that the intensity of a sensation increases as the log of the stimulus, which is known as Fechner’s law. His general formula for arriving at the number units of steps in any given sensation was $S = c \log R$, where S designates the sensation, R the numerically estimated stimulus, and c a constant that must be experimentally determined. Later research has conclusively demonstrated that Fechner’s law is not universally applicable.

351 SCHRÖDINGER 1920, which demonstrates that the laws of color mixture operate independent of the brightness of different colors. Here he also presents a theoretical approach to comparing the differences in brightness. For an English translation of this article, see Erwin Schrödinger, “Outline of a Theory of Color Measurement for Daylight Vision,” in *Sources of Color Science*, ed. David L. MacAdam (Cambridge, MA: MIT Press, 1970), pp. 134–182.

other considerations, he further posits a function of color coordinates that is meant to represent his theoretical concept. If this degree of difference, which has been empirically confirmed in only a few instances, proves to be true in a broader number of cases, then colors of equal brightness would be able to be coordinated on a spherical triangle in such a way that the difference of the two color points would be proportional to their distance as measured along the great circle of the sphere. In this representation, however, the straight lines of the ordinary representation would not correspond to great circles but rather to particular curves of the fourth order, that is, colors that are created from a mixture of two distinct components would not in fact lie on the shortest line connecting them. Such a representation is therefore hardly suitable for practical purposes. As long as the question of sensation differences within the color space remains unclarified, the problem of their representation cannot currently be addressed, and researchers will have to be careful not to read too much into the faulty representations of these relationships that have hitherto been used.³⁵²

Iris Runge contacted Schrödinger in 1929 in order to bring this putative discrepancy to his attention; the length and detail of his response indicate the seriousness with which he regarded her critique of his work:

Dear Miss Runge!

Your observation is very interesting, but it does not really concern an error on my part. On the basis of the first sentence on page 511, I rather took the liberty of placing the inscribed ellipse arcs through the white point of the *standard* color triangle and of simply stating that I considered colors of equal brightness to be located in this triangle. On the simple triangle representation, once freed from its three-dimensional representation, all colors with identical stimulus *types* – but different stimulus *strengths* – will overlap at every point. I can think of several examples of this. Of course, the elliptical arcs have only the property of specifying the shortest color lines and not, in addition, the property of indicating the distance yielded by their *Euclidian* arc lengths. But I never claimed anything otherwise.

Your remark did, however, lead me to consider the following thoughts. If the distance between white ($x_1 = x_2 = x_3 = 1$) and the spectral yellow of equal brightness ($x_1 = x_2; x_3 = 0$) is calculated using the formula

$$\int ds = 2ar \cos \frac{\alpha \sqrt{x_1 x'_1} + \beta \sqrt{x_2 x'_2} + \gamma \sqrt{x_3 x'_3}}{h};$$

$$h = \alpha x'_1 + \beta x'_2 + \gamma x'_3 = \alpha x'_1 + \beta x'_2 + \gamma x'_3$$

this would presumably yield far too small a value on account of the extraordinarily smallness of γ (Note: The result can be compared with the Fechner step, e.g., if the result is 0.07, that means that, under the observed conditions, in which the Fechner step amounts to 1%, there would be only seven barely distinguishable intermediate steps between pure white and the yellow of the same brightness.) I suspect that the value is too small because it would disappear entirely if $\gamma = 0$.

I have just made the small calculation, and hopefully I have done so correctly. Much to my amazement I have discovered that things are not as bad as I had anticipated. With Kohlrausch's values (Exner certainly overestimated the strength of the yellow coloration of the macula and has therefore, perhaps, underestimated the value of blue), that is, with $\alpha = 1$, $\beta = 0.618$, $\gamma = 0.047$, I still find the aforementioned distance to be 0.336, and thus there are 34 intermediate steps if the Fechner step is 1%. This is not at all impossible.

352 Iris RUNGE 1929/31a, p. 333.

Incidentally, at one point in the past I even entertained the possibility that the value of blue could actually be zero (see the enclosed article from the academy proceedings). If this were true, of course, then my entire system of colorimetry and the ability to improve upon it would suddenly be faced with insuperable difficulties. It's hard to say how things really are. In any case, it would still be interesting to reexamine the result above concerning the distance between white and yellow; in fact it could be possible that my solution is much too low. If anyone ever does test my result, this same person would also have to determine the brightness coefficients, especially the value of blue, with greater accuracy. Then again, the ratios are indeed rather favorable, if for no other reason than that the relation is quadratic: A value of γ that is four times greater engenders, in theory, only twice the number of intermediate steps, etc.

Here I have also taken the opportunity to enclose my article from Müller and Pouillet's reference work, which you might find of some use on account of your interest in such matters. Thank you for motivating me to reconsider my earlier conclusions, and please accept my warmest greetings.

Sincerely yours, E. Schrödinger³⁵³

From 1927 to 1933, Schrödinger served as Max Planck's successor at the University of Berlin, where he came to know Iris Runge through the physical colloquia. A few months after the correspondence cited above, she was invited to write the main article on colorimetry for the second edition of the *Handwörterbuch der Naturwissenschaften*, a comprehensive reference tool that was published in 1933.³⁵⁴ Her article provides a systematic survey of the research conducted in this field as well as an evaluation of Schrödinger's contributions to it. From what she wrote it is also clear that, by that time, no one had taken it upon himself (or herself) to test, in a sufficiently thorough manner, Schrödinger's formula for calculating the precise difference in brightness between two colors.

Differential Equations for the Photocurrent in Semiconductors

Shortly after transferring to Osram's electron tube laboratory, Iris Runge turned her attention to a project that proved to be an interesting transition from her work on theoretical optics to the subject of electron currents. Together with her colleague Rudolf Sewig, she wrote an article – "Über den inneren Photoeffekt in kristallinen Halbleitern" [On the Internal Photoelectric Effect in Crystalline Semi-

353 A letter from Erwin Schrödinger to Iris Runge – dated March 12, 1929 – in [STB] 739. The *macula lutea*, or "yellow spot," is the central part of the retina that is responsible for fine detail in our vision. The article referred to at the end of the letter is SCHRÖDINGER 1926a.

354 Iris RUNGE 1933. The *Handwörterbuch der Naturwissenschaften*, which was prepared by a team of editors, consisted of ten volumes. Its first edition was published serially between 1912 and 1915, its second edition between 1931 and 1935. From a letter to her mother dated August 23, 1931 [Private Estate], it is known that Iris Runge was invited to write this contribution in September of 1930, that she began to write it on July 27, 1931, and that the final version was due to be submitted by September 1 of the same year.

conductors] – that drew upon the studies of photoelectric phenomena that had recently been undertaken at multiple research laboratories.³⁵⁵

After it had been discovered in 1873 that the resistance of a circuit element composed of crystalline selenium would decrease or increase depending on its exposure to light – an observation that spurred the creation of the photocell – other “semiconductors” of this sort were discovered whose electrical resistance similarly changed under the influence of light or heat. While at Osram, Sewig measured the “photocurrent” in thallium photocells by making oscillographic recordings, and Iris Runge derived differential equations, based on the existing assumptions regarding the occurrence of secondary photoelectric currents, for their current flow over time. The solutions to her equations happened to correspond quite well with the experimental findings on thallium cells, reflecting both the rise in current induced by their sudden exposure to constant light as well as the current curves produced by their intermittent exposure to light of various frequencies.³⁵⁶

Assuming regular alternations between exposure and non-exposure to constant light, which she represented with a Fourier cosine series, she derived the following formula for the current i :

$$i = \frac{i_b}{2} (1 - e^{-kt}) + \frac{2ki_b}{\pi} \left\{ \frac{\omega}{\omega^2 + k^2} \sin \omega t - \frac{\omega}{9\omega^2 + k^2} \sin 3\omega t + \frac{\omega \sin 5\omega t}{25\omega^2 + k^2} - \dots + \frac{k}{\omega^2 + k^2} \cos \omega t - \dots \right\}$$

The value of the constant k could be determined from the oscillogram of the rise in current during moments of sudden exposure to constant light.

With this formula, a problem of technical importance was thus depicted theoretically. Photoelectric currents in crystalline semiconductors do not respond to changes in light exposure without inertia; rather, they asymptotically approach a final value that is dependent upon a broad variety of conditions (intensity, color, thickness, etc.). The dependence of this value on light frequency, which complicated certain engineering processes, ultimately occasioned this study of the time-dependent photoelectric properties of thallium cells.

Although Iris Runge and Rudolf Sewig failed to mention in their article who had been responsible for its respective experimental and mathematical components, conclusions can be drawn about this from other sources.³⁵⁷

355 See RUNGE/SEWIG 1930 and Appendix 4.3. Among the studies referred to in this article is T. W. Case's "Notes on the Change of Resistance of Certain Substrates in Light," *Physical Review* 9 (1917), pp. 305–310, which involved the use of an amplifier to demonstrate that semiconductor conductivity could be influenced by light. Case's methods, as the article indicates, are discussed by Bernhard Gudden, *Lichtelektrische Erscheinungen*, Struktur der Materie 8 (Berlin: J. Springer, 1928).

356 This has also been an important area of research in more recent times; see, for instance, Helmut Baumert, "Mathematisches Modell zur Deutung der durch intermittierende Belichtung von Phytoplanktern hervorgerufenen Mehrleistung der Photosynthese," *International Review of Hydrobiology* 61 (1997), pp. 517–527.

357 A letter from Rudolf Sewig to Iris Runge – dated October 18, 1937 – in [STB] 740.

3.4.5 Electron Tube Research

I enjoy making calculations and engaging in mathematical thinking, and I do this to improve the design of radio tubes, even though I consider radio broadcasting to be a rather pernicious thing. Yet this is hardly the fault of the tubes themselves, which also have more beneficial applications.³⁵⁸

A radio tube is an electron tube, that is, an electronic device consisting of two or more electrodes enclosed in an evacuated or gas-filled envelope that is made of glass or another material (as of the 1930s, for instance, steel and ceramic tubes were also used). Electron tubes were developed for creating, rectifying, amplifying, and modulating electrical signals. Before the introduction of the transistor, the electron tube was the only active and controllable electronic device.³⁵⁹

The most basic type of electron tube is the diode; it contains two electrodes – a cathode (or filament) and an anode (or plate) – and is used to convert alternating current into direct current and to demodulate amplitude-modulated radio signals. The triode, which was the first electronic amplification device with three active electrodes, contains a cathode, an anode, and a grid for controlling the anode current. Tubes have been developed to have two grids (tetrode), three grids (pentode), and as many as six (octode).

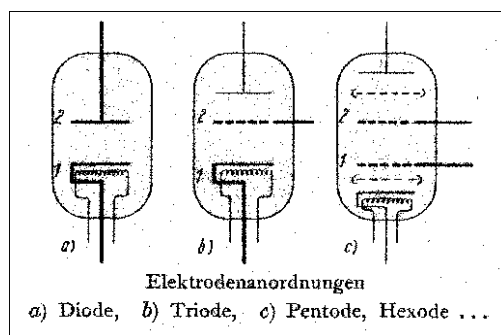


Figure 15: Diode, Triode, Pentode (Iris RUNGE 1937b, p. 439).

During the 1920s, the chief application of electron tubes was in the construction of radio broadcasting devices. Transmitter tubes, for instance, were developed for directional radio and radar, among other things. In the 1930s, researchers began to investigate how the existing electron tubes might be suitable for dealing with short waves and ultra-short waves, and how new tubes – as well as new methods of measurement and calculation – could be invented for such applications. Through

³⁵⁸ A letter from Iris Runge to her sister Ella – dated January 17, 1937 – in [STB] 740.

³⁵⁹ On the fundamental developments in the history of electron tubes, see MORTON/GABRIEL 2007; HEMPSTEAD/ WORTHINGTON 2005; GÖÖCK 1988; BOGNER 2002a, 2002b, 2002c; and SCHARSCHMIDT 2009.

the late 1950s, the main achievements of this research included the development of miniature tubes, subminiature tubes, and nuvistors. Osram, in addition to electron tubes, designed and manufactured X-ray tubes, fluorescent tubes, and Braun tubes, which are cathode ray tubes named after the physicist Karl Ferdinand Braun, a pioneer of radio and television technology. Although the focus of the present section will be the mathematical treatment of problems presented by electron tube research, other types of tubes and additional aspects of lighting and communications engineering will also enter the discussion.

During the period in question, the general mathematical knowledge possessed by engineers was to a large extent inadequate. Although a number of mathematical models and approaches already existed for treating problems of diode rectifiers and electron tubes with grids, these new methods had not yet been incorporated into most university curricula. Erdmann Thiele, for instance, has offered the following estimation regarding the ability of these engineers to make calculations pertaining to a particular rectifier:

Regarding the complex problems of vacuum engineering and designing a mercury vapor rectifier, engineers faced a nearly insuperable obstacle – they *could not calculate anything*, their education having left them unequipped for such a task. While they knew how to calculate and build transformers, motors, and generators, their instructors had never whispered a word to them about the calculating methods that were required to construct rectifiers.³⁶⁰

Not only did Iris Runge have a command of these mathematical methods, but she had also been introduced to the classical principles of electron theory while studying at the University of Göttingen, where she attended Max Born's lectures on the topic. She was also relatively quick to assimilate the latest findings in the field of theoretical physics, and she contributed to the refinement of its methods. The broad scope of the themes addressed in the reports and publications that she wrote at the electron tube laboratory includes the photoelectric effect of crystalline semiconductors (see Section 3.4.4), energy transport in the dark space of glow discharges, mathematical approaches to parallel inverters, Braun tubes, X-ray tubes, multi-grid tubes, and magnetic field tubes – all of this in addition to her work on mathematical statistics that was discussed above in Section 3.4.2.³⁶¹

The studies analyzed below have been divided into two topics of research that occupied Iris Runge from 1929 to 1944, namely the theory of electron emission and the calculation of tube parameters (see also Section 3.2.3 and Appendix 4.3). It should be noted that this division is not entirely unproblematic, for the calculation of tube parameters also required a high degree of theoretical knowledge. Nevertheless, the initial focus will be on research of a more fundamental sort, and this will be followed by an analysis of her studies that concerned the calculation of the actual coefficients of tubes (and of some circuits as well). Even though certain

360 THIELE 2003, p. 158. A mercury vapor rectifier is an electrical rectifier used to convert high-voltage alternating currents into direct currents. The resulting direct currents were essential to transmitter tubes, radar, radio relay systems, etc.

361 For the titles of her laboratory reports and publications, see Appendix 3 and 5.

physical and technical principles will have to be explained, the concentration will remain on how Iris Runge went about her mathematical work, on what mathematical paradigms and instruments were applied and made available to engineers and manufacturers, and on the nature and relevance of her theoretical contributions.

3.4.5.1 Contributions to the Theory of Electron Emission

Certain solids emit electrons from their surfaces when they are exposed to heat (so-called thermionic emission), to electromagnetic radiation (photoemission), or to an electric field (field emission). The operation of electron tubes, X-ray tubes, and photocells – among other electronic devices – depends on the emission of electrons from metals. In the case of electron tubes, electrons are emitted thermionically from a heated cathode filament, a process that is variously known as the Edison effect, the Edison-Richardson effect, or simply the thermionic effect. Subjected to thermal energy, electrons are able to overcome the electronic work function of a metal or an oxide coating.³⁶² If the free electrons are not drawn away by an electric field, they will form a cloud around the cathode that results in a negative charge in the nearby electrodes. Electron currents flow between the directly or indirectly heated cathode and the anode of an electron tube, and these currents can be controlled by the grid that is placed between them.

In 1901, the British physicist Owen Willans Richardson formulated a mathematical equation for this phenomenon, an accomplishment for which he was later awarded the Nobel Prize (1928). His experiments indicated that the electron current emitted by a heated filament depended exponentially on the temperature of the filament in question, and he defined the maximum current that a cathode could emit – the saturation current I_s – as follows:

$$I_s = AT^{\frac{1}{2}}e^{\frac{-b}{T}}$$

where T designates absolute temperature, b a constant, and A the Richardson constant, which depends above all on the metal being used and on its surface finish.³⁶³ For technical applications it was important to keep the cathode temperature as low as possible, a fact that explains both the use of materials with low work functions and the development of the oxide cathode.³⁶⁴

362 A work function is the smallest amount of energy required for an electron to leave a given surface. This energy is measured in electron volts (eV).

363 In 1914, Richardson reformulated this equation in terms of quantum theory (see DÖRFEL 2006). On the further development of this formula by Saul Dushman, a researcher at General Electric (USA), and on the contacts between the researchers at Osram, Telefunken, and GE, see Appendix 4.2.

364 With an eV of 1.0, barium oxide and strontium oxide have a relatively low work function, for which reason cathodes were designed with a barium oxide coating. For a summary of Iris Runge's contribution to the development of an oxide cathode, see Appendix 5.3, No. 2.

If the saturation current of a cathode (I_s) is not totally collected by the anode – on account of insufficient anode voltage (U)³⁶⁵ – then a space charge will form that returns excess electrons to the cathode in question. This effect could be expressed with the aid of Poisson's equation, and by taking energy balance and anode current (I) into account, a differential equation could be derived whose integration yielded a general law governing the phenomenon of space charge. Irving Langmuir expressed this law, which had been discovered by a number of scientists independently, in the following mathematical terms:

$$I \approx \frac{1}{a^2} U^{\frac{3}{2}},$$

which holds if $I < I_s$ and where a designates the distance between the anode and the cathode in a given diode tube.³⁶⁶ This law, which defines the relationship between anode current (I) and anode voltage (U), is usually given today as

$$I = KU^{\frac{3}{2}}$$

in the case of diodes with space-charge limited currents. In this formulation, K represents a space-charge constant that depends on the particular shape and arrangement of the electrodes.

Walter Schottky, a researcher at Siemens & Halske, remarked in 1920 that he was “the first to have devised a mathematical model for a triode that takes into account the effects of space charge.”³⁶⁷ Together with Horst Rothe of Telefunken and Hellmut Simon of Osram, Schottky summarized recent research in the field in a contribution to the *Handbuch der Experimentalphysik* [Manual of Experimental Physics], which was published in 1928.³⁶⁸ This article included a discussion of Arnold Sommerfeld's recently formulated electron theory of metals, which was based on the quantum-statistical studies by Enrico Fermi and Paul Dirac and which also accommodated Pauli's exclusion principle.³⁶⁹ Sommerfeld demonstrated that, with respect to the emission of electrons from a metal surface, the principles derived from the classical electron gas theory remain widely valid, and

365 Here the German abbreviation U (voltage) is used instead of English V , as noted in the Introduction.

366 Irving Langmuir, “The Effect of Space Charge and Residual Gases on Thermionic Current in High Vacuum,” *The Physical Review* 2 (1913), pp. 450–486. For a contextualized discussion of the achievements of Langmuir, Julius Edgar Lilienfeld, and Walter Schottky, see DÖRFEL 2006.

367 W. Schottky, “Zur Raumladungstheorie der Verstärkerröhren,” *Wissenschaftliche Veröffentlichungen aus dem Siemens-Konzern* 1 (1920), pp. 64–70, at 64. See also Section 3.4.5.2.

368 SCHOTTKY/ROTHE/SIMON 1928, which is titled “Glühelktroden und technische Elektronenröhren” [Thermionic Cathodes and Technical Electron Tubes]. See also KIRCHNER 1930; SOMMERFELD/BETHE 1933.

369 See SOMMERFELD 1927, p. 825. Pauli's exclusion principle is a principle of quantum mechanics that was formulated in 1925 by Wolfgang Pauli, an Austrian physicist. Regarding electrons in a single atom, it states that no two electrons can have the same quantum number. Working independently, Enrico Fermi and Paul Dirac relied on this principle in their contribution to statistical mechanics that would come to be known as Fermi-Dirac statistics.

that this is so even in light of Fermi-Dirac statistics. With the help of new mathematical instruments, Sommerfeld recalculated the Richardson effect, and he presented his findings in an article on the electron theory of metals that appeared in the encyclopedic *Handbuch der Physik*.³⁷⁰

In a co-authored survey of research on electron emission, Hans Rukop, Walter Schottky, and Rudolf Suhrmann referred to the close connection between thermionic and photoelectric work functions, to the approaches toward the atomistic calculation of work functions, and to several studies devoted to tubes and rectifiers.³⁷¹ This article, which was published in 1935 in the series *Physik in regelmäßigen Berichten* [Physics in Regular Reports], was updated by Rukop in 1941 to incorporate the latest developments in national and international scholarship.³⁷²

Iris Runge's theoretical contributions to this area of research were instigated, at least at first, by her supervisor Adolf Güntherschulze, and they were predominantly concerned with providing mathematical descriptions of electron tubes that could be put to use in the field of high-frequency engineering. The studies to be discussed in this section address the following themes:

1. At Güntherschulze's request, Iris Runge calculated the energy distribution in hollow-cathode glow discharges.
2. Having examined the laws of electron motion in time-varying fields, she created new calculating methods for multi-grid tubes that took into account the transit time of electrons.
3. She contributed to the theory of split-anode magnetic field tubes (magnetrons) and created a fundamental theoretical model for the four-split magnetic field tube.

Below it will be necessary to evaluate how Iris Runge's approaches to these problems compared to those of other researchers in her field, to define the dominant methodology that she employed, and to outline how her results have been received in the history of scholarship. It goes without saying that many of the problems that she addressed, especially those concerned with velocity-modulated tubes, remained significant for many years after her contributions were published. She numbers among the first researchers to tackle these issues mathematically.

370 SOMMERFELD/BETHE 1933. Hans Bethe, the co-author of this article, had written a dissertation under Sommerfeld's supervision on the theory of electron diffraction (1928). For further discussion concerning the electron theory of metals and its later developments, see Olaf Tamaschke, "Über die mathematischen Grundlagen der quantenmechanischen Elektronentheorie in unendlichen Kristallgittern," *Annalen der Physik* 463 (1961), pp. 76–98; as well as SEELIGER 1922; HODDESON et al. 1992; and KAISER 1987.

371 RUKOP/SCHOTTKY/SUHRMANN 1935. See also RUKOP 1936a.

372 RUKOP 1941.

Calculating the Energy Distribution in Hollow-Cathode Glow Discharges

Glow discharges were employed in vacuum engineering to clean the contaminated surfaces of vacuum systems, and the light that they emitted also served as a source of illumination in fluorescent tubes and glow lamps.³⁷³ General laws governing discharge tubes had been discovered by Friedrich Paschen and John Sealy Townsend, and a similarity law for glow discharges was formulated by Ragnar Holm in 1914.³⁷⁴ In Berlin, the use of hollow cathodes in gas-discharge lamps (glow lamps, fluorescent tubes and lamps) was being studied by Güntherschulze and Arved Lompe at Osram and by Max Steenbeck and Alfred von Engel at Siemens-Schuckert.³⁷⁵ These researchers determined that, at a given cathode fall voltage, a higher current density could be achieved with hollow cathodes than with planar cathodes. At high currents, that is, the fall of potential at a hollow cathode is significantly less than it is at a planar cathode with the same surface area.³⁷⁶

In 1929, Güntherschulze assigned Iris Runge to determine the energy transport in the dark space of glow discharges, and her efforts resulted in an article with that very title (“Energietransport im Dunkelraum der Glimmentladung”). In this study, which was published in 1930 in the *Zeitschrift für Physik* and summarized the following year in the *Technisch-wissenschaftliche Abhandlungen aus dem Osram-Konzern*, she calculated the distribution of the energy that is transferred in various directions by the collision of ions into gas molecules, and she took into account the effects of successive collisions of this type. She further created a theoretical model to account for the energy absorbed by ions in the field between two collisions, and her model enabled her to predict when this absorption would result in an insufficient transport of energy. Thus she was able to estimate the amount of energy, created directly by collisions, that would be discharged to the cathode in the case of abnormal cathode fall and for cathode fall regions (dark spaces) of various thicknesses.

373 Glow discharges are discharges of gas that occur at low pressures between cold electrodes. The color of the glow depends on the gas being used.

374 John Sealy Townsend is renowned for his part in discovering the so-called Ramsauer-Townsend effect, which defines the interaction of electrons with certain gas molecules.

375 See Adolf Güntherschulze, “Glimmentladung an Hohlkathoden,” *Zeitschrift für technische Physik* 11 (1930), pp. 49–54; Alfred von Engel and Max Steenbeck, *Elektrische Gasentladungen*, 2 vols. (Berlin: Springer, 1932–1934); Arved Lompe, “Beitrag zur Erklärung der Wirkungsweise der Hohlkathoden,” *Zeitschrift für Physik* 109 (1938), pp. 310–311. See also K. T. Compton and P. M. Morse, “Theory of Normal Cathode Fall in Glow Discharge,” *Physical Review* 30 (1927), pp. 305–317.

376 With respect to discharge tubes, cathode fall (or “the cathode fall of potential”) refers to the difference in potential that exists between a cathode and a point in the negative glow. Cathode fall will remain constant so long as the cathode is not entirely covered by the negative glow, i.e., when the potential is distributed in the manner that is most conducive to ionization, and this condition is known as *normal* cathode fall. If the cathode is entirely immersed in the glow, however, cathode fall will increase along with an increase in current, and this is known as *abnormal* cathode fall.

In Iris Runge's model, molecules and ions were regarded as elastic hard spheres, and the impacted molecule was taken to be stationary:

In the case of an oblique collision of elastic spheres, i.e., in such a case where the center and the direction of the colliding ion form an angle φ , the velocity component ($\cos \varphi$) will be transferred entirely onto the molecule that is traveling in the direction of the center, whereas the component that is traveling perpendicular to it will be preserved in the ion with a value of $\sin \varphi$. In order to determine the energy that is transported from the molecule in the direction φ , the value $\cos^2 \varphi$ must be multiplied by the probability of another collision occurring within the angle φ . This probability is $1/\pi \cos \varphi d\omega$, where $d\omega$ is the surface region of the sphere with which the direction intersects, given that every cross-sectional surface element of the stationary molecule can be struck by the center of the incoming ion with equal probability. Accordingly, the energy transported from the molecules amounts to $1/\pi \cos^3 \varphi d\omega$. If this is integrated over all acute angles φ , one arrives at $1/2$; on average, therefore, half of the ionic energy will be transferred to the molecule while the other half will remain with the ion.³⁷⁷

It is worth mentioning that her model allowed her to correct the value that had previously been calculated by Güntherschulze and Arthur von Hippel. In a footnote to the quotation above, she remarked: "Instead of $1/2$, researchers have falsely claimed this energy fraction to be $1/4$, as it appears in A. v. Hippel, *Ann. d. Phys* 81 (1926), 1094, and A. Güntherschulze, *ZS.f. Phys.* 49 (1928), 361."³⁷⁸

On the basis of her assumptions regarding the collision mechanism, Iris Runge offered exact calculations for one, two, and three collisions, and by using Fourier series she was able to present an approximate calculation for the $(n + 1)^{\text{th}}$ collision. In order to calculate the Fourier coefficients, she applied a tabular method involving twelve equidistant coordinates that had been developed by Carl Runge and Hermann König. This she supplemented with an extended calculation based on twenty-four equidistant coordinates, which yielded a higher degree of accuracy. She provided a graphical representation of five distribution curves in polar coordinates; she determined the receding value by means of graphical integration; and she clarified the additional correlations that had to be considered in order to ensure the accuracy of her model. Her distribution curves revealed a lower limit for the energy that will reach a cathode directly by means of collision. In the case of abnormal cathode fall – and depending on the type of gas that is used – this energy ranges from fifty-five to ninety-four percent of the total energy being discharged.³⁷⁹

377 Iris RUNGE 1930d, p. 175.

378 Ibid.

379 The method of Carl Runge and Hermann König is published in RUNGE/KÖNIG 1924, pp. 218–223. Calculations of this type had a lasting influence on the field; see, for instance, A. von Engel, *Ionized Gases*, 2nd ed. (Oxford: Clarendon, 1965; repr. 1994); and N. N. Christov, "On the Potential Distribution in the Cathode Fall Region of a Glow Discharge," *Plasma Physics* 17 (1975), pp. 993–996.

Transit-Time Effects in Electron Tubes

The time required for electrons to move between the grid and the anode of an electron tube is finite. If the transit time becomes a significant fraction of the oscillation period of the oscillating circuit, i.e., if control fields change in less time than an electron needs to traverse a field (which is the case with short wavelengths at high frequencies), then phase shifts occur.³⁸⁰ The electron tubes that had been produced to create undamped waves for low or medium frequencies were incapable of generating ultra-short wavelengths.³⁸¹ In order to understand how to make use of this frequency range, researchers were driven in two directions.

The first direction consisted of attempting to reduce the transit time of electrons. For example, the voltage (potential difference) was increased between the anode and the cathode, whereby the acceleration of electrons was increased. This development led to several types of disk seal triodes, which were designed to ensure the shortest possible distance between the cathode, grid, and anode. The disadvantageous effect of this design, namely that the increased kinetic energy of the electrons transformed into heat, encouraged the pursuit of new heat-resistant materials, a pursuit that was necessarily subject to physical limitations.

The second avenue of research was to design a new tube altogether, one that deliberately capitalized on the transit time of electrons. These efforts resulted in the creation of the klystron tube and the magnetic field tube, and it was to developments of this sort that Iris Runge made significant contributions.³⁸² She began to engage intensively with the theory of velocity-modulated tubes in the middle of the 1930s, and this engagement culminated in a comprehensive laboratory report with the title “Ableitung der Gleichungen für eine Elektronenentladung in veränderlichen Feldern in ebenen Elektroden” [Deriving Equations for Electron Discharge in Time-Varying Fields in the Case of Planar Electrodes].³⁸³ This report would serve as the basis of two published articles, both of which appeared in 1937.

Even though she was still employed by Osram, the first of Iris Runge’s two articles – “Zur Berechnung des Verhaltens von Mehrgitterröhren bei hohen Fre-

380 For a graphical illustration of phase shift, see GÖÖK 1988, p. 200. Low frequency refers to radio frequencies from 0 to 10,000 Hz, high frequency from 10,000 Hz to 300 GHz.

381 Wavelengths ranging from $\lambda = 100\text{m}$ to $\lambda = 10\text{m}$ constituted the so-called transoceanic band (later known as short waves); those ranging from $\lambda = 10\text{m}$ to $\lambda = 1\text{m}$ were designated as ultra-short waves; and those that are even shorter were known as dm- and cm-waves (see RUKOP 1936, p. 109). Today, the notion of the microwave designates electromagnetic waves with wavelengths ranging from one meter to one millimeter, that is, with frequencies ranging from 300 MHz to 300 GHz.

382 A prototype of the klystron tube, in which a velocity-modulated beam of electrons could be bunched to generate higher frequency and power than had previously been possible, was developed by the Göttingen-trained physicist Oskar Heil and his wife Agnesa Arsenjeva. See their article “Eine neue Methode zur Erzeugung kurzer, ungedämpfter, elektromagnetischer Wellen großer Intensität,” *Zeitschrift für Physik* 95 (1935), pp. 752–762; and SAKAR et al. 2006, pp. 340–341.

383 [DTMB] 6604, pp. 105–131 (see also Appendix 5.1, No. 36).

quenzen” [On Calculating the Performance of Multi-Grid Electron Tubes at High Frequencies] – was nevertheless printed in the journal *Die Telefunken-Röhre*, which was edited by Hans Rukop. Here she situated her contribution within the history of scholarship and stressed that, whereas previous scientists had concentrated on singular case studies, her concern was with the general and overarching problem that confronted this field of research. Relying on a method developed by Johannes Müller,³⁸⁴ her later colleague at Telefunken, she derived formulas for the direct and alternating current characteristics of electron discharges between planar electrodes for such cases in which the transit time of electrons was comparable to the period of alternating current. In contrast to her predecessors, she was the first to apply mathematical formulas to those spaces in which, as she wrote, “the initial electrode potential is unequal to zero, and especially to those in which the terminal electrode constitutes a negatively biased grid, behind which there is still a space where the transit time of electrons is likewise finite.”³⁸⁵

First she formulated equations for the electron discharge in time-varying fields (for space charge and, for the first time, its saturation), after which she treated the constant and alternating components separately. In the case of constant components, given values were assigned to the voltage and the current, upon which the determination of the transit time was dependent. For the alternating components, she first presented the voltage and the convection current as a function of the transit time and the total current, a formulation that she then inverted to express the total current and the convection current as a function of voltage.³⁸⁶

Although the mathematical “patterns of order” that she used were well known at the time (Poisson’s equation, potential theory), Iris Runge was the first to apply them to the general problem of velocity-modulated tubes described above. In order to facilitate the application of these numerical methods in the hands of engineers, she also provided a number of graphical representations that would be of assistance during the production process (the appendix to her laboratory report contained four pages of illustrations that were not included in her articles). One example will suffice to clarify her general approach: In her description of direct current behavior, she presented the following equation for the correlation between electron transit time (τ) and the transit time of space charge (τ_s) (Space-charge transit time is a pure function of the current and the distance between electrodes):

384 See Johannes Müller, “Elektronenschwingungen im Hochvakuum,” *Zeitschrift für Hochfrequenztechnik* 41 (1933), pp. 156–167.

385 Iris RUNGE 1937a, p. 142.

386 The term convection current was introduced by the physicist Max Abraham in his *Theorie der Elektrizität*, in which he regarded electrical currents as convection currents of moving electrons (the latter as elementary quanta), and he understood cathode rays to be convection currents of negative electrons (see ABRAHAM 1905). The total current consists of the physical flow of electrons (“convection current”) plus the displacement current, a phenomenon that is explained below. According to Felix KLEIN (1927, p. 27), the latter work was one of the most popular textbooks of the day. Abraham, who had studied under Max Planck, taught as a lecturer at the University of Göttingen from 1900 to 1909.

$$\frac{2 + \left(\frac{\tau}{\tau_r}\right)^3}{3 \frac{\tau}{\tau_r}} = \sqrt[3]{\frac{i_n}{i}} \left\{ 1 + \sqrt{\frac{U_2}{U_1}} \right\},$$

Where U_1 and U_2 were the actual voltages used in the case under investigation, and i_n designated the current, limited by space charge that pertained to U_1 . Here she explained:

In order to gain a clear impression of the values of the transit time, it is useful to represent the possible condition by means of a field whose abscissa denotes i/i_n and whose ordinate denotes U_2/U_1 . The left side of the equation is a decreasing function over τ/τ_r if $\tau/\tau_r < 1$, an increasing function if $\tau/\tau_r > 1$; the minimum for $\tau = \tau_r$ is:

$$\frac{2+1}{3} = 1.$$

Thus it is apparent that solutions of τ/τ_r for every value of i/i_n can only exist if

$$1 + \sqrt{\frac{U_2}{U_1}}$$

lies above

$$\sqrt[3]{\frac{i}{i_n}}.$$

Therefore the curve

$$1 + \sqrt{\frac{U_2}{U_1}} = \sqrt[3]{\frac{i}{i_n}}$$

forms a boundary, beneath which stable conditions are impossible.³⁸⁷

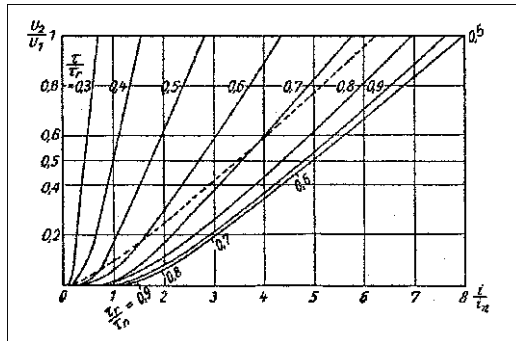


Figure 16: Transit-Time Ratios at Different Currents and Voltages (Iris RUNGE 1935a, p. 135)

³⁸⁷ Iris RUNGE 1937a, p. 135.

At the boundary line just mentioned (see [Figure 16](#)), the transit time was defined by $\tau/\tau_r = 1$. Iris Runge demonstrated that, by using the appropriate equation for any point on the diagram that corresponds to a plausible discharge state, the electron transit time could be determined for a given voltage U_I .

In her second article from 1937 – “*Laufzeiteinflüsse in Elektronröhren*” [The Effects of Transit Time in Electron Tubes] – she addressed the question of energy consumption. As before, she positioned her contribution, which was the first to concern this topic, within the spectrum of international scholarship:

Because the latest advances in high-frequency engineering have made increasing use of wavelengths at which the transit time of electrons no longer decreases during the period of oscillation, it is necessary to study more closely the laws of electron motion in time-varying fields. If possible, it will also be useful to reduce these laws to simple graphical representations, which would enable the swift recognition of certain correlations under known conditions. The mathematical approach to this problem, at least in the case of planar arrangements, has been variously treated by such researchers as Müller, Zuhrt, Benham, Llewellyn, and North.³⁸⁸ I myself have contributed to the matter, specifically for cases of saturation current, in the journal *Telefunken-Röhre*. Here I would like to extend these considerations to the question of energy consumption and to discuss, above all, the conditions under which it is possible to generate negative resistance with electron currents of this sort.³⁸⁹

After explaining the fundamental nature of the problem, Iris Runge formulated an equation for the alternating current that flows through the capacity of the discharge path if no charge is present:

$$\frac{1}{d} \int \frac{1}{4\pi} \frac{\partial E}{\partial t} dx = \frac{1}{4\pi d} \frac{\partial U}{\partial t} = j\omega C \cdot U,$$

where the field strength E is the gradient of the potential. She identified the expression under the integral on the left side of the equation as the displacement current. This is a hypothetical flow of electrical charge that complements the convection current as an equal function of time in the entire space and also possesses the ability to generate a real current in the electrodes and in the conductor circuit that is identical to it. She explained:

388 The researchers referred to here are Johannes Müller; H. Zuhrt, who was then working at the Technical University in Berlin; W. E. Benham, a British physicist and the author of “Electronic Theory and the Magnetron Oscillator,” *Proceedings of the Physical Society* 47 (1935), No. 1; Frederick B. Llewellyn, an American electrical engineer who had been honored by the Institute of Radio Engineers (IRE) for his contributions to high-frequency vacuum tubes; and D. O. North, who was a frequent contributor to the *Proceedings of the IRE*. On North in particular, see Mischa Schwartz, “History of Communications. Improving the Noise Performance of Communication Systems: 1930s to Early 1940s,” *IEEE Communications Magazine* 48 (2010), pp. 18–19.

389 Iris RUNGE 1937b. If an electric current near an operating point exhibits a partially sloping characteristic, this is known as negative resistance. In conjunction with the elements of a circuit that determine its frequency, this effect can compensate for the inevitable loss resistance of an oscillator circuit, among other resonators. Negative resistance is thus used to offset the damping resistance of a circuit (damping refers to the transformation of oscillation energy into other forms, which leads to the reduction of signals, oscillations, and waves).

When an alternating current of sufficiently high frequency is introduced between the electrodes of an electron discharge, the electrons in transit are accelerated with alternately stronger and weaker forces, and thus there appear spatial variations in the convection current. The continuity equation of the electrical charge requires that any spatial change in the convection current has to be connected to a temporal change in the space charge and must also, therefore, be connected to the field strength [...]. Convection current + displacement current = total current.³⁹⁰

The convection current and the displacement current of an electron tube could be examined apart from one another by both experimental and mathematical means, and Iris Runge was the first to demonstrate this latter possibility in a variety of case studies. Without relating all of the details, it can simply be underscored that she examined the discharges in electron tubes in four different cases, each distinguished by the spatial distribution of its static potential: The first case was that of normal thermionic emission, if the outflow velocity of electrons could be disregarded (here the potential follows the Child-Langmuir law of space charge). The second was that of a cathode at zero potential, if the voltage is higher than the present current according to Langmuir's space charge formula, i.e., if the cathode is saturated (in contrast to the first case, here the initial slope is unequal to zero, and thus there is positive field strength at the cathode). The third and fourth cases concerned discharge spaces with a positively biased grid as an entrance electrode, through which the electrons would pass into the space with a limited velocity. In particular, the third case involved those instances in which the potential of the first electrode is less than that of the next (a retarding field), and the fourth involved those instances in which the second electrode possesses an even higher potential, and thus the electrons were further accelerated (if the second electrode happens to be a grid, then there is the matter of the grid's effective potential, something that plays a significant role in the case of multi-grid tubes).

Iris Runge calculated the spatial potential distribution and the spatial distribution of the real components of the convection-current amplitude for all four cases and presented her results graphically. She also created a graph to represent the dependence of grid conductance on frequency (see [Figure 17](#)).³⁹¹ Finally, she demonstrated that the negative conductance of a grid would be strongest where, in the case of the retarding field, the space charge was greatest (this was a practical concern). In doing so, she referred to the experimental studies of Horst Rothe, the researcher at Telefunken, whose observations confirmed her theoretical results.

390 Iris RUNGE 1937b, p. 438.

391 The dependence of grid conductance on frequency concerns the real alternating current that flows through the conductor circuit connected to the grid: "More output will thus be taken from the anode circuit than is necessary for the creation of kinetic electron energy; the surplus will be emitted to the grid, so that negative damping will take place in the grid circuit" (Iris RUNGE 1937b, p. 440). On October 10, 1937, Iris Runge described a mathematical approach to the limiting frequency for oscillation excitation; she calculated the grid conductance; and she provided a formula for the electron transit time to the grid (see [DTMB] 6604, pp. 75–76; and Appendix 5.1, No. 40).

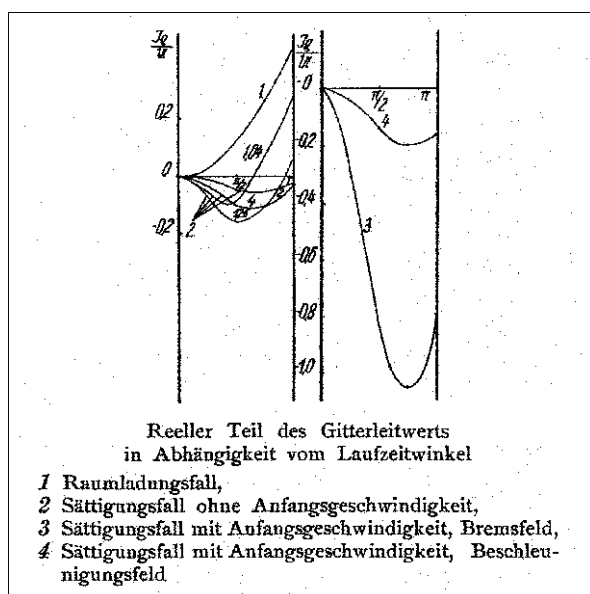


Figure 17: The Real Component of Grid Conductance in Relation to the Transit-Time Angle (I. RUNGE 1937b, p. 440).

Once published, both of her articles were widely cited. The Telefunken researchers Horst Rothe and Werner Kleen incorporated her results into their books on electron tubes, and they were mentioned by Hans Rukop in a report on electron tubes and rectifiers (in a section on single- and multi-grid amplifiers).³⁹² Maximilian Julius Otto Strutt, a researchers and director at the Philips Corporation in Eindhoven, cited her articles in the second edition of his book *Mehrgitter-Elektrodenröhren* [Multi-Grid Electron Tubes], where they are referred to in three chapters (on calculating and measuring dynamic tube capacities, the influence of electron transit time on input admittance, and measuring the influence of electron transit time on transconductance).³⁹³ As late as 1952, Iris Runge's study of transit-time effects was cited in Werner Kleen's *Mikrowellen – Elektronik* [Microwaves – Electronics], where he applied her results in a section on calculating the complex conductance of space charge diodes.³⁹⁴

³⁹² RUKOP 1941, p. 71.

³⁹³ STRUTT 1940, pp. 192–199, 209–213, 213–222, respectively. On the research conducted at Philips's Naturkundig Laboratorium, see DE VRIES 2006.

³⁹⁴ KLEEN 1952.

Magnetrons and Four-Split Magnetic Field Tubes

Electron tubes that use magnetic fields to control the flow of electrons operate according to the principle of velocity-modulated tubes. These magnetic field tubes, which have important applications even today, were fundamental to the success of British and American radar engineering during the Second World War.³⁹⁵ For some time, Iris Runge and her brother Wilhelm were also at the forefront, so to speak, of this area of research.

It had been known for many years that the electron current in tubes could be controlled – to strengthen a signal or generate oscillations – not only by grids, but by magnetic fields as well. In an article from 1936, Hans Rukop mentioned studies by P. K. Hewitt (1902), F. K. Vreeland (1905), and Robert von Lieben (1906), in which the principle was treated theoretically, and he also cited the work of Albert W. Hull (General Electric, NY), who had first put these theories to practical use and who had also, incidentally, given the magnetron its name.³⁹⁶ By his time, as Rukop pointed out, the development of the magnetron had branched into two directions: There were magnetrons built according to Hull's design, which were based on a controlled and therefore *varying* magnetic field, and there were magnetic field tubes (high-vacuum tubes with thermionic cathodes) designed to have a *constant* magnetic field (without any special control fields).³⁹⁷ Rukop noted further that it was common in the scholarly literature to see the term *magnetron* being used for both developments.³⁹⁸

395 On the role of radar engineering during the war, see BURCHAM/SHEARMAN 1990; LYON 1995; COLLINS 1948. For a discussion of the development of magnetrons at General Electric (Wembley), see CLAYTON/ALGAR 1989, esp. pp. 125–129. There are many types of magnetic field tubes today – including cavity magnetrons, cylindrical magnetrons, circular magnetrons, rectangular magnetrons, and sputtering magnetrons – and their applications include microwave ovens, lighting systems, and radar. The gyrotron is also a type of magnetron, though further developed, that is used for heating plasmas in fusion research. Because of the broad range of radiation frequencies, that they can generate (visible light, microwaves, soft X-ray radiation), gyrotrons have a wide variety of applications (see GOETZ et al. 2007).

396 RUKOP 1936a, pp. 112–113. See A. W. Hull, “The Magnetron,” *Journal of the American Institute of Electrical Engineers* 40 (1921), pp. 715–723. Hull had been working on this research topic since 1916 and supported his ideas with the work of the Swiss physicist Heinrich Greinacher, who had published a mathematical description of the magnetron in the *Verhandlungen der Deutschen Physikalischen Gesellschaft* 12 (1914), p. 856. Hull's magnetron was used as an amplifier in radio devices.

397 Hull's theory of electron paths was quickly adopted in Germany, as is indicated by the following article: Werner Braunbek, “Die Vorgänge in einer Elektronenröhre unter Einwirkung eines Magnetfeldes,” *Zeitschrift für Physik* 17 (1923), pp. 117–136. The practical relevance of the magnetron to radar engineering was not recognized until 1940, when the British researchers John Randall and Harry Boot developed a cavity magnetron (a magnetron with a cavity resonator). This innovation was based in part on a multi-cavity resonant magnetron that had been designed in 1935 by Hans Erich Hollmann, a German electrical engineer (see BURCHAM/SHEARMAN 1990; SAKAR et al. 2006, pp. 339–340).

398 RUKOP 1936a, p. 7.

That both of these research directions were pursued in Germany from early on is clear from the example of a dissertation, “Die Magnet-Charakteristiken eines Drei-Elektrodenröhres” [The Magnetic Characteristics of a Tube with Three Electrodes], which was completed in 1929 by Johanna Völker.³⁹⁹ Völker had conducted this research at the University of Jena under the supervision of Abraham Esau, who – like Hans Rukop at the University of Cologne – held a full professorship in technical physics that was funded by the Carl Zeiss Foundation. Basing her work on Hull’s magnetron, which had two electrodes, she examined triodes and tetrodes in constant and varying magnetic fields and reached the conclusions that only tubes with two electrodes were effective in this case and that the performance of magnetic alternating fields is high so long as there are high-frequency oscillations (which only appear, as she noted, “in particular types of tube circuits”). As the efforts discussed below will indicate, subsequent experimental findings proved to be more difficult to explain mathematically.

According to Rukop’s report, the majority of research before the middle of the 1930s was devoted to tubes with *constant* magnetic fields. These contained a rod-shaped thermionic cathode surrounded by a coaxial cylinder (as an anode). This anode could be cut lengthwise into separate segments, each of which received the same direct voltage (a so-called split anode), and the magnetic field would form somewhat parallel to the axis of the cylinder. In order to generate oscillations, a system capable of oscillating – a resonant circuit or Lecher system – would be connected either between the anode and the cathode or, in case of a split anode, between the individual anode segments.⁴⁰⁰

An electron tube with a constant magnetic field was first described in 1924 by the Czech physicist August Žáček,⁴⁰¹ and Erich Habann, a doctoral candidate at the University of Jena, had demonstrated the principle of a two-split anode in the same year. In his dissertation, Habann made use of and provided calculations for the spiral path of electrons in a magnetic field.⁴⁰² When, in 1929, the Japanese scientist Kinjiro Okabe became the first to generate waves in the centimeter range

399 See TOBIES 2009.

400 The Lecher system is a special arrangement of wires named after Ernst Lecher, an Austrian physicist.

401 Žáček had studied for some time under Hermann Theodor Simon, the professor of electricity at the University of Göttingen. For additional biographical details about Žáček, see R. H. Fürth, “Prof. August Žáček,” *Nature* 193 (1962), p. 625.

402 Erich Habann had studied theoretical physics (under Max Planck) and mathematics (under Richard von Mises) at the University of Berlin. During the First World War, he worked on developing high-frequency telephone lines at a military laboratory directed by Max Wien, under whose direction in Jena he earned a doctoral degree with a thesis entitled “Eine neue Generatorröhre” [A New Generator Tube] (see [UA Jena] Bestand M, No. 587). His dissertation, which was published in the journal *Hochfrequenztechnik und Elektroakustik* [High-Frequency Engineering and Electroacoustics], was both heavily theoretical (he made use of Laplace’s equation, Maxwell’s equations, the continuity equation, and potential theory) as well as experimental (see HABANN 1924; and also NAGEL 2006).

with split anode magnetrons,⁴⁰³ research on these devices began to escalate at laboratories around the world, including those of Osram and Telefunken.

In the 1930/31 annual report of her research activities at Osram, Iris Runge recorded that she had studied the magnetron effect of transmitter tubes and calculated “at which limiting frequencies a split anode receives more electrical power than an un-split anode” (see Appendix 5.3, No. 4). In this matter her work began to overlap with that of her brother Wilhelm; because his main concerns were directional radio and radar research, he was necessarily interested in designing suitable tubes for the generation of centimeter waves.

In an article published in 1934 – “Schwingungserzeugung mit dem Magnetron” [Oscillation Generation with the Magnetron] – Wilhelm Runge remarked: “For nearly a year, we have been studying these tubes at the Telefunken laboratory in order to create generators for all aspects of decimeter-wave technology.” Having explained the oscillation mechanism and its development in anode cylinders of up to four splits, it seemed as though “the problem of generating power for decimeter waves has been resolved satisfactorily.”⁴⁰⁴ However, practical methods of modulating the oscillations were still lacking, and six years later he offered the following evaluation: “When we began to study the reflection problem with very short pulses, we generated oscillations with magnetrons that, today, we have come to regard much as Mr. Zenneck has come to view the older wireless devices. We falsely considered this tube technology to be obsolete.”⁴⁰⁵ In 1936, Wilhelm Runge had assigned a small group of researchers with the task of developing velocity-modulated transmitter tubes. To this group belonged the physicist Waldemar Ilberg, who designed a prototype of the four-split magnetron.⁴⁰⁶

However, this line of research was not supported with consistency because it clashed with the intentions of Telefunken’s board members and the military authorities, who happened to prefer grid-controlled electron tubes.⁴⁰⁷ The actual applicability of the magnetron to radar technology was first made known to German researchers at the beginning of 1943, when a British airplane was shot down over Rotterdam. The reasons for why Germans had long overlooked this potential application have already been discussed elsewhere.⁴⁰⁸ After the discovery of the British technology, as Wilhelm Runge later noted, research at Telefunken turned to focus on “reproducing, replicating, and understanding the English centimeter-wave technology, to which improvements were made from that point until the end of the war.”⁴⁰⁹

403 See OKABE 1930.

404 Wilhelm RUNGE 1934, p. 5. and p. 13.

405 Wilhelm RUNGE 1940, p. 17.

406 Waldemar Ilberg, at Telefunken from 1929 to 1945, had earned a doctoral degree in 1925 from the University of Leipzig; the title of his dissertation was “Untersuchungen über den elektrooptischen Kerr-Effekt” [Studies on the Electro-Optic Kerr Effect].

407 See the second volume of SCHARSCHMIDT 2009.

408 See HANDEL 1999; ECKERT 2000.

409 Quoted from Wilhelm Runge’s autobiography (archived in [DTMB] 4413, p. 50).

At the electron tube laboratories of Osram and Telefunken, magnetic field tubes were largely researched and developed for their applicability to communications engineering. As Roland Göök has explained:

In Germany it was the case that Dr. Fritz, under the direction of Professor Hans Rukop, had designed magnetron tubes quite early on, but unfortunately only for purposes of communications engineering. This is because German scientists were of the opinion that centimeter waves were unsuitable for reflection and therefore also for radar. Only when the English “Rotterdam device” – the centerpiece of radar warfare – was thrust under their noses in 1943 did Germans begin to take the development of magnetrons seriously.⁴¹⁰

Karl Fritz had written his first reports on the magnetron in 1934, and in 1936 he derived a theory of the transit-time oscillations of the magnetron that he went on to apply to two-split and four-split magnetic field tubes.⁴¹¹ In a report from 1941, Rukop wrote that Fritz’s concept of the “order of oscillation,” which concerns the number of electron circulations during each period of high frequency, had brought order to the theory of magnetic field tube oscillations, and he added: “In a magnetic field tube, the electrons move along a cardioid path, whereas this path is circular in a constant magnetic field without an electric field. It is immediately apparent that a period of excitation in the zero-split tube must be identical with the path between two homologous points, e.g. two points in the proximity of the anode. In order to be able to call this an excitation of the first order, an electron circulation must be defined as a cardioid curve. This differs from the definition of a circulation as a 360° path because a cardioid curve represents more than 360°. To be precise, it is exactly 450°, for instance, if the curve in question is a recurring four-part rosette.”⁴¹² Although Rukop provided a comprehensive survey of national and international scholarship, he did err in one regard. Karl Fritz did indeed make use of the term “order of oscillation,” but nowhere in his 1936 article does he describe the course of electrons as a cardioid curve. This description does appear, however, in a laboratory report that was written by Iris Runge in that same year. Entitled “Theorie des Schlitzanodenmagnetrons” [The Theory of the Split-Anode Magnetron] and completed shortly before her scheduled research trip to the United States, this comprehensive report begins with the following words:

The task of this theory is to describe the movement of electrons under the influence of a field in such a comprehensive manner that the following phenomena are explained:

1. The static behavior of tubes, i.e., the appearance of the “critical magnetic field” and the negative characteristic curves for transverse fields.

410 GÖÖK 1988, p. 206.

411 See Karl Fritz, “Theorie der Laufzeitschwingungen des Magnetrons,” *Telefunken-Zeitung* 17 (1936), pp. 31–36. The titles of Fritz’s laboratory reports were “Zur Schwingungserzeugung mit Doppel-Anoden Magnetron” [On Generating Oscillations with a Dual-Anode Magnetron] and “Die Grundlagen, auf denen jeder beliebige Magnetron-Oszillator aufgebaut ist” [The Principles upon which Every Magnetron Oscillator is Designed]; they are archived in [DTMB] 4811 and 6665, respectively.

412 RUKOP 1941, p. 14.

2. The creation of slow oscillations of the order $n > 4$, and the decrease in the area $n = 0$.
3. The creation of oscillations for the optimal cases $n = 2$ in four-split magnetrons and $n = 4$ in two-split magnetrons.
4. The weak oscillations of the order $n = 1$.⁴¹³

In the first case she considered static behavior without a transverse field and also explained the cardioid curves that were later mentioned by Rukop. Iris Runge attributed the recognition of such curves to Albert W. Hull:

In the absence of electric voltage, electrons influenced by a magnetic field will move along a circular path, at least to the extent that they have any velocity. If positive voltage is applied to the cylindrical anode, the paths will curve more strongly in the vicinity of the cathode and less so when they are farther away from it. In cases of minimal space charge, the potential is distributed according to a logarithmic curve, and therefore the greatest part of the potential drop exists near the cathode. Thus it is possible to make approximate calculations on the assumption that electrons will maintain a radial acceleration only at the cathode, from which they will go on to follow a purely circular path. In the case of stronger space charge, however, the distribution of the potential approximates $r^{2/3}$. This case has been treated with precision by Hull. Here the electron paths are cardioid curves whose equation in polar coordinates is $r = k (\sin 2/3\varphi)$, where the angle φ grows in unison with the time t and where the constant k depends on the voltage and the magnetic field.⁴¹⁴

This is the only place in the entire report where Iris Runge alludes to the work of another author; the remainder of its content represents her own work exclusively. Her theory of the split-anode magnetron was incorporated into the reports and articles of her colleagues at Osram and Telefunken and also proved to be foundational to her own publications on the topic.

Referring to the possible numerical and graphical methods at her disposal, she described her approach to the first point in the report as follows:

If, in addition to the anode voltage, a positive or negative supplementary voltage is applied, then the paths of the electrons will no longer be the same in all directions. The general calculation of these paths may indeed be very difficult. However, because the potential distribution for both the two-split and four-split systems can be calculated, the paths can thus, in increments, be constructed graphically. This is because their curvature can be determined at each point from the field strength and the potential gradient.⁴¹⁵

Iris Runge provided graphical illustrations of the electron paths and discussions of their forms, and chose to leave numerical calculations out of her report. This was the case not only in her treatment of the first point, but also in her approach to the other three. For the second point she considered the example of the so-called dy-

413 [DTMB] 6604, pp. 155–174, here at 155.

414 Ibid., pp. 155–156. To this she also added: “In what follows we will refer to such curves as ‘cordiols’ (*Kordiolen*), although they only somewhat resemble the curve that customarily bears this name.” This term, which in fact never recurs in the German literature, is telltale of the independence that characterizes the report as a whole.

415 Ibid., p. 157.

natron oscillation system,⁴¹⁶ and for the third she discussed a frequency domain in which the voltage applied to the anode segments altered throughout the transit time and no longer matched the trajectory curves that had been construed for the static case. She applied a different approach to these issues, which involved “investigating the exchange of energy between the electron and the anode segments,” and which Karl Fritz had also adopted in his 1936 study. Regarding the terms “right phase” and “false phase,” which Fritz and Rukop frequently employed, Iris Runge explained:

The motion of electrons represents a certain instantaneous current that flows between the anode segments and that is completely determined by the location and velocity in their path. If this instantaneous current is multiplied by the respective instantaneous values of the prevailing transverse voltage, then instantaneous power is obtained. This will be positive if the electron is supplying energy to the current and negative if the electron is drawing energy from it. The value of the integral of this power over the entire electron path is the contribution that the electron makes to the energy balance, which can likewise be either positive or negative. If positive, the electron is called “right phase”; if negative, “false phase.”⁴¹⁷

The main goal in the third and fourth cases was to investigate the efficiency of the tubes in question. On the basis of symmetry ratios, Iris Runge deduced that “the paths between the split segments will make the greatest contribution to the balance if they culminate in the maximum or minimum voltage, and the electrons will be right phase if they pass through a split in the direction $\pm$, false phase in the opposite case.” She demonstrated the conditions under which right-phase electrons would predominate. Moreover, she provided a theoretical explanation of the so-called tilted magnetic field, which was an important concept in the work of Fritz and Rukop, by calculating the lines of potential energy and presenting her solutions graphically. She was able to prove that the oscillation states differed in the case of their being two or four splits and that greater efficiency could be achieved with a four-split anode.

This topic presents a convenient opportunity to demonstrate Iris Runge’s close involvement in international research. In September of 1936 she traveled to the United States, where she visited, among other places, the research laboratory of the Radio Corporation of America (RCA) in Harrison, New Jersey.⁴¹⁸ Here, George Ross Kilgore was experimenting on magnetrons, something he had been doing even before he came to RCA in 1934 (he had previously worked at the Westinghouse Research Laboratories). According to Karl David Stephan, the approach

416 The dynatron, which was also invented by Hull, is a tube with three electrodes: a hot cathode, a perforated anode, and a supplementary anode (plate). This supplementary anode, during normal operation, was kept at a lower voltage than the perforated anode. The secondary emission of electrons from the perforated anode traveled to the supplementary anode, which allowed for the creation of negative resistance. The tube was capable of generating oscillations over a wide range of frequencies and also of functioning as an amplifier.

417 [DTMB] 6604, p. 161.

418 Despite the professional aspects of this trip, it was largely undertaken for personal reasons (see Section 4.3.4).

to magnetrons at the time was predominantly empirical, the mathematical principles having hardly been developed:

In terms of theory, there wasn't much. The period of the high-frequency oscillations appeared to be related to the time it took electrons to follow their curved paths in the magnetic field from the filament to one of the two anodes. But the electrodynamic problem posed by electron motion in the high-frequency split-anode magnetron was too complex to solve with the analytical techniques of the 1930s. No one really understood how it worked.⁴¹⁹

It can be gathered from Iris Runge's report about this trip that, having read Kilgore's latest publication before her departure,⁴²⁰ she discussed the theory of the split-anode magnetron with him and was able to observe his experiments. Because Kilgore neglected mathematical methods in his work, she was of the opinion that she and her colleagues were further advanced in their own research:

Dr. Kilgore's work space is a research laboratory through and through – a delivery of tubes seems to be entirely out of the question. For a while we discussed the theory of the split-anode magnetron; the ideas that Kilgore has formulated about the process essentially agree with our own and with those found in the scholarship, for instance in the work of Megaw.⁴²¹ Dr. Kilgore is clearly unable to determine the special position of the oscillation states with $n = 2$ and $n = 4$ in the case of four-split and two-split magnetrons. He only distinguishes oscillations on the basis of negative characteristics, on the one hand, and periods of transit time on the other. Also, he regards the former to be more relevant for practical reasons because of the possibility of achieving greater power and efficiency. Then he showed me his tubes, of which we had already seen illustrations from his recent article in the *Proc. Inst. Rad. Eng.* 24, No. 8, 1936. These were very large tubes, radiant- or water-cooled, in which the actual magnetron system occupied only a very small space. With these he is able to produce an output of 50 to 100 watts at wavelengths of 50 cm and an efficiency of 25-30%.⁴²²

Iris Runge described Kilgore's experiments and how the cardioid curves of the electrons could be made visible, but noted that certain problems of modulation and external control had not been addressed and that only the simple two-split tube was being investigated. On November 6, 1936, she presented her impressions of the trip as part of an internal lecture series held at Osram (see Section 3.3).

In another contribution to this theme, Iris Runge analyzed an article on decimeter wave transmitters with split-anode magnetrons by Friedrich-Wilhelm Gundlach, who had stressed: "Split-anode magnetrons are the only oscillation generators that allow for the generation of decimeter waves with high power and decent efficiency."⁴²³ Gundlach referred to new methods of measuring frequency, power,

419 STEPHAN 2001, p. 744 (an original English quotation).

420 G. R. Kilgore, "Magnetron Oscillators for the Generation of Frequencies Between 300 and 600 Megacycles," *Proceedings of the Institute of Radio Engineers* 24 (1936), pp. 1140–1158.

421 Eric Megaw was a Dublin-born radio engineer who, as of 1928, conducted research on cavity magnetrons at General Electric in Wembley.

422 [DTMB] 6604, p. 152. On the development of electron tubes at RCA, see Alfred N. Goldsmith et al., eds., *Electron Tubes (1935–1941)* (Princeton: RCA Review, 1949).

423 GUNDLACH 1936, p. 201. Gundlach was then an assistant to Heinrich Fassbender at the Institute for Electrical Oscillation Theory and High-Frequency Engineering at the Technical

and oscillating currents, and he suggested possible means of eliminating the disturbances caused by back-bombardment.⁴²⁴ This last issue was highly relevant to Iris Runge's work at Osram. Building upon findings made by Kurt Gerlach and Friedrich Hülster at Telefunken, she prepared a report, in October of 1938, on the phenomenon of back-bombardment in magnetron tubes. Here she treated the problem mathematically and calculated the oscillation efficiency that would correspond with Gerlach and Hülster's experimental results. This was followed by a subsequent report, which she completed four months after joining Telefunken, on the operations of the four-split magnetic field tube. Trying to make a place for herself in her new work environment, she sent copies of this report with individualized cover letters to Karl Steimel, Horst Rothe, and Ludwig Ratheiser (see Appendix 5.1, No. 49–No. 56). Her findings were ultimately published as an article in the 1940 volume of *Telefunken-Röhre*; its introduction contains the following explanation:

A simplified description of the potential field might look as follows. The alternating current emitted from the anode segments is superimposed above a radial direct current in which, as in Hull's example, the voltage is assumed to be of the proportion $r^{2/3}$. Throughout the entire middle region of the field, the alternating field is extremely minimal, practically equal to zero. It becomes observable only near the periphery, where it is tangentially directed at the four splits but radially directed at the spaces between them. The influence of such superimposed alternating fields should, first of all, be calculated for a planar system, for here the equations of motion can be fully integrated. Only then should the corresponding phenomenon be examined in the case of a cylindrical system, the mathematical treatment of which is necessarily restricted to methods of approximation.⁴²⁵

She considered four different cases of the planar system, for each of which she derived equations and drew the appropriate curves (Figure 18). Here she intended only to demonstrate qualitatively that an electron – subjected to an increasing field strength y that is parallel to x – will be deflected at higher values of y if the field strength is working against the direction of x , and will be deflected at lower values of y if the field strength is operating in the same direction. Her model calculation based on the presupposition that the path of an electron in a planar direct voltage field with a perpendicularly aligned magnetic field will be a typical cycloid if the electron at the first electrode enters the field with a velocity of zero.

University in Berlin. He later completed a dissertation that was published as *Das Verhalten der Habannröhre als negativer Widerstand* (Berlin: VDI-Verlag, 1938) and summarized in *Elektrische Nachrichtentechnik* 15 (1938), pp. 183–200 (see POGG. VIIa, VIII). In this dissertation, he combined numerical, graphical, and experimental methods. On the basis of a physical model of a Habann tube, he calculated the course of electrons; applied well-known graphical methods to electrical alternating fields; and tested his results experimentally. Iris Runge's analysis of Gundlach's 1936 article is archived in [DTMB] 6604, pp. 139–142.

424 A so-called back-bombardment apparatus was required for the operation of transmitter tubes (magnetic field tubes) working in the area of 1 cm, and such tubes were still being developed as late as 1944.

425 Iris RUNGE 1940, p. 33. See also RATHEISER 1941.

Konstantes Wechselfeld // y $Y_1 = Yq \sin \omega (t - t_0)$	Zykloide mit variablem Rollkreis $\omega t_0 \sim 0$: Vergrößerung $\omega t_0 \sim \pi$: Verkleinerung, später Vergrößerung	} Bild 2
Konstantes Wechselfeld // x $X_1 = Yq \sin \omega (t - t_0)$	Zykloide mit variablem Rollkreis $\omega t_0 \sim -\frac{\pi}{2}$: Verkleinerung, später Vergrößerung $\omega t_0 \sim +\frac{\pi}{2}$: Vergrößerung	} Bild 3
Zusatzfeld // y von Kathode zu Anode wachsend	Feldrichtung positiv: große Zykloide negativ: kleine Zykloide	} Rollkreis langsam wachsend } Bild 4
Zusatzfeld // x von Kathode zu Anode wachsend	Feldrichtung positiv: wachsender Rollkreis- radius, Leitlinie abwärts gerichtet negativ: abnehmender Rollkreis- radius, Leitlinie aufwärts gebogen	} Bild 5

Figure 18: A Summary of Four Case Studies Concerned with the Planar Direct Voltage Field of a Magnetic Field Tube (I. RUNGE 1940, p. 38).

Iris Runge likewise examined – in the case of a *cylindrical* system – the electron paths, the interaction of electrons, and the efficiency of the four-split magnetic field tube. This achievement, though novel, was made on the basis of known mathematical methods, namely the equations of motion with initial conditions defined in accordance with her simplified model, the solution of the corresponding differential equations, and the application of graphical methods (since the integral did not have a closed-form solution). A few words should be said about her simplified model, for this enabled her to provide approximate descriptions of the conditions and to calculate the efficiency of the tube in such a way that her results agreed with the practical measurements that had been made.

Whereas the path of an electron in a radial direct current field with a magnetic field can be calculated exactly for certain potential distributions, the calculation for the superimposed alternating current field was more complicated. Even if the spatial supplementary fields were taken into account in accordance with the motion of the electron passing through the field, this still did not yield an equation that could be integrated. Therefore Iris Runge introduced a simplified model, according to which the tangential alternating current field would concentrate in a very narrow area along the edge of the circular discharge space. The electron will

then move along its entire path under the exclusive influence of the radial direct current field. However, by flowing through a short but very powerful field zone, it will suddenly receive supplementary velocity at the culmination point. This change in the electron path, which is brought about by the supplementary velocity p , could be solved mathematically. By using the equations of motion and taking into account the initial conditions that were valid at the culmination point, she attained the following integrals:

$$\varphi = \int_r^1 \frac{dr}{\sqrt{r^{2/3} - r^2 + p^2 \left(1 - \frac{1}{r^2}\right)}} \pm \int_r^1 \frac{dr}{r^2 \sqrt{r^{2/3} - r^2 + p^2 \left(1 - \frac{1}{r^2}\right)}}$$

Considered as functions of the lower limit, these integrals yielded the equations of the electron trajectory in polar coordinates, which she further discussed and plotted for defined values of p . On the basis of further considerations about the interaction of electrons, she also derived a formula for the rise in energy of an electron culminating at the coordinates φ , Θ :

$$\Delta U = \cos\left(\Theta - \frac{2}{3}\varphi\right) \cos^2 \varphi - \cos\left(\Theta - \frac{2}{3}\varphi + \frac{\pi}{3}\right) \sin^2 \varphi.$$

With this formula she could provide a qualitative picture of how the supplemental energy was distributed at different phases and directions (see Figure 19), and she was able to determine the efficiency of the tube to be approximately fifty percent.

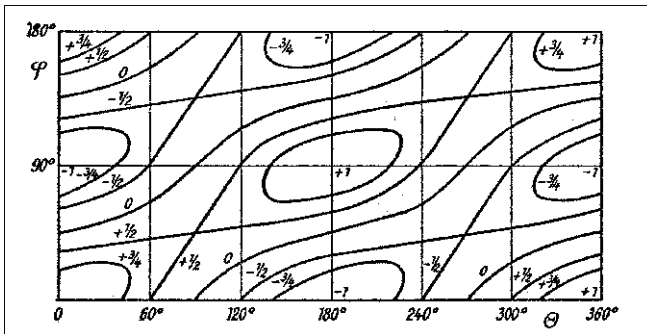


Figure 19: Lines of Identical Energy Consumption for Electrons Culminating at φ , Θ
(Iris RUNGE 1940, p. 45).

In the section on magnetic field tubes in his survey on the topic of high-vacuum tubes and rectifiers, Hans Rukop summarized Iris Runge's theoretical contributions with these words: "I. Runge calculated electron precipitation from the course of electron paths affected by energy withdrawal and thus determined the approximate efficiency of tubes."⁴²⁶ Friedrich-Wilhelm Gundlach acknowledged her ar-

⁴²⁶ RUKOP 1941, p. 79.

ticle for its role in establishing the “theoretical principles” of split-anode tubes in his report on velocity-modulated tubes for the FIAT Review of German Science: “Some model calculations have been made to explain the operations of the split-anode magnetron. Runge, for instance, analyzed the paths of electrons in a cylindrical system under a number of simplified conditions.”⁴²⁷

After Telefunken had begun to intensify its radar research in 1943, Iris Runge produced further model calculations for magnetrons with time-varying magnetic fields.⁴²⁸ In a laboratory report from July 5, 1943, she offered the following summary of her activity:

I have calculated the trajectories of electrons that have, by means of an alternating voltage with separated pulses, been made to enter into a space with crossing electric and magnetic fields. From this it is then possible to calculate the energy exchange of these electrons with an oscillating circuit, and by comparing this with the amount of absorbed energy it is possible to determine the efficiency of the tube. At a wavelength of 10cm, an efficiency of approximately 28% is achieved.⁴²⁹

The goal in this case was to formulate an equation to test a hypothesis of her colleague Max Geiger, namely that it might be effective to combine in some way the advantages of a triode (with a control grid) with the advantages of a magnetic field tube. To this end she calculated electron paths by integrating the equations of motion for an electric alternating current field that is perpendicular to a magnetic direct current field.

Iris Runge’s final two laboratory reports – “Electron Paths in a Magnetron with an Extended Cathode, with Space Charge Taken into Consideration” (May 5, 1944) and “The Effect of Space Charge in the Matter of Velocity Modulation” (November 7, 1944) – make it clear that she concerned herself with the theory of magnetic field tubes and with the influence of tube designs on the paths of electrons until nearly her final days at Telefunken, even after the tube research laboratory had been relocated to the Prussian province of Lower Silesia. Among the mathematical methods that she employed were Poisson’s equation, electron equations of motion, and well-known numerical and graphical approaches to solving such equations.⁴³⁰ In a footnote to her very last report, particularly to its section on

427 GUNDLACH 1948, p. 211.

428 The intensification of research in the area of radar technology is reflected, for instance, in a report by Lothar Oertel from December 1, 1944: “Vergleichende Betrachtungen zum Magnetron mit Innen- und Aussenkathode” [Comparative Studies on Magnetrons with Internal and External Cathodes]. Oertel, a researcher at Telefunken, had been awarded a doctoral degree in 1937 by the University of Breslau; his supervisor was Erwin Richard Fues, who had studied under Arnold Sommerfeld. Records further indicate that the director Karl Steimel was also an active participant in radar research (see [DTMB] 5299).

429 [DTMB] 5212, p. 2003.

430 The report from May 5, 1944 begins: “The calculation of the paths of electrons in a magnetron with an extended cathode can be made most easily if one begins with a given electron current that is leaving the cathode. The Poisson equation $\Delta U = 4\pi\rho$ and the electron motion equations under the influence of a radial electric field and an axial magnetic field lead then,

Carrying out the Calculations, she added: “This has already been treated in part by I. Runge, ‘On Calculating the Performance of Multi-Grid Tubes at High Frequencies,’ *Telefunken-Röhre* No. 10, 1937.”⁴³¹

The reports that she completed after 1941 did not result in publications. In these she was essentially concerned with modifying her earlier work or with the application of theory to the concrete problems presented by new tube designs. This latter task required the continuous refinement of her models. As late as 1956, Gundlach could make the following remark about magnetic field tubes with split anodes: “Even today, despite the existence of fundamental and comprehensive studies, the mathematical treatment of all their details continues to present difficulties.” New and different mathematical theories underlie the gyrotron, which is presently the most powerful microwave oscillator.

3.4.5.2 Calculating the Parameters of Electron Tubes

Three main parameters lie at the heart of calculating the performance of electron tubes, and these must be considered alongside the various electrical circuits that can be used. The coefficients in question are transconductance S (*Steilheit*), the penetration factor D (*Durchgriff*), and the anode (or plate) resistance R_i (*Innerer Widerstand*). Although the correlation of these parameters in the case of a simple triode was discovered empirically, around the same time, by researchers in several countries, it would come to be known as the Barkhausen equation: $S \times D \times R_i = 1$.⁴³² This would later be formulated as follows:

$$S = \left(\frac{\partial I_A}{\partial U_G} \right)_{U_A = \text{const}} \quad D = - \left(\frac{\partial U_G}{\partial U_A} \right)_{I_A = \text{const}} \quad R_i = \left(\frac{\partial U_A}{\partial I_A} \right)_{U_G = \text{const}},$$

where I_A designates the anode current, U_A the anode voltage, and U_G the grid voltage. It is important to note that the German terms and concepts regarding these parameters can differ slightly from those found in the Anglophone literature on the subject; the most significant of these differences will be pointed out in the discussion below.

Transconductance (S), which is also known as mutual conductance, expresses the change in the anode current divided by the change in grid voltage at a constant anode voltage. It is thus a measure of the amplification of a signal.

by means of applying graphical or numerical methods, to the extraction of the functions $r(t)$ and $\varphi(t) = dr/dt$ and from here also $\varphi(r)$ and $U(r)$, where r , φ are the polar coordinates of the electron, U is the potential at the location of the electron, and t designates time.” This report consists of sixteen pages, four of which contain mathematical proofs and six of which contain graphical representations of the course of electron paths, of the potential curves, and of other phenomena (see [DTMB] 5265, Report No. 171).

431 [DTMB] 5292, p. 2807.

432 On the historical development of the Barkhausen equation, which is named after the German physicist Heinrich Barkhausen, see BOSCH 2005.

Anode resistance (R_i) is defined as the ratio of the change in anode voltage to the change in anode current, with the grid voltage remaining constant. According to the equivalent circuit diagram (Figure 20), in which the anode battery is assumed to be free of loss resistance on account of its low anode resistance, the location of this latter resistance is parallel to the “output (load).” It is therefore not sensible, if the goal is to achieve higher amplification, to choose the load resistance arbitrarily. The effective load resistance is determined by means of the parallel circuit and does not exceed the smaller of the circuit’s two components. In a triode, the anode resistance results from the rise in the current-voltage (I_A/U_A) characteristic curve at the operating point (ideally from a $U^{2/3}$ parabola), and is relatively small. This means that, if the output load is a resonant circuit, it will always be damped by the (relatively minimal) anode resistance, which entails negative consequences for bandwidth and amplification.

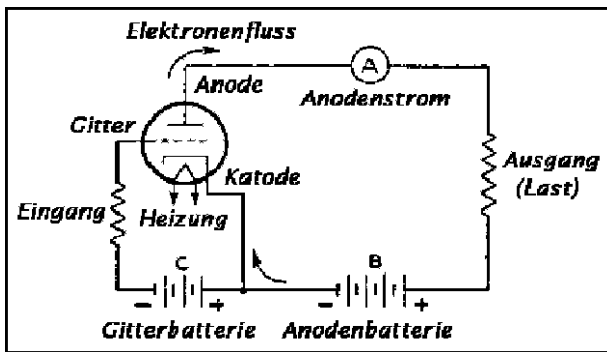


Figure 20: A Triode Circuit Diagram

The term *penetration factor* (*Durchgriff*) is uncommon in the English literature on the subject, in which its reciprocal, the *amplification factor*, is typically preferred.⁴³³ Designated by the symbol μ , the amplification factor of a tube is the ratio of a change in anode voltage to the change in grid voltage that would be required to return the anode current to its original value, and it allows for the voltage gain of a current to be predicted. As the reciprocal of the penetration factor, in other words, the amplification factor represents the theoretical limit of the voltage gain that can be achieved in a given tube.

All of this is valid in the case of triodes. Things are more complicated, of course, in the case of multi-grid tubes; the most common of these was the pentode, which consisted of an anode, a cathode, a control grid (*Steuergitter*), a screen grid (*Schirmgitter*), and a retarding grid (*Bremsgitter*). The screen grid, which was invented in 1916 by Walter Schottky, functioned to “screen” the anode and thus

433 On the concept of the penetration factor as it is used in German research, see ROTHE/KLEEN 1943, p. 83; MÖLLER 1929, p. 12; BARKHAUSEN 1954, p. 18; ROTHE/KLEEN 1948, p. 43.

drastically reduced the penetration factor of the anode voltage (see Figure 21). Because of this, moreover, the current-voltage characteristics level off above a certain anode voltage; the anode resistance is high; and the penetration factor, as the inverse limit of the voltage gain, is small. These features, among others, accounted for the technological advantages of multi-grid tubes.

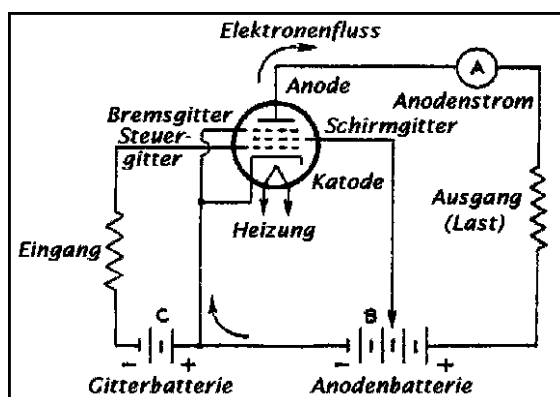


Figure 21: A Pentode Circuit Diagram

Iris Runge's contributions to the calculation of tube parameters will be surveyed more closely in five selected areas of emphasis: 1) The oscillations of systems with negative current-voltage characteristics, in which Iris Runge produced significant results pertaining to the problem of relaxation oscillations; 2) calculating the oscillatory processes of parallel inverters, for which she simplified previous methods and solved certain problems for the first time; 3) bias currents and ignition conditions, for which she refined existing approaches and developed graphical methods of calculation; 4) vacuum determination in the case of indirectly heated receiver tubes, for which she created new methods of calculation and corrected a notable error by Heinrich Barkhausen, whose textbooks on electron tubes enjoyed an international reputation⁴³⁴; and 5) formulas and nomograms for the penetration factor (again, the inverse amplification factor), in which regard she offered a systematic review of international research and presented a contribution of her own.

⁴³⁴ See, for instance, O. H. Schade, "Beam Power Tubes," *Proceedings of the Institute of Radio Engineers* 26 (1938), pp. 320–364, in which Barkhausen's textbook is cited on page 325.

The Oscillations of Systems with Negative Current-Voltage Characteristics

Iris Runge had been examining the phenomenon of relaxation oscillations, which are now referred to as limit cycles, since as early as 1930 (see Appendix 5.3, No. 4; 5.4, No. 5). In doing so, she was participating in a lively and international research topic that had been initiated by the Dutch physicist Balthasar van der Pol, a student of John Ambrose Fleming and Joseph John Thomson.⁴³⁵ After completing his doctoral degree, he joined the research laboratory of Philips in Eindhoven, where he directed the radio research division as of 1925. In 1927, Van der Pol published the first study of nonlinear oscillations in a triode tube, and here he presented the equation to which his name would be attached (an ordinary differential equation that can be written as a second-order system and solved using the Runge-Kutta procedure).⁴³⁶ This equation is relevant because it allowed for the problem of resistance to be treated mathematically, particularly the desirable phenomenon of “negative resistance” in an amplifier.

When an electron tube is biased in such a way that the operating point lies in the region of negative resistance, this tube can function as an amplifier. Tubes can also be biased to alternate rapidly between two states in accordance with changes in applied voltage. Even before it was theoretically and experimentally established, in 1933, that negative resistances could occur in electron tubes as a result of limited electron transit times at defined frequencies,⁴³⁷ Iris Runge was able to provide a theoretical explanation for relaxation oscillations. She examined the generation of oscillations in systems with negative current-voltage characteristics, and her work in the laboratory resulted in an article with the self-explanatory title “Über Schwingungen von Systemen mit negativer Charakteristik.” Here she demonstrated that, in a circuit with a capacitor parallel to its series resistor, the oscillations produced by a system with a negative current-voltage characteristic are in fact relaxation oscillations. For her experiment she used a circuit with two electron tubes and a negative current-voltage characteristic that had been developed by Karl Steimel, who would later become her supervisor at Telefunken. Having derived the differential equations for the voltage and current balances of the circuits,

435 See Giorgio Israel, “Technological Innovation and New Mathematics: Van der Pol and the Birth of Nonlinear Dynamics,” in LUCERTINI et al. 2004, pp. 52–76. John Ambrose Fleming was the first professor of electrical engineering at London University College, and he is best known for having invented the first electron tube in 1904. This tube, a diode, was used for detection in wireless communication. Fleming worked as a consultant for the Marconi Wireless Telegraph Company and other companies in the industry.

436 Balthasar van der Pol, “On Relaxation-Oscillations,” *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science* 2 (1927), pp. 978–992; this article is reprinted in the first volume of his *Selected Scientific Papers*, ed. H. Bremmer and C. J. Bouwkamp (Amsterdam: North Holland Publishing Co., 1960). Philips & Co. was founded in 1891 as a light bulb factory with ten employees. It was made a public corporation in 1912 and began to manufacture radio tubes in 1918.

437 On the history of this development, see E. W. Herold, “Negative Resistance and Devices for Obtaining It,” *Proceedings of the Institute of Radio Engineers* 23 (1935), pp. 1201–1223.

she obtained a formula for the period of oscillation that was supported, at least for one of the circuits, by the experimental work of the Italian physicist Augusto Righi.⁴³⁸ She was able to prove that, in both cases, the frequency of the relaxation oscillations was inversely proportional to the capacitor value (C).⁴³⁹ By means of oscillographic recordings, she also explained the transition from relaxation oscillations to harmonic oscillations. She was the first to treat these significant issues theoretically with existing mathematical methods. Relaxation oscillations – a type of periodic, non-sinusoidal oscillation with a saw-tooth or triangular waveform (in contrast to harmonic oscillations) – continue to be used in oscilloscopes to deflect electrons horizontally.

Iris Runge's findings were incorporated into the textbook *Elektronenröhren als Schwingungserzeuger und Gleichrichter* [Electron Tubes as Oscillation Generators and Rectifiers], which her colleagues Horst Rothe and Werner Kleen published in 1941. Her work is cited in the second chapter of the book, which concerned the generation of downward sloping characteristic curves by means of electron tubes ("Erzeugung fallender Kennlinien mittels Elektronröhren").⁴⁴⁰

Calculating the Oscillatory Processes of Parallel Inverters

In a 1933 article co-authored with Heinz Beckenbach, Iris Runge offered a theoretical clarification concerning the parallel inverter (she is listed as the main author). This study originated as a laboratory assignment that she completed with her colleague Konrad Meyer (see Appendix 5.4, No. 6), to which Beckenbach later supplied experimental data.

With a parallel inverter circuit it is possible transform direct current into an alternating current by means of controlled tubes, an ability that has wide-ranging applications in electrical engineering. During this transformation, oscillatory processes take place that, at the time, proved to be rather difficult to calculate. It was not until the beginning of 1933 that Walter Schilling, then an employee of AEG's research institute, presented a method for addressing this problem in the case of a purely sinusoidal alternating current. The main component of his calculation, as he wrote, amounted to determining the amplitudes of the fundamental frequency and the higher harmonics of a Fourier analysis of the process.⁴⁴¹ Iris Runge simplified

438 An important figure in the development of electromagnetism, Augusto Righi was therefore indirectly influential to wireless telegraphy. He was the first to obtain the double refraction of electromagnetic waves, and he conducted pioneering research on the photoelectric effect.

439 Iris RUNGE 1932; see also DENNHARDT 2009.

440 See ROTH/KLEEN 1941, p. 19.

441 Walter Schilling, "Die Berechnung der elektrischen Verhältnisse in einphasigen selbsterregten Wechselrichtern," *Archiv für Elektrotechnik* 27 (1933), pp. 22–34. See also SCHILLING 1938 and 1940. Schilling had been an employee at Osram from October 8, 1923 until at least 1929 (see [DTMB] Photo Album).

this method and applied it to a case that Schilling had not considered feasible. She remarked:

The aim of the present study is to supplement and refine Schilling's recent findings. It first seeks to present, in a clearer fashion, the physical ramifications of Schilling's formulas, for which a more concise derivation is then provided. Second, the case of the open circuit will be treated mathematically, something that Schilling did not think could be done.⁴⁴²

From an engineering standpoint, the matter of the open circuit was important because it allowed for the load current to be switched off without any breakdowns. Her contribution was soon put to use by electrical engineers who had studied under Adolf Güntherschulze at the Technical University in Dresden and under Otto Schumann at the Technical University in Munich.⁴⁴³

Bias Currents and Ignition Conditions

In November of 1934, Iris Runge submitted a study entitled "Über Vorströme und Zündbedingungen bei gasgefüllten Glühkathodenröhren" [On Bias Currents and Ignition Conditions in Gas-Filled Thermionic Cathode Tubes] to the *Zeitschrift für technische Physik*. Here she explained the conditions that govern ignition in a triode if, before the ignition takes place, electrons are already present and the voltage is sufficient for ionization but insufficient for ignition itself. As long as the negative grid voltage is sufficiently high, ignition will not occur. The physicists Hans Klemperer and Max Steenbeck, both researchers for Siemens-Schuckertwerke in Berlin, had already revealed that the effect of a single ion could be regarded as being equivalent to a small increase in grid voltage. Iris Runge generalized this observation to demonstrate that it had implications not only for the starting-current region, but also for the space-charge region and for the validity of a given current-voltage characteristic. For purposes of practical application – that is, for enabling engineers to identify the bias current and the ignition point from the characteristic curve – she also developed an appropriate graphical method.⁴⁴⁴

442 RUNGE/BECKENBACH 1933, p. 377.

443 See H. U. Neidhardt, "Untersuchung der Frequenzhaltung am selbstgesteuerten und selbstgeführten Parallelwechselrichter im resonanzähnlichen Zustand," *Archiv für Elektrotechnik* 29 (1935), pp. 241–258; and Teh-hsin Kuo, "Berechnung der Strom- und Spannungsverhältnisse eines selbsterregten Parallelwechselrichters," *Zeitschrift für Physik* 93 (1935), pp. 769–788.

444 Iris RUNGE 1935. For the article by Hans Klemperer and Max Steenbeck, see *Zeitschrift für technische Physik* 14 (1933), pp. 341–349. Klemperer immigrated in 1936 to the United States, where he taught at MIT.

Vacuum Determination in Indirectly Heated Receiver Tubes – Calculations and a Correction

On October 12, 1937, Iris Runge sent an article entitled “Vakuummessung an mittelbar geheizten Empfängerröhren” [Vacuum Measurement in Indirectly Heated Receiver Tubes] to Wilhelm Hort with the hope that it might be accepted for publication in the *Zeitschrift für technische Physik*.⁴⁴⁵ This article was co-authored by her colleague Günther Herrmann, who had not yet completed his doctoral degree; Herrmann was responsible for the experimental side of the study, Iris Runge for its theoretical component.⁴⁴⁶ Their paper concerned the practically important problem of determining the pressure dependence of indirectly heated tubes on the so-called vacuum factor, which denotes the ratio of a tube’s ion current to its electron current. According to their analysis of international scholarship, the previous studies on the topic had been exclusively experimental. A comparison between empirical and mathematical results was altogether lacking; above all, no one had yet to analyze the concrete and quantitative connection between the available experimental data and the data provided by gas-kinetic and ion theory. Iris Runge supplied this desideratum, and in doing so she also identified and corrected an error that had been made by Heinrich Barkhausen.

Barkhausen had stated, as a function of the pressure, a certain value for the vacuum factor C that Iris Runge and Herrmann could confirm neither mathematically nor experimentally.⁴⁴⁷ The calculation of a vacuum factor is based on the differential ionization curve, that is, the number of ions s per electron on a 1cm path at a given unit of pressure as a function of the electron velocity in volts.⁴⁴⁸ Using a known curve for this function, Iris Runge derived the number of ions (N) per electron that are formed in a tube, assuming that $s(V)$ corresponds at each space point to the potential value that is there. This she integrated over the entire discharge path and multiplied by the pressure p . For tubes in which the potential variation can be regarded as linear, the vacuum factor is obtained by the following formula:

$$C = \frac{N}{p} = \frac{x_a - x_g}{V_a - V_{st}} \int_{V_{st}}^{V_a} s dV,$$

445 A copy of this cover letter is archived in [DTMB] 6604, p. 74.

446 HERRMANN/RUNGE 1938.

447 The value in question is found in Heinrich Barkhausen, *Lehrbuch der Elektronenröhren und ihre technischen Anwendungen*, 4th ed., 4 vols. (Leipzig: S. Hirzel, 1931), vol. 1, p. 11.

448 HERRMANN/RUNGE 1938, p. 15. Electron velocity in volts (*Voltgeschwindigkeit*) is a term that is still used today. It was coined by Philipp Lenard, who demonstrated that the speed of an electron is defined by the amount of voltage that the electron has accelerated through; see, for instance, W. Kossel, “Zu P. Lenards 80. Geburtstag,” *Die Naturwissenschaften* 30 (1942), pp. 317–318. An electron volt (eV) equals the amount of kinetic energy that is gained by an unbound electron as it accelerates through a potential difference of one volt.

where V_{st} is the effective voltage of the grid. The integration was executed graphically, and the result was applicable for all distances and voltages. It was further asserted that, if the potential is nonlinear, since the potential distribution, has to be plotted for every special case and that this can likewise be integrated graphically:

$$C = \frac{N}{P} = \int_{r_k}^{r_a} s(V(x)) dx$$

In the theoretical section of the article, Iris Runge discussed the specific conditions that had to be taken into account while mathematically modeling the problem. She explained how the calculation of C could be made in the cases where temperature correction was either taken or not taken into account. It is in this regard that she identified the source of Barkhausen's error:

As things stand, it impossible to determine the proper temperature of the electron space without a certain degree of arbitrariness, and this is especially the case in multi-grid tubes. An exact determination of this temperature is, of course, entirely out of the question, for the space itself is imprecisely defined and its temperature is certainly not uniform. In what follows, the goal is necessarily restricted to establishing the relevant temperature within a set of plausible limits. This will allow us to attain an approximate idea of whether, by means of the influence of temperature, the measured ion currents might be made to agree with the ionization curves. It is noteworthy that no previous study on the theory of the ionization manometer has addressed the matter of temperature, even despite the fact that temperature significantly influences the quantitative relationship between ion current and pressure.

In part, this investigation has also been instigated by the fact that Barkhausen's theoretical estimation seems to support his remarkably high experimental value of C . For his calculation, in any case, the value of the free path for electrons at an atmospheric pressure of 10^{-5} is 4 to 6 times too small in light of the values that are assumed today. According to our estimation, the non-consideration of temperature yields once again a factor of 1.5. Moreover, because the ionization probability is set at 1 for the sake of simplicity, this explains the total variation of more than an order of magnitude.⁴⁴⁹

Heinrich Barkhausen corrected his mistake in the subsequent edition of his textbook, in which he incorporated Iris Runge and Günther Herrmann's value for the dependence of the vacuum factor on pressure. Even in the tenth edition of his book, which appeared in 1962 (Barkhausen died in 1956), their 1938 article is referred to in a chapter on the principles of electron tube theory.⁴⁵⁰

Formulas and Nomograms for the Penetration Factor

The challenge of mathematically expressing the penetration factor – the inverse amplification factor – can be regarded as one of the key problems of electron tube calculation. Because the tubes were always being redesigned and modified (especially to be smaller), mathematical models regularly had to be refined in order to

449 HERRMANN/RUNGE 1938, p. 16.

450 See Heinrich Barkhausen, *Lehrbuch der Elektronenröhren und ihre technischen Anwendungen*, 10th ed., 4 vols. (Leipzig: S. Hirzel, 1962), vol. 1, p. 20.

serve the changing needs of engineers. Formulas had existed for calculating the penetration factor since 1919; because they had been created independently by scholars in several countries, however, a standardized system of notation did not exist. Iris Runge systematized the formulas that had been developed before the year 1940.

Her investigations were based on her long experience with determining, mathematically and experimentally, the transconductance and penetration factors of a great variety of electron tubes. As early as 1930, she had already begun to approach the penetration factor theoretically: “In regards to these developmental experiments, the matters of the location of the space charge and its effects on the penetration factor were investigated both theoretically and experimentally. This investigation is still underway.”⁴⁵¹ In 1931 she examined how a particular penetration factor could be achieved on the basis of concrete design factors for an electron tube with a grid made of wires or radial bars:

If the grid of a tube is made of radial bars instead of wires, the penetration factor diminishes. By measuring three small experimental tubes – at the request of Dr. Hoepner – I determined to what extent the diameter of the grid wires would have to be increased in order to be equivalent to the variously sized grid bars that are used. After this, I calculated the bar width that would be required to achieve a particular penetration factor in a large tube.⁴⁵²

From the 1931/32 annual report of her research activities (Appendix 5.4, No. 4), we learn that Iris Runge had already been engaged with the development and evaluation of nomograms and penetration factor calculations. Ten years later, the results of these early investigations would be incorporated into her systematic review article on the topic.

In 1941, this latter article – “Die Berechnung des Durchgriffs auf Grund der Potentialverteilung” [Calculating the Penetration Factor on the Basis of the Potential Distribution] – was published in the journal *Die Telefunken-Röhre*. Here she not only provided a comprehensive survey of the formulas that had been developed internationally; she also created a number of nomograms for these formulas. Organizing the survey according to the possible arrangements of electrodes – planar or cylindrical (see [Figure 22](#)) – she developed a uniform system of notation for the formulas, which she then presented in five clear tables.⁴⁵³ These tables serve practical needs by referring to the scholarly sources of the formulas and by clarifying their applicability to various types of tubes.⁴⁵⁴ The article opens with the following remarks:

451 [DTMB] 6603, p. 134; see also Appendix 5.3, No. 2.

452 Ibid., p. 136; see Appendix 5.3, No. 7.

453 Two of these tables ([Tables 4](#) and [5](#) in the original article, which contain formulas of her own) are reproduced below in [Figures 21a](#) and [21b](#).

454 Iris Runge describes what sort of mathematics she and other researchers had used to calculate the penetration factor, but she did not demonstrate in detail how the formulas were derived. There is in fact no scholarship on the subject in which this information is provided.

Based on the principles of potential distribution, calculations of the penetration factor date back to the earlier days of electron tube development in general, and the formulas developed at that time remain significant to the present day. Since then, however, a number of refinements have been made; especially in recent years, the requirements of tube designs have led to several modifications and improvements in these formulas. It is thus of some interest to review these developments once again and to compare the individual formulas in terms of their usefulness to special purposes. To do so, it is first necessary to distinguish between the two basic types of tube, namely those with a planar system and those with a cylindrical system. The more uncommon systems [...] will not be considered here.⁴⁵⁵

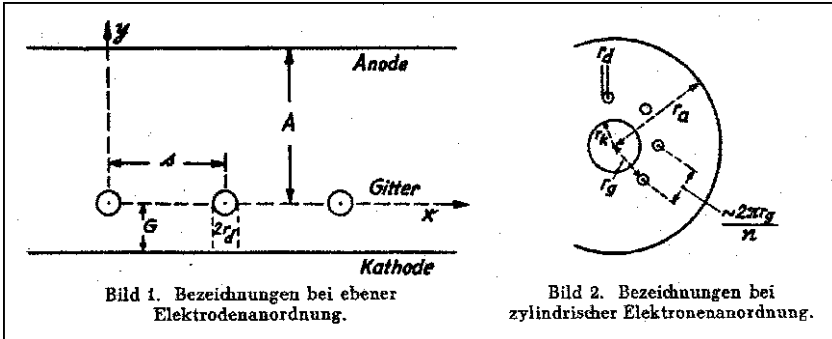


Figure 22: An Illustration of the Planar and Cylindrical Arrangements of Electrodes in an Electron Tube (I. RUNGE 1941, p. 230).

In 1919, as Iris Runge pointed out in her article, Walter Schottky became the first to calculate the potential distribution of triodes – with *planar* systems – by using Maxwell’s differential equations of the electromagnetic fields.⁴⁵⁶ She explained Schottky’s model and noted that it was no longer suitable for the latest tube designs. Schottky had regarded the triode grid as consisting of parallel and equidistant wires arranged in a third plane between the anode and the cathode. According to his model, the grid wires were charged *lines*. Because the potential is constant along the length of the wires, the solution for the potential of the grid alone turns out to be the real part of a complex function with poles at equidistant points – a log sine function. The influence of the anode was taken into account by assuming there to be a second, oppositely charged grid mirroring the first along the anode planes. In addition, the cathode was thought to be *very far away*, such that there would be no field strength at it. Thus the potential distribution was entirely determined by the level of field strength at the anode. Schottky was able to express the

⁴⁵⁵ Iris RUNGE 1941, p. 229.

⁴⁵⁶ For an evaluation of this procedure, see Iris RUNGE 1941, p. 229; and MÖLLER 1929, pp. 196–198. Maxwell’s equations, which are fundamental to classical electrodynamics, had been reformulated for vector analysis by Oliver Heaviside; in this form, around the middle of the 1890s, they found their way relatively quickly into German textbooks (see Felix KLEIN 1927, pp. 47, 60; PUCHTA 1997).

potential distribution by means of the potentials of the grid and the anode, and he gave the penetration factor as a ratio of coefficients:

$$D = \frac{s}{2\pi A} \ln \frac{1}{2 \sin \frac{\pi r_d}{s}},$$

where s is the distance between the grid wires, r_d the radius of the grid wire, and A the distance between the anode and the grid.

Schottky's model, which was highly simplified, was only valid if the ratio of the wire diameter to the distance between the wires was sufficiently small and the cathode was considered to be infinitely distant. This hardly ever corresponded to practical realities, and thus the need arose to modify the formula for the penetration factor to account for both thicker grid wires and the defined distance between the cathode and the grid. Stressing that it was necessary to incorporate the width of the grid wires into the mathematical model, Iris Runge referred to approaches that had been developed at General Electric (New York) and had later been adopted by Franz Ollendorff in Berlin.⁴⁵⁷ Her eye for identifying problems concerning the size of wires had already been sharpened by her research on the measurements of thin filaments (see Section 3.4.3.1), and so she developed special formulas of her own to account for various thicknesses (see Figures 21a and 21b).

The second inadequacy of Schottky's triode model, namely the assumption of a cathode infinitely distanced from the grid, was first addressed by Lothar Oertel, who joined Telefunken immediately after completing his doctorate in Breslau. His article on the subject contained an error, however, which Iris Runge recognized and corrected.⁴⁵⁸ In 1939 – and independent of Oertel – the British researcher John Heaver Fremlin, who worked for Standard Telephone and Cables Ltd. until 1945, also published a formula on this topic. Although he treated the dependence of the grid-cathode distance in a more satisfactory manner, he failed to consider the thickness of the wire.⁴⁵⁹ Iris Runge considered combining the approaches of Oertel and Fremlin:

457 See F. B. Vodges and Frank R. Elder, "Formulas for the Amplification Constant for Three-Element Tubes in which the Diameter of Grid Wires is Large Compared to the Spacing," *Physical Review* 24 (1924), pp. 683–689; and Franz Ollendorff, "Berechnung des Durchgriffs durch enge Steggitter," *Elektrotechnik und Maschinenbau* 52 (1934), pp. 585–591. Ollendorff was a lecturer and chief engineer at the department of theoretical electrical engineering at the Technical University in Berlin. He went into exile to Palestine in 1933, where he was given a professorship in 1938. In 1960 he was awarded an honorary doctoral degree by his former German employer.

458 Lothar Oertel, "Zur Theorie der Elektronenröhren, deren Gitter-Kathoden-Abstand kleiner ist als die Steigung," *Telefunken-Röhre* 12 (1938), pp. 7–17. Her correction of his error (see Iris RUNGE 1941, p. 233) was also mentioned in the textbook by Horst Rothe and Werner Kleen, who reproduced her tables of formulas (see ROTHE/KLEEN 1943, p. 84).

459 John H. Fremlin, "Calculation of Triode Constants," *The Philosophical Magazine* 27 (1939), pp. 709–741. See also DYSON 1990.

For practical reasons it was necessary to combine the methods of Oertel and Fremlin. On the one hand, this was done in order to determine the ratio of the grid wire diameter to the pitch at higher values; on the other hand, it was also done in order to observe the influence of the finite distance between the grid and the cathode at low values.⁴⁶⁰

With her formulas, she was also able to address a new problem that arose with the design of smaller tubes with minimal grid-cathode distances, namely the so-called island effect (*Inselbildung*). In their 1955 book on high-vacuum electron tubes, Horst Rothe and Werner Kleen based their discussion of the mathematical treatment of the island effect on Iris Runge's article, which they considered of significant relevance to determining the parameters of modern tubes.⁴⁶¹ According to her formulas, the penetration factor proved to be a variable along the system and could be approximately represented as the sum of a constant D_∞ and a superimposed sine function.⁴⁶²

An unresolved question in 1941 was how to determine the penetration factor in cases with minimal grid-anode distances. Iris Runge explained that, in such cases, a twofold infinite system of charge lines had to be treated with a doubly periodic potential function, and that the problem of potential could be solved with the help of an elliptical function, as had been demonstrated in 1937 by Louis Rosenhead and S. D. Daymond of the University of Liverpool.⁴⁶³ In 1938, the Hungarian physicist T. Glosios adopted this method to calculate the characteristic curves of electron tubes, but he paid no attention to the issue of minimal grid-anode distances.⁴⁶⁴

A comparison between Iris Runge's article and Hans Rukop's from the same year reveals the latter's more casual approach to mathematics. Rukop simply remarked: "L. Oertel developed formulas and T. Glosios tables for calculating the characteristic curves and the penetration factor for cases in which the grid path was greater than grid-cathode distance."⁴⁶⁵ Iris Runge, who had corrected Oertel's formula, noted that Glosios had calculated characteristic curves with the methods of Rosenhead and Daymond "in order to treat the dependence of the median penetration factor on the voltage ratio U_g/U_a , for which it had been sufficient to derive the potential function without recourse to elliptical functions."⁴⁶⁶ By making approximate calculations, she demonstrated that, for an accuracy of one to two percent, the doubled periodicity would only have to be considered if the grid-anode distance was less than approximately one third of the grid pitch.

460 Iris RUNGE 1941, p. 232.

461 See ROTHE/KLEEN 1955, pp. 123–131, which is a chapter titled "Das Potentialfeld weitmaschiger Gitter (Inselbildung)" [The Potential Field of Wide-Meshed Grids (Island Effect)].

462 Iris RUNGE 1941, p. 231.

463 L. Rosenhead and S. D. Daymond, "The Distribution of Potential in Some Thermionic Tubes," *Proceedings of the Royal Society* 161 (1937), pp. 382–405.

464 T. Glosios, "Berechnung der Kennlinien von Elektronenröhren (Trioden)," *Hochfrequenztechnik und Elektroakustik* 52 (1938), pp. 88–93.

465 RUKOP 1941, p. 66.

466 Iris RUNGE 1941, p. 232.

Regarding the penetration factor in the case of *cylindrical systems*, formulas had likewise been published since 1919 by such researchers as Max von Laue, Max Abraham, and Joseph John Thomson. Initially derived for bar grids, these formulas were later modified to suit spiral-seam grids and ring grids (*Ringgitter*), and they were ultimately made to account for defined cathode diameters (which yielded closer approximations of the actual ratios in the case of indirectly heated tubes). All the formulas for the cylindrical system that had been published up to 1938 were restricted in that the radius of the wire was assumed to be small and their mathematical models were based on a charged line or curve instead of on a cylindrical or toroidal quantity. Aware of these insufficiencies, Iris Runge developed a new formula of her own that took into account the limited diameter of the grid wires. Concerning the article by Franz Ollendorff – mentioned above – she stressed:

In order to be able to make calculations for grid wires with larger radii, it is possible to superimpose – in light of Ollendorff's findings – the appropriate dipoles and multi-poles over the simple charge of the circumferences. These are to be determined in such way that the potential on the toroidal surfaces, which correspond to the surfaces of the grid wire, is constant.⁴⁶⁷

Her formula was applicable in practice to an important type of ring grid with certain specifications.

Konstantes Glied des Durchgriffs D_{∞} .		
Laue, Abraham J. J. Thomson	Stabgitter	$\frac{1}{n} \frac{\ln \frac{r_g}{r_d}}{\ln r_a/r_g}$
Elias	Ringgitter mit $\frac{2r_d}{s} < 0,1$ und dünnere Kathode	$\frac{s}{2r_g \pi} \frac{\ln \frac{s}{2\pi r_d}}{\ln r_a/r_g}$
Tellegen	Schraubengitter	$\frac{s}{2r_g \pi} \frac{\ln \frac{s}{2\pi r_d}}{\ln r_a/r_g}$
Oertel	Ringgitter mit $\frac{2r_d}{s} < 0,1$ und dicker Kathode	$\frac{s}{2r_g \pi} \frac{\ln \frac{s}{2\pi r_d}}{\ln r_a/r_g}$
Runge	Ringgitter mit $\frac{2r_d}{s} < 0,4$	$\frac{s}{2\pi r_d} \frac{\ln \frac{s}{2\pi r_d}}{r_g/r_d \ln r_a/r_g} + \frac{1}{2} - \frac{\pi r_d}{12s} \left(1 - \frac{1}{8} \left(\frac{r_d}{r_g}\right)^2\right)$

Figure 23a: A Table of Penetration Factor Formulas for Electron Tubes with Cylindrical Systems and a Constant Penetration Factor (I. RUNGE 1941, p. 238).

467 Ibid., p. 237.

Amplitude A des variablen Gliedes des Durchgriffs.		
Oertel	Ringgitter mit $\frac{2r_d}{s} < 1$ und dicker Kathode	$2 \sqrt{\frac{r_k}{r_g}} e^{\frac{-2\pi(r_g - r_k)}{s}} \left[\frac{\ln r_g/r_k}{\ln r_a/r_g} + D_{\infty} \frac{\ln r_g/r_k}{\ln r_a/r_g} \right]$
Runge	Ringgitter mit $\frac{2r_d}{s} < 0,32$; $D_{\infty} < 50\%$; $r_g/r_k < 4$	
	$2 \sqrt{\frac{r_k}{r_g}} e^{\frac{-2\pi(r_g - r_k)}{s}} \left[\frac{\ln r_g/r_k}{\ln r_a/r_g} + D_{\infty} \frac{\ln r_g/r_k}{\ln r_a/r_g} \left(1 - \frac{2\pi r_d}{s} \left(1 - e^{\frac{-2\pi r_d}{s}} \right) \right) \right]$	

Figure 23b: A Table of Penetration Factor Formulas for Electron Tubes with Cylindrical Systems and a Variable Penetration Factor (I. RUNGE 1941, p. 239).

Iris Runge arranged the formulas for planar systems into three tables and those for cylindrical systems into two. Her third table for planar systems – not illustrated here – contained formulas that she herself had derived on the basis of Fremlin's and Oertel's contributions, as mentioned above. Her first table for cylindrical systems was valid for a constant penetration factor D_{∞} , and the second for a variable penetration factor with the amplitude A (see [Figures 23a](#) and [23b](#)).

Table 15: Variables of the Penetration Factor Formulas for the Nomograms.⁴⁶⁸

Formulas for	System	Variables	Number
D_{∞}	Planar	$A \ r_d \ s$	3
	Cylindrical	$r_a \ r_g \ r_d \ s$	4
$D_{\max}$ $D_{\min}$ and A	Planar	$A \ G \ r_d \ s$	4
	Cylindrical	$r_a \ r_g \ r_k \ r_d \ s$	5

In another section of the same article from 1941, Iris Runge discussed nomographic representations of the penetration factor and she explained, having surveyed the possible variables ([Table 15](#)), the usage of her preferred nomogram with four examples (for one example, see [Figure 24](#)). These nomograms enabled engi-

⁴⁶⁸ Iris RUNGE 1941, p. 239. For her illustrations of the planar and cylindrical systems, see [Figure 22](#).

neers both to determine the penetration factor for a given tube design and to construct a tube with a predetermined penetration factor.

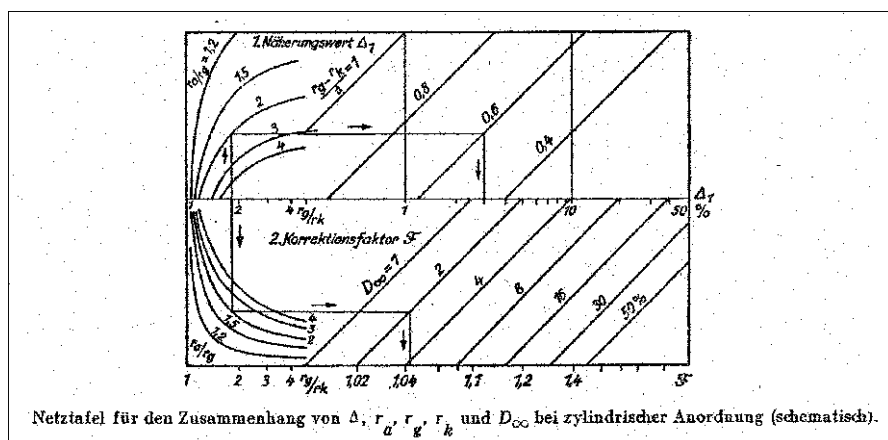


Figure 24: A Nomogram for Determining the Penetration Factor (I. RUNGE 1941, p. 242).

The results of Iris Runge's study, its systematic notations, and its tabular presentation were incorporated nearly verbatim into later textbooks on electron tubes. In their 1943 book on the principles and characteristic curves of the latter (*Grundlagen und Kennlinien der Elektronenröhren*), for instance, Horst Rothe and Werner Kleen introduced a section on the penetration factor with these sentences: "In what follows, the previously published formulas for the penetration factor will be presented. For information about how they were derived, see especially the study by Runge [1941]."⁴⁶⁹ They went on to reproduce Iris Runge's division of formulas for planar and cylindrical systems as well as her presentation of the formulas in the clearly-arranged tables. In their later textbook on high-vacuum electron tubes, which was published in 1955, Rothe and Kleen repeated these same formulas and tables once again, adding: "Information on the way in which these formulas were derived and on their various areas of applicability can be found especially in the studies by Runge and Fremlin."⁴⁷⁰ Iris Runge's work was also cited in an article from 1951 by Max Landsberg, a professor of mathematics at the Technical University in Dresden who was similarly concerned with the theory and calculation of penetration factors.⁴⁷¹

469 ROTHE/KLEEN 1943, p. 83. Iris Runge's findings would reach an international audience, mostly by way of Rothe and Kleen's textbook (see ZAREW 1955, p. 330, for instance).

470 ROTHE/KLEEN 1955, p. 124. Here they referred to Fremlin's article from 1939, which Iris Runge had already cited in 1941, and to J. H. Fremlin, R. N. Hall, and P. A. Shatford, "Triode Amplification Factors," *Electrical Communication* 23 (1946), pp. 426–435.

471 Max Landsberg, "Zur Theorie und Berechnung des elektrostatischen Durchgriffs der ebenen und zylindrischen Dreipolröhre im Falle zweidimensionaler Potentialverhältnisse," *Zeit-*

3.5 MATHEMATICAL CONSULTING – A SUMMARY

This section will provide a summary of the features that distinguished the role of experts and that of Iris Runge in particular, in the field of industrial research. There are three matters to be discussed, namely the relationship between experimental and mathematical work, the desired characteristics of mathematicians working in the industrial sector, and the differences and similarities between Iris Runge's activity and that of mathematicians at other institutions.

3.5.1 On the Relationship Between Experimental and Mathematical Work

Professor Pirani says that I should stick to making calculations and leave the experiments to those who are better at them. My talent, as he put it, is far less common.⁴⁷²

In her recent study on the creation of knowledge in physics and biology laboratories, Karin Knorr Cetina made the conscious decision to exclude theory from her considerations.⁴⁷³ In the case of industrial research, however, it is clear that theoretical models (physical and mathematical) and their experimental verification were tightly intertwined. Such research typically involved the following steps: developing a mathematical description of a given problem based on a theoretical model; providing a mathematical analysis of the problem (calculating equations with the appropriate numerical, graphical, or instrumental method); testing these results experimentally; evaluating and modifying the model in the case of deviant results; making and experimentally verifying new calculations. It was necessary for the results of such calculations to be presented to engineers in an intelligible form (often with the help of nomograms). Moreover, the algorithms for the calculations had to be configured by the mathematical experts in such a way that engineers with little mathematical expertise could produce their own results in the shortest possible time.

By neglecting to acknowledge or examine theoretical models, the impression is left that mathematics, as a science of potential structures or order patterns, somehow does not play an integrative role in the production of scientific knowledge. Despite Knorr Cetina's effort to demonstrate the epistemic disunity of the

schrift für angewandte Mathematik und Physik 2 (1951), pp. 375–393. Landsberg's doctoral research, completed in 1947, was conducted in Dresden under the supervision of one of Carl Runge's former students, Friedrich-Adolf Willers.

472 A letter from Iris Runge to Carl Runge dated August 29, 1924 [Private Estate].

473 See KNORR CETINA 1999, pp. 14–17, where she remarks, for instance, "Physics theory, then, is not in this book; it is simply not the focus of it" (p. 16; an original English quotation). However, the third chapter of her book – "Particle Physics and Negative Knowledge" – demonstrates that this exclusion is ultimately infeasible, for her explanations there cannot stand on their own without references to models, quantitative correlations, and calculations. By regarding the theoretical model as something entirely distinct from practical experimentation, she hazardingly underestimates its role in the scientific process.

modern sciences,⁴⁷⁴ mathematics can in fact be regarded as a *unifying* epistemic methodology. This pathway to knowledge is distinguished, again, by the pursuit and design of mathematical structural elements and by the experimental evaluation of the design's applicability to a given problem.⁴⁷⁵ A single mathematical paradigm, moreover, can be suitable for finding solutions to a diverse array of problems. For example, the partial differential equation, which Fourier first developed to analyze heat conduction, can be used in a number of fields to describe a great variety of distribution processes, so long as the appropriate initial and boundary conditions are known.

The extent to which mathematics can be used in the treatment of a physical/technical problem depends in large measure on the established principles of the field in question. George A. Campbell, renowned for applying mathematical methods to the problems of long-distance telegraphy and telephony, was an industrial researcher at the American Telephone and Telegraph Company in New York (he had also studied for a year under Felix Klein at the University of Göttingen). In a lecture delivered in 1924 at the International Mathematical Congress in Toronto, he made the following remarks about the application of mathematics:

[O]nly a very small part of nature has been accommodated unto use, yet even this has given us such widely useful devices as the heat engine, the telegraph, the telephone, the radio, the airplane and electric power transmission. It is impossible to conceive that any of these devices could have been developed without the aid and intervening of mathematics.⁴⁷⁶

As the chairman of the German Physical Society, Jonathan Zenneck was called upon to give the inaugural address to the 1937 Conference of Mathematicians and Physicists in Bad Kreuznach (Iris Runge was in attendance). Here he criticized the neglect of mathematics in interesting terms:

Indeed there are areas of physics in which one can get by with a minimum of mathematics; or, to put it more accurately, there are areas in which the experimental physicist has not progressed far enough to have developed principles that are conducive to precise mathematical examinations. Yet there are other areas of physics in which one would be absolutely helpless without the aid of mathematics. And if mathematical instruction is to be restricted to secondary school, it will be physics and the engineering sciences that will pay the price.⁴⁷⁷

Like Campbell, Zenneck recognized that practitioners of communications engineering could not afford to dismiss mathematical methods. By that time it was no longer contentious that mathematical models necessarily presented simplifications, that they concentrated only on the essentials of a problem, and that they could

474 See KNORR CETINA 1999, pp. 2–5.

475 See NEUNZERT/ROSENBERGER 1991, p. 130.

476 See CAMPBELL 1926, p. 550 (an original English quotation).

477 For the text of Zenneck's address, see the *Zeitschrift für technische Physik* 11 (1937), pp. 346–348. Zenneck began his speech by inviting the audience to join him in saying: "Unser Führer und Reichskanzler 'Sieg Heil'." In his own addresses, Karl Mey (Osram) is known to have avoided this ritual pronouncement, which was mandated by the authorities (see HENTSCHEL/HENTSCHEL 1996, pp. 178–180).

only represent an approximation of reality. It is typically the case, after all, that the equations themselves are mathematically exact and can be proven. The extent to which their solution corresponds to reality depends on empirical data. Wherever certain theoretical correlations and correct initial and boundary conditions were not taken into account – the temperature dependence of a problem, for instance, in which case Iris Runge corrected one of Heinrich Barkhausen's conclusions – then the results will necessarily contradict reality. Even before the advent of computers, however, approximate solutions could be so reliable as to determine whether it would be possible (and sensible) to design tubes, circuits, and other technologies with certain specifications as opposed to others.

It is not surprising that Iris Runge – at first the sole mathematician working in her laboratory at Osram – did not restrict or care to restrict herself exclusively to the theoretical side of things. Throughout her career, periods of predominantly experimental activity (though always with a theoretical eye) alternated with periods of intensive theoretical work. Admittedly, the experimental assignments that characterized her early career became fewer and fewer once the comparative value of her theoretical expertise had been recognized. Her great enthusiasm for having won the opportunity to work as a mathematician, as she expressed in letter after letter, hardly waned during her years at Osram and Telefunken.

While it is true that Iris Runge was more than aware of her talent for mathematical and theoretical work, she nevertheless had to carve out such a position for herself and prove her competence in unfamiliar arenas. In a discussion with her father about whether, because of him, she was “naturally disposed to the theoretical,” she expressed regrets about not having conducted enough experimental research during her studies: “Professor Pirani says that I should stick to making calculations and leave the experiments to those who are better at them. My talent, as he put it, is far less common. But he himself is a practitioner and therefore holds in higher esteem those things that he happens to be less adept at.” She continued: “Whenever possible, I will make it a point not to neglect the practical side of things, for this is what is truly stimulating, and if I restrict myself to analyzing the empirical observations of others, then I will remain nothing but a sort of lackey or henchman.”⁴⁷⁸ These remarks reflect the bias of the time against the value and usefulness of mathematical problem solving,⁴⁷⁹ and thus we repeatedly encounter phases of her career during which she participated in the experiments of others or conducted experiments independently. Instruments, materials, and assistance were generously at her disposal.

To solve a problem mathematically required a deep awareness of its underlying physical, technical, and economic conditions. Proper methods of measurement had to be chosen or developed in order to arrive at accurate values that could be used in a mathematical model. Iris Runge therefore closely monitored the activity of those assigned to conduct her experimental groundwork; she was quick to re-

⁴⁷⁸ A letter to her parents dated August 29, 1924 [Private Estate].

⁴⁷⁹ On this bias, see the discussions in FERGUSON 1992; SEISING 2005.

cognize, for instance, an unsystematic approach in the experiments of her colleague Walter Heinze:

My experimental assignment, the only one in all of March, is still underway; the bulbs that I need have not yet been built and things are always breaking, so the project is at a standstill. But everything else is moving right along. I've been entrusted with Dr. Heinze's work in his absence, and I have had some success, at least to the extent that I've managed to systematize several of his haphazard experiments in such way that it's now clear that he could not have proceeded in such a way. I've received some recognition for this, for he probably would have published his results as they were. Today I gave Jacoby another lesson in mathematics; he insisted that I explain my recent calculations to him.⁴⁸⁰

Again, a constellation of physical theory, experimentation, and applicable mathematical models was required to understand and forecast certain correlations. More often than not, in fact, the experiments were theoretically oriented.⁴⁸¹ This interplay can be demonstrated with a concrete example from the year 1924:

I conducted another impromptu experiment, for instance, that was actually quite interesting. What I wanted to determine was whether there was a thermoelectric force between tungsten and molybdenum that could possibly be used for measuring high temperatures. Nothing could be easier! Copious amounts of tungsten and molybdenum are readily available; in a matter of fifteen minutes, a technician compressed a contact point out of it; thermocouples are also here, as are resistance furnaces with hydrogen streams. There is also an assistant at my disposal – *for the asking* – who accurately manages the circuit. I only had to put each of the wire pairs into a quartz tube, put both of these into the furnace, hang two galvanometers on it, turn it on and measure away. Before this experiment I knew nothing at all about thermoelectric forces, and therefore I was astounded to watch the temperature leap to 700° before it began to fall. [...] I looked into the matter and discovered that, in many different pairs of wires, two such measurements had been observed (mostly at low temperatures), and that the Ansatz is generally made to be a parabola of the second order. I tested everything again in a second furnace, one that can reach 1600°, and this indeed produced a very good parabola that passed through zero into the negative at 1400°. [...] Now I have to come up with a configuration that can achieve an even higher temperature, one that is beyond the scope of the thermocouple and has to be measured with a pyrometer. If it turns out that the curve continues to be a parabola, then these negative currents could indeed be used quite well as a measure of temperature.⁴⁸²

According to Thornton C. Fry, this manner of working, which involved a close engagement with technical objects, was typical of the industrial mathematicians who were active at the time. Despite the fact that theory and experimentation were never fully disentangled, however, the two poles nevertheless remained distinct, as is suggested in a letter from Iris Runge to the physicist Lise Meitner:

480 A letter to her parents dated May 28, 1923 [Private Estate].

481 On the different types of experiments that were conducted by industrial researchers, see STEINLE 2005 and the review of the latter book by G. Berg, which was published in *NTM: International Journal of History and Ethics of Natural Sciences, Technology, and Medicine* 14 (2006), pp. 194–195.

482 A letter to her parents dated August 29, 1924 [Private Estate]. The English phrase *for the asking* appears in the original.

Much to my enjoyment, I have been granted the opportunity to conduct some experiments of my own. Thus I have experienced anew how delightful it is to deal directly with the nature of a problem instead of having to contemplate the findings of others.⁴⁸³

Having transferred to Telefunken's electron tube laboratory, where, under the direction of Erik Scheel, greater emphasis was placed on mathematical methods, Iris Runge found herself among a group of active mathematicians and was able to confine her activity to making calculations. It had been recognized at Telefunken – just as it had at the Bell Laboratories – that such calculations could yield considerable economic benefits.

While there, Iris Runge provided model calculations for electron tubes; she systematized penetration factor formulas for practical use; she developed methods for calculating characteristic curves and for calculating the proportionality factor and control bias voltage of a triode with a non-vanishing space charge; and she developed a general method – based on the geometric properties of a tube, its voltages, and the density of its currents – for determining the potential in and around the plane of a retarding grid.⁴⁸⁴ Her approach of combining numerical and graphical methods can be demonstrated by many examples, among them her 1942 report “Das Potential in der Nähe des Bremsgitters einer Pentode mit ebenen Elektroden” [The Potential Near the Retarding Grid of a Pentode with Planar Electrodes], which she summarized as follows:

The dependence of the effective potential of the retarding grid on the voltages of the anode and the screen grid, on current density, and on the geometric properties of the tube was theoretically investigated in the case of a planar electrode system. A method for calculating the effective potential of the retarding grid was provided, and a graph was designed from which the potential curve can be determined.⁴⁸⁵

Because her assignments were often less than challenging during the early stages of her career, she focused her enthusiasm then on conducting theoretical studies in her spare time and on contributing to Marcello Pirani's publications.⁴⁸⁶ Things were different toward the end of her industrial career, however, when she was working at Telefunken during the war. Here, where Iris Runge would later be

483 This letter, which is dated November 26, 1938, is preserved in the [Churchill Archives] MTNR 5/15. The complete text is reproduced in Appendix 7.

484 For a list of Iris Runge's laboratory reports from 1941 and 1942, see Appendix 5.2.

485 [DTMB] 5157, p. 1. Erik Scheel vouched “for the accuracy” of this report, which was distributed to Dr. Rukop, Dr. Steimel, Dr. Rothe, and other research divisions at Telefunken. On the organizational structure of the corporation's research departments, see Section 3.2.4.

486 In a letter to her parents – dated January 9, 1924 – Iris Runge described her early activity at Osram as follows: “Work is going well. Nothing earth-shattering or even strenuous, only some relaxing and somewhat mechanical tinkering: drawing graphs, making measurements, reading scholarship, and other odds and ends – all of which are going well. If Osram doesn't want to challenge me for my salary, I suppose that's their business.” In another letter, this dated November 7, 1926 [Private Estate], she wrote the following about Pirani's opinion of her: “Pirani, who indeed has high ambitions for me, also hopes that we can continue to collaborate; he says that he appreciates my vim and vigor and that my work is very sound.”

described as having “specialized in treating mathematical valve problems,” her work had evolved into a regular routine of making calculations. Such work, the purpose of which was to predict and minimize experimental problems and therefore save expenses, had become a normal part of the daily operations at the electron tube laboratory. The majority of her findings left a mark on contemporary research and continued to be incorporated into textbooks.

3.5.2 Some Characteristic Features of Industrial Mathematicians

In 1941, Thornton C. Fry described the role, the ideal characteristics, and the necessary qualifications of mathematicians working in the industrial sector.⁴⁸⁷ Even though his examination was restricted to men conducting research in the United States, the general features that he identifies seem to apply no less to German researchers. They also, moreover, shed considerable light on how it was possible for Iris Runge to achieve such a reputable position in her male-dominated field.

“The typical mathematician,” according to Fry, “feels great confidence in a conclusion reached by careful reasoning. He is not convinced to the same degree by experimental evidence. For the typical engineer these statements may be reversed.”⁴⁸⁸ Interested in proving formulas, mathematicians are more disposed than engineers to generalize. Iris Runge’s manner of working was distinguished by just such things. When collaborating with other researchers, she invariably took the responsibility of providing theoretical explanations of technical correlations. Her laboratory reports usually contained such detailed mathematical derivations that they often had to be shortened when published in academic journals.

Fry described the role of the industrial mathematician as that of a consultant – “not a project man,” in his words. One aspect of this was that, unlike engineers, mathematicians were not in a position to develop patentable technologies on their own. As far as it is known, Iris Runge did not patent anything, though certain measuring devices and circuits were of her own design.⁴⁸⁹ Her theoretical knowledge was simply prerequisite to the patentable work of her colleagues. Or as Kurt Fränz expressed it: “The knowledge of theoretical limits enables the engineer, who is seeking a practicable solution, to test whether it would be beneficial or not to come closer the theoretical limit in question.”⁴⁹⁰

487 See FRY 1941, pp. 256–259.

488 Ibid., p. 258 (an original English quotation).

489 This is not to say that women in general did not acquire patents. Several did – Isolde Ganswindt-Hausser, Anne Marie Katsch, Edel-Agathe Neumann, and Marga Faulstisch, for instance – though they were predominantly active on the experimental side of research, see TOBIES 2008a. The British scientist Hertha Ayrton (see Section 2.3) also registered patents: five on mathematical dividers, thirteen on arc lamps and electrodes, and the rest on air propulsion. On such achievements by American Women see ZIERDT-WARSHAW et al. 2000.

490 FRÄNZ 1986, p. 7. In 1933, Kurt Fränz, who had been a student of Erwin Schrödinger, had to abandon his intended dissertation, which was to be supervised by Peter Pringsheim. After

In order to have engineers request mathematical advice and accept the validity of a theoretical solution to their problem, it was crucial for mathematical consultants to possess a high level of expertise and to be as multifaceted as possible: “No one wants the advice of mediocrity,” as Fry wryly observed.⁴⁹¹ Knowledge of a broad spectrum of calculation methods was necessary to cope with the great variety of problems presented by light bulb and electron tube research. On the one hand, probability theory and statistics were used to explain matters of quality control and to come to a theoretical understanding of certain technical problems that were in need of a more constructive solution. On the other hand, there were many numerical problems to be solved. The majority of these required the solution of linear equation systems – the pursuit of numerical solutions to ordinary and partial differential equations, to integral equations, and to approximation problems concerning functions, curves, and surfaces. The solutions, moreover, were expected to be as accurate and efficient as possible. In order to supply engineers with fast and convenient ways to approach their work, graphical methods were also developed. For purposes of harmonic analysis (Fourier analysis), calculating templates and other mechanical instruments were used to simplify the calculation process for engineers and assistants lacking in mathematical expertise.

From the perspective of today, Iris Runge’s work would seem to encompass the entire field of business-related mathematics (probability theory and statistics) and techno-mathematics. Today, of course, there are specialists for each individual subfield, whereas in Iris Runge’s time this could only be said of the Bell Telephone Laboratories. The scope of her competence is reflected in her numerous reports and publications, in her discovery and correction of many errors and inaccuracies in the work of her colleagues and prominent scholars, in the use of her studies by researchers beyond the walls of Osram and Telefunken, in the adoption of her findings into textbooks, and in the invitations she received to give lectures and to contribute survey articles to reference books.

On its own, however, such wide-ranging expertise was not enough to be an effective mathematical consultant in an industrial laboratory. In addition, Fry described some general personal characteristics of mathematicians that could facilitate their collaboration with other researchers (engineers, physicists, and so on), namely a sympathetic and gregarious demeanor, an ability to translate mathematical solutions into the language of those who will apply them, a shrewdness to act as a partner and not as a competitor, and a selfless approach to introducing mathematical knowledge to those who might benefit from it. Each of these features can be attributed to Iris Runge. As early as her first weeks and months at Osram, she was enthusiastic about explaining mathematical methods to her supervisors (Jacoby, Pirani) and about the opportunity to serve as a mathematical consultant to her co-workers (Heinze, Lax). That she was generous in sharing her theoretical

Karl Willy Wagner had been removed from his office in 1936, Fränz lost his position at the Heinrich Hertz Institute for Oscillation Research. He was ultimately hired by Telefunken.

491 FRY 1941, p. 259 (an original English quotation).

and mathematical knowledge is clear not only from her joint publications with her experimental colleagues. In addition to reviewing and summarizing German and international scholarship, she was also willing to evaluate unpublished manuscripts by her fellow researchers at Osram. Her generosity in this regard can be illustrated with a telling example:

Among her laboratory records, a memorandum has survived in which she offered a highly critical evaluation of a study by Siegfried Wagener on calculating the grid temperature of a receiver tube. Here she expressed misgivings about endorsing the work for publication, and these concerned both its general organization and its mathematical execution, which she assessed in detail (see Appendix 5.5). The significance of her critique lies in its context and in its implications for Wagener's later career. Having begun to conduct research on this topic while working in Richard Jacoby's experimental laboratory, Wagener wanted to use this study as a doctoral dissertation at the University of Berlin. Iris Runge's memorandum was issued on February 12, 1935, and Wagener submitted the dissertation to his advisor, the physicist Arthur Wehnelt, on March 31 of the same year. Wagener, therefore, was left with more than a month to make revisions. In the final, published version of his dissertation, he acknowledged the assistance of a number of people, Iris Runge not among them. He expressed his gratitude to Walter Heinze for instigating his research; to the director of Osram, Dr. Karl Mey, for the opportunity to work at the company; and especially to Dr. Jacoby, his immediate director, "for his valuable assistance during the final stages of the project."⁴⁹² The assistance in question owes a great deal to Iris Runge, whose input had obviously remained anonymous to Wagener. Even though, by that point, she was no longer working directly for Jacoby, she nevertheless went out of her way to assist her former supervisor's evaluation of Wagener's work. His dissertation ultimately received the grade *very good* (*valde laudabile*), and his oral examinations received the same grade from the physicists Wehnelt and Erich Schumann, and the grade of *excellent* from the mathematician Erhard Schmidt. Iris Runge's critical analysis helped to point Wagener in the right direction. In 1937 he published an article on his dissertation topic and in 1943, together with his colleague Günther Herrmann, he published a book on oxide cathodes that would see several German editions and an English translation – *The Oxide-Coated Cathode* (1951).⁴⁹³

Iris Runge was happy to provide her "seasoned mathematical advice," as it was called in a letter to her by the electrical engineer Rudolf Sewig, who had briefly collaborated with her at Osram before following Güntherschultze to pursue an academic career at the Technical University in Dresden. In this same letter,

492 Siegfried Wagener, *Die Berechnung der Gittertemperatur von Empfängerröhren* (Berlin, 1935), p. 148. See also the archived documentation concerning Wagener's doctoral degree in [UAB] Phil. Fak. No. 790, pp. 1–13, where there is also a manuscript of the thesis itself.

493 See Siegfried Wagener, "Die Berechnung der Gittertemperatur von Elektronenröhren," *Zeitschrift für technische Physik* 18 (1937), pp. 270–280; and HERRMANN/WAGENER 1943, 1944, 1951. Like Iris Runge, Wagener similarly transferred from Osram to Telefunken.

Sewig remarked that Erich Trefftz, her recently deceased cousin, had been the only person at the university from whom he could seek mathematical assistance without any reservations.⁴⁹⁴

During the 1930s, more and more young and well-trained mathematicians were hired to work in electron tube laboratories; their expertise, however, was typically specialized to address singular problems. They did not, that is, possess the wide-ranging scope of mathematical knowledge that Iris Runge had brought with her to the job and that she had steadily kept up to date. With these skills she advanced, both at Osram and Telefunken, to a unique position of mathematical authority, the memory of which must have survived her retirement from industry in 1945. She numbered among the few industrial mathematicians of her time who possessed each of the essential qualities that, according to George Ashley Campbell, were required of her role: “powers of observation, clear physical concepts, quick resourcefulness, creative imagination and constant persistency.”⁴⁹⁵

3.5.3 A Comparative Look at the Work of Mathematicians in Other Areas of Research

It should be stressed once again that, before 1945, the most common career path in Germany for those educated in mathematics was to work as teachers in secondary schools, and that this was no less the case for women than it was for men. Approximately eighteen percent of those who earned a doctoral degree in mathematics between the years 1907 and 1945 – men and women alike – went on to work in this capacity. During these same years, however, it was nearly impossible for women to work in academia. Although technically permitted to qualify for professorships as of February 21, 1920 – to complete, that is, a post-doctoral thesis or *Habilitationsschrift* – only two women mathematicians in all of Germany were hired as tenured professors: Magarete von Wrangell and Mathilde Vaerting, both in the year 1923. Vaerting is especially noteworthy for having studied mathematics, physics, and philosophy, and for having been actively engaged in promoting the mathematical and scientific education of young women. Her research concerned topics of psychology, the teaching of mathematics, and sociology, and her professorship at the University of Jena, which she was awarded without having earned the *Habilitation* qualification, was in the field of pedagogy.⁴⁹⁶

494 A letter from Rudolf Sewig to Iris Runge dated November 18, 1937 (in [STB] 740). The main topic of this letter was the numerical and graphical determination of current-voltage curves. In 1931 Sewig had gone to Dresden and in 1941 he became a full professor at the University of Hamburg. In 1948 he was hired as an associate professor of applied physics at the Technical University in Braunschweig, where he also worked as a technical director and board member for the Voigtländer Corporation (see [UABs]).

495 CAMPBELL 1926, p. 551 (an original English quotation).

496 See TOBIES 2008a; ABELE/NEUNZERT/TOBIES 2004.

Between 1919 and 1945, six women did complete a post-doctoral thesis in mathematics at a German university: Emmy Noether in 1919 (modern algebra; she was exempted from the regulations of the time by the University of Göttingen), the Austrian Hilda Geiringer in 1927 (applied mathematics; University of Berlin), Ruth Moufang in 1936 (principles of geometry; University of Frankfurt/Main), Helene Braun in 1940 (number theory; University of Göttingen), Maria-Pia Geppert in 1942 (statistics; University of Gießen), and Erna Weber in 1945 (biostatistics; University of Jena).⁴⁹⁷ Although each of these women produced outstanding research, they could not obtain a paid professorship unless they went into exile abroad (Noether and Geiringer), or persevered until after the end of the war.

If women wanted to earn a living by conducting mathematical research, the only options were to work in an industrial laboratory or to secure a position at either a private or public research institute. In addition to the research facilities housed by the large corporations of the electrical, communications, iron, and steel industries, new research opportunities for highly trained mathematicians also arose in the burgeoning aviation industry, which had been growing rapidly throughout the 1930s in anticipation of rearmament and war.

The purpose of the present section is to compare what has been learned about the mathematical research conducted at Osram and Telefunken with that which had taken place in other areas of industry. This can be accomplished despite the fact that the organizational structures of most of the institutions in question remain somewhat opaque (that is, whereas something is known about certain individuals and their work, far less is known about the specific organization of research activity within the aviation industry and others). The goals here will be to identify the dominant mathematical methods in comparable areas of research, to examine the existing evidence concerning the relationship between mathematical and experimental work in various institutions, to see whether specific mathematics departments were ever established, and to note when and where women researchers were able to attain distinguished positions.

As to which areas of applied mathematics became increasingly influential during the years 1939 to 1945, such information can be gathered from the so-called FIAT reviews of German science, which began to be published in 1948. From these reviews it would hardly be possible to consider separately each of the mathematical paradigms that were applied at each of the individual institutions, but that is also not the intention of the present investigation. It is far more typical, in any case, for a single mathematical approach to be used to understand a great variety of processes. Moritz Epple has already examined the construction of similar calculation methods at various institutions of aviation technology; he has described, for instance, the development of a calculation technique, based on numerical and graphical methods, for determining a given boundary layer with defined initial

497 See TOBIES 2008a. Sabine Brühne, a doctoral candidate at the University of Wuppertal, is currently completing a dissertation on the work of Geppert and Weber: *Erna Weber, Maria Pia Geppert und die Entwicklung der Biometrie in Deutschland*.

conditions. His study has also underscored the tendency of industrial mathematicians to formulate their methods in such a way that, with the help of appropriate diagrams, they can be easily applied by engineers and assistants less versed in mathematics.⁴⁹⁸

Among Iris Runge's contemporary industrial mathematicians, Irmgard Lotz (later Flügge-Lotz) can be mentioned first of all. Having devoted her dissertation to heat conduction in circular cylinders of finite length under special boundary conditions, a study that was accepted by the Technical University in Hanover in 1929, Lotz ultimately dedicated herself to solving primarily theoretical problems at the Kaiser Wilhelm Institute for Fluid Dynamics in Göttingen, which was then directed by Ludwig Prandtl. In 1931, on account of her great talent for solving differential equations, she was able to develop a means of solving the important problem of lift distribution on aircraft wings, a method that is still associated with her name.⁴⁹⁹ Another industrial mathematician in Göttingen, namely Helmut Wielandt, published first-rate mathematical studies on spectral and matrix theory and developed a method of iteration that still bears his name. He undertook these studies while working at the Göttingen Institute for Aerodynamic Research (*Aerodynamische Versuchsanstalt*).⁵⁰⁰

Moritz Epple and Volker Remmert have pointed to the theory of conformal (angle-preserving) maps as having been a fundamental mathematical tool in the field of fluid dynamics. This theory – relevant as it was to fluid mechanics, potential theory, and the theory of complex-valued functions – was of considerable value to the military as well.⁵⁰¹ It enters our discussion as the subject of a 1930 dissertation – “Die konforme Abbildung durch die Gammafunktion” [Conformal Mapping by Means of the Gamma Function] – that was submitted to the Technical University in Dresden by Ingeborg Ginzler, who became an expert in wing design at the Göttingen Institute for Aerodynamic Research and later took a position in the American aviation industry.⁵⁰² About conformal maps, Lothar Collatz wrote the following in a FIAT review:

During the war, conformal maps were used in large number in the field of aerodynamics. Their principal application was to the airflow around such profiles as the wings and fuselages of airplanes. [...] From the perspective of practical analysis it is noteworthy that the classical methods of conformal mapping were insufficient with respect to the precision required by aerodynamics, in which special emphasis is placed on mapping the boundaries in order to calculate lift distribution.⁵⁰³

498 EPPLE 2002a, pp. 334–336; see also MEHRTENS 1996.

499 After 1945, Irmgard Flügge-Lotz continued her research in France and the United States, and in 1960 she became a professor at Stanford University. For biographical details about her, see OGILVIE/HARVEY 2000, p. 456–457.

500 See MEHRMANN/SCHNEIDER 2002.

501 EPPLE/REMMERT 2000; see also NAAS/SCHMID, vol. 1, pp. 954–956.

502 See TOBIES 2004.

503 COLLATZ 1948, p. 61.

The mathematician Arnold Fricke, a student of Georg Hamel, earned his doctorate in 1941 with a dissertation on the ballistic theory of lateral gunfire from a moving aircraft. Research for this thesis, which was filed under a disguised title, was conducted in Braunschweig at the Hermann Göring Imperial Institute for Aeronautical Research (*Reichsluftfahrtforschungsanstalt 'Hermann Göring'*). Here, Fricke was engaged in projects to improve the state of German warfare – in developing new theories of gun scope design and deflection (shooting moving targets), and in formulating a more rapid means of calculating the flight path of an airplane, which is essential to the tactics of aerial combat. Another trained mathematician, Marie-Luise Schluckebier, was employed in this same capacity. The military relevance of such work is obvious, and Fricke's results were sent from the Institute for Aeronautical Research to the cast steel factory of the Krupp Corporation. His research entailed the development of numerical and graphical methods as well as the application and refinement of probability theory (a clearer idea of his results, which were kept classified, was made possible by examining the contents of his private estate).⁵⁰⁴ As of 1942, the Austrian mathematician Wolfgang Gröbner conducted similar research at the same aeronautical institute; his chief tasks were to calculate integral tables and to compare the estimated hit probabilities of fully automatic machine guns and fragmentation missiles during aerial combat strikes.⁵⁰⁵

A student of Richard von Mises, Hans-Joachim Luckert completed his doctorate in 1933 with a thesis entitled “Über die Integration der Differentialgleichung einer Gleitschicht in zäher Flüssigkeit” [On Integrating the Differential Equation of a Sliding Layer in Viscous Fluid]. He went on to work at the aircraft factories of Henschel in Berlin and Arado in Rostock-Warnemünde, and he described his research in the aviation industry as follows:

Here we are faced with the most multifarious questions from all areas of mathematics: It is essential to be familiar with function theory, potential theory, integral equations, among other things. As far as I am concerned, such skills are necessary in this environment in order for a mathematician both to earn his keep and be satisfied with his work.⁵⁰⁶

Two studies on the work conducted by the mathematician Ruth Moufang at the research institution of the Krupp Corporation have brought a number of things to light.⁵⁰⁷ Primarily an expert in the principles of geometry (her academic career was hindered by the Nazi administration), she was hired by Krupp in November of 1937 to apply mathematical methods to problems of technical mechanics, materials research, elasticity theory, and to problems of diffusion as well. Like Iris

504 See TOBIES 2005b.

505 Heinrich Reitberger (University of Innsbruck) has commemorated Wolfgang Gröbner in an essay that can be read online at: http://www.oemg.ac.at/DK/Didaktikhefte/2003_Band_36_Bozen/Reitberger2003Bozen.pdf.

506 LUCKERT 1937, p. 244. On Luckert, who worked as an aeronautical researcher in Canada after 1947, see Elizabeth Lumley, ed., *Canadian Who's Who*, vol. 39 (Toronto: University of Toronto Press, 2005), p. 801.

507 See PIEPER-SEIER 2008; RADTKE 2005.

Runge at Osram, Moufang was required to solve differential equations and boundary value problems.

As was typical of the light bulb and electron tube research at Osram, a close relationship similarly existed between the mathematical and experimental work at other research institutions, which likewise assigned projects to multifaceted teams. It is known of Ruth Moufang's work at Krupp, for instance, that she also contributed to experiments on creating larger curving and reversible temperature characteristics in bimetals. In the case of aeronautical research, there are multiple instances of practical experiments and mathematical analysis working hand in hand. To take one example, Melitta Schiller – who had studied mathematics, physics, and flight mechanics before moving to Berlin-Adlershof to join the German Institute for Aeronautical Research – is known to have combined experimental research and test flights with certain mathematical equations for purposes of establishing, among other things, the ideal position of propellers and engines in the Junkers G 31 airliner. Further evidence for the synthesis of mathematical and experimental research is provided by Adolf Fricke, who remarked that he had made certain ballistic calculations “on the basis of film footage taken from the front of airplanes.”

Given that Fricke could rely on data provided by a department of gun camera analysis, however, it is clear that the division of scientific labor was rather advanced. Hans-Joachim Luckert's reports about his activity at the Henschel and Arado aircraft factories similarly indicate that he was able to concentrate predominantly on mathematical work. After passing her teaching examination in 1939, the future professor of mathematics Ruth Proksch worked for some time for the Fieseler aircraft manufacturer in Kassel. Like those of Luckert, her assignments were typically mathematical; her focus was on calculating the lift distributions of wings, horizontal and vertical stabilizers, and ailerons. In his analysis of the Kaiser Wilhelm Institute for Fluid Dynamics, Moritz Epple refers to the division of labor between “talented experimenters and engineers,” on the one hand, and “mathematically talented colleagues” on the other.⁵⁰⁸ Whereas by 1939 there were only eighteen researchers employed at this institute, the mission of which was to address the fundamentally theoretical problems of hydro- and aerodynamics, the German Institute for Aeronautical Research, which had disassociated from the Kaiser Wilhelm Institute in 1937 and begun to conduct research on direct assignment from the military, experienced an inflation of scientific personnel much like what had occurred at Osram, Telefunken, and other industrial firms.

An unanticipated result of my examination of Telefunken's organizational structure was the identification of a mathematics working group among the tube researchers employed there. Its primary task was to engage with theoretical questions and determine mathematically whether and how certain electron tubes ought to be constructed. Because this group was given the title “Pre-Development,” it

508 EPPLE 2002a.

was not until the research activities of each of its individual members were analyzed that it was possible to recognize the predominantly mathematical nature of the group's assignments as a whole. At the Kaiser Wilhelm Institute for Fluid Dynamics directed by Ludwig Prandtl, where the research undertaken was similar to that conducted in industrial laboratories – including matters relevant to the war – mathematicians were typically paired with experimental scientists to work together on single projects; there is no evidence, that is, of there having been specific groups devoted exclusively to mathematics.⁵⁰⁹ Aside from the so-called calculating offices mentioned in Section 3.1 of this chapter, which were largely staffed by electrical engineers to assist with problems of high-voltage and telecommunications engineering, very few departments have been identified that were solely concerned with mathematics. Many references have already been made, of course, to the mathematics division of the Bell Laboratories, which was founded in 1928. Up until now, the only known division of this sort within a German research institution had been the department of “industrial mathematics” at the aforementioned Imperial Institute for Aeronautical Research in Braunschweig, which was formed in 1942 and directed by the Austrian mathematician Wolfgang Gröbner. Mathematicians had been a part of this institute since its inception in 1936, at which point they were assigned to conduct weapons research within a department of theoretical ballistics. Historians are only just beginning to investigate how many additional mathematics divisions might have been established for military research during the Second World War. For now, at least, there are simply too few known sources on the subject. However, a recorded speech by a former researcher at Telefunken, which was held in 2008, confirms that there had been approximately 1,500 academically trained employees at the company and reveals for the first time, moreover, that there had been a special group of mathematicians housed within a subdivision devoted to electron research (see Section 3.2.4).

During the war, the growing need for people to make calculations was met with an increase in staff, and this new workforce consisted mostly of women with secondary school educations. Without any remarkable mathematical qualifications, they were nevertheless capable of using slide rules, mechanical calculators, calculating templates, and graphical or numerical tables. Engaged in making technical calculations, these professional groups of women were even given special departments of their own at various aeronautical research institutions.⁵¹⁰

509 See *ibid.*

510 For more information about these groups of professional calculators, see MEHRTENS 1986, pp. 333–334; OECHTERING 2001, pp. 30–32; EPPLE 2002a, p. 336. Informative too in this regard is the autobiographical novel *Insel ohne Leuchtf Feuer* (1959; the 30th edition appeared in 2004) by the author Ruth Kraft, who, as a young woman during the war, had worked in one of the technical calculating departments staffed by women at the V2 rocket factory in Peenemünde. COLLATZ (1990, p. 286) mentions that, in the year 1940, there were “approximately 110 young women making calculations” under the supervision of Alwin Walther at the Institute for Numerical Mathematics of the Technical University in Darmstadt, where employees were similarly engaged in rocket research.

By investigating the research divisions within the electrical and communications industries, it has been possible to identify women who had held prominent positions. The high level of Iris Runge's own position is evidenced, for instance, by her placement among Telefunken's laboratory directors in a 1947 report issued to the British occupying forces (see Plate 15) and by the fact that, at Osram, she had held the title of senior officer (*Oberbeamtin*) as early as 1929.

Since the 1920s, a number of women with degrees in mathematics, physics, or chemistry enjoyed similarly high positions in these industries. At Osram, for instance, the chemists Magdalene Hüniger and Ilse Müller were likewise working as senior officers as early as 1929, and the physicist Ellen Lax also held a senior position ("*Hauptbeamtin*"). Having published with Marcello Pirani while still a student and having earned a doctorate in 1920 at the University of Berlin, Hildegard Miething had a correspondingly prominent position at Siemens & Halske.⁵¹¹ Whereas it was unlikely for women working in the traditional chemical industry to achieve a status that would allow them to make patentable discoveries – as Jeffrey Johnson has shown⁵¹² – this was not the case in the more recently established communications industry. Here, women found themselves in a position to produce patentable results and they were able to occupy managerial roles. At Telefunken, for instance, Isolde Ganswindt-Hausser attained several patents and directed a research group concerned with amplifier development.⁵¹³ Anne Marie Katsch, in the 1920s, likewise patented her innovations while conducting research on thermionic cathode tubes for the Erich F. Huth Corporation and the Society for Wireless Telegraphy in Berlin.⁵¹⁴

These positions achieved by women in the field of industrial research are generally comparable to the rank of department director at the various institutes of the Kaiser Wilhelm Society (today the Max Planck Society). A number of women worked in this capacity as well. In 1934, for example, the mathematician Irmgard Lotz was entrusted to lead a department of theoretical aerodynamics at the Kaiser Wilhelm Institute for Fluid Dynamics. Beginning in the 1920s, the praiseworthy tendency to fill leadership positions according to professional qualifications, regardless of the race and gender of the candidates, is observable in both the

511 Miething's doctoral dissertation, "Tabellen zur Berechnung des gesamten und freien Wärmehalts fester Körper" [Tables for Calculating the Total and Free Heat Content of Solid Bodies], was supervised by Walther Nernst. From 1918 to 1921 she worked as a researcher in Telefunken's electron tube laboratory, after which she joined the heat laboratory and the laboratory for measuring devices at Siemens & Halske. For biographical data on Miething and other women researchers in the electrical industry, see TOBIES 2008a, pp. 323–330.

512 See JOHNSON 2008.

513 Isolde Ganswindt joined Telefunken's electron tube laboratory on August 1, 1914. In 1929, she and her husband transferred to the Institute of Physics at the Kaiser Wilhelm Institute of Medical Research in Heidelberg. Her electron tube patents were considered so important that, as late as 1937, the patent department at Siemens & Halske continued to pay licensing fees, both to her and to Telefunken, for the rights to use them (see [DTMB] 2926; and FUCHS 1994).

514 See TOBIES 2008a. For information on Katsch's patents, see HERZ/KATSCH 1941/42.

businesses of the communications industry and the relatively independent Kaiser Wilhelm Institutes.⁵¹⁵

While it is true that more and more women, during the Second World War, enjoyed prominent positions in industrial laboratories and research institutions, one of the simple causes of this trend was the shortage of qualified men to fill these roles. Vacancies were left as men were called upon to join the military campaign, and it is for this reason, for instance, that Ilse Müller and Hildegard Warrentrup were promoted to conduct electron tube research at Telefunken. In 1940, similarly, the mathematician Maria-Pia Geppert was put in charge of the statistics department at the William G. Kerckhoff Institute for Researching, Diagnosing, and Healing Heart and Circulatory Diseases, which was based in Bad Nauheim and later became a Max Planck Institute. The mathematician Ruth Moufang was promoted in 1942 to direct a department at the research institution of the Krupp Corporation,⁵¹⁶ and Dora Wehage is reputed to have become the chief mathematician at the Army Research Center in Peenemünde.⁵¹⁷ The need for scientific personnel was so acute that Melitta Schenk Gräfin von Stauffenberg (née Schiller), despite being classified as “half-Jewish,” was treated on equal terms with so-called “Aryans.” As late as May of 1944, she was still contracted by the government to direct the *Versuchsstelle für Flugsondergeräte e.V.*, a center for testing airplane parts.⁵¹⁸

The increasing orientation of mathematics toward solving practical problems of engineering, which was expedited by a rise in state-contracted military research, was part of the general relaxation of the boundaries that once defined the classical scientific disciplines. Paul Forman has discussed how the internal relations of the sciences had begun to shift as pressure was felt to economize scientific processes,⁵¹⁹ and this trend can be traced to the 1920s. It was in this climate that new mathematical fields began to develop – fields that would be referred today as techno-mathematics and business mathematics – and with this development came an array of new professional opportunities for mathematicians. The ambivalence of this early class of industrial mathematicians toward its proximity to military research is a theme to be explored at greater depths in the following chapter, which concerns the multifarious interactions between science, politics, and society.

515 See VOGT 2007 and 2008b.

516 The particular department that she directed remains unknown.

517 Dora Wehage earned a doctoral degree at the Technical University of Berlin. Her dissertation, which concerned the use of the planimeter for determining multiple integrals and for integrating partial differential equations, was published as: *Verwendung des Planimeters zur Bestimmung mehrfacher Integrale und zur Integration partieller Differentialgleichungen* (Berlin: Springer, 1929).

518 For brief biographies of women researchers in the aviation industry, see TOBIES 2008a, pp. 115–118.

519 See FORMAN 1997.

4 INTERACTIONS BETWEEN SCIENCE, POLITICS, AND SOCIETY

The mathematical work conducted in the research laboratories of the Osram and Telefunken Corporations, as analyzed in the previous chapter, persisted nearly unchanged throughout the political turbulence of the Weimar Republic, the Nazi dictatorship, and the Second World War. The development of applied mathematical methods – of business and techno-mathematics – unfolded with striking consistency, and this owes much to the continuity of personnel at these industrial firms. German aerodynamics and aeronautics, as Moritz Eppler has noted, similarly witnessed an “astounding continuity of the scientific workforce” that spanned the period from imperial times to the founding of the federal republic.¹ In general, businesses held fast to their research personnel throughout periods of crisis and left their scientific affairs in the hands of prominent experts. They also, however, buckled under (admittedly massive) political pressure by dismissing the last of their Jewish research directors in 1938.

After 1933, the surge in military contracts necessarily entailed a more pronounced military influence on electron tube research, even if the reports after the war tend to veil this influence.² Of course, the mathematical methods of solving problems in this arena had been developed internationally and existed outside of any political superstructure. They could be used for the sake of designing civilian radio tubes no less than for the construction of military devices, regardless of national borders and political allegiances.

The fundamental interrelations that existed between science, politics, and society during this era have been the subject of numerous studies, including some devoted to the advances of applied mathematics. Here the aim will be to investigate the political positions of the German industrial researchers who have stood at the heart of this book. Among the questions to be addressed are the following: To what extent could industrial businesses seal themselves off from political indoctrination? Did industrial laboratories provide a niche for oppositional political

1 Eppler 2002a, p. 307.

2 Karl Steimel’s official report on the state of German electron tube technology at the end of the war, for instance, does not go into detail about the role of military contracts. This report is archived in [DTMB] 07845 and 04416; see also Berthold Bosch’s contribution in *Funkgeschichte* 89 (1993), p. 93. An internal report on this same subject, written by Günter Herrmann in 1945, discusses the firm’s relationship with the military in clearer terms. Half-way through the war, civilian tubes were put to military use, whereas in the years before the military authorities had required their electron tubes to be designed according to unique specifications (see [DTMB] 7779, pp. 104–106).

thinking? Did Iris Runge, who had been engaged in social activism since her youth and who had achieved an insider position as a mathematical expert at Osram and Telefunken, become a political outsider after the upheaval of 1933? How did she cope with the forced exile of many of her friends and colleagues and with the consequent decay of her social network? What can be gathered about her attitude toward National Socialism and the war?

4.1 SOCIAL AND POLITICAL PROBLEMS – VIEWS AND OPINIONS

Of course I would like very much to be on the management's good side, but *only* on account of my accomplishments and by no means on account of my political sensibilities.³

Having moved to Berlin to begin her new career as an industrial researcher, Iris Runge found herself in the capital of the Weimar Republic, which was then governed by the Social Democratic Party. Here there were not only close relations between politics, business, science, and culture; Berlin was also home to a multifaceted proletarian subculture marked by consumer and residential cooperatives, welfare movements, community theater organizations, socialist youth groups, and workers' athletic associations. The Social Democrats had become the strongest political party as early as the 1890 parliamentary elections; although the emperor still ruled from his palace in Berlin, the majority of the city's residents was already living and thinking according to Social Democratic principles even before the First World War.⁴

Iris Runge, who had campaigned in Göttingen on behalf of the Social Democrats before the 1919 elections (see Section 2.6.7), continued to support this platform after her relocation. However, pleased to have found a position that suited her ambitions and talents, and with the Social Democrats in power, she somewhat relaxed her political activism. That said, she intervened when she could on behalf of the working class and she was not averse to judging her supervisors with a critical eye.⁵ She was also a regular reader of a liberal newspaper. At first she subscribed with her landlady to the *Deutsche Allgemeine Zeitung*, a national paper that had enjoyed the official endorsement of the Imperial government, but she quickly canceled her subscription.⁶ A month later she turned to the *Berliner Tage-*

3 A letter from Iris Runge to her parents dated August 14, 1923 [Private Estate].

4 See BOBERG/FICHTER/GILLEN 1984. On the fundamental social developments of the era, see WEHLER 2003.

5 This much is clear from a letter dated August 14, 1923 [Private Estate].

6 From 1923 to 1929, Iris Runge rented furnished accommodations in the home of a certain Miss Virchow, which was located on Dahlmannstraße 10¹ in Berlin-Charlottenburg. Here she did not have to care for the cleaning or the heating. However, in a letter to her mother – dated December 13, 1925 [Private Estate] – her request for certain Christmas gifts makes it clear that she did her share of the chores: “A hammer, a set of pincers, and some flat tongs. For Miss V is not very handy in this regard, and in our household I am clearly the man who has to take care of such things.”

blatt, which had come to represent the best of German journalism under its progressive editor-in-chief, Theodor Wolff.⁷

The following discussion will address Iris Runge's attitude toward a number of political trends and events, including inflation and strikes, election results, anti-Semitism, fascism, bolshevism, and democracy.

4.1.1 The Inflation and Strikes of 1923

Iris Runge had arrived Berlin just as the period of monetary inflation in Germany – one of the greatest currency devaluations ever known – was at its peak. Caused in part by the desperate financing of the First World War, this economic crisis was marked by drastic pay cuts, mass unemployment, and social unrest. Shortly after joining Osram, she was confronted with the prospect and imminent reality of an industry-wide strike. A letter to her parents from this time provides some indication of the internal conflicts that she faced:

I truly enjoy the morning train ride to the factory. Occasionally it's very full, but it's still nice to be a part of the vibrant crowds and to see everyone pouring through Osram's gates. On a recent commute I had a conversation with a young man who works as a physicist at Siemens. He told me that there would inevitably be a strike throughout the entire metal industry, and that it would be initiated by the white-collar employees, not the workers. For February, company management wanted to increase January's salary by 100%, but the employees are demanding a 150% raise. The strike is supposed to begin on Monday unless an agreement is reached. The man said that he himself is entirely against the strike. I, too, think it would be terrible, but this is because I enjoy my work so much that I would pay to do it (if I had the money). But this is hardly a tenable position.⁸

A strike did indeed take place in July of 1923. Following Richard Jacoby's (unofficial) recommendation, Iris Runge took a few days of vacation during this event. Soon she reached the conclusion, however, that the demands of the employees were justified in light of the rapidly declining purchasing power of the currency. Having established her position on the strike, she was later amazed to discover the opinion of her immediate supervisor:

Jacoby is in total support of the employers. On the one hand it is clear that he regarded the strike as an example of terrible and detestable behavior – not as a just means of expressing opposition – and that he was moved by paternal interests to prevent us from compromising ourselves by participating. On the other hand he refused to admit that the industry has in fact profited from the devaluation at the expense of the employees, even though this is so obviously the case! Of course, I have come to adopt a position that is the direct opposite of

7 See her letters written June 22–26, 1923 [Private Estate]. Under Theodor Wolff, the *Berliner Tageblatt* became one of the capital's leading newspapers, rivaled only by the *Vossische Zeitung*. In 1933, Wolff was fired from his position on account of his Jewish heritage. The paper was forced to align its content with the doctrines of National Socialism, and it ceased publication in 1939.

8 A letter dated March 4, 1923 [Private Estate].

his own. For however much as I love Jacoby, I simply can't support him on these two issues; and the thought of doing so simply to endear myself to the management like an obedient child – *puh*, no way!! Of course I would like very much to be on the management's good side, but *only* on account of my accomplishments and by no means on account of my political sensibilities.⁹

In the end, the employee strike lasted only one day, and the researchers working under Jacoby did not participate (the corporate management had already agreed to meet their demands). However, the workers were once again given insufficient wages – the reparations were incommensurate with the ever-rising inflation – and the level of discontent became so high that, only a week later, nearly all of the factory workers and a good number of white collar employees went on strike again. Siemens and Osram began to pay part of their wages and salaries with margarine instead of money, for the banks had run dry.

Iris Runge's thoughts in her letters to her parents reflect the economic and political developments of the time, which had been condensed into single rally cry: "Cuno's Resignation!" The independent politician Wilhelm Cuno, who had been appointed Chancellor of the Republic in 1922 on account of his expertise in economics, was failing miserably. After the French and Belgian occupation of the Ruhr in January of 1923, he called for a passive resistance that involved the cessation of coal exports to the occupying nations. This policy succeeded only in damaging the German economy and in driving up the already high rate of inflation. Summer strikes left many businesses incapacitated; gas was not being supplied; and the unrest was such that Cuno and his cabinet, which was largely composed of economic experts, stepped down on August 12, 1923 following a vote of no confidence by the Social Democrats. Work resumed at Osram only three days later,¹⁰ but strikes began anew, and by October the company was forced to operate on an abbreviated production schedule. The work in the laboratories carried on, however, and the researchers continued to be paid their unreduced salaries.

As of December 1, 1921, Iris Runge was earning 600 Marks a month as a teacher at the Salem Castle School, an income that she supplemented by working as a private tutor.¹¹ By December of the next year, her salary had increased there to 10,000 Marks a month, in addition to free room and board. She also received the same sum of money (10,000 Marks) to cover her expenses during the school vacations.¹² By January of 1923 her monthly salary had been doubled to 20,000 Marks.¹³ The inflation rate continued to soar during that year, so much so that Osram paid her 400,000 Marks for her first month on the job (March). After the

9 A letter to her parents dated August 14, 1923 [Private Estate].

10 Ibid. On the social development during the period of inflation, see FELDMAN 1997.

11 She mentions her salary in letters to her parents dated February 12, 1922 and May 28, 1922 [Private Estate]. She was paid 25 Marks an hour to tutor Hans Schwerin in mathematics. Schwerin was the nephew of Marianne Landau (née Ehrlich; the wife of the mathematician Edmund Landau) and the grandson of Paul Ehrlich, a Nobel Prize winner.

12 These sums are mentioned in a letter dated December 8, 1922 [Private Estate].

13 This is known from a letter to her parents dated February 11–14, 1923 [Private Estate].

currency reform, she received 239 Marks in pay for December of 1923, and further revaluations were scheduled to be implemented the following month.¹⁴ In comparison to the relatively high salary that she earned as a researcher, the factory workers at Osram were paid an hourly wage of only 22 Pfennigs. This amounted to only 5.30 Marks per week during the shortened work schedule that was initiated in January of 1924. “How they are expected to survive off of that,” she wondered, “remains a mystery to me.”¹⁵

4.1.2 Responses to Election Results

Iris Runge adopted critical positions with respect to matters of party politics, she remained true to her belief in social justice for the working class, and she voted for the Social Democrats. On December 14, 1924, she wrote to her mother:

Regarding the elections, I too am somewhat disappointed that the right-wing parties weren't more demonstrably ousted. That said, the Social Democrats are not really what they used to be; I can hardly call them my own anymore, though I voted for them this time all the same. Four weeks before the elections, I bought a copy of *Vorwärts* to read the profiles of the party leadership, and I have to say that I was deeply disappointed. [...] And yet I could not convince myself to vote for another party. Even though the Liberal Democratic newspapers make for better reading and present educated opinions and showcase liberal ideas, I still believe that all of the “bourgeois” parties excessively promote the interests of business owners. According to my own sense of social justice, the scale has not yet tipped enough in favor of the working class.¹⁶

Four years later, after the parliamentary elections of 1928, she was openly pleased by the success of the Social Democratic Party, which, with twenty-nine percent of the votes, had received more support than any other. At the same time, she expressed her misgivings about the highly fragmented state of national politics:

You're right – I'm highly satisfied with the outcome of the elections, although I don't have great faith in the abilities of the Social Democratic leaders. However, since none of the other parties' leaders is any more capable, I think it will be a good thing for the Social Democrats to learn to bear the responsibility of being the majority party. I was also quite surprised by the losses of the German Democratic Party, and I also find it somewhat embarrassing that thirty-one different parties had registered for the election. [...] Now there are three Social Democratic parties: the Social Democrats, the “Old Social Democrats,” and the Independents. And the case is even worse with the bourgeois parties. How stupid!¹⁷

14 This information is taken from letters dated March 4–5, 1923 and January 9, 1924 [Private Estate]. According to another letter, this dated August 14, 1923 [Private Estate], Iris Runge belonged to the highest tax bracket at the time. In 1933 she earned a gross monthly salary of 544 Reich Marks (see [UAB] R 387, vol. 2, p. 12v).

15 A letter to her parents dated January 9, 1924 [Private Estate].

16 A letter dated December 14, 1924 [Private Estate]. *Vorwärts* [Onwards], a daily newspaper, was founded in 1876 as the central publication venue for Social Democratic platforms.

17 A letter to her mother dated May 29, 1928 [Private Estate]. See also KOLB 2002.

4.1.3 Social Criticism and the Rejection of Anti-Semitism

It is precisely this opinion – that anarchists and socialists are dangerous and that people have to stick together at all costs to safeguard authority and personal property – that is rampant and that the likes of us will never truly understand.¹⁸

Iris Runge made this remark about Upton Sinclair's documentary novel *Boston*, an "attitude-changing" work of social criticism that she passed along for her mother's enjoyment.¹⁹ Her own social-critical views and her position against anti-Semitism, as examined above in Chapter 2, were common themes in her letters to her mother about literature and the theater. Together they discussed, for instance, Martin Andersen Nexø's *Pelle the Conquerer*, a multi-volume novel in which the protagonist rises to the leadership of the Danish Social Democrats.²⁰ She praised John Galsworthy's play *Loyalties*, which offered a severe critique of anti-Semitism and the aristocracy: "He depicts the way all of high society bonds together to cover up a theft committed by one of their own young men, all the while fully neglecting the rights of the victim of the crime, a Jew who has behaved impeccably. The work is very well done, at times shockingly funny and at times superbly touching."²¹ She and her mother were jointly fond of Arnold Zweig's anti-war novel *The Case of Sergeant Grischa* – "especially on account of its acute sense of justice"²² – and Iris Runge ordered a copy of Thomas Mann's speech "An Appeal to Reason," in which she was eager to find "a liberal member of the middle class advocating for Social Democracy."²³ Having read Mann's address, she commented:

In my opinion, Mann's fundamental goal of reconciling the middle class with socialism is absolutely correct. If I disagree with anything, it is his complete dismissal of Marxism. Although I am hardly a fervent Marxist, I agree with Hendrik de Man that Marx's thinking can serve an intermediate political function. I would rather not simply spare people the valid insights of historical materialism, even if I don't consider this philosophy to have all the answers.²⁴

18 A letter to her mother dated September 9, 1930 [Private Estate].

19 A letter to her mother dated September 27, 1930 [Private Estate]. The novel was published in German in 1929.

20 Originally written in Danish (*Pelle Erobreren*), the novel appeared in German as *Pelle der Eroberer: Roman in vier Büchern* (1926).

21 A letter dated January 24, 1926 [Private Estate]. The play was published in German as *Gesellschaft: Schauspiel in drei Akten* (1925). John Galsworthy, who was the first president of the international writers' association PEN, won the Nobel Prize for literature in 1932. Many of his works, which often contain ironic representations of the haute bourgeoisie and the nobility, criticize the social conditions in Great Britain. Another of his recurring motifs is the depiction of unhappily married women.

22 A letter dated December 14, 1930 [Private Estate]. The original German novel, *Der Streit um den Serganten Grischa*, was published in 1928.

23 A letter dated December 14, 1930 [Private Estate]. This speech – "Deutsche Ansprache: Ein Appell an die Vernunft" – was delivered in Berlin on October 17, 1930 and published as a brochure in the same year. An English translation of it will be cited below in Section 4.1.5.

24 A letter dated December 14, 1930 [Private Estate]. On Hendrik de Man, see Section 4.2.2.1.

4.1.4 The Workers, the Intelligentsia, and the Capitalists

How can someone believe that anything good can come of the initiatives of the capitalists, especially if one is aware of what type of people they are? (In this regard I have particular colleagues in mind, with whom I have dealings on a regular basis.)²⁵

Although she hardly turned her back on her middle class background, which was reflected in her professional stature at Osram, Iris Runge nevertheless sympathized with the positions of the working class. Her sympathy for these causes derived from a keen sense of social justice that was fueled by Marxist theory. In reaction to the empty factory on May 1, 1931,²⁶ she discussed the relationship that existed at the company between the white-collar employees – the “brains” of the business – and the upper management, and she contemplated the effects of the Weimar Republic’s social policies on the contentment of the working class:

Later I asked my colleagues at BUTAB about how things were in other businesses,²⁷ and it really seems as though white-collar employees nearly everywhere behaved rather passively and simply stood around the empty factories on the first of May. On another note, I found it quite interesting what my former boss openly explained to me: first, that the sentiment among the white-collar employees was gradually shifting in favor of the corporate position; second, that the director himself was one of such employees; and finally that senior officials (which I have now been for two years) are expected to be in solidarity with the corporate leadership! I was already aware that this was tacitly the case, but not that it was some sort of official company policy. Without a doubt, this will result in greater intimacy between the company “brains” and the capitalist class. For the directors – with their high salaries, profit-sharing bonuses, and other perks – can surely be called capitalists, and this can also be said of the upper management, who can all expect to rise up the ranks. It is hard to tell at which rank, in fact, support begins to sway in favor of the workers, and this seems like an entirely typical “bourgeois” attitude – to be so content with the system as a whole. They are only ever discontent with their individual situation, but deep down they know quite well that the system benefits them in so many respects, and not just materially. Those who feel restrained by capitalism in their work life seem to be more and more rare. Will this trend cause the bourgeois attitude to seep into the working class to such an extent that even they will be

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- 25 A letter from Iris Runge to her mother dated October 23, 1932 [Private Estate]. One of the of Osram’s managers, the physicist Alfred R. Meyer, for instance, was a supporting member of the SS, the Nazi Protection Squadron founded in 1925 (see LUXBACHER 2003, p. 87).
- 26 May Day was not made an official holiday in Germany until 1933, a shrewd political gesture by the Nazis. As early as 1919, this same legislative measure was introduced by the Social Democratic Party but defeated by the right-leaning branches of the bourgeois opposition.
- 27 BUTAB was the acronym of the trade federation *Bund der technischen Angestellten und Beamten* [Union of Technical Employees and Officials]. This organization was formed in 1919 by a merger of the *Deutscher Techniker-Verband* [Association of German Engineers] and the *Bund der technisch-industriellen Beamten* [Union of Technical and Industrial Officials]; the combined union dissolved in 1933. For more on the history of these unions, see the book *25 Jahre Technikergewerkschaft: Festschrift zum 25 jährigen Jubiläum des Bundes der technisch-industriellen Beamten (BUTIB) und zum 10 jährigen Jubiläum des Bundes der technischen Angestellten und Beamten (BUTAB) im Mai 1929*, edited by the Bund der technischen Angestellten und Beamten (Berlin: Industriebeamten-Verlag, 1929). Iris Runge was a member of BUTAB from 1929 to 1933.

content with the current system? I suppose “reformism” can be blamed for this. I find it refreshing that Heimann has shown how the implementation of social policies can change the *essence* of capitalism. Yet, quite the contrary, it is typical of someone like Wunschuh to install social policies for the sole reason of keeping the present system intact.²⁸ The spread of bourgeois values can serve only to put an end to the expansion of social welfare reforms, and this – I regret to believe – is a development that will almost surely come to pass.²⁹

In this case, Iris Runge agreed with the Social Democratic sociologist and economist Eduard Heimann, who had attempted to formulate a general theory of social policy.³⁰ Largely dispensing with Marxist philosophy, Heimann defined the goal of social policy as “the institutional precipitation of social ideals upon capitalism.” For him, effective social policy was necessarily Janus-faced, having both a conservative and a revolutionary component; that is, it had to conform with the capitalist system in order to change it gradually from within. In this way, he imagined, a type of socialism could emerge in which the proletariat would not have “to exchange its historical right for a new world order, forged in the spirit of social freedom, for a cheap socio-political dish of moderate capitalism.”³¹

Although Iris Runge dreamed of this peaceful path to social justice, in a certain sense she was reluctant to express her political hopes:

Sometimes I think as though it's truly my duty to inundate you with my political opinions, and to try to influence Binsi and Ella as well. But it really goes against my nature to proselytize to others in such a way. It's somewhat easier for me to do this to members of the proletariat. With them there is the feeling that, by showing them a means to improve their own situation, it is truly possible to help them achieve what would undoubtedly be just for them. But I find that members of the “bourgeoisie” have to realize on their own that the only upright thing to do is to take the side of the working class – *If feeling fails you, vain will be your course.*³²

28 Dr. Josef Wunschuh, a journalist and publicist with close ties to industry, had worked for some time as a public relations officer for a metal processing company in Düsseldorf and later influenced Nazi social policies; see one of his own books, *Gerüstete Wirtschaft* (Berlin: Frundsberg, 1939), and WEISBROD 1978.

29 A letter written at some point in 1931 to Hendrik de Man [IISH].

30 See Eduard Heimann, *Soziale Theorie des Kapitalismus* (Frankfurt: Suhrkamp, 1929; repr. 1980). Heimann was born into a Jewish merchant family. His father, Hugo Heimann, was a publisher who represented the Social Democratic Party in the Berlin City Council, the Prussian House of Representatives (*Abgeordnetenhaus*), and the National Parliament (*Reichstag*). The family emigrated to the United States in 1933, and Eduard Heimann returned to Hamburg in 1961, where he had formerly held a professorship in theoretical and practical social economics from 1925 to 1933.

31 See PRELLER 1978.

32 A letter to her mother dated November 29, 1931 [Private Estate]. The italicized ending of this quotation is a line from Goethe's *Faust*; the translation is from Johann Wolfgang von Goethe, *Faust: Part One*, trans. Philip Wayne (New York: Penguin, 1949), p. 49. At the time the letter was written, Iris Runge's sisters Ella and Aimée (Binsi) lived in her vicinity in Berlin.

4.1.5 Fascism, Bolshevism, Democracy

However vilified it might be, I have to say that democracy still strikes me as the most promising option.³³

During the global economic depression of 1929, financial hardship and a growing mistrust of the governing parties led to a radicalization of politics.³⁴ After the elections held on September 30, 1930, the Social Democratic Party remained the strongest party in Germany, but the National Socialist German Workers' Party rose to the second position, having earned more than eighteen percent of the vote. In Berlin itself, the German Communist Party and the Social Democratic Party were roughly equal, and the National Socialists were in third place. In the National Parliament, 107 seats were awarded to right-wing politicians, whereas there had been only twelve of such representatives in 1928. In his aforementioned "Appeal to Reason," Thomas Mann, who was married to Katia Pringsheim (daughter of the Jewish mathematician Alfred Pringsheim) and who had won the Nobel Prize in literature in 1928, described National Socialism as "a mighty wave of anomalous barbarism, a primitive popular vulgarity," and as having produced "a political scene in the grotesque style, with Salvation Army methods, hallelujahs and bell-ringing and dervishlike repetition of monotonous catchwords, until everybody foams at the mouth." Is it really possible for the German people to conform, Mann wondered, "to the wish image of a primitive, pure-blooded, blue-eyed simplicity, artless in mind and heart, that smiles and submits and claps its heels together?"³⁵

Paul J. Goebbels, who in April of 1930 was made the Reich Minister of Propaganda for the Nazi Party, had mobilized Nazi supporters not only against Thomas Mann but also, in December of 1930, against the film *All Quiet on the Western Front*, which was based on the novel *Im Westen nichts Neues* by Erich Maria Remarque. About the ban on this Oscar-winning American movie, Iris Runge commented: "It is very clear to see that these people are afraid of any *anti-war* propaganda because they are hard set on waging another war."³⁶ At the time, the militant intentions of the National Socialists could be seen by anyone willing to see them.³⁷

33 A letter from Iris Runge to her mother dated August 23, 1931 [Private Estate].

34 See SWET 2007.

35 Thomas Mann, "An Appeal to Reason," in *Order of the Day: Political Essays and Speeches of Two Decades*, trans. Helen T. Lowe-Porter et al. (New York: Knopf, 1942), pp. 55, 57, 59, respectively.

36 A letter to her mother dated December 14, 1930 [Private Estate]. Erich Maria Remarque touched a nerve with his novel, which was serialized in the *Vossische Zeitung* beginning in 1928, with his representation of the physical and mental suffering experienced by common soldiers in the First World War. When it was published as a book in 1929, *Im Westen nichts Neues* sold a million copies within a year. The work became famous internationally, and Hollywood quickly bought the rights to produce a film adaptation. German conservative and radical-right parties were just as quick to instigate a campaign against Remarque.

37 See, for instance, KEMPNER 1983.

Removed as we are by eighty years from these events, it is easy to recognize the often prophetic nature of Iris Runge's remarks about bolshevism and fascism. Concerning the former, for instance, she wrote:

Ye shall know them by their fruits. So much is said and written about them that their agenda is known to those who don't even care about what they stand for. What the bolsheviks are doing is certainly a colossally interesting experiment, and it is hard not to be somewhat impressed by it. Of course, it is not socialism, and thus it can hardly be regarded as a repudiation of socialism if the experiment should fail. On the contrary, I think it would be a terrible and misguided experience if the Russians really go through with their five-year plan, which has recently been portrayed by the *Berliner Tageblatt*, for instance, as absolutely promising. Far too many have been led to believe that it would be entirely fine to force "happiness" upon the people by means of violence and oppression. I consider this to be an unacceptable manner of proceeding, and if it really is carried out to the end, I am sure that there will be cruel repercussions.³⁸

Fail it did. The phrase "experiment of bolshevism" was popularized among Weimar intellectuals by Arthur Feiler's book of that name (*Experiment des Bolschewismus*). Iris Runge rejected Feiler's position as an individualistic expression of bourgeois ideology and she repeatedly criticized the "experiment" as a minority dictatorship and a violent regime opposed to the ideals of socialism.³⁹ She went on in the same letter to offer a similar critique of the violent methods employed by the National Socialists and the Italian fascists:

And it seems to me that Mussolini's reforms and successes are no worse. Since they could only be imposed by muzzling free speech and by incarcerating the political opposition, they can be of no value whatsoever. Our fascists here in Germany right now are swearing their allegiance to violence and blind submission and to the reversal of democratic principles. [...] For they are essentially opponents of democracy, and as soon as they come into power, they will use their authority to eliminate all democratic institutions one by one, and they will set themselves up as permanent rulers.⁴⁰

Iris Runge sent an English copy of H. G. Wells's *The Autocracy of Mr. Parham* (1929) to her mother, to which she attached the following note:

It's not quite as good as some of Wells's other great works, but it's not too far off. In any case, it's quite entertaining, and from it you'll be able to experience something of the essence of fascism. I found it especially interesting, at least, that even in cool and damp England there seems to be certain political inclinations that resemble the fascism here and

38 A letter to her mother dated June 9, 1931 [Private Estate]. This comment begins with a quotation of Matthew 7:16. The term bolshevism stems from the Russian word for 'majority' (*bol'shinstvo*). It was the name of the faction of the Social Democratic Workers' Party of Russia that became the Communist Party of the Soviet Union in 1918.

39 She expressed these opinions in a letter dated October 25, 1931 [Private Estate]. Feiler's book, the first edition of which was published in 1929, soon appeared in English as *The Experiment of Bolshevism*, trans. H. J. Stenning (London: G. Allen & Unwin, 1930). On the experience of foreigners in Russia between 1921 and 1941, see HEEKE 2003.

40 A letter to her mother dated June 9, 1931 [Private Estate]. It should be noted that Iris Runge's spelling of the word *Fascismus* is truer its Italian root (*fascismo*) than is the typical German spelling (*Faschismus*).

elsewhere. But don't think for a minute that our fascism here could be anywhere near as educated and humane.⁴¹

To this she added that she could not agree with the philosophy presented in Wells's *The World of William Clissold* (1926), namely that "one can hope to expect the world's salvation from the efforts of the great industrialists. Indeed, the latter could perhaps bring such a thing about, but can you imagine them doing anything that doesn't serve to enhance and secure their positions of power?"⁴²

Written as they were by a politically engaged woman researcher – one who maintained, moreover, "that I differ from the majority of the middle class, despite my bourgeois intellectual roots, by firmly embracing a revolutionary attitude"⁴³ – these letters on current events enable us to see the historical manifestations of bolshevism and fascism within a concrete social context. Historians today clearly fall short whose hypotheses reduce the causes of these highly contextualized forms of government to some abstract need for a substitute religion or to a mythically inspired popular movement.⁴⁴

In the fall of 1931, the National Socialists, the German National People's Party, the SA (*Sturmabteilung*, a Nazi paramilitary organization), and the *Wehrverband* (another right-wing paramilitary group) united to form the so-called Harzburg Front in opposition to the centrist government of Chancellor Heinrich Brüning. This event led to a renewed schism among the Social Democrats, in response to which Iris Runge pessimistically remarked:

Indeed, the future does not look very bright, especially here in Germany. It is uncanny to realize that such a colossal number of people here share such irrational and barbaric opinions. Today they beat up harmless people on the street who happen to look Jewish to them. *What next?* If they really do rise to power, we will certainly have to prepare ourselves for a few things.⁴⁵

Iris Runge recognized quite clearly that the National Socialists were waging a demagogic publicity campaign, and she also understood the underlying causes of its success:

Your question – about how it is that Hitler's supporters can call themselves "socialists" – is entirely justified. The matter has to be approached in the following way: By "socialism" is meant not the form of a given state (e.g. democracy or dictatorship) but rather the form of its society, i.e., it is a matter of the legal, economic, and cultural status of the entire spectrum of its people. Because National Socialism arose out of the discontent of the broader masses (essentially the proletariat and low-level employees and civil servants), its agenda naturally includes the promise of providing these people with a better standard of living and of generally creating more just, humane, and healthy conditions. That they use the word

41 Ibid. Wells's novel appeared in German as *Der Diktator oder Mr. Parham wird allmächtig* (1931), but both Iris Runge and her mother read the English original.

42 Ibid.

43 A letter to her mother dated December 14, 1930 [Private Estate].

44 See, for instance, BIZEUL 2009, p. 10.

45 A letter dated October 25, 1931 [Private Estate]. The question *What next?* appears in English in the original.

“socialism” for this is just a testament to how deeply the demands of the true socialists, which include such just and desirable goals, have been ingrained into the national consciousness. The perversity and mendacity of the National Socialists lie in the fact that they neither seriously recognize nor offer serious alternatives to the scientifically grounded proposals of the true socialists for bringing about a more just social order, but rather they restrict themselves to fomenting the discontented masses to reject the “prevailing system.” This is closely connected to their preference for dictatorship over democracy. [...] Moreover, the theory of an all-powerful *Führer* fits very nicely with the old principle of the capitalist, who is the “king of his own castle.” It is for this reason that the major industries support the National Socialists, while the latter call themselves a workers’ party and seek to entice the support of unemployed and demoralized members of the middle class (and also workers, with whom they can wage war) by promising everyone a glorious future. At the same time they are banking on the growing mood of nationalism, on the allure of military propaganda, and on the German addiction to being subjects under an authoritarian regime.⁴⁶

The opinions expressed here reflect Iris Runge’s close relationship with Hendrik de Man, the Belgian Social Democrat and activist.⁴⁷ At first she believed that these political developments would lead to a civil war or a revolution. As the Nazis rose to power, she bemoaned the further splintering of the Social Democrats but nevertheless expressed her ardent hope that the forces of democracy would “lure the youth and the intellectuals away from National Socialism toward a socialism worthy of the name.”⁴⁸ Unfortunately, things turned out otherwise.

4.2 SOCIAL AND POLITICAL ACTIVISM

More and more, my love of Germany has come to be like Heinrich Heine’s: *When I think of Germany at night, My sleep is gone and killed outright.*⁴⁹

Wilhelm Deimler expressed to Iris Runge, in a letter written in 1912, “that we share nearly the same views about all of these social issues. It is only about the actualization of these views that we have really butted heads.”⁵⁰ To express one’s opinions is one thing; to act upon them is another matter altogether. Considering Iris Runge’s full schedule at the industrial laboratory and the research projects that occupied so much of her spare time, it can be imagined that little time was left for her to engage in the political activity that she had once been attracted to by Leonard Nelson.⁵¹ Despite these restrictions, she was nevertheless motivated by political and social realities to make such activism a priority in her life.

46 A letter to her mother dated October 25, 1931 [Private Estate].

47 See Section 4.2.2.1 below.

48 A letter dated August 23, 1931 [Private Estate].

49 A letter from Iris Runge to her mother dated December 4, 1932 [Private Estate]. Here she is quoting the first two lines of Heine’s poem “Night Thoughts” (1844).

50 See Section 2.5.4.

51 For a period of time in 1932, as is known from her letters, there was no work on Saturdays, so that she was briefly able to enjoy a full weekend. The work week typically ended on Saturday at one o’clock in the afternoon.

This section will focus on Iris Runge's participation in groups that allowed her to give concrete expression to her convictions, namely the Social Working Group in Eastern Berlin (*Soziale Arbeitsgemeinschaft Berlin-Ost*), and the Social Democratic Party of Germany. As a member of the latter, she fostered a relationship with the Belgian reformer Hendrik de Man, and she volunteered for the Workers' Samaritan Federation (*Arbeitersamariterbund*) and for the child welfare organization known as the Children's Friends (*Kinderfreunde*).

4.2.1 The Social Working Group in Eastern Berlin

In the summer of 1922, Iris Runge had come to Berlin to volunteer for the *Soziale Arbeitsgemeinschaft Berlin-Ost* – or SAG, as it is abbreviated – in order to be reminded, as she put it, of what a member of the working class even looked like. In fact, when she joined Osrarn in March of 1923, she initially rented an apartment that was made available to her by this organization.⁵² Even though she would soon move to Charlottenburg (and ultimately to Wilmersdorf and Spandau) in order to be closer to her workplace on Sickingenstraße,⁵³ she maintained close ties to the SAG until its founder, Friedrich Siegmund-Schultze, was driven into exile by the Nazis in 1933.

In September of 1911, Siegmund-Schultze left his parsonage at the Court Church in Potsdam and moved with his wife, sister, and several student collaborators to Berlin-Friedrichshain in order to perform charitable and class-conciliatory deeds in this predominantly working-class area of the city. Here he founded the SAG, an organization for social reform that aimed to bring together impoverished workers with educated members of the middle class. This community service and housing project, which was based near the Silesian Train Station (today the Ostbahnhof), had been modeled after similar programs abroad and was soon able to exert a positive influence beyond the confines of eastern Berlin. Among other things, the project involved instructional courses for workers that were taught by university students, a program with successful precedents in other cities (as noted in Chapter 2, Iris Runge had taught such courses as a student in Göttingen). With

52 The apartment was located in Berlin-Friedrichshain on Friedrichstraße 63 (the name of the street was changed in 1971 to the Straße der Pariser Kommune). On the international activity of the SAG and its role in the popular education movement (*Volksbildungsbewegung*), see SACHBE 2007; TENROTH et al. 2007.

53 After four weeks in Friedrichshain, she moved to an apartment on Dahlmannstraße 10¹ in Charlottenburg. In July of 1929 she moved into an apartment within a single-family house near Heidelberger Platz in Wilmersdorf (Rudolstädter Straße 66); in October of the same year she moved down the street to Rudolstädter Straße 7; and in April of 1935 she moved into an apartment on Teltower Straße 12 in Berlin-Spandau Ruhleben. These moves are documented in her letters dated April 10, 1929; June 19, 1929; October 1929; and January 21, 1935 [Private Estate]. The buildings on Rudolstädter Straße were destroyed in the war; for photographs of the apartment building on Teltower Straße, see Plate 16.

this educational program at its core, the SAG expanded the reach of its social activity to members of the working class throughout the capital, and it did so without a religious agenda.⁵⁴ Siegmund-Schultze, who had established Germany's first Youth Welfare Office (*Jugendamt*) in 1919 and who had been a supporter of Leonard Nelson and Minna Specht's "International Youth Federation" (*Internationaler Jugendbund*), received in 1925 a professorship in youth research and juvenile welfare at the University of Berlin.

Iris Runge's association with the SAG can be interpreted both as an expression of her social sympathies for those in need and also as a pursuit for like-minded members of the middle class. In October of 1923, just after the currency reform had incited looting and unrest on the streets of Berlin, she wrote the following about one of her visits to the organization: "The things said there about hardship truly weigh heavily on the heart. It is enough to make one donate money immediately and feel ashamed to be thanked for such a paltry sum."⁵⁵ With her mother she discussed the establishment of so-called public houses (*Volkshäuser*), which had been conceived of in Germany and elsewhere to serve as educational facilities for the members of workers' organizations. In industrial cities, the public houses also functioned as administrative office spaces, local gathering places, and venues for national and international conferences. They further alleviated the needs of workers by providing libraries, reading rooms, affordable restaurants, and bath houses.

Siegmund-Schultze's SAG not only tended to the practical issues of social welfare, but it also promoted theoretical discussions by sponsoring academic forums. Well-connected internationally, Siegmund-Schultze participated, for instance, as one of the German delegates at the meetings of the League of Nations in Geneva. When Aimée Runge sent her daughter a newspaper clipping from the *Manchester Guardian* that concerned Siegmund-Schultze's activities, Iris Runge responded:

Many thanks for the excerpt from the *Manchester Guardian* on Siegmund-Schultze; he does indeed receive much recognition wherever he ventures in the world. He recently told us, moreover, that he is on close terms with Dr. Sahm, who is now the mayor of Berlin. The two of them stayed in the same hotel in Geneva during the latest meeting of the League of Nations. Hopefully this connection will be of some help in securing formal municipal support for SAG's public houses.⁵⁶

54 See SIEGMUND-SCHULTZE 1930, p. 425. Friedrich Siegmund-Schultze, incidentally, belonged to the same family as that of the mathematician and historian Reinhard Siegmund-Schultze, who is currently a professor at the University of Agder in Norway.

55 An undated letter written in September or October of 1923 [Private Estate].

56 A letter to her mother dated April 25, 1930 [Private Estate]. The independent politician Heinrich Sahm, who remained the mayor of Berlin until 1935, is known to have dismissed the employees of the local government who did not support the Nazi regime. The League of Nations was founded in Geneva on January 10, 1920 with the goal of securing a lasting peace. Germany, which had been a member since 1926, renounced its membership when the National Socialists came to power in 1933.

Siegmund-Schultze was arrested by the Nazis in 1933 and deported to Switzerland. The SAG continued to exist until 1940, but during the period of National Socialism it became obvious, in Iris Runge's estimation, "that it is no longer possible to conduct any social work without first obtaining a Nazi stamp of approval."⁵⁷

4.2.2 Social Democracy

In a curriculum vitae from 1947, Iris Runge noted that she had become a member of the Social Democratic Party in 1929.⁵⁸ From the sources, however, it is clear that she in fact *rejoined* the party in that year (see Section 2.6.7). This year was also marked by her new position at Osram, a job that she began after Pentecost (May 21–23). It was at this time, which coincided with the onset of the global economic depression, that she came to know Hendrik de Man, the Belgian Social Democrat.⁵⁹ Her renewed membership with the Social Democratic Party also went hand in hand with her volunteer work for the Workers' Samaritan Federation and the Children's Friends, two organizations that enjoyed the party's endorsement.

4.2.2.1 Hendrik de Man

[...] this matter is more important to me right now than any other, and Osram will certainly be able to manage without me for a few days.⁶⁰

In August of 1929, Iris Runge's acquaintance with the Flemish Hendrik (Henri) de Man was more important to her than anything else. In his books, which appeared in German in 1926 and 1927, De Man was especially concerned with the cultivation of a socialist citizenry, with psychology, with culture, and with showcasing the virtues of socialism to intellectuals. In fact, many German intellectuals, including Iris Runge and her mother, did indeed read his work with approval and enthusiasm.

Having attended one of De Man's lectures toward the end of June in 1929, Iris Runge wrote him a letter that resulted, as she later wrote, "in the remarkably swift development of a friendship." It also resulted, as early as August of the same year, in a rendezvous between the two in Amsterdam. Despite the fact that De Man had already been married twice by this point and that he had two children, one twelve and the other sixteen years old, she nevertheless felt a personal attraction to him; after all, he was gentlemanly, urbane, versed in art and history, and he shared her

57 A letter to her sister Ella dated September 10, 1938 and archived in [STB] 663, p. 29.

58 [UAB] R 387, vol. 2, p. 14.

59 On Hendrik de Man, see in addition to his private estate [IISH], DODGE 1979; BRÉLAZ 1985, 2000; STEUKERS 1986; OSCHMANN 1987; and LEUSCHER 1990.

60 A letter from Iris Runge to her mother dated August 5, 1929 [Private Estate]. The important matter in question was a meeting with Hendrik de Man.

political convictions. In the end, however, she set aside her initial idea of becoming his third wife and restricted herself to supporting his work.⁶¹ With that in mind, she went on to meet him in Berlin, Frankfurt, and Switzerland; and she read through the manuscript of his book *Die sozialistische Idee* (1933), offering critical feedback concerning its content, organization, and style that would be incorporated into the finalized text.⁶² Their discussions concentrated on such things as comfort and luxury being “indicators of social rank” and on De Man’s “thesis about the cultural unity that prevails at certain historical moments,” which she illustrated with supporting examples from the youth movement and from her own personal experiences:

At one of the party assemblies, the chairman – a conventional city council member – seriously wanted to prevent a young party member from contributing to the discussion on the grounds that the young man should simply listen while the adults are talking and not say a word until he has grown up and learned a thing or two! Can you think of a more bourgeois thing to say? In 1929! Luckily the matter had to be put to a vote, and the majority of the party members had a somewhat more modern attitude. The young man, it should be said, went on to speak in an intelligent and orderly manner. In any case it is clear that the boundary between the new and the old does not necessarily correspond with the boundary between the proletariat and the bourgeoisie. All in all, however, I enjoyed this gathering and felt content to have rejoined the party.⁶³

Just three years older than Iris Runge, Hendrik de Man had joined a socialist youth organization in Antwerp – the so-called *Jonge Wacht* – as early as 1902. While studying in Brussels and Ghent, he was expelled from the university in 1905 for having participating in demonstrations in support of the workers’ rebellion in Russia. He then transferred to the University of Leipzig, where he was influenced by Karl Lamprecht’s psychological theories of history and the experimental psychology of Wilhelm Wundt. While working as a freelance journalist for the *Leipziger Volkszeitung*, he also served as the co-director, with Karl Liebknecht, of the international administration of socialist youth organizations, which had been founded in 1906.⁶⁴ He returned to Belgium in 1911 at the instigation of Emile

61 In a letter to her mother dated June 2, 1930 [Private Estate], she explained: “In general I regret it very much that we even discussed the possibility of marriage during the first six to eight weeks of our relationship, but at the time I genuinely believed that it might come to that. Then again, I did have my doubts about whether it would be the best thing to do, for it would have been very difficult to care for his children, and I’m still not convinced that I ever want to become a housewife. [...] For now we enjoy a budding camaraderie that will have to develop under rather complicated and burdensome circumstances [...]. For, as you know, Hendrik de Man is an important figure throughout Europe and not simply in an academic sense (so much could be said of Max von Laue) but rather as a political personality and as a leader of the people.”

62 See letters from Iris Runge to Hendrik de Man [IISH].

63 A letter from Iris Runge to Hendrik de Man dated December 12, 1929 [IISH].

64 See LEUSCHER 1990, pp. 126–134.

Vandervelde, a Belgian politician and fellow Social Democrat.⁶⁵ While serving as an officer during the First World War, De Man traveled to Russia in 1917 in order to report about the ongoing revolution. His radical views repeatedly led to conflicts within his own party and later caused him to lose an American professorship in social psychology at the University of Washington in Seattle, where he had been vocal in his support of exploited farm workers. He ultimately went on to teach from 1922 to 1926 at the Academy of Labor in Frankfurt (*Akademie der Arbeit*), and in 1929 he was made the first professor of social psychology at the University of Frankfurt.⁶⁶

De Man's unique ideas regarding the actualization of socialism have been discussed by many scholars. On account of his psychologically oriented approach to the matter, he was especially interested in an earlier work by Marx that concentrated on personal characteristics to a greater extent than did the later writings.⁶⁷ In a 1913 essay entitled "Der neu entdeckte Marx" [The Newly Discovered Marx], De Man spoke of the *humanist* thread of Marxism that he detected in this work, which he contrasted with the *materialist* Marxism that had attracted so much attention. He explained the three components of the text as follows:

The economic component contains disquisitions on capital, labor, private property, profit, basic pensions, and so on, that can be regarded as his earliest groundwork for *Das Kapital*. The critical-philosophical section culminates in a critique of Hegelianism and Young Hegelianism and represents a preliminary stage of his 1845 book *The Holy Family*. In the final, positive-philosophical section of the work, he concentrates on the connections that exist between man and nature, the division of labor and social alienation, labor and culture, physical need and industry, private property and communism, etc. This last section strikes me as offering the most insight. Unlike both of the other sections, in which he discusses ideas that he would treat in his later works more comprehensively, maturely, and precisely, here he presents ideas that recur only in an embryonic form in some of his earlier works and are never addressed at such length in his later writings. Though never rehearsed, however, these ideas are silently of prerequisite and essential importance to a proper understanding of Marx's later thinking.⁶⁸

Having underscored the relationship between philosophical presuppositions, economic conditions, and sociological realities, De Man appealed for the "recognition

65 At this time, Emile Vandervelde was the president of the Second Socialist International (a coalition of socialist parties founded in 1889). After the First World War he served as a minister of various departments of the Belgian parliament, and he was the leader of Belgian Labor Party (*Parti Ouvrier Belge*) from 1928 until his death in 1938. Hendrik de Man succeeded him in this office.

66 The Academy of Labor was founded on March 3, 1921 at the University of Frankfurt as "the first German university for the working people." It was closed in 1933 but reconstituted as a foundation after the Second World War (1951) by the State of Hesse and the Confederation of German Trade Unions (*Deutscher Gewerkschaftsbund*).

67 See Karl Marx, *Ökonomisch-philosophische Manuskripte*, ed. Barbara Zahnpfennig (Hamburg: Meiner, 2005). For an English translation of this work, see Karl Marx and Friedrich Engels, *Economic and Philosophic Manuscripts of 1844*, trans. Martin Milligan (New York: International Publishers, 1964).

68 DE MAN 1932, p. 225.

of a Marxist humanism that has been overlooked by contemporary Marxist theorists.”⁶⁹ His ideas on the existence of this humanism, which are further developed in his book *Die sozialistische Idee*,⁷⁰ are reflected in many of Iris Runge’s political opinions.

From her discussions with De Man, she was able to establish a firm position regarding the emergence of National Socialism, even if De Man would later be accused of being a Nazi collaborator.⁷¹ To her mother she wrote: “Soon I’ll send you an excellent article by De Man on ‘the *Führer* and the masses’.”⁷² In February or March of 1932, she took the initiative to translate and edit one of his brochures on the topic of nationalism and socialism. This material was meant to be published in the Social Democratic monthly *Der Kampf* [The Struggle], but the journal closed its operations before her contribution could appear in print.⁷³

With the exception of his 1927 sociological study *Der Kampf um die Arbeitsfreude*, which was translated into English as *Joy in Work* (1929), all of De Man’s books were blacklisted by the Nazis as deserving of incineration.

4.2.2.2 The Workers’ Samaritan Federation and the Children’s Friends

Iris Runge’s participation in the causes of the Social Democratic Party was not limited to attending meetings and supporting the academic work of Hendrik de Man. In a letter written on the occasion of her mother’s birthday on May 29, 1931, she referred to her to experience as a volunteer for the Workers’ Samaritan Federation at a first-aid center in Berlin and to a Baltic-Jewish woman with whom she had tended to the needs of a group of children.

Today the Workers’ Samaritan Federation is a politically independent and non-religious welfare and relief organization. A consolidation of regional Workers’ Samaritan “colonies,” it was formed in 1909 as a response to the expulsion

69 Ibid., p. 276. For an analysis of the early writings of Marx, see SCHAFF 1970; SÈVE 1972. On De Man’s interpretation of them, see LEUSCHER 1990.

70 See especially the eighth chapter of DE MAN 1933, “Die Intellektuellen und die Kulturspaltung” [Intellectuals and the Cultural Divide].

71 Having returned to Belgium in 1933, De Man was named the director of the office of social research by the Belgian Labor Party. In this capacity he developed the so-called “Plan de Man” in order to alleviate the consequences of the foregoing economic crisis. In a manifesto published on June 28, 1940, while he was serving as the finance minister and chairman of the party, he greeted the German occupying forces as liberators of the working class, and he assisted in the formation of a consolidated labor union that was loyal to the Nazi regime. In 1946, even though he had since acted in accord with Belgian interests and had been banned from publishing and from making public appearances by the Nazi authorities, he was nevertheless convicted *in absentia* of treason for having been a Nazi collaborator.

72 A letter dated November 29, 1931 [Private Estate]

73 See a letter from Iris Runge to Hendrik de Man dated April 3, 1932 [IISH]. The last issue of *Der Kampf*, which had been edited by the Austrian Social Democrats Friedrich Adler and Julius Braunthal, was published early in 1934 (vol. 27, issue 2).

of all Social Democrats and union members from the German Red Cross,⁷⁴ and thus the Federation was especially supported by the Social Democratic Party.

In 1929, the Berlin branch of the Workers' Samaritan Federation opened a first-aid station on Lake Tegelse, where a lifeboat had been in use since May of 1927. The new facility consisted of a boathouse, three lifeboats, and a first-aid station with an infirmary, a doctor's office, a kitchen, and overnight accommodations for the nursing staff and the boat crew. Near the boathouse stood a tower from which the activity on lake could be overseen. Iris Runge's decision to volunteer at this waterside first-aid station probably owed something to the facts that she was a strong swimmer and that she owned her own canoe. After moving to Berlin she spent many Sundays rowing along the waterways of the city,⁷⁵ often accompanied by one of the Bergs, her brother Wilhelm, Magdalene Hüniger, Cora Berliner⁷⁶ – with whom she discussed economic issues – or by her aforementioned Baltic acquaintance, whom she had come to know through the Social Democratic Party:

I should add that on Monday I had a guest to bring along, namely Sascha Rosenthal, a bright and well-educated Baltic woman of Jewish heritage whom I know from the Party and with whom I am caring for a group of children between the ages of six and nine. She was absolutely delighted to take a ride in the boat.⁷⁷

It is worth mentioning that she christened her boat with the name of the Chinese goddess "Kuan Yin" (Guanyin), a deity venerated for her mercy and sympathy for the poor and often depicted in conjunction with a dragon, a symbol of intelligence and strength.

Iris Runge also volunteered as a teacher for the Reich Task Force of Children's Friends (*Reichsarbeitsgemeinschaft der Kinderfreunde*), which was made a prominent organization in 1924 under the leadership of Kurt Löwenstein, a Social Democratic member of parliament. In addition to members of the Social Demo-

74 See BOBERG et al. 1984, p. 292. In 1902, a law was passed that protected the Geneva Cross as a sign of a neutrality and assigned to the Red Cross the duty of making medical attention available to the military in the event of war. On the history of the Red Cross, see Ralf Bernd Herden, *Roter Hahn und Rotes Kreuz: Chronik der Geschichte des Feuerlösch- und Rettungswesens, von den Syphonari der römischen Kaiser über die dienenden Brüder der Hospitaliter-Ritterorden bis zu Feuerwehren und Katastrophenschutz, Sanitäts- und Samariterdiensten in der ersten Hälfte des 20. Jahrhunderts* (Norderstedt: Books on Demand GmbH, 2005).

75 In a letter to his brother Richard dated July 8, 1925, Carl Runge wrote: "Iris has a two-seat canoe that she keeps near the Wannsee train station, and Wilhelm recently bought a Canadian canoe that is remarkably stable and spacious" (archived in [STB] 526). As is known from a letter dated April 8, 1928 [Private Estate], Iris Runge maintained the canoe herself by calking, painting, and lacquering it.

76 The content of their conversations is mentioned in a letter to her mother dated June 2, 1930 [Private Estate].

77 A letter dated May 29, 1929 [Private Estate]. On the illegal activity that took place on the Berlin waterways after 1933, see Elfriede Brüning's autobiography: *Und außerdem war es mein Leben* (Munich: DTV, 2004).

cratic Party, its executive board also consisted of representatives from the Confederation of German Trade Unions (*Allgemeiner Deutscher Gewerkschaftsbund*), the Workers' Welfare Association (*Arbeiterwohlfahrt*), and the Socialist Workers' Youth Organization (*Sozialistische Arbeiterjugend*). Löwenstein had studied theology and philosophy, attended rabbinical school, and earned a doctorate in pedagogy at the University of Berlin (1910). A pacifist, he volunteered for the Red Cross during the First World War. Between the wars he was active in the area of educational policy, first for the Independent Social Democratic Party and later for the Social Democratic Party; as both the head of the public school system in Berlin and the city councilman for adult education in Berlin-Neuköln, he was able to implement a number of social initiatives: income-based tuition, free school meals, and university preparatory courses for adult learners and members of the working class.⁷⁸

The goal of the Children's Friends was to harness the educational potential of groups in order to provide individual children with beneficial learning conditions and a sense of solidarity. The leaders of the groups, known as "helpers" (*Helfer*), were either members of the Socialist Workers' Youth Organization or the Social Democratic Party. The non-authoritarian and gentle pedagogical approach of the helpers was meant to serve the children as a counterweight against the ideological pressures felt in the schools and on the streets. In general, the intention was to nurture children in the spirit of the labor movement, enlightenment, and humanitarianism, and to do so without subjecting them to authoritarian drills, without deluding them with religious myths, and without keeping them in the dark regarding taboo issues of sexuality. The hope was to make them opponents of war and immune to militarism and nationalism.⁷⁹ Without a doubt, this was an environment in which Iris Runge could feel at home:

I still have to tell you that I've abandoned my plans to go to England. Instead, I intend to go with the Children's Friends to a summer camp in July. This year it will take place in Lübeck – not on the sea, but on a lake that is said to be very beautiful. I'm now a "helper" within this organization, and I'm interested in getting to know how they run their summer camps, which are planned every year. [...] By now there are thousands of helpers in Germany who participate in the program by taking the children on hikes and, as I mentioned, accompanying them to camps in the summer. The oldest, who are between ten and fourteen, sleep in tents, but my group of younger children (six to nine years old) gets to stay in cabins with beds. There will be 800 children in all!⁸⁰

In 1931, as she notes, she canceled her plan of vacationing in England to spend her summer holiday as a volunteer for the Children's Friends, and in 1932 she

⁷⁸ See RADDE et al. 1993.

⁷⁹ See EPPE 2000, 2006; KINDERFREUNDE 2006; GRÖSCHEL 2006.

⁸⁰ A letter to her mother dated June 9, 1931 [Private Estate]. In a later curriculum vitae, moreover, Iris Runge mentioned that she had also served as a district treasurer for the Children's Friends (see [UAB] R 387, vol. 2, p. 11v).

would do the same.⁸¹ By the end of the Weimar Republic, approximately 200,000 children, “helpers,” and parents belonged to this organization. In 1930, however, the Bavarian government reduced the program to such an extent that it was effectively banned; it was accused of politicizing the youth, breeding socialism, encouraging coeducation, and criticizing the schools, the Church, and the traditional home. Elsewhere the camps belonging to the Children’s Friends were violently attacked, as in Stuttgart and near Greifswald, where a young camp leader was shot by “police officers with Nazi sympathies.”⁸² In 1933, both the Children’s Friends and the Workers’ Samaritan Federation were outlawed by the National Socialist government.

4.3 TO EMIGRATE OR REMAIN IN GERMANY?

On March 21, 1933, the National Socialist newspaper known as the *Völkischer Beobachter* [National Observer] printed the following report:

Wednesday will mark the opening of the first concentration camp, which is located near Dachau and has the capacity to detain 5,000 people. To be collected here are all of the communist functionaries and, to the extent that it is necessary, those functionaries of the *Reichsbanner* and the Social Democratic Party who pose a threat to the stability of the state. This is to be done because it will be impossible in the long run, given the overburdened condition of the state apparatus, to detain all of these functionaries in the existing prisons.

It is obvious that Iris Runge had not yet encountered this news when, on the same day, she wrote the following to her mother:

You don’t need to worry about me, by the way (I don’t think that anything should happen). [...] And in the meantime everything here has been broken up – the groups, the gatherings, etc. In general it seems – though I’ve spoken with no one about this – that everyone is simply adjusting to the thought of abandoning all resistance whatsoever, and that this shift is rightly making the opposition rather nervous about its chances. In any case, I am happy to relay to you the pleasant news that my National Socialist neighbors have moved out of the building [...].⁸³

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- 81 According to a postcard to her mother that was written on July 3, 1932 [Private Estate], Iris Runge traveled with a group of eight children to another summer camp near Lübeck. After the death of her father in 1927, she typically spent her summer vacation with her mother and her sisters Aimée and Ella. In 1927 they vacationed in Langeoog, in 1928 in Italy, and in 1929 she and her sisters traveled by ship from Hamburg to IJmuiden with stops in Amsterdam, Nordkapp, and Spitsbergen.
 - 82 A letter from Iris Runge to her mother dated October 23, 1932 [Private Estate]. Incidentally, the Social Democrat Willy Brandt, who was the Chancellor of West Germany from 1969 to 1974, was a member of the Children’s Friends organization as a child.
 - 83 A letter from Iris Runge to her mother dated March 21, 1933 [Private Estate]. Iris Runge’s apartment was in a building owned by a Jewish couple (Herzog). When these landlords went into exile in 1934, the building was put into receivership. Iris Runge left this apartment in January of 1935.

This section will examine whether Iris Runge truly kept silent during these years, choosing simply to devote herself to her mathematical work; it will discuss the ways in which she maintained contact with her political associates and with her Jewish friends and acquaintances; and it will investigate how she weighed the decision between emigrating abroad and remaining in Germany.

4.3.1 Political Contacts after 1933

At the beginning of the year 1933, Iris Runge consciously avoided making any political comments in her letters to her mother: “First, because there is now so little to experience in this regard and, second, because it is forbidden to talk about even these few experiences.”⁸⁴ She limited the topics of her correspondence to such things as museum visits (twentieth-century art, Käthe Kollwitz⁸⁵), theater performances (Shakespeare, Goethe’s *Faust II*, Gerhart Hauptmann’s *Florian Geyer*⁸⁶), her boat trips in Berlin, her vacation plans, and books.

Most of the books that had featured in their previous discussions were banned in 1933. Among the works that landed on the Nazi’s “funeral pyre” were those by Thomas and Heinrich Mann, Martin Andersen Nexø, Upton Sinclair, Theodor Wolff, Erich Maria Remarque, Kurt Tucholsky, Karl Marx, Charles Darwin, Albert Einstein, H. G. Wells, Arthur Feiler, and Eduard Heimann. Nevertheless, Iris and Aimée Runge continued to pursue and read socially critical literature.⁸⁷

84 A letter dated May 29, 1933 [Private Estate].

85 In 1933, Käthe Kollwitz was forced out of the Prussian Academy of Arts and dismissed from her position as a director of master drawing classes for having signed the so-called “Urgent Call for Unity” (*Dringender Appel für die Einheit*) in opposition to National Socialism. She herself had not been a member of any political party.

86 Gerhart Hauptmann, a Nobel Prize winning author, opted to become a member of the National Socialist German Workers’ Party in the middle of 1933.

87 She read Harriet Beecher Stowe’s *Uncle Tom’s Cabin*, which was recommended to her by her friends and relatives who had emigrated to the United States. Tomáš Garrigue Masaryk’s autobiography, *President Masaryk Tells His Story*, which was published in German in 1936, was immediately on Iris Runge’s wish list. She became interested in Masaryk – a philosopher, author, and Czechoslovakian politician with utopian ideas about the future of society – while editing Hendrik de Man’s book about him in 1932. As late as 1936, she was still able to buy a copy of H. G. Wells’s *The World Set Free*, in which the advent of nuclear warfare was predicted, but in 1937 she wrote: “Wells is no longer available for sale; his works are now forbidden, which is a telling symptom of things to come.” A comparison between the works of Wells and John Galsworthy, whose books could still be purchased, prompted her to remark: “I am also very fond of Wells, but he is essentially a thinker. Although he often creates true-to-life characters, their purpose is really to support one of his theses or to experience a particular problem. It is all very interesting how he does it, and perhaps it is even more important than a purely artistic representation. I think that, as intellectuals and scientists, we are inclined to prefer this factual type of writing. If a problem is interesting, it doesn’t seem to bother us if the characters playing it out occasionally fade into the background. And yet I think that it would be somewhat shortsighted to declare that Wells’s approach is more important than Galsworthy’s.” This quotation is from a letter

Iris Runge spent the summer vacation of 1933 not only advising her old Bremen friend Magdalene Thimme; in August she also traveled to Switzerland, where she could send letters internationally without danger and where she could reunite with Hendrik de Man. Regarding this visit, she commented to her mother about meeting De Man's daughter: "As planned, the other morning I went to Zurich to meet little Li [de Man]; she was still very enthusiastic about the vacation trips that she had taken with her father."⁸⁸ Later on, in April and May of 1935, De Man's children would in fact spend several weeks staying with Iris Runge in Berlin.

In addition to these children, she welcomed the visits of "all sorts of young women who care to come over, and it's nice to be able to provide for them in the same way that I was able to earlier."⁸⁹ A sense of her sly but ongoing political activity can be detected in these harmless remarks. In a later survey taken after the war, she responded to a question about her "participation in anti-fascist illegal endeavors between 1933 and 1945" with the blunt answer: "Yes, political gatherings, Children's Friends organization."⁹⁰ Children whom she had cared for as a member of this organization continued to visit her after 1933: "I have invited my club of girls (there are now only six) over to my apartment on June 1st, and I'm thinking about entertaining them with juice and cakes."⁹¹ These and other well-wishers, who came over on what was her birthday (June 1), led her later to proclaim that she "went to bed that night with the feeling that, beyond my family members, there are still indeed a few bands of people out there with whom I have something in common. The following day, for instance, I met with a few people with whom I have a relationship that is similar to mine and Emmi's."⁹²

The political gatherings that she mentioned were disguised as athletic and cultural events. Thus she was very careful when commenting about her friend Emmi Danske, who had also been a Social Democrat: "Recently there was a convivial evening with the choir, an event to which I had brought along Emmi D. and a few other acquaintances from Wilmersdorf. It was quite nice, for included among the 'performances' were a few recitations that, though uncontroversial in themselves, were clearly and deliberately of significance to the current situation."⁹³ Later she noted: "[...] two of my proletarian friends are coming over for coffee soon, and then we'll all go together to the community choir concert, in which I'll be per-

dated June 13, 1937. For her other literary discussions during this period, see her letters dated January 15, 1938 and May 29, 1938 [Private Estate].

88 A letter to her mother dated August 31, 1933 [Private Estate].

89 A letter dated March 11, 1935 [Private Estate].

90 [UAB] R 387, vol. 2, p. 11v.

91 A letter dated May 29, 1933 [Private Estate].

92 A letter to her mother dated June 5–6, 1933 [Private Estate].

93 A letter dated February 11, 1934 [Private Estate]. Iris Runge repeatedly mentions her acquaintances in Wilmersdorf, who had presumably been members of the Workers' Samaritan Federation (for a photograph of Iris Runge and some of her fellow members of this organization, see Plates 9b and 9c). See also a letter dated January 21, 1934 [Private Estate], in which she mentions Emmi Danske along with a certain Minna, Hermann, and Marie.

forming.”⁹⁴ There are similar political undertones in her comments about a “young acquaintance of mine who is to teach us something about playing the flute,”⁹⁵ and in her remark that “the young men arrived there as planned; I saw them directly after the flute lesson.”⁹⁶ Iris Runge also taught English to a thirteen-year-old boy whose family was planning to emigrate. At the beginning of 1936 she became the legal guardian of Margot Zielke, who was the daughter of a working-class woman. The young woman lived for some time in Iris Runge’s household, where she would later come to eat dinner on Friday evenings. Zielke availed herself of the opportunity to borrow Iris Runge’s books, and she enjoyed making use of her electric sewing machine, with which she was kind enough to tailor and mend some of Iris Runge’s clothing.⁹⁷

Iris Runge frequently met with her cousin and childhood friend Erich Trefftz, who was actively engaged in protecting the rights of his Jewish colleagues.⁹⁸ She did not break off her contact – renewed toward the end of the Weimar Republic – with her childhood friend Erwin Marquardt, who in 1933 was dismissed from his positions as the Social Democratic director of an adult education center and as a senior municipal officer in Berlin even despite his attempts to reconcile and work with the Nazi authorities:

Consider this: M[arquardt] has been fired, and only fourteen days after I had last seen him, which was in May. At that time I felt somewhat shocked and alienated by his ambition to come to terms with the whole situation. It must have been especially terrible for him to put in such an effort – against his better conscience – only to have it turn out this way.⁹⁹

Then there were the small interactions and encounters that would occasionally raise her spirits, as when she reported: “Yesterday I sold concert tickets to Löbe, who proceeded to call me a ‘dear child’ and kiss my hand!”¹⁰⁰ Paul Löbe, a Social Democrat who had served as the president of the national parliament from 1920 to 1924 and again from 1925 to 1932, was imprisoned by the Nazis for six months in 1933. At the time of this encounter, in February of 1934, he was working for the Walter de Gruyter publishing house. Later, in 1944, he was arrested again by the Nazis for his connection with Carl Friedrich Goerdeler’s resistance circle against Hitler. When questioned after 1945 about her behavior during the Nazi era, Iris Runge responded:

94 A letter dated November 21, 1934 [Private Estate].

95 A letter dated April 15, 1934 [Private Estate].

96 A letter dated May 29, 1934 [Private Estate].

97 These events are documented in letters dated February 2, 1936; August 16, 1936; January 15, 1938; and August 18, 1946 [Private Estate].

98 See Erich Trefftz’s estate, which is archived in the [UA Dresden]. Especially enlightening in this regard is Trefftz’s correspondence with the (Jewish) mathematician Otto Blumenthal, who had been David Hilbert’s first doctoral student.

99 A letter to her mother dated February 11, 1934 [Private Estate]. See also her letters on the topic of Erwin Marquardt dated May 31, 1936 and December 29, 1936 [Private Estate].

100 A letter from Iris Runge to her mother dated February 11, 1934 [Private Estate].

In 1929 I rejoined the Social Democratic Party, with which I had already been closely associated since my student years. I was actively engaged in the activities of the party and the labor union, as well as in the Workers' Samaritan Federation and the Children's Friends movement. After 1933 I continued to participate in a working group with approximately ten other women that met every month to discuss political issues and our Marxist *Weltanschauung*.¹⁰¹

In another account she stressed: "We came together on a monthly basis, discussed issues of Marxist ideology, and collected donations for the families of our imprisoned acquaintances."¹⁰²

4.3.2 Jewish Friends and Acquaintances

Here we are forced to live under the weight of horror and shame.¹⁰³

Lise Meitner, the prominent Austrian physicist, converted to Protestantism as an adult, but this did not deter the Nazis from declaring her Jewish and necessitating her emigration after the annexation of Austria in 1938. In November of that year, Iris Runge wrote Meitner a letter in which she expressed her horror about the circumstances in Germany, her feeling of increasing helplessness, and her hope of finding some solace in her mathematical work (see Appendix 7). A great concern for the safety of her relatives, friends, and acquaintances is reflected in many of Iris Runge's letters after 1933. "Hopefully you will be able to bear, with characteristic steadfastness, the great sadness and heaviness of the situation," she expressed in a birthday letter to her mother, written after Nerina (Nina) and Richard Courant had emigrated to England.

During the 1920s in Berlin, she had enjoyed relationships with many Jewish friends and acquaintances, and she did not put an end to these relationships after 1933. During her early years in Berlin, she regularly spent time with the pediatrician Charlotte Landé, but the latter moved to Frankfurt for professional reasons in 1926. Their acquaintance began in Göttingen, where Landé had worked from 1914 to 1917 as an assistant pediatrician under Friedrich Göppert and where her brother Alfred had been David Hilbert's research assistant before moving in 1914 to complete his doctoral degree under Arnold Sommerfeld in Munich. The Landés came from a politically engaged Jewish household. Their father, a lawyer, and also their mother were active on behalf of the Social Democratic Party in the Rhineland.¹⁰⁴

101 [UAB] R 387, vol. 1, pp. 7–8.

102 Ibid., vol. 2, p. 14.

103 A letter from Iris Runge to Lise Meitner dated November 26, 1938 and kept in the [Churchill Archives] MTNR 5/15. On the daily life of German Jews until 1945, see KAPLAN 2005. For information on Lise Meitner's life and work, see SIME 1997. There were only three female physicists in Germany who were able to complete a *Habilitation* before 1933, namely Lise Meitner, Hertha Spöner, and Hedwig Kohn. All three went into exile during the Nazi dictatorship. On Hedwig Kohn, see WINNEWISER 2005.

104 For a biography of Charlotte Landé, see BÖHM 2003.

A respected physicist, Alfred Landé permanently left Germany for the United States in 1931, where he had previously held two visiting research positions. Charlotte Landé, who was released from her public position in 1933 and who married in 1934, ran a private practice in Berlin until 1937, at which point she also decided to follow her brother's example and go into exile.

With her former schoolmates from Hanover, Cora Berliner and Elisabeth (Elli) Rosenberg – Edmund Husserl's daughter – Iris Runge scheduled a regular "ladies' tea time" (*Damenthee*) in Berlin. Elli Rosenberg was married to the art historian Jakob Rosenberg, an expert in Dutch painting who was made the head curator of the Bode Museum's print collection in 1930. With the couple, Iris Runge was happy to be able to cultivate her interests in art. On June 2, 1933, she visited Elli in Berlin-Eichkamp with a large bouquet in hand:

On June 2nd, which is Elli's birthday, I wanted to visit her and hear how things were going for them. [...] Elli told me that, at least for the moment, they had no immediate concerns, but that it is impossible to know what will happen, for anyone can be denounced at any time for any reason and then wake up the next day without any rights and very few prospects.¹⁰⁵

Because Jakob Rosenberg had served in the First World War, he was able to keep his position at the museum until 1935. In 1936, they went into exile in the United States, where he became a professor at Harvard and the curator of the print collection at the Museum of Fine Arts in Boston.

In 1919, Cora Berliner became the first woman in the Weimar Republic to serve as an official in the government's Ministry of Economics, and in 1923 she was named a senior government official (*Regierungsrätin*). From 1924 to 1933, she collaborated closely with the director of the National Office of Statistics, and in 1927 she worked as an economic advisor at the German embassy in London. In 1930 she became a professor of economics at the newly founded Institute for Vocational Pedagogy in Berlin, a position that she had to forfeit in 1933. "I was recently at Cora's home again," Iris Runge wrote to her mother, "and she is working at full speed (on a voluntary basis) at the Office of Central Affairs, which she joined quickly after her dismissal from her previous position. Now she has no pension to speak of, but there is some possibility, as she told me, that she might be granted something later on."¹⁰⁶ Cora Berliner was a member of the Central Association of German Citizens of Jewish Faith (*Zentralvereins deutscher Staatsbürger jüdischen Glaubens*), which had been established in 1893 to represent assimilated, middle-class Jews in Germany. She also joined, in April of 1933, the Central Committee for Aid and Reconstruction (*Zentralausschuss für Hilfe und Aufbau*), a social and economic organization for German Jews. In 1938, the Central Association was outlawed by the Nazis. Berliner continued to care for others, however, by facilitating their plans for emigration. Beyond spending a brief period of time in Palestine in 1936, she herself remained in Germany. By the time emi-

105 A letter dated June 5–6, 1933 [Private Estate].

106 A letter to her mother dated February 11, 1934 [Private Estate].

gration was officially banned in October of 1941, it was too late; her plan to survive in Berlin – by going into hiding – went tragically awry.¹⁰⁷

As mentioned briefly in another context above, Iris Runge was also close to the family of the physicist Otto Berg, who with Ida and Walter Noddack had discovered the element rhenium by means of X-ray spectroscopy.¹⁰⁸ She went on walks and took boat rides with the Bergs, who invited her to several of their family events, including the confirmation celebration of Otto's son Richard. About the family's plans in 1934, she wrote:

Richard has decided to emigrate to Palestine with a group of young men and women, where they intend to start a communal settlement. Everything has been painstakingly planned out in advance regarding what sort of skilled labor will be needed on the site. He has already resigned from the Zuntz Corporation and will begin to study agriculture in the spring. Eva, however, although she initially intended to go along, now has hopes of becoming a teacher at a Jewish school and will stay in Germany.¹⁰⁹

Otto Berg's other son, Wolfgang (Wolf), earned a doctoral degree in physics in 1932 under Peter Pringsheim at the University of Berlin; he lost his research assistantship in 1933: "At the Berg household I recently heard that things are going well for Wolf and his young wife; they said that he found a two-year research position in Manchester. Things are somewhat worse for Otto, however; he has aged considerably, and it is clear that he has been suffering."¹¹⁰

Rose Ewald, the daughter of Paul Ewald, left Germany for Columbus, Ohio in 1936.¹¹¹ By that time, the emigration of her friends and colleagues must have

107 See GEDENKBUCH 1995, p. 104; HILDESHEIMER 1984; QUACK 2005. Iris Runge last mentioned her "friend Cora" in a letter dated July 10, 1939 [Private Estate].

108 In 1909, Otto Berg had intended to conduct postdoctoral research under Eduard Riecke in Göttingen, but he ultimately accepted a position in the industrial sector. See TILGNER 2000, and a letter from Aimée Runge to Carl Runge dated December 15, 1909 (archived in [STB] 523, p. 99).

109 A letter from Iris Runge to her mother dated February 11, 1934 [Private Estate]. Richard and Eva, the children of Otto and Julie Berg, had been raised as Christians (on the confirmation celebration, see Iris Runge's letter dated March 3, 1927 [Private Estate]). A. Zuntz GmbH, the Jewish-run coffee company where Richard had been employed, was compulsorily "Aryanized" in 1933.

110 A letter from Iris Runge to her mother dated November 19, 1933 [Private Estate]. For excerpts of Wolfgang Berg's doctoral thesis, which was entitled "Über die Auflösung der Jod-Fluoreszenz durch Magnetfelder und durch Fremdgase" [On the Quenching of Iodine Fluorescence by Means of Magnetic Fields and Carrier Gases], see *Zeitschrift für Physik* 79 (1933), pp. 89–107. Berg was able to continue his research on X-ray diffraction under William Lawrence Bragg, a Nobel Prize winning physicist (see Section 2.5). In 1936, he joined the research laboratory of the Kodak Company in Harrow (Middlesex), and in 1961 he became a professor of photography at the Swiss Federal Institute of Technology in Zurich.

111 Iris Runge relates this news in a letter to her mother dated April 27, 1936 [Private Estate]. In September of 1939, while in the United States, Rose Ewald married the physicist Hans Bethe, a former student of Arnold Sommerfeld who had also gone into exile. Rose's father, Paul Ewald, had resigned from his position as rector of the Technical University in Stuttgart in 1933. According to the definition of the Nazis, he was classified as a "quarter-Jew," and

seemed like a normal occasion – Reinhold Rüdenberg, Marcello Pirani, and Hubert Plaut had all left by then.¹¹² This sense of normality was obviously sinking in across the nation; in his autobiography, for instance, the physicist Max Steenbeck even associated these times – in which the Olympic Games were also being held in Berlin – with a strong feeling of economic revival. In December of 1936, Iris Runge wrote to her mother about Otto and Julie Berg’s planned departure to London and about other acquaintances who had since moved to South Africa or were intending to emigrate to North America, but still she concluded: “[...] at the same time, I am really quite busy and life is altogether pleasant.”¹¹³

After the Bergs had finally emigrated to London in 1938,¹¹⁴ Iris and Ella Runge embarked upon a “Scottish” vacation during the June of that year. The trip began in Hamburg, where they met with Felix Klein’s youngest daughter Elisabeth Staiger before their departure. In 1933, the latter had lost her position as a school principal (*Oberstudiendirektorin*) in Hildesheim for refusing to conform to the Nazi image of women and for protesting the dismissal of her Jewish colleagues. Staiger was demoted and forced to relocate to Hamburg-Harburg.¹¹⁵ After a fourteen-hour trip on a steamboat, Iris and Ella Runge arrived in Newcastle, and from there they traveled by train to Edinburgh, where they visited Hedi and Max Born. They then went to Glasgow, where a cousin was expecting them, and on their return journey they met with several acquaintances in London.¹¹⁶

he had been married to the Jewish Ella Philippson since 1913. In 1938, he went into exile in Great Britain along with his wife and mother (see BETHE/HILDEBRANDT 1988). On the various reasons for why some of Sommerfeld’s students went into exile, see ECKERT 2011.

112 Still under contract with the Siemens Corporation, Rüdenberg emigrated on April 2, 1936 (see WALOSCHEK 2004, p. 186).

113 A letter dated December 14, 1936 [Private Estate].

114 Iris Runge discusses the Bergs’ final emigration to London in a letter dated March 20, 1938 [Private Estate]. Part of the Berg family continued to live on Eichkampstraße 122 in Berlin as late as 1947. In a personnel survey taken in that year, Iris Runge listed “Mrs. Prof. Berg” as one of three people under the rubric “Who can recommend you?” (see [UAB] R387, vol. 2, p. 11r.).

115 For a comprehensive discussion of Elisabeth Staiger’s career, see TOBIES 2008e.

116 Iris Runge’s report to her mother about this trip, which she included in a letter dated July 10, 1938 [Private Estate], ought to be quoted here: “Now I finally remember who wanted me to greet you on her behalf. It was Hedi Born, whom we met in Edinburgh. It was an extremely nice time, and I’m pleased that everything there is going so well for them and that they are happy to be there. He was honored by the university and given a good position, and they have an adorable house with a lovely yard. Their oldest daughter, Irene, is married to a very kind and young Englishman, who teaches at a school. [...] The younger daughter, Gritti, will perhaps also marry soon [...]. We also saw their son Gustav. He seems to be a very kind young man, and he asked about Courant’s children. Born himself looks much older – his hair is now completely gray. And yet he still plays the piano wonderfully, perhaps better than ever. His performance was captivating, in fact. He played along with a Dutch physicist who was also visiting at the time.” In 2007 I had the opportunity to ask Gustav Born, who was seventeen years old at the time of the Runges’ visit, whether he might remember anything about it, but he had no recollection of the occasion.

By the end of 1938, the persecution of German Jews had become an even more urgent topic in Iris Runge's letters. The so-called *Kristallnacht*, an organized series of attacks against Jewish citizens and their businesses, took place throughout the night of November 9, and on November 14 a resolution by the university senate in Berlin forbade Jews from attending academic colloquia and from using the university library. Iris Runge wrote to Lise Meitner about the "weight of horror and shame" that she was living under in Germany, and to her mother she expressed her deep concern about her friends and relatives still living in Berlin: "It is terribly, terribly sad that it will now be impossible for Maleen to remain here. This is a great cause for distress. Hopefully she will be able to move to a place where it will be possible for them to embark upon a tolerable life."¹¹⁷ By this point, Iris Runge was attempting to suppress her sorrows and emotions by focusing ever more intently on her work.

4.3.3 At Osram and Telefunken During the Period of National Socialism

A great number of Jewish employees have just been released by our firm as well.¹¹⁸

Indeed, work is the only thing that can keep one alive; it somehow maintains its value no matter how insane the world has become.¹¹⁹

These quotations represent opposite poles in the mind of a person who, though a political outsider during the Nazi era, was nevertheless working for an industry whose products were crucial to the rearmament and to the war itself. Here the concern will be the political atmosphere of Iris Runge's professional settings and its effect on the daily operations of Osram and Telefunken. The goal will be to examine the extent to which the field of industrial research was able to provide a safe haven for political dissent. In the same vein, it also has to be asked whether there were any pronounced reservations about being a cog in the machinery of military research.

It has already been shown on several occasions that international corporations, including AEG and Osram, had played a financial role in the rise of Hitler's politi-

117 A letter dated December 11, 1938 [Private Estate]. Maleen, the daughter of René du Bois-Reymond, had married Walter Berg. She was still in Berlin in 1945, as is clear from a letter from Iris Runge to her relatives written throughout May of 1945 [Private Estate]. This moving and illuminating letter is reproduced in Appendix 8.

118 A letter from Iris Runge to her mother dated June 5–6, 1933 [Private Estate]. Among the archived documents of the Osram Corporation there is a list – dated June 9, 1933 – with the title "Employees Dismissed on Account of Their Non-Aryan Ancestry" (see [LAB] 449). There are forty-one names on this list (eleven upper-level employees and thirty additional employees with salaries), including two managers from the development department: the chemist Dr. Felix Bobek (released on September 30, 1933) and the physicist Dr. Curt (Kurt) Samson, an executive dismissed on December 31, 1933.

119 A letter from Iris Runge to Lise Meitner (see Appendix 7).

cal party.¹²⁰ The historical records of Osram contain documentary evidence of the surprisingly short amount of time that it took for the Nazis to exert their political influence on the company. One of the first measures, enacted in April of 1933, required the previous labor unions to be disbanded and replaced by employee representatives who were faithful to the Nazi Party.¹²¹ On May 10, 1933, the so-called German Labor Front (*Deutsche Arbeitsfront*) usurped the role of the independent labor and trade unions, all of which were forced join the new organization. The right to strike was abolished. With the ratification of the “National Labor Regulation Law” (*Gesetz zur Ordnung der nationalen Arbeit*) on January 20, 1934, the foundation of the German Labor Front was officially legitimized, and the relationship between employers and their employees was defined according the *Führerprinzip*, or “leader principle.” One of such “leaders,” Hermann Schlüpmann, who had come to Osram from the Auer Company, made drastic managerial decisions in this capacity at Factory D, where he fired many employees for political reasons in November of 1933.¹²² An active Nazi women’s organization was established. Occasioned by the Nuremberg rallies – and with the approval of company management – the National Socialist groups at Osram organized trips to party gatherings, at which individual meetings of Osram’s “party faithful” also took place. On October 7, 1935, a district representative of the Nazi Party gave a speech at Osram’s Factory S about “the meaning of the new Nuremberg Law (*Judengesetz*),” an anti-Semitic measure concerned with defining who was Jewish. Whereas, in 1927, factory management had discouraged workers from listening to the radio during their lunch breaks,¹²³ the mass medium was now welcomed as a means of spreading propaganda within the business. The workers and the employees had to assemble in conference rooms to listen to broadcast speeches by Hitler, Rudolf Hess, and Goebbels, and they typically had to stay late to compensate for these lost work hours. They were given free tickets to attend a reading by the National Socialist poet Will Vespers that was held in Factory D, and they were required to participate in the marches on May Day, which was now a holiday, and to file onto the streets of Berlin to greet and cheer the visits of Mussolini, the Italian fascist leader.¹²⁴

120 See SUTTON 1999.

121 See [LAB] 443 Osram 1933–45, Notice No. 113/33: “Consequent to the repeal of Notice No. 109/33 on April 11, 1933, the members of the labor representatives of Factory D – including the wire factory and the development division – will hereafter be appointed at the suggestion of the district leadership of the National Socialist German Workers’ Party in the same manner as they were temporarily announced by the Chief of Police in the official document of June 14, 1933.” Thirteen representatives were named to the labor committee and eight to a committee of salaried employees. Two of the latter were appointed from the research divisions, namely Gustav Lorff and Dr. Willy Böttcher (a chemist).

122 Correspondence of a communist nature was discovered at Osram’s Factory D on November 8, 1933, and five employees were dismissed in the wake of this discovery (see [LAB] 443).

123 See the corporate notice archived in [LAB] 653, vol. 1, p. 962.

124 See [LAB] 435. Wilhelm Runge described similar events that were taking place at Telefunken, including the dismissal of Jews from the executive board (see [DTMB] 4413).

Just as certain Jewish researchers had been able to retain their positions after 1933 at the Kaiser Wilhelm Institutes, a number of important Jewish research directors were able to do the same at Osram and Telefunken, at least at first. Following the ratification of Nuremberg Laws on September 15, 1935 and other ordinances of a discriminatory sort, the majority of the latter opted to go into exile.¹²⁵ The corporate executives at Osram knowingly facilitated their emigration by sending them abroad on business trips. Those who were neither willing nor able to leave the country – usually on account of their age – did not escape a gruesome fate.

For “Aryan” employees who were opposed to the ruling party, the field of industrial research offered a somewhat protected space that was relatively free from political indoctrination, especially if the political allegiances of the supervisors were not firmly on the side of the National Socialists. The majority of the research directors at Osram’s and Telefunken’s electron tube laboratories did not belong to the Nazi party. This is true, for instance, in the cases of Max Weth, Willy Statz, Hans Rukop, and Karl Steimel. Only Peter Kniepen, who led an electron tube department but was not a full director, is known to have been a party member. In August of 1945, the latter was therefore dismissed from the company, though he would later be rehired on account of a sponsorship letter written by Weth and Statz.¹²⁶ Günther Herrmann joined the *Sturmabteilung* paramilitary group (SA) as a student in May of 1933 and was a troop leader in that organization until 1937; the physicist Eberhard Uredat noted that he had been a horseman for the cavalry regiment of the SA from January to August of 1934.¹²⁷ The political affiliations of the employees who were released from Telefunken immediately in 1945 can only be speculated. Among these, for instance, was Siegfried Wagener; he ran a private radio tube laboratory near Hanover until 1947 and ultimately came to work for the British and American electrical industry.

At Osram there was also an underground cell of the German Communist Party, and it is known that certain engineers there had been engaged in industrial espionage for the Soviet Union since the 1920s.¹²⁸ The toolmaker Robert Uhrig of Osram’s department for radio tube experiments had been leading an illegal cell of the Communist Party as of 1929; he was also in charge of a network of oppositional groups from 1938 to 1942, at which point he was arrested along with two hundred

125 Among these were Marcello Pirani and Hubert Plaut of Osram and Otto Böhm of Telefunken, whose position as the director of product development was given to Wilhelm Runge on December 1, 1935.

126 This document – dated September 30, 1946 and archived in [DTMB] 135, p. 6 – shows that Kniepen had been affiliated with the National Socialist German Workers’ Party as of May 3, 1938. He was allowed to be reappointed to his position because he had had no official functions in the party.

127 See [DTMB] 00199, pp. 97–125 (personnel profiles).

128 See S. V. Zhuravlev, “*Ich bitte um Arbeit in der Sowjetunion*”: *Das Schicksal deutscher Facharbeiter im Moskau der 30er Jahre*, trans. Olga Kouvchinnikova and Ingolf Hoppmann (Berlin: Links, 2003), p. 12.

fellow conspirators who would ultimately be sentenced to death.¹²⁹ Some researchers, too, had belonged to the Communist Party and were active in the resistance, including the physicist Robert Rompe, who had studied under Peter Pringsheim at the University of Berlin before joining Osram's Research Society for Electrical Lighting in the early 1930s.¹³⁰ The Prague-born chemist Felix Bobek, a former student of the famous chemist and later Nobel Laureate Otto Hahn, was released from Osram for being Jewish but remained active in the anti-fascist opposition until his arrest in 1938.¹³¹

The development and production of the business's products depended on the work of people whose opinions spanned the entire political spectrum from left to right, and those researchers who were unaffiliated with the Nazi Party were free to contribute their creative ideas. "Work," as Iris Runge wrote to her exiled friend Lise Meitner, "is the only thing that can keep one alive." What she explained to her sister Ella in 1937 – "I enjoy making calculations and engaging in mathematical thinking, and I do this to improve the design of radio tubes" (see Section 3.4.5) – was presumably not written with the possibility in mind that her knowledge could also be of use to military research. After all, there was already a special department for that. Yet in the same letter she also noted, ostensibly in response to the proliferation of Nazi propaganda, that "I consider radio broadcasting to be a rather pernicious thing." Yet again, although she was a resolute opponent of National Socialism, Iris Runge could nevertheless not avoid having to assist the Army Weapons Agency by furnishing it with a report that would be used for military ends (see Appendix 5.6).

In his multi-volume history of electron tubes, Wolfgang Scharschmidt leaves the impression that the majority of the tubes used by the German army and air force were developed at Telefunken, whereas Osram had been chiefly responsible for conducting preliminary research.¹³² This is an oversimplification, however, given the close collaboration that took place between the two firms and given that Osram's entire electron tube laboratory was put under the control of Telefunken in 1939. It is well known that Telefunken had established its own department for the development of military tubes in 1933, and that industrial research necessarily goes hand in hand with the needs of a given industry's clients. The different businesses competed for contracts, and these were increasingly being issued by the military authorities. The developmental and experimental work of Osram's researchers – their theoretical and mathematical work not excluded – cannot be discussed without considering its technological applications, and it should be

129 See FIEBER 2002.

130 See Rainer-Bernd Barth and Werner Schweizer, *Der Fall Noel Field: Schlüsselfigur der Schauprozesse in Osteuropa* (Berlin: Basisdruck, 2009), pp. 432–433. See also Rompe's articles in volumes 2–5 (1931–1943) of the *Wissenschaftlich-technische Abhandlungen aus dem Osram-Konzern*; HOFFMANN 2005; and NAGEL 2007b, pp. 256–258.

131 See SCHARSCHMIDT 2009, vol. 4, p. 5.

132 Ibid.

repeated that, by the middle of war, tubes designed for civilian purposes were also being used in military equipment.¹³³ Far from being of nominal or secondary importance, as Helmut Maier has noted, the fundamental and theoretical research being conducted at German businesses was of *de facto* relevance to the war efforts.¹³⁴ It is situations such as these that reveal the Janus-faced nature of modern science,¹³⁵ and the newly established field of industrial mathematics was not exempt from this unfortunate reality.

It is ultimately necessary to separate professional activity, which necessarily led to corporate profits and brought stability to the state, from the political opinions of individual researchers, which were far from uniform. Recognized for her mathematical expertise – and not especially for her political disposition – Iris Runge was careful enough to treat these two realms separately as early as 1923. She continued to carry out her industrial research without interruption, all the while regarding her work as apolitical despite the fact that many of her colleagues were spared the battlefield on account of their crucial contributions to military research. Many of her other fellow scientists, however, were sent to the front and replaced by women or prisoners of war. Simply put, her work was a means of individual survival.

Karl Steimel, under whose supervision electron tube research was continued during the war, served as the director of Telefunken's developmental laboratories and was additionally made the executive director of Telefunken's factory in Schöneberg. He reported that, before the war, more than one hundred million tubes had been built worldwide according to his own proposals and patents, and that Germany had earned a great deal of revenue from the licensing fees that had been paid for the right to use his inventions. He oversaw the work of approximately eight hundred employees. According to his estimation, the scope and accomplishments of the laboratories under his direction were unique in all of Europe and paralleled only by those of the laboratories of the Radio Corporation of America (RCA). In remarks made after the war, he failed to associate his scientific work at Telefunken with the political authorities who had funded so much of it. He also managed to downplay the political significance of the government position that he was handed during the war. As mentioned in another context above, Steimel was appointed by the government in 1943 to supervise and coordinate the research and development of electron tubes throughout all of Germany. He wrote the following about this appointment in a letter posted on June 16, 1945:

In addition to my work in private industry, I was personally appointed by the Government Research Council and by Minister Speer to supervise the nationwide research and development that was taking place in my area of work. This appointment represented an unambiguous testament to the quality of my technical leadership in the field. Given that I was nei-

133 See [DTMB] 7779, pp. 101–106.

134 See MAIER 2002, p. 18.

135 See MEHRTENS 1990.

ther a member nor an affiliate of the National Socialist German Workers' Party, it is clear that my appointment to this position was made on the basis of my qualifications alone.¹³⁶

From 1943 to 1945, the Government Research Council mentioned here was led by Hermann Göring, who would be sentenced to death by the judges of the Nuremberg Trials.¹³⁷ The way in which scientists will adapt to a given political system was as various then as it is today. That said, it is in general quite typical of scientists to deny any responsibility for the actual ends to which their discoveries are put to use. Steimel's autobiographical comments exhibit a special brand of political chameleonism. In the same letter quoted above – written, again, in June of 1945 – he reported that he had received orders from the high command of the Russian army to establish an institute for electron tube research in central Russia, and that he would be required to provide staff for this new institute with personnel from his own laboratories. This happens to contradict the information that was fed to the scientists who were actually relocated to Russia in 1946. Whereas the latter were told that they were needed there because certain contracts had been breached in the Soviet Union, the truth certainly lies elsewhere, for Steimel had known about everything in advance.¹³⁸ Given that he appears on the recently disclosed list of Nazi war criminals that had been assembled by the so-called Gehlen Organization,¹³⁹ and given that, having just established a research institute on the outskirts of Moscow, he accepted an executive position at Telefunken in 1952 and then at AEG, it is apparent that Steimel was adept at blowing with the wind.

4.3.4 A (Business) Trip to the United States

In 1933, Iris Runge commented as follows about her mother's concern that it might not be ideal for her grandchildren (the Courants) to be raised abroad: "But the world is large and colorful and interesting in all of its corners and belongs to all of us. I don't understand at all why their children should not grow up there. [...]. Of course it is clear that it would be best for you if they could have stayed here,

136 A letter from Karl Steimel to the District Mayor of Berlin-Zehlendorf dated June 16, 1945 and archived in [DTMB] 3483, pp. 66–69 (the quotation is from p. 67). For the full text of this letter, see Appendix 9. The "Minister Speer" referred to is Albert Speer, who was the Minister of Armaments and Munitions from 1942 to 1945.

137 On the role of the Government Research Council in the formation of Nazi scientific policy, see the novel arguments presented in FLACHOWSKY 2008.

138 For Steimel's report on his orders from the Russian army, see Appendix 9. On the opinion promulgated by the newspapers about why the scientists were transferred abroad, see a letter by Iris Runge dated January 3, 1946 [Private Estate]; Wilhelm Runge's remarks in [DTMB] 4413, p. 92; ALBRECHT et al. 1992; and Chapter 5 below. Excerpts of Steimel's letter have been printed in BOSCH 1991.

139 See the Nazi War Crimes Disclosure Act: Alphabetized Chart (released on September 10, 2002 and accessible online). It should be noted that this is not necessarily an incriminating list, and that Steimel's appearance on it is mentioned here only as an indication of the circles in which he was active.

but this might also not be the best place to raise a family right now.”¹⁴⁰ On her mother’s birthday in 1935, Iris Runge expressed her wish that “this year might bring you a lovely and interesting trip to America.” Because her sister Nina would not be available to travel with her mother that year, Iris Runge decided, in 1936, “to persuade Osram into giving me a paid vacation [...]. I have already spoken to Dr. Weth about the matter and told him that I would have to travel in any case in order to accompany you.”¹⁴¹

The physicist Max Weth, who had been the director of Osram’s electron tube factory since 1930, authorized her to take a six-week absence from the firm.¹⁴² A scientist himself who attended conferences abroad, Weth was sympathetic to her request. In terms of politics, moreover, he and Iris Runge also saw eye to eye (unlike those circulated in the other factories at Osram, the newsletters distributed from his office were formulated in such a way as to avoid any Nazi salutation).¹⁴³ At the same time, Weth also authorized Iris Runge to take an official business trip to the United States. Trips of this sort were regularly made in the 1930s by Osram’s directors, especially to RCA (Harrison, New Jersey), to General Electric (Schenectady, New York), and to the Westinghouse Lamp Company (Bloomfield, New Jersey). In February of 1936, for instance, Marcello Pirani traveled to RCA, a visit that occasioned a report on the magnetron, a report that benefitted, incidentally, from Iris Runge’s mathematical advice.¹⁴⁴

In September of 1936, Iris Runge visited the tube factories of the Tung-Sol Company and of RCA. Because both of these businesses were headquartered in New Jersey, it was therefore not an inconvenient detour for her to make from the main purpose of her trip, which was to see the Courant family in New York.¹⁴⁵ Her assignment from Osram was to inquire about specific experimental results at RCA’s magnetron laboratory and to learn about more general matters concerning the organization and production processes at both businesses, which then housed the two leading electron tube laboratories in the United States.¹⁴⁶ It can be gathered from her reports that she was called upon to investigate the production facilities, the patent departments, the production materials (the preference for glass or metal), the production methods (“not according to the principle of the assembly line” at Tung-Sol), and the way that tubes were inspected. Even though most of these topics lay beyond the immediate scope of her expertise, her reports neverthe-

140 An undated letter from Iris Runge to her mother [Private Estate].

141 A letter to her mother dated March 26, 1936 [Private Estate].

142 Iris Runge mentions this in a letter to her mother dated May 22, 1936 [Private Estate].

143 See [LAB] 280 and 444.

144 Reports about trips to America were prepared by Max Weth, Erich Wiegand, and Marcello Pirani in 1935 and 1936, and by Wiegand and Willy Statz in 1938 (see [DTMB] 06410, 06480).

145 Iris and Aimée Runge embarked from Southampton on August 26, 1936. They traveled to Montreal on the “Empress of Australia,” a Canadian Pacific Liner, and arrived on September 2. On the following day they took the eight-hour train ride to New York.

146 See [DTMB] 6604, pp. 152–154. On magnetron research, see Section 3.4.5.1 above.

less contain highly detailed information on such technical problems as pump automation, welding techniques, electrical sockets, lacquering, melting processes, annealing, grid wiring machines, the production of new base plates for metal tubes, etc.¹⁴⁷ It was with respect to the “inspection” of tubes that there was a closer connection to the matter quality control, a process for which Iris Runge had partly been responsible at Osram.

While in New York, she and her mother stayed at the household of Nina and Richard Courant. The details of the personal portion of her trip are documented in a letter to her mother, who would remain with the Courants until the beginning of December. This was written on October 3, 1936 during her return voyage from Montreal – aboard the “Duchess of Bedford” – and from it we learn that Iris Runge spent the final days of her journey in Halifax, where she was hosted by Winthrop Pickard Bell, a Canadian former student of the philosopher Edmund Husserl at the University of Göttingen.¹⁴⁸ It would be to go too far afield to relate her full itinerary, which even included excursions to both Montmorency Falls and Niagara Falls.

There was yet another motivation behind her trip to the United States, however, and this was related to her burgeoning interest in the history of science: “Rather than go to Columbus, I will make an effort to see my dear George Sarton. Hopefully it will be possible to do so.”¹⁴⁹

4.4 FINDING REFUGE IN THE HISTORY OF SCIENCE

“Life is indeed no longer beautiful,” or so expressed Iris Runge on May 11, 1934 as she began to investigate whether she might be able to forge a new life for herself in the United States. This section will explore how the history of science not only provided her with some refuge from the dire political situation in Germany but also how the field presented her with a possible career opportunity. It will be shown, first of all, that such an opportunity was suggested to her by one of the most prominent historians of science, namely the Belgian-born George Sarton. The focus will then shift to Iris Runge’s own historical work, which she herself would ultimately interpret as a substitute for the political engagement that had formerly occupied her free time:

147 See [DTMB] 6616, pp. 15–28.

148 While in Göttingen, Winthrop Pickard Bell had been close to Carl Runge and his family. He studied at Mount Allison University, Harvard, and Cambridge before completing his doctoral degree at the University of Göttingen. Although he had submitted his dissertation in 1914, the official conferral of his degree was delayed until 1922 on account of the First World War.

149 A letter to her mother dated April 27, 1936 [Private Estate]. She entertained the idea of visiting Columbus (Ohio) in order to reunite with Rose Ewald.

I used my newfound leisure time, which arose from the necessary cessation of my political activity, to write a detailed personal and scientific biography of my father. This project was completed in 1943, and in 1944 it was accepted for publication by the Göttingen Academy of Science [...].¹⁵⁰

4.4.1 George Sarton – A New Career Opportunity in the United States

Having studied chemistry, physics, and mathematics, George Sarton turned his attention to the history of science. In 1911, he was awarded a doctoral degree from the University of Ghent for a dissertation on Isaac Newton's *Philosophiae Naturalis Principia Mathematica* (1687), and in the following year he founded *Isis*, the first international journal concerned with this new historical discipline. In 1924, moreover, he was one of the initiating forces behind the establishment of the History of Science Society in the United States. Like Iris Runge, Sarton had long been a proponent of social democracy; after the outbreak of the First World War, he emigrated to the Netherlands, to Great Britain, and ultimately to North America, where he enjoyed a long career as a historian of science at Harvard University.¹⁵¹

In 1934, Sarton traveled to Portugal to preside over the Third International History of Science Congress, which took place between September 30 and October 6. Iris Runge met with him in England – a meeting that was presumably facilitated by Hendrik de Man – and there he offered her a position as his research assistant with an annual salary of 2,000 dollars. She discussed this proposal with her mother in November of the same year, and her letter captures the seriousness with which she was considering the possibility of emigration. Here she not only mentioned some of the books that she would have to read; she also made it clear that she had already begun to study the history of science in her spare time:

Regarding my recent activity: Whenever possible, I have been going to the Institute for the History of Science twice a week to read through the first volumes of Sarton's work, in which I have been discovering the gaps in my knowledge. When it has seemed especially important to do so, I have then been making an effort to fill in these gaps by reading the original sources themselves. I typically stay there for around three hours [...].¹⁵²

In letters to Nina and Richard Courant in New York and to the philosopher and historian Winthrop Pickard Bell in Canada, Iris Runge inquired about the cost of living in the United States, and their responses led her believe that she might have requested too high of a salary from George Sarton:

It seems possible, after all, to live rather well on of a sum of \$2,000, though I presumed at the time that my request was in fact quite low. Nina confirmed this as well in her recent let-

150 [UAB] R 387, vol. 2, p. 14.

151 See PYENSON 2007; and *Isis* 100.1 (2009), a commemorative issue with the title "The Vision of George Sarton."

152 A letter to her mother dated November 21, 1934 [Private Estate]. On the Institute for the History of Science at the University of Berlin, founded in 1930, see SCHNECK 2001.

ter to me. So now I am beginning to think that my request from the good Sarton might even have been a little too high. But it's too late to change things at this point, for it would seem somewhat "petty" to write him about it now. I suppose I'll simply have to wait and see. If he writes me soon to say that the matter can't go through, then I'll be able to reply that I've since asked about the appropriateness of the salary and come to another opinion about it. Of course, that would mean that the whole opportunity might have to be postponed. For if I don't submit my resignation to Osram by the first of January, it will be difficult to begin the new job officially before the first of July [...]. In any case, I have been making progress with my reading of Sarton's work and his journal, and I am becoming more and more convinced that it is a marvelous subject and that it would be a fantastic thing just to contribute to it, so much so that the question of salary really isn't of great importance. Based simply on the colossal work that went into the first volumes of his book, it is clear that Sarton is an astonishing person. On top of that, there is also the fascinatingly direct and impartial way in which he conveys to his readers the great faith he has in the value of his work. If you're interested in an example, go to the library and read his introduction to the first issue of *Isis* that appeared after the war (I think it's number 6 in volume 2), and then read his subsequent remarks on "War and Civilization."¹⁵³

Sarton, as it happened, was not able to create a position for her in the end, but Iris Runge was hardly regretful of having familiarized herself with this new area of study. "Quite the contrary!" she responded to her mother's question along those lines, adding:

Of course I'm sorry that nothing could come of it, but it was truly an exciting and refreshing experience simply for the possibility to present itself at all. Both the trip to England and the opportunity to have met Sarton make me happy and grateful. And the time I spent reading his book was the first thing to have brought me any pleasure in a year and a half. And I don't intend to put an end to this type of work. Thank God that I have once again realized how to enjoy life, and now I will have to carry on here in Germany, although I have little faith that spring will come any time soon, as you so hoped it would.¹⁵⁴

In February of 1937, after Iris Runge and her mother had returned from their trip to the United States, Sarton contacted her to explain "that he was greatly in need of help, but the university was not willing to provide him with funding for a new assistant."¹⁵⁵ At the time, Sarton was still a lecturer at Harvard, where he did not receive a full professorship until 1940.

It would ultimately prove unrealizable for her to abandon industrial mathematics for the sake of pursuing a new career as a historian of science. Her interest in the field arose in 1934 and coincided – not coincidentally – with the new political climate in Germany and with her appointment under her new supervisor Willy Statz, whose appreciation of her mathematical work was minimal at best. The mathematician Kurt Reidemeister faced a similar situation during these years and

153 A letter from Iris Runge to her mother dated November 21, 1934 [Private Estate]. For the article in question, see George Sarton, "War and Civilization," *Isis* 2 (1914/19), pp. 315–321. The English title appears as such in the letter.

154 Quoted from the letter cited in the previous note. Iris Runge had been studying the first two volumes of George Sarton's *Introduction to the History of Science* (Baltimore: Williams & Wilkins, 1927–1931).

155 A letter from Iris Runge to her mother dated February 20, 1937 [Private Estate].

likewise turned his attention to the past. In 1933, he lost his professorship in Königsberg for political reasons, but he was soon reinstated at the University of Marburg, where he went on to devote his research to the history of Greek and Roman science and philosophy.¹⁵⁶ Moritz Epple has interpreted the shift of Reidemeister's interests as being a sort retreat from the political circumstances around him – as an example, that is, of so-called “internal exile” (*innere Emigration*).¹⁵⁷ This may be so, but several other mathematicians can be identified who turned to examine the history of their discipline simply because their creative energies had begun to wane. Such a shift of interest, in other words, can take place in the absence of any political motivations.

Iris Runge's case was somewhat different. For her, the application of mathematics became merely a “job,” whereas her joy in life came to lie in her historical research. Like her grandfather Emile du Bois-Reymond and his son René, she sought to understand science as a deep and yet continuously unfolding tradition.¹⁵⁸

4.4.2 The History of Science in Her Free Time

No, my work on Dad's biography has nothing to do with Osram, of course. I'm doing it exclusively in my own time and for my own pleasure.¹⁵⁹

Even though Iris Runge's decision – instigated by George Sarton – to approach the history of science in a professional manner led neither to an anticipated career change nor to her emigration to the United States, her continued work in the field, which she conducted in her leisure time, nevertheless yielded exceptional and significant results. Chief among these was her study “Zur Geschichte der Spektroskopie von Balmer bis Bohr” [On the History of Spectroscopy from Balmer to Bohr] and the scientific biography of her father, *Carl Runge und sein wissenschaftliches Werk* [Carl Runge and his Scientific Work].¹⁶⁰ These topics, of course, represented familiar and interesting territory to her: “Currently I am deeply engaged with my preliminary research on Dad's contributions to spectroscopy, and I have to say that it's fascinatingly interesting.” At the same time she was undertaking an intensive search for primary sources: “Aren't there any of Dad's letters from this time that might shed some light on the matter? For instance, where has the ‘epistolary diary’ disappeared to that he kept along with some of his childhood friends?”¹⁶¹

156 See DAUBEN/SCRIBA 2002, pp. 505–506.

157 EPPLE 1999, p. 383.

158 On the work of Emile du Bois-Reymond, see especially DIERIG 2006.

159 A letter from Iris Runge to her mother dated February 20, 1937 [Private Estate].

160 IRIS RUNGE 1939, 1949, respectively. On the place of Carl Runge in the history of spectroscopy, see also HENTSCHEL 2002; HENTSCHEL/TOBIES 2003; and RICHENHAGEN 1985.

161 A letter to her mother dated February 20, 1937 [Private Estate].

This type of work, admittedly, was not entirely new to her. For instance, her reference article on colorimetry had similarly required her to survey and evaluate both historical and contemporary studies.¹⁶² It was new, however, for her to spend the vast majority of her free time conducting historical research, an activity that allowed her both to be consumed in a world beyond her unfortunate political milieu and to restore contact with some old acquaintances:

I've already considered that I could get in touch with Planck, which I will certainly do. But since I'm now right in the middle of working on these spectroscopic studies, my first personal visit should probably be to Kayser, and then to Paschen.¹⁶³

Over the Easter of 1937, Iris Runge paid a visit to Heinrich Kayser, then eighty-four years old, in Bonn, and from her conversation with him she was able to receive new insights into Kayser's and her father's earlier collaboration in the field of spectroscopy, a project that had been instigated by none other than Emile du Bois-Reymond (see Section 2.1). In her essay "On the History of Spectroscopy from Balmer to Bohr," she especially underscored the fact that the Swiss mathematician Johann Jakob Balmer, the Swedish physicist Johannes Rydberg, and Carl Runge had each surmised the mathematical principles underlying the relation between wave lengths and the spectral lines of atoms. This assisted, she went on, in determining formulas that widely corresponded with empirical measurements and that could ultimately be explained by Niels Bohr's model of the atom (1913). When her essay appeared in the May 1939 issue of the *Zeitschrift für den physikalischen und chemischen Unterricht* [Journal for the Teaching of Physics and Chemistry], Iris Runge sent offprints of the piece to her mother (as a birthday gift), to additional relatives and acquaintances, and to the scientists with whom she had discussed the topic over the course of her research:

I have already received several kind letters regarding my offprint. Paschen wrote me a comprehensive response immediately after he had received and read my article. Imagine that! Planck sent me only a brief letter acknowledging that he had received it, but both Kayser and Born wrote me at length. I also received personal letters about the article from Aunt Fanny, Aunt Lily, and Putti, who also took the opportunity to wish me a happy birthday.¹⁶⁴

In February and March of 1938, while conducting more intensive research on Carl Runge's days as a student and lecturer, she met with Max Planck on several occa-

¹⁶² Iris RUNGE 1933.

¹⁶³ A letter to her mother dated March 13, 1937 [Private Estate]. Kayser and Paschen had worked alongside Carl Runge in the field of spectroscopy. Paschen had lost his position as president of the Imperial Institute of Technical Physics in 1933 by abruptly ending a celebration in honor of the National Socialists' political victory (he took down the Nazi flag). Paschen was replaced in this capacity by the National Socialist Johannes Stark, an experimental physicist and Nobel Prize winner (1919), but he was allowed to keep his honorary professorship at the University of Berlin.

¹⁶⁴ A letter to her mother dated June 16, 1939 [Private Estate]. Her letters from Max Born, Heinrich Kayser, and Friedrich Paschen are preserved in [STB] 787–795. Excerpts of these letters have been printed in HENTSCHEL/TOBIES 2003.

sions. From him she was able to procure the aforementioned epistolary diary that had circulated among Carl Runge, Planck, and two other of their fellow students. Iris Runge had a copy made of the original, or at least of most of it, and then she returned it to Planck. Although the original diary has unfortunately been lost, the majority of its unique and valuable content has nevertheless and luckily survived in the form of Iris Runge's copy.¹⁶⁵

In her letters we find some reflections on her methodological approach to the history of science. After studying the primary sources in close detail, for instance, she would not write a word about them until she comprehended the full meaning and significance of the material before her:

I don't know how other people might approach the matter, but I refuse to write a word of this biography in a casual manner. First I will have to study all the material so that I can form an image in my mind of everything that ought to be related, and only then will I be able to forge a written narrative. Because it is impossible for me, of course, to remember all of the details that I have gathered thus far, I have been making copious notes. These will serve as the raw material of the study, and later it will certainly be the case that some of this material will have to be changed entirely, expanded, or abbreviated.¹⁶⁶

At the same time, Iris Runge endeavored to expand her general knowledge of history. With her sister-in-law Maria Runge, for instance, she went to the Berlin Academy of Science to attend a lecture by Karl Brandt, a professor of history at the University of Göttingen. With her mother she held discussions about the history of art, which she considered to be of more importance than the history of conquests and acts of violence, and she maintained that a proper understanding of the past could only be gained by studying the history of ideas.¹⁶⁷ She strengthened her grasp of the history of mathematics with the help of Felix Klein's *Vorlesungen über die Entwicklung der Mathematik im 19. Jahrhundert*, a book that would later be translated into English as *Development of Mathematics in the 19th Century* (1979). Her main goal in reading this book was to improve her understanding of Karl Weierstraß's mathematical thinking and thus of Carl Runge's early work, which had been written under Weierstraß's supervision. Having purchased and read Klein's *Vorlesungen*, Iris Runge gushed with praise and enthusiasm:

[...] this is a truly magnificent book: Klein has surely been a remarkable personality. Perhaps it would be even more necessary to write his biography instead! But that would be a job for Putti, though I seriously doubt that she will do it. Well, if my biography of Dad turns out to be a great *success*, I could then do the same for Klein. Putti and her sisters would certainly be willing to put all of his private correspondence at my disposal.¹⁶⁸

165 For an edition of the diary, with commentary, see *ibid.*

166 A letter to her mother dated April 14, 1937 [Private Estate].

167 *Ibid.*

168 A letter from Iris Runge to her mother dated February 25, 1938 [Private Estate]. "Putti" was the nickname of Elisabeth Klein (later Staiger). The English word *success*, incidentally, appears in the original letter. The only book-length biographical study of Felix Klein happens to be my own (TOBIES 1981), but it is high time for a new one to be written.

While still wading through her father's mathematical studies in May of 1939, she was prompted to ruminate about the nature of "pure" and "applied" mathematics:

My progress with the biography has slowed down considerably, and this is because I now have to hack through Dad's mathematical contributions. Because my knowledge of pure mathematics is a little rusty, it has not entirely been easy for me to understand everything. I have to do all sorts of research on the side, and I have to read through each of his articles at least three to four times before his ideas are clear to me, but most of these works of his are behind me by now. They are truly beautiful, and it is something of a shame that neither he nor I continued to work in the field of pure mathematics. And yet I can understand very well why he stopped, for it is much more fascinating to capture the processes of nature in mathematical models, even though such models never come with the perfection and satisfaction that pure numbers can offer.¹⁶⁹

In July of 1939, Iris Runge spent two weeks with her old friend Eva Roemer on the Starnberger See, where she could work leisurely on writing her father's biography.¹⁷⁰ In his own biographical profile of Carl Runge, published in the *Dictionary of Scientific Biography*, Paul Forman relied heavily on Iris Runge's work, which provides a comprehensive and historically contextualized analysis of Carl Runge's life and scientific achievements.¹⁷¹ Of special significance is her discussion of her father's contributions to applied mathematics, a field with which she was particularly familiar. She summarized the scope of her father's expertise as follows:

Runge [...] defined applied mathematics as the methodology employed by any mathematical authority. In his mind, applied mathematics also included – in addition to the disciplines enumerated above – the practical numerical methods for solving ordinary linear and non-linear equations, and similarly for solving ordinary and partial differential equations. It also encompassed the calculation of series and the execution of curve fitting, Fourier analyses, etc. To this can be added, of course, the graphical methods for solving the same types of problems.¹⁷²

The book first appeared in print, after long delays caused by the war and the immediate post-war period, in the spring of 1949. Its publication, however, which was the fruit of her intellectual activity away from work, was not enough to guarantee that she could embark upon a new career. Iris Runge quickly abandoned her initial post-war plan of establishing herself as a scientific journalist, though not before first completing an article on Lise Meitner for the women's magazine *Sie*

169 A letter to her mother dated May 11, 1939 [Private Estate]. In the same letter she noted that, having transferred to a new position at Osram, her mathematical work there was once again "fun" and respected by the engineers (see Section 3.2.3).

170 A letter to her mother dated July 10, 1939 [Private Estate].

171 See FORMAN 1981.

172 IRIS RUNGE 1949, p. 120. Regarding the "disciplines enumerated above," she referred to geodesy, descriptive geometry, and graphical statics.

[She] and agreeing to deliver a series of lectures on the women's movement at the adult education center in Berlin.¹⁷³

George Sarton, who was one of seventeen others to receive a free copy of Iris Runge's book,¹⁷⁴ renewed contact with her shortly after the war. He could not have helped but notice, after all, that she was a regular subscriber to his journal *Isis* and that she was also a standing member of the History of Science Society.¹⁷⁵ In a way, Iris Runge's relationship with Sarton came full circle when she found herself editing the German translation of a Russian biography of Isaac Newton,¹⁷⁶ a topic that had been central to Sarton's own dissertation. After the 1951 publication of this biography, Iris Runge – who had then been working for one year as a professor of theoretical physics at the Humboldt University in Berlin¹⁷⁷ – applied for a lectureship in the history of science and mathematics at the Free University in the same city. It will be fitting to bring this section to a close by mentioning that it was Max von Laue, the very man who had asked for her hand in marriage more than four decades earlier, who recommended Iris Runge's for this position, which was ultimately never established.¹⁷⁸

173 For the article, which appeared under her initials I. R., she received a payment of 120 Marks (see her letter to Estelle du Bois-Reymond dated April 20, 1946 [Private Estate]). On the lecture series, see [STB] 769 and Iris Runge's diary entry on November 28, 1945.

174 Iris Runge's list of people to receive one of her gratis copies of the biography, which is archived in the [Private Estate], includes Richard Courant (USA), Winthrop Pickard Bell (Canada), Marcello Pirani (Surry, England), Mrs. M. Berg (London), Arnold Sommerfeld, and her friends Elisabeth Staiger and Magdalene Thimme.

175 Iris Runge expresses as much in a letter to Estelle du Bois-Reymond dated August 18, 1946 and in a letter to the science historian I. Bernhard Cohen dated September 17, 1950 [Private Estate].

176 VAVILOV 1951.

177 See Chapter 5.

178 In two letters to Iris Runge – dated May 5, 1951 and September 7, 1951 [Private Estate] – Max von Laue mentioned that he had recommended her for the teaching position to Professor Lassen and Professor May. Neither of these professors at the Free University, it should be noted, could be said to have shared Iris Runge's political values. As early as 1933 – and immediately after Hans Rukop had resigned from his professorship in technical physics at the University of Cologne – the physicist Hans Lassen closed a letter with *Heil Hitler* in which he noted: "Professor Rukop directed this institute with myself and two other private assistants. Because I am now taking over the work of Mr. Rukop, it is necessary that the same number of assistants be made available to me" (quoted from [UA Köln] Zug. 9, 265). The biologist Eduard May had worked on projects concerned with biological warfare at the concentration camp in Dachau.

4.5 WAR

Why a special section on the war, especially if continuity supposedly prevailed? The major turn of events, after all, took place at the war's end. This section will briefly consider how the war and its end had weighed on Iris Runge's mind.

Continuity defined her mathematical work on the development of new electron tubes. Military research? This had existed at Osram and Telefunken before the beginning of the war, even if this theoretical expert did not connect her own work with it. A mere niche for survival? The role of German professionals during the war was complex and has since been the subject of numerous interpretations.¹⁷⁹ In comparison with the research of industrial mathematicians that had been conducted before September 1, 1939, their subsequent field of activity hardly varied. The one major change in Iris Runge's career occurred just two months before the war began, when she was transferred from Osram to Telefunken and found herself among a research group of fellow mathematicians. Her few surviving observations about these years at Telefunken convey a sense of distance and alienation, as in the following commentary about the company Christmas party in 1939:

Today we received our Christmas bags in the factory. I am now an employee at Telefunken, and they have a custom here of giving all of their workers and salaried employees a Christmas package, that is, a large paper sack full of gifts. Most of it is just grub – a bottle of wine (!), a pack of ginger bread, a little pack of colorful pastries – but there was also a mechanical pencil and a book. We were allowed to select a book from a list of sixty, and I chose a copy of Bismarck's memoirs. I do not find this custom of theirs to be very appropriate. Gift-giving is a highly personal affair and is entirely incongruous with this sort of mass distribution process, in which the giver is an anonymous concept and the receiver is just one of thousands. But of course their whole reason for doing this is to mask the genuinely impersonal relationship we have with "The Firm." *One senses purpose and it makes one cross.*¹⁸⁰

By working on the development of traveling-wave tubes and magnetic field tubes, Iris Runge was pursuing a research topic that became increasingly important over the course of the war. Karl Steimel, her supervisor, coordinated the research efforts in this field (which included the development of magnetrons, centimeter-wave technology, and measuring devices); he was responsible for ensuring – under the aegis of the so-called "Rotterdam" consortium of businesses, research institutions, and military authorities – that foreign electron tubes and other tech-

179 Scholarship on the use and development of mathematics during the Second World War is cited in Section 1.2.3. See also MAAS/HOOIJMAIJERS 2009; SACHSE/WALKER 2005.

180 A letter to her mother dated December 21, 1939 [Private Estate]. The translation of the last sentence – a quotation from Goethe's *Torquato Tasso* (II.1) – is taken from Johann Wolfgang von Goethe, "Torquato Tasso," trans. Charles E. Passage, in *Plays: Egmont, Iphigenia in Tauris, Torquato Tasso*, ed. Frank G. Ryder (New York: Continuum, 1993), p. 173. The first two volumes of Otto von Bismarck's autobiography, which were published in 1890, were followed by a third volume that was unauthorized by the family. For a discussion of Emile du Bois-Reymond's reaction to the alienating effects of mass production, see DIERIG 2006, p. 260.

nologies were either copied or improved.¹⁸¹ Telefunken, the majority of whose researchers was exempt from serving on the front, increased its research staff during the war to accommodate the profusion of military contracts. The archival records reveal, for instance, that the mathematician Hans Reichardt was hired in 1943 and that his task, as assigned by the military command, was to address the mathematical problems presented by the field of radar engineering.¹⁸² That there were probably more of such assignments than the records indicate – and thus more mathematical research groups – was suggested by the late Rolf Rigo, who joined Telefunken after having earned a degree in electrical engineering in 1939 (see [Table 12](#) in Section 3.2.4). Iris Runge continued to deploy her mathematical knowledge to make calculations for the improvement of electron tubes, all the while hoping for an end to the war:

Notschrei (1941)¹⁸³

Iris Runge

Und wenn wir besiegt werden und ins dunkelste Elend
gehn,
das ist immer noch besser als weiter auf der falschen
Seite zu stehn.
Der Seite, auf der Deutschland nun schon acht Jahre steht,
die den Geist verachtet und die Freiheit verlästert und
schmäht,
die den schnöden Erfolg mit dem höchsten Preise krönt,
die nackte Gewalt verherrlicht und das Recht verhöhnt.

A Cry of Distress (1941)

by Iris Runge

To be besieged and to enter the dark depths of
misery,
remains preferable to occupying the wrong side
of history.
This side, which has now been Germany's for some eight years,
it calumniates the intellect and liberty
besmeared;
it honors foul success with the highest of awards,
glorying in raw violence while justice it abhors.

Continuity likewise defined her recreational scholarship on the history of science. For Iris Runge, this activity functioned as a sort of elixir of life during these politically unbearable times. After she had finished the biography of her father, she immediately turned to the next project. Although Marcello Pirani was living in

181 See the minutes of this consortium's meetings at:
http://www.cdvandt.org/agr_protocols.html; and also Kai Handel's contribution in MAIER
2002, pp. 250–272.

182 See [DTMB] 3084.

183 [STB] 801.

exile in England, she nevertheless began – confident that the war would soon come to an end – to assemble material for a third edition of his book on graphical methods (see Section 3.4.1.2).

But to what degree was continuity a feature of her everyday personal life? The family stuck closely together. Aimée Runge spent much of September of 1939 with her children in Berlin, where Wilhelm and his family, Ella, and Iris were all living at the time. “Everything here is running its normal course,” as Iris Runge wrote after her mother had returned to Göttingen: “A great deal of time is wasted by having to stand in line for groceries [...].”¹⁸⁴ This had been the “normal” course of things since the beginning of the war. Everyone was assigned to a particular store to buy groceries and forbidden from shopping anywhere else. So as not to strain the food supply, so-called “Stew Sundays” (*Eintopfsonntage*) were initiated. Coal became scarce in the winter of 1940, during which Iris Runge took in her cousin Anni Trefftz, whose unheated apartment in Berlin-Schöneberg had become uninhabitable.¹⁸⁵ She also assisted her sister Ella, a pediatrician, during the latter’s Saturday evening shifts. In April of 1939, Ella had moved both her residence and her medical practice from the Thuringian town of Nordhausen to Pankower Allee in Berlin. Because of the banishment of Jewish physicians, there was now a nationwide shortage of medical professionals (on October 1, 1938, all of the remaining Jewish physicians in Germany had been stripped of their licenses).¹⁸⁶ Iris and Ella Runge spent their vacations together and dreamed of one day living under the same roof. Their correspondence with Nina and Richard Courant, who had since become American citizens, continued to take place by way of Aimée Runge. On November 3, 1940, Iris Runge informed her mother: “Now the alarms have been sounding here two to three times a week.”¹⁸⁷ Air raid sirens. The war had made its way back to Germany, and Aimée did not live to see its end. She passed away in 1941 just a few months after the death of her sister Ellen, who had been living with her in Göttingen.

Forced laborers and concentration camp prisoners were put to work in Telefunken’s electron tube factories. As directors of these factories, the researchers Willy Statz, Erich Wiegand, and Friedrich Wegener were responsible for managing this new workforce from Eastern Europe.¹⁸⁸

184 A letter to her mother dated October 25, 1939 [Private Estate].

185 See a letter from Iris Runge to her mother dated January 28, 1940 [Private Estate]. Having studied in Cambridge and worked in Newcastle, Anni Trefftz returned to Germany and passed her teaching examinations at the University of Göttingen. In 1920 she became the City Official for Social Welfare in Berlin.

186 See SEIDLER 2007.

187 A letter from Iris Runge to her mother dated November 3, 1940 [Private Estate].

188 On August 26, 1926, Russian women were assigned janitorial duties; the work of Polish women is also mentioned in later records (see [LAB] 444, vol. 1). On the managerial activity of the directors Erich Wiegand and Friedrich Wegener at the Telefunken plant in Erfurt, see MOCZARSKI et al. 2002, pp. 163–165.

At the beginning of 1945, after (re)relocating from the Lower Silesian town of Liegnitz back to Berlin, Iris Runge experienced the final stages of the war. An eight-page letter documents the survival strategy of a portion of Berlin's population. Here she described the situation with respect to provisions, transportation, and news gathering; the calm and rational way in which a fire was extinguished in her neighborhood; her successful deterrence of a rape attempt made by a Russian soldier; her pleasure in response to the first official order issued by the bolshevists, which was to tidy up the streets; and, of course, her great happiness about the end of the war. "That most of the Nazi leaders are either dead or captured," she declared, "is most reassuring."¹⁸⁹

Deutschland
Iris Runge

1935
Als ich Deutschland liebte,
hat ich mich geirrt.
Drum ist meine Liebe
Nun so ganz verwirrt.

Die, an die ich glaubte,
gabs in Wahrheit nie.
Die sich Deutsche nennen,
Fremde sind mir die.

Und mir ist wie einem,
der im Dunkeln tappt:
Hab ich eine Heimat
also nie gehabt?

1945
Trümmer rings und Scherben
Ungeduld und Neid.
Krank ist Deutschlands Seele.
Alle tragen Leid.

Alle hungern, frieren.
Dennoch kannst Du sehn,
wie sie unverdrossen
an die Arbeit gehn.

Und mein Herz ist glücklich:
Fühl ich doch, dass man
dies zertretne Deutschland
wieder lieben kann.

Germany
by Iris Runge

1935
When I loved Germany,
How greatly I erred,
For now my love seems so
Utterly absurd.

The object of my faith,
Ceased indeed to be,
And Germans proud by name,
Are alien to me.

And now I am someone
Fumbling through the night:
Has my homeland really
Never been in sight?

1945
Wreckage and shards abound,
Impatience and hate.
The German soul is ill.
Sorrow won't abate.

All are cold and hungry.
Yet it's clear to see
How still they labor onward
With great industry.

And my heart rejoices,
For I feel it's true
That this trodden Germany
Can be loved anew.

189 A letter from Iris Runge to her relatives dated May 10, 12, and 27, 1945 [Private Estate]. The entirety of this letter is reproduced in Appendix 8.

4.6 A POLITICAL PRÉCIS

The sources at my disposal have made possible a historical reconstruction that underlines certain connections between science, politics, and society that existed within a few particular branches of industrial research during the Weimar Republic and the era of National Socialism. Whereas detailed studies of this sort have already been devoted to the history of German universities, the Kaiser Wilhelm Institutes, and the German Research Foundation,¹⁹⁰ a general lack of sources has precluded a comprehensive historical investigation of the broader scientific community that supported the German industrial sector. It is known that numerous German electrical engineers were active members of the German Democratic Party and were generally stronger supporters of the Weimar Republic than were their counterparts in the coal, iron, and steel industries.¹⁹¹ The sources reveal, however, that even the relatively young electrical industry was quick to succumb to the political authority of the National Socialists, even if the sphere of industrial research offered something of a safe haven for oppositional thinking.

Osram and Telefunken were traditionally staffed by electrical engineers and physicists who espoused democratic political positions, and they offered professional opportunities to many researchers regardless of a candidate's religion or gender.¹⁹² Their parent company, AEG, had been founded by Emil Rathenau, who came from the Jewish middle class. His son Walther Rathenau, who became the president of AEG in 1915 and was active in politics, once wrote:

Every German Jew experiences a painful realization in his youth that remains with him the rest of his life, namely when he first becomes fully conscious of the fact that he came into the world as a second-class citizen and that no amount of competence or wealth can do anything to free him from this situation.¹⁹³

This provides some explanation for why many talented Jewish researchers would sidestep the bumpy road leading to an academic career and go straight into industry, where there were fewer prejudices, and where the evaluation of professional achievement depended less on such factors as race, religion, sex, and political views (before 1933, that is). To be Jewish, of course, did not necessarily entail that one was either a pacifist or a supporter of the working class. The Jewish research director Richard Jacoby, for instance – whose work and professional destiny were brought to light in the pages above, who had many patents to his name, and who encouraged the application of mathematical methods – was politically aligned

190 See especially MAIER 2002, 2007a, 2007b; RÜROP 2008; FLACHOWSKY 2008; and TRISCHLER/WALKER 2010.

191 See MOMMSEN 1998.

192 In her study of radium research in Vienna, Maria Rentetzi describes a similarly liberal situation in which the careers of women and Jewish scientists, at least before 1938, were free to develop (see RENTETZI 2009).

193 Walther Rathenau, *Staat und Judentum: Eine Polemik* (Berlin: S. Fischer, 1918), pp. 188–189. See also GALL 2009; PULZER 2003.

with the industrialists and capitalists. Walther Rathenau, who was assassinated in 1922 while serving as Germany's Foreign Minister, had supported the armament policy during the First World War and encouraged the deportation of Belgian civilians to work as forced laborers in Germany. As a cofounder of the German Democratic Party, he also mixed with right-wing, conservative circles. Military research, to which industrial cooperation was so essential, also had a tradition at AEG.¹⁹⁴

That said, one of the founders of Telefunken, Graf Georg von Arco, had not only cofounded the pacifist New Fatherland League (*Bund Neues Vaterland*) during the First World War; he also served as the chairman, from 1921 to 1923, of the German Monistic League (*Deutscher Monistenbund*), which promoted the dissemination of scientific knowledge, encouraged a secular ethos, and maintained a pacifist stance after the First World War.¹⁹⁵ Along with the likes of Albert Einstein, Paul Löbe, Thomas and Heinrich Mann, and Arnold Zweig, Georg von Arco was one of the founding members of the Corporation of Friends of the New Russia (*Gesellschaft der Freunde des Neuen Russlands*), which was inaugurated on June 1, 1923.

The purpose and existence of this latter organization should be discussed in the context of German foreign policy. After Germany and Russia had been economically, politically, and academically ostracized by the Western European victors after the First World War, the two nations ratified the Treaty of Rapallo, which was signed by Walther Rathenau on April 16, 1922, in order to normalize their diplomatic relations by renouncing their respective financial and territorial claims. Based on this development, German businesses began to shift their orientation to the Soviet Union, a fact that explains, for instance, why Arco celebrated his sixtieth birthday in Moscow in 1929. During this year, in fact, German relations with Russia were far less unusual than some have claimed.¹⁹⁶ It was not only the case that "the interesting experiment of bolshevism" was on everybody's mind, as can be gathered from Iris Runge's correspondence (see Section 4.1.5); Moscow also played host to a "Week of German Engineering" in January of 1929 under the auspices of Albert Einstein.¹⁹⁷ The Association of German Engineers agreed on a collaboration with Russian colleagues that resulted in engineering conferences, attended by German representatives, being held twice a month on Soviet soil. Hans Rukop, whom Arco had appointed to oversee electron tube research at Telefunken in 1914, accepted an invitation in October of 1929 from the Soviet Commission for National Education to give lectures in several cities in the Soviet Un-

194 See WEISS 1996; the latter's contribution in MAIER 2002, pp. 109–141; and WEISS 2005.

195 After 1922, the New Fatherland League became the German League for Human Rights (*Deutsche Liga für Menschenrechte*). The German Monistic League was founded in 1906.

196 See FUCHS 2004; HEEKE 2003.

197 HEEKE 2003, p. 66. It is less commonly known that Einstein, who is so famous for his contributions to theoretical physics, was also accomplished in the field of engineering. He himself did not attend the event in Moscow.

ion, and these would not be his first trips to the east.¹⁹⁸ Among the many others to travel to Russia during these years can be counted the mathematician Richard von Mises and the physicist Max Born (who both attended the Sixth Congress of Russian Physicists in August of 1928); the mathematicians Emil Julius Gumbel, Emmy Noether (a guest professor in Moscow in 1928/29), and Marie Torhorst; as well as Arnold Sommerfeld, Peter Debye, and Peter Pringsheim, who participated with Max Born and other German scientists in the first All-Union Congress of Soviet Physicists, which took place in Odessa during the late summer of 1930.¹⁹⁹

When the global economic crisis dawned in 1929, bringing with it the imminent threat of mass layoffs,²⁰⁰ many parties responded to the popular call for a political upheaval. The overtures expressed in the literature of the Social Democratic Party – namely for solidarity with the common people, for a socialist overhaul of the economic system, and for stricter regulations of the banking and credit industries (how familiar!)²⁰¹ – are each reflected and supported in the letters that Iris Runge wrote during this period. Because systemic changes of this sort were naturally unappealing to the banks and to the representatives of heavy industry, these businesses threw their support behind Hitler's party, with which other industrial factions had also made arrangements for the sake of securing government and military contracts.

The Jewish executives and board members at Osram and Telefunken, such as the prominent lawyer William Meinhardt,²⁰² were forced to resign as early as 1933, and other Jewish employees were gradually released in the subsequent years under the pressure of the National Socialists. Even if certain indispensable experts were able to remain as directors somewhat longer than expected (Richard Jacoby, for instance), every Jewish employee had ultimately been released from Osram and Telefunken by 1938, as was also the case for Jewish researchers who were still working at universities or serving as the editors of scholarly journals.

The board members at Osram and Telefunken who were responsible for research and development and who held their positions until the end of the war, such as the physicists Karl Mey and Hans Rukop, were later judged to have operated –

198 The letter of consent that Rukop received from the German Office of Foreign Affairs to travel to Russia, which was dated August 16, 1929, began with these words: "Because you are already familiar with Russia [...]" (see [UA Köln] Personalakte H. Rukop, Zugang 17, No. 4184).

199 See Max Born's letter to Einstein dated November 20, 1928 in BORN/EINSTEIN 2005. On Emil Julius Gumbel, see VOGT 1991. On Emmy Noether, see TOBIES 2003; and TORHORST 1982/1986. The attendees of the First All-Union Congress of Soviet Physicists (1930) are recorded in MEYENN 2002.

200 In Osram's corporate records, for instance, it is mentioned that the first employees to be fired in response to the economic crisis would be married woman laborers, of which there were thirty at the time (see [LAB] No. 654, p. 267). This policy was maintained until November 13, 1931.

201 See, for instance, a report released by the Social Democratic News Service (*Sozialdemokratischer Pressedienst*) on February 17, 1932.

202 On William Meinhardt, see LUXBACHER 2003, pp. 282–284.

both within their businesses and as members of scientific associations – as political independents during the Nazi era.²⁰³ Rukop, offended by the necessity of filling out political surveys in 1933, resigned from his professorship in Cologne and returned to his former position on Telefunken's executive board. There, within the department of electron tube research under his control, he was able to maintain a political atmosphere that was largely immune to the interference of party politics. The researchers working under Steimel did so in the name of technological progress and seemingly without any misgivings about the military relevance of the products that they were helping to produce. As Herbert Mehrstens has suggested, the majority of German experts in mathematics and engineering went about their work in a decidedly apolitical manner, though they also felt beholden to "nation and fatherland" (*Volk und Vaterland*).²⁰⁴ It is impossible to know for sure whether Rukop had abandoned his professorship in order to work with more political freedom or whether there might not be some other reasons. Regardless, his position in industry allowed him to act under far less surveillance. A fitting counterexample is the case of Abraham Essau. Like Rukop, Essau had worked at Telefunken and had held an industry-funded professorship (his at the University of Jena). Unlike Rukop, however, Essau decided to stay in academia – he was appointed university rector on April 1, 1932 – and as a consequence he obsequiously joined the Nazi Party in May of 1933.²⁰⁵

A politically active researcher like Iris Runge – who had recognized the dangers of National Socialism early on; who had been engaged in the Social Democratic Party, the Samaritan Workers' Federation, and the Children's Friends movement; and who had not kept her critical opinions of her supervisors to herself – was nevertheless able to keep her position as an industrial researcher on the basis of her acknowledged talent. Even though the act of solving mathematical problems never lost its allure to her, there is a sense that her work life had grown rather routine and uninspiring. When pondering her job, that is, she was no longer moved to rejoice as she had earlier been impelled to do ("life is wonderful!").²⁰⁶ Whereas, before 1933, Iris Runge was eager to bring her research projects home with her after work, her free time during the Nazi era was devoted to surreptitious political gatherings and, above all, to the history of science.

There were still other researchers, of course, who were not personally threatened by the Nazi regime; in fact, they saw in National Socialism an opportunity to advance their own careers. Even if they were not necessarily in full agreement with the political direction of the country, they were nevertheless caught up in the prevailing spirit of change and optimism. It is in such terms that Max Steenbeek, a researcher at Siemens-Schuckert, described these years in his autobiography. Just

203 See especially HOFFMANN/WALKER 2007.

204 See MEHRTENS 1995 and 1996a.

205 See [UA Jena] Bestand BA, No. 930.

206 A letter from Iris Runge to her parents dated March 4, 1923 [Private Estate]. Quoted above in Section 3.2.2.

as it was a mark of distinction to be invited to join one of the Kaiser Wilhelm Institutes, as happened to Peter Debye and Werner Heisenberg, it was no less of an honor to participate as supervisors in nationwide research consortiums, as did Hans Rukop and Karl Steimel, or to become, like Wilhelm Runge, a member of the prestigious German Academy of Aeronautical Research (*Deutsche Akademie der Luftfahrtforschung*).²⁰⁷ Individual researchers carried on with their professional duties much as they did before 1933, and most of them were able to appreciate their jobs as one of the few steady factors during these otherwise tumultuous years. In this regard, the calculation of electron tube parameters was a scientific task like any other.

Businesses profited from the armament and wartime policies of the “Third Reich,” especially because the principal clients during these years were the government and the military. The electron tube laboratory experienced a seamless transition from its peacetime activity, during which it had already developed various tubes for the military, to its role in fulfilling wartime contracts. That said, the intended application of electron tubes shifted during the 1930s from radio broadcasting to the technologies required by numerous branches of the military (see Section 3.2). The mathematical principles underlying the design of electron tubes, which were of equal value to all conceivable applications, were undoubtedly used to serve military ends. As an industrial mathematician, Iris Runge was unable to elude the disdainful exercise of satisfying a direct request for expert advice from the military authorities (see Appendix 5.6).

In the end, there was considerably more room for political dissent in the field of industrial research than could be expected in government institutions. The researchers who were active in the laboratories of Osram and Telefunken, or at least in those that have been examined here, were largely opposed to the Nazi dictatorship and did not belong to the National Socialist German Workers’ Party. At the same time, they still functioned as part of the larger system, a fact that underscores, as mentioned earlier in this chapter, the Janus-faced nature of both the acquisition and the application of scientific knowledge.

207 Founded in 1936 and dissolved in 1945, the German Academy of Aeronautical Research consisted of only thirty-six members (see [DTMB] 4413, p. 56)

5 POST-WAR DEVELOPMENTS AND CONCLUDING REMARKS

Even worse are all of these deportations, about which you've surely read in the newspaper. These have affected several of my acquaintances, former Telefunken people. In any case, I'm very pleased to have turned down the job that was offered to me by my former boss, Dr. Steimel, because the laboratory that I would have joined has been strongly affected by these events, including Steimel himself. I'm quite happy to be working at the university now, which is a hundred times better.¹

German scientists whose research had been relevant both for civilian and military purposes were generally faced with two difficult alternatives after the Second World War. They had to decide, that is, between abandoning either their country or their field of expertise. According to the resolutions of the Allied Control Council, which had been established at the Potsdam Conference in July and August of 1945, communications and electrical engineering were deemed relevant to military research, and therefore the production and development of communications equipment and electrical devices could only be recommenced on German soil in a closely monitored and tightly restricted manner.² A look at the post-1945 fates of the former electron tube researchers at Osram and Telefunken reveals that a great many of them relocated to new German cities or left the country altogether.³

Karl Steimel, a university-trained mathematician and the director of electron tube development at Telefunken who in 1943 had been given nationwide supervisory responsibilities in the field, remained a leading figure in German industry. Even before the calling together of the Potsdam Conference, he had managed to secure a position of authority under the Soviet occupying power, first in eastern Berlin and for several years in Russia itself. As evidenced by his letter to the district mayor of Berlin-Zehlendorf, which was discussed above, Steimel had made arrangements before June 16, 1945 to open an institute for electron tube research on the outskirts of Moscow (see Appendix 9). As part of this task, he was required to select researchers for this new institute from his own staff. The latter worked for some time in the eastern half of Berlin – specifically at the so-called Laboratory, Design Office, and Experimental Plant “Oberspreewälder” in Oberschöneweide

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- 1 A letter from Iris Runge to Estelle du Bois-Reymond dated November 3, 1946 [Private Estate].
 - 2 See the *Official Gazette of the Control Council for Germany* (Berlin: Allied Secretariat, 1945–1948), Nos. 1–19; *The Conference of Berlin (The Potsdam Conference), 1945*, Foreign Relations of the United States: Diplomatic Papers 7015–7163 (Washington, D.C.: Government Printing Office, 1960); and ABELSHAUSER/SCHWENGLER 1997, pp. 205, 226–227.
 - 3 The moves of these researchers after 1945 are documented in [DTMB] 6734. See also the references to many of these researchers in Sections 3.2.3 and 3.2.4 above.

(*Labor, Konstruktionsbüro und Versuchswerk Oberspree*) – before being relocated to Fryazino (near Moscow) in October of 1946.⁴ Whereas the newspapers reported on compulsory relocations and deportations, not everyone seems to have been fully informed that their new jobs would take them farther east than merely eastern Berlin. It is clear from Steimel's letter, however, that this had been the intended goal all along. Steimel himself was able to return to Germany in 1952. After spending a few weeks in East Berlin, according to his son, he was reappointed to his former executive position at Telefunken in West Germany.⁵ In 1956 he founded a new research institute for AEG, which was located in Frankfurt am Main, and in 1962 he was made the chief research director at the latter corporation. Steimel was awarded an honorary doctorate and an achievement award by the Association of German Electrical Engineers (*Verband Deutscher Elektrotechniker*).⁶

Following the end of the war, Berlin was occupied exclusively by Soviet troops until June 30, 1945, after which the other occupying powers seized their own defined territories both in the city and throughout all of Germany. Whereas a number of Telefunken's researchers had decided early on to work for the Soviets, others went on to collaborate with the other occupying authorities. On July 1, 1945, American troops forced approximately forty executives from the Zeiss Optical Company (*Optische Werke Zeiss*) and the Schott Glass Factory (*Glaswerke Schott*) – both in Jena, Thuringia – into the backs of trucks and took them to southern Germany. A good amount of historical research has already been devoted to this and other compulsory relocations of German researchers and managers whose work had been deemed relevant to the war efforts.⁷

Siegfried Wagener, whose work on oxide cathodes Iris Runge had critiqued (see Section 3.5.2 and Appendix 5.5), went on to work in a managerial capacity for various British and American companies after 1945. He ultimately retired in Switzerland as the director of electronics at the European headquarters of Union Carbide, an American corporation based in Cleveland, Ohio. Werner Kleen, who had led the development of military tubes at Telefunken and published, with Horst Rothe, a book series on electron tubes that cited Iris Runge's latest results, proceeded to work at the Centre de Recherches de Compagnie Générale de T. S. F. in Paris from 1946 to 1950 and at the Instituto Nacional de Electrónica in Madrid from 1950 to 1952, at which point he returned to Germany to join Siemens & Halske's electron tube factory. In 1956 he was awarded an honorary professorship by the Technical University in Munich, and from 1968 to 1971 he served as the di-

4 The names of twenty-one of these researchers are recorded in [DTMB] 07813, pp. 2–4. See also ALBRECHT et al. 1992; and NAIMARK 1995.

5 The author would like to thank Professor Andreas Steimel for this information.

6 For a recent biographical article on Karl Steimel, see NDB, vol. 25.

7 See, for example, KUROWSKI 1982; BOWER 1987; TRISCHLER 1992; and TOBIES 2005b. A representative example is the secret military project of the United States known as Operation Overcast. Begun in 1945 and later renamed Operation Paperclip, this project aimed to naturalize several German scientists as American citizens.

rector of the European Space Research and Technology Centre in Noordwijk (see Section 3.2.4). It should also be noted that, in 1957, he was named a fellow of the Institute of Radio Engineers in New York (IRE), and that he was later recognized, in 1982, with the Frederik Philips Award, which is bestowed by the Institute of Electrical and Electronics Engineers (IEEE).⁸ Another figure to be named is Max Knoll, the co-inventor of the electron microscope and the director of a research group within Telefunken's television department from 1932 to 1945 (see Section 3.2.4). After working at Princeton's Department of Electrical Engineering from 1948 to 1956, Knoll was installed as the first professor of electronics at the Technical University in Munich.

As of 1947, other former researchers at Telefunken were able to continue their work on electron tubes within the British zone of western Berlin. Among these was Horst Rothe, who retained an executive position. In response to an application submitted on July 4, 1947, the British authorities permitted German companies to conduct fundamental research in the field of electron tubes (see Appendix 10 and Plate 15). However, research of an applied sort remained subject to authorization as late as 1950, for which reason Telefunken decided to move its business operations to Ulm in Bavaria.⁹ In 1956, Rothe received a professorship in communications engineering at the Technical University in Karlsruhe (Baden), and two years later he arranged for the establishment of an associate professorship in high frequency engineering and electronics, a position that was made a full professorship in 1964. He was also named a fellow of the American IRE, an institute that would merge with the IEEE in 1963.¹⁰

After the war it became a typical career path for former industrial researchers to make use of their talents as university professors. Before turning to Iris Runge's particular case, it seems appropriate to mention a few others who followed this trajectory. Friedrich Wilhelm Gundlach, whose pre-1945 area of expertise had been velocity-modulated tubes and whose FIAT Review explicitly mentions Iris Runge's mathematical work on magnetic field tubes, was able to complete a *Habilitation* at the Technical University in Karlsruhe while working as a laboratory director in one of Siemens & Halske's plants in that city. In the fall of 1949 he became a professor and the head of the Institute for Telecommunications at the Technical University in Darmstadt. Gundlach's 1949 book, *Grundlagen der Hochfrequenztechnik* [Principles of High Frequency Engineering], and his *Taschenbuch für Hochfrequenztechnik* [Handbook for High Frequency Engineering], which he co-edited with Hans H. Meinke, both became standard works in the field. In 1954, Gundlach transferred as a full professor to the Institute for High Frequency Engi-

8 See [DTMB] 7779, 6734; and POGG.

9 See the semi-annual report – for the period of April 1 to September 30, 1950 – of Telefunken's department of electron tube development, which was directed by Horst Rothe in Berlin (archived in [DTMB] I.2.060, C 00199).

10 See *Proceedings of the IEEE* 54.8 (1966); and *Nachrichtentechnische Zeitschrift* 17 (1974), p. 233.

neering at the University of Berlin, where his research focused once again on velocity-modulated tubes, as well as on semiconductors, microwaves, and digital radar, among other things. Like Werner Kleen and Horst Rothe, Gundlach was also made a fellow of the IEEE. Wilhelm Runge, too, was given an honorary professorship at the Technical University in Berlin, a position that he held from 1953 to 1964 in addition to his managerial role at Telefunken. Having worked at Telefunken from 1929 to 1945, Waldemar Ilberg returned to his home town of Leipzig, where he completed a *Habilitation* in 1947 on the subject of electrophysics and was given a full professorship. Erik Scheel, whose mathematical talents had been instrumental to the electron tube research at Telefunken and who had worked closely with Iris Runge as of 1939, became a lecturer at the Technical University in Karlsruhe, where he had already completed his *Habilitation* in the year 1937. Herbert Daene, another former researcher at Telefunken, worked as a professor of astrophysics in Potsdam after 1945.¹¹ Finally, Walter Heinze, with whom Iris Runge had shared her first work space at Osram and who had been in charge of Telefunken's department of television tube development, went on to establish a division for electron tube development at the Funkwerk Erfurt, a radio factory put under the authorization of the Soviet occupying power at the end of the war. Heinze would complete his *Habilitation* at the University of Jena in 1954 and would become, in 1958, a professor of electronics at the College of Electrical Engineering in Ilmenau.¹²

Though somewhat older than the men named above, Iris Runge was likewise presented with the opportunity to enter academia and thus to avoid the unwelcome prospect of having to work on behalf of one of the occupying powers. At that time it was unusual for women researchers of her age to embark upon such a career; an examination of her motives reveals two explanations that reflect, respectively, the professional and political aspects of her character. Her professional motivation was largely based on her expertise in mathematics:

Mathematics is indeed a beautiful affair. As soon as one's mathematical abilities are recognized, everything is fine and one is treated with the utmost respect. I'm left with the impression that Berlin is now suffering from a severe shortage of people with such abilities, so much so that it feels as though I almost have a monopoly on the subject. Working with the students has been highly enjoyable, and working with theoretical physics, of course, has been even better.¹³

Following the closing of Telefunken's electron tube laboratory after the war, Iris Runge began to earn her living by giving private mathematics lessons, by delive-

11 See POGG.

12 The College of Electrical Engineering in Ilmenau (*Hochschule für Elektrotechnik*) has since become the Technical University of Ilmenau (*Technische Universität Ilmenau*). Walter Heinze was appointed rector of the College in 1958 (see [UA Ilmenau] Personalakte; [UA Jena] Habilitationsakte). For more information about Heinze's career, see SCHARSCHMIDT 2000; HOFFMANN/HERBST 2006.

13 A letter from Iris Runge to Estelle du Bois-Reymond dated June 9, 1946 [Private Estate].

ring lectures on practical mathematics at the adult education center in Spandau, and by working as a teaching assistant at the Technical University in (western) Berlin.¹⁴ As a teaching assistant, she graded assignments for Ernst Mohr, a professor of applied mathematics, and for Aloys Timpe, a former student of Felix Klein who taught business mathematics.¹⁵ From her letters we know that her income at this time was extremely low, never exceeding 100 Marks a month, and for this reason she took on an additional assistantship under the theoretical physicist Friedrich Mögliche at the University of Berlin, which was located on the eastern side of the city (later the Humboldt University).¹⁶

Friedrich Mögliche was hired as a professor in January of 1946. Having studied theoretical physics under Erwin Schrödinger and Max von Laue, Mögliche earned a doctoral degree in 1927 and completed his *Habilitation* three years later. He soon made a name for himself in the field of wave optics, which was also one of Iris Runge's areas of research. Because his political differences with the Nazi regime had prevented him from beginning an academic career, Mögliche turned to the industrial sector, where he had the opportunity to work, for instance, for Osram's Research Society for Electrical Lighting.¹⁷ At Osram he came to know and appreciate Iris Runge, and so he hired her to be his second research assistant on May 15, 1946. In a letter to the university administration, he explained that her twenty-two years of service as an industrial researcher should be taken into consideration when determining her salary:

She is a first-class scientific authority who was exclusively engaged in conducting scientific research during her time in industry. It is this very research, in fact, that has occasioned me to install her as an assistant at the Institute for Theoretical Physics. Accordingly, her experience in the industrial sector is of fundamental importance to her current work at my institute.¹⁸

This is a fitting place to revisit Iris Runge's achievements as a researcher in the electrical and communications industries, work that she undertook under the motto *Berechnen statt Stöpseln*, that is, "calculation instead of trial and error."

First, however, it will be necessary to offer a few explanatory remarks about the German verb *stöpseln*, which stands at the heart of her formulation (the verb is made a noun when capitalized). Related to English *stop*, the word *stöpseln* has meant 'to plug, to block' since as early as the sixteenth century. In electrical engi-

14 See the personnel questionnaires filled out by Iris Runge on May 28, 1946 and February 2, 1948 (both of which are archived in [UAB] R 387); and see her diary entry from November 28, 1945 (in [STB] 769).

15 Ernst Mohr had completed his doctoral degree in 1933 under the supervision of Hermann Weyl in Göttingen. In 1944 he was sentenced to death by a Nazi tribunal, but the end of the war fortunately prevented this sentence from being carried out.

16 On the post-war state of the physics faculty at the University in Berlin-East, see HOFFMANN 2010. The name "Humboldt University" was not introduced until February 8, 1949.

17 On Friedrich Mögliche's academic abilities and his rejection of National Socialism, see HOFFMANN/WALKER 2003.

18 A letter by Friedrich Mögliche dated October 14, 1946 (in [UAB] R 387, vol. 1, p. 21).

neering, the related term *Stöpsel* was and continues to be used – alongside the more familiar word *Stecker* – for any sort of electrical plug or connector. It has been used, for instance, to designate the detachable and temporary connections that are used during the experimental phases of circuit board and switchboard design. By means of a *Stöpsel*, electrical connections can be both made and broken, and as a component of more sophisticated testing technologies it can allow engineers to avoid such things as soldering or tinkering with screws. In this way it can be tested (*gestöpselt werden*) whether a given circuit can be realized, and experimental designs can be set up both quickly and easily, the components of which are available to be used again in subsequent experiments. With reference to such a process, the word *Stöpseln* more or less came to mean ‘trial and error’.

That a trial-and-error approach to things long dominated in the laboratory setting was stressed to me by Horst Beeken, who not long ago served as the head of a department of development for Telefunken in Berlin.¹⁹ However, once the experimental and engineering processes had been well defined, it became possible to make advance calculations and thus to reduce the efforts of trial and error to a minimum. This new style of thinking – “calculation instead of trial and error” – represented a paradigm shift in the industrial laboratory that was gradually adopted at Osram and Telefunken during the 1920s. Driven to economize their operations, these international businesses turned to applying mathematical methods to their light bulb and electron tube research and to using statistical methods to monitor and control production processes. It became a dictate of reason and economic efficiency to evaluate these processes on a mathematical basis and to test the practicality of new product ideas with mathematical models.

During the worst of the inflationary period after the First World War, Osram invested in mathematical talent by hiring Hubert Plaut, who held a doctorate in mathematics, to lead its department of technical statistics, and by hiring Iris Runge, whose dissertation in physical chemistry was distinguished by its use of mathematical methods, to lend her mathematical expertise to the processes of design, development, and production. It is no coincidence that the people who implemented this new style of thinking, namely a woman and an avowedly Jewish mathematician, happened to be “outsiders” in the university system of the 1920s. These two had a decidedly easier time establishing themselves in industry than they would have had in a university setting, and they found themselves working under research directors who welcomed and encouraged a mathematical approach to solving problems. These directors included the chemist Fritz Blau, who had insti-

19 My personal conversation with Horst Beeken took place on September 23, 2009. Beeken, who has several patents to his name and who had been responsible for managing the radio technology during the 1972 Olympics in Munich, said that approximately eighty percent of the developmental work in his department had relied on the method of trial and error instead of calculation. Our meeting brought to light a surprising coincidence, too, namely that Iris Runge had lived from 1935 to 1966 in an apartment building in Berlin-Spandau that Beeken later inherited from his grandfather.

gated Iris Runge, Hubert Plaut, and Richard Becker to write the first book on the application of statistics to problems of mass production; and the chemist Richard Jacoby, who sought mathematical lessons from Iris Runge and built her reputation at Osram as a mathematical authority. Among these directors, too, was the physicist Marcello Pirani, who worked on the side as a professor at the Technical University in Berlin and who had been quick to recognize and promote the value of Iris Runge's and Plaut's mathematical expertise within Osram's laboratories.

If these figures and their accomplishments have remained in relative obscurity – and the same can be said about the dawn of industrial mathematics in general – this has had much to do with the “outsider” positions held by the cast characters that had been marshaled together to design and produce products for the electrical and communications industries. They died, emigrated, were murdered, or simply walked away from industrial research after the war. Their efforts have further been obscured by the fact that electron tubes were ultimately deemed to have been relevant to the German military. This judgment resulted in the ban of electron tube development on German soil after 1945 and in the displacement of experts who otherwise might have been in a position to report about the history and developments of this area of research. Neither the FIAT Reviews of German Science, which had been prepared for the American occupying power, nor Karl Steimel's report on the state of electron tube research, which he compiled for the Soviet authorities, go into any detail about the role of mathematics in industrial research.

The present study has demonstrated that Osram and Telefunken undoubtedly profited from the use of mathematics in their developmental laboratories. Iris Runge, above all, was able to establish herself as a mathematical authority on account of her contributions to Osram's light bulb and electron tube research. Having been transferred to Telefunken, she was able to install herself among a group of mathematicians whose sole assignment was to make calculations that might facilitate the development of electron tubes. She distinguished herself throughout her industrial career by her ability to create mathematical models for problems of physics, chemistry, engineering, and business. Among her many contributions can be numbered:

1. The mathematical treatment of problems of materials research, ranging from the diffusion problems of binary systems addressed in her dissertation to her quantum-statistical analyses in the field of solid state physics.²⁰ Her contributions in this area addressed both the problem of so-called “homogenization,” which remains relevant today, as well as issues pertaining to similarity and dimensional analysis.

20 For the latter contributions, see Iris RUNGE 1950a, 1950b. She also addressed the matter of quantum statistics in a lecture – “Wahrscheinlichkeit und Statistik in der Anwendung auf physikalische und biologische Probleme” [The Application of Probability and Statistics to Problems of Physics and Biology] – that she delivered during the summer semester of 1950 (for the general contents of this lecture, see [UAB] R 387, vol. 2, p. 19).

2. The systemization of existing graphical methods in the second edition of Marcello Pirani's *Graphische Darstellung in Wissenschaft und Technik* [Graphical Representation in Science and Engineering] and the creation of her own graphical methods for many specific practical problems.
3. The systematic representation of statistical methods and their applicability to problems of mass production (with special reference to the concrete problems of light bulb production) in the textbook co-authored with Richard Becker and Hubert Plaut.
4. The development of a quality control formula for medium-sized control samples.
5. The systemization, dissemination, and presentation of her knowledge in the fields of color vision and colorimetry, which she ultimately consolidated for publication in the *Handwörterbuch der Naturwissenschaften* [Concise Dictionary of the Natural Sciences].
6. The design of new scientific devices (optical micrometer, colorimeter) and the improvement of measuring instruments that can be said to have stimulated the development of research technologies in a variety of fields.
7. Contributions to the theory of electron emission, including a contribution to the theory of velocity-modulated tubes and the development of a mathematical model for a four-split magnetic field tube, the results of which were incorporated into international textbooks on the subject.
8. The calculation of electron tube parameters, the systematic tabular representation of previous formulas derived for calculating the penetration factor, and the development of her own formulas for specific tubes. Several of her results in this area of research were still being cited in textbooks as late as 1955.
9. The correction of errors or inaccuracies made by both young and established scientists (Heinrich Barkhausen, Adolf Güntherschultze, Arthur von Hippel, Lothar Oertel, Lord Rayleigh, Erwin Schrödinger, Siegfried Wager), corrections that were enabled by her strong theoretical knowledge and her mathematical approach to problem solving.
10. All told, Iris Runge's contributions as a mathematical consultant yielded wide-ranging results with relevance to engineering, physics, chemistry, and industry.

The practice of mathematics in industrial laboratories required wide-ranging qualifications. My analysis of the personnel structures at Osram and Telefunken has revealed that the first generation of industrial mathematicians (and those who promoted the use of mathematics) had received their fundamental education at universities, as opposed to having attended technical universities or apprenticed. Based on their years of study at the University of Göttingen, an international center for science and mathematics, Iris Runge, Wilhelm Runge, and Reinhold Rüdtenberg were able to introduce new mathematical research methods to their res-

pective workplaces – Osram, Telefunken, and Siemens-Schuckert. The directors Jacoby and Pirani had also received a broad university education that allowed them to recognize and appreciate mathematical talent. At the beginning of the 1930s, the tube research at Telefunken was placed under the direction of Karl Steimel, another university-trained mathematician who was able to identify and foster the abilities of a new generation of electrical engineers.

Efforts have been made in recent scholarship to determine which institutions had stood at the forefront of pre-war scientific research, and which institutions had only been recognized for their innovation after the fact, as was the case with Ludwig Prandtl's Kaiser Wilhelm Institute for Fluid Dynamics in Göttingen.²¹ Regarding the relationship between theoretical and practical research in industrial laboratories, the sources examined for this book make it clear that the economic interests of the businesses always held sway over the scientific interests of the individual researchers. A good deal of fundamental and theoretical research was indeed conducted by various industries, but the aim of this research was typically to enable the development of new products. A theoretical model of a magnetron, for instance, may have represented an advancement in mathematical methods, but it could also be used to serve specific civilian and military purposes. It would be idle in this context to draw a fine line between the theoretical and the practical, in the same way that it would be idle to deny – as Felix Klein and Carl Runge had shown during the early years of the twentieth century – the essential unity of pure and applied mathematics.²²

Whereas the groundbreaking research of the Kaiser Wilhelm Institute for Fluid Dynamics, as Moritz Epple has discussed, was enabled to some extent by its (relative) independence from the state, the research conducted at Osram and Telefunken came to be restricted, at least in part, by the large number of contracts from the government and the military. Though already oriented toward mass production, Telefunken nevertheless had to resort to short-term solutions to satisfy the enormous quantities of specialized electron tubes that had been ordered by the military. These contracts led to shifts in both the research interests and the personnel of the company; television research, for instance, was reduced and outsourced to Paris, and the funding for research on centimeter-wave technology was drastically cut. Numerous new types of tubes, none of which was of great significance from an engineering perspective, were developed for each branch of the armed forces, and it was only toward the middle of the war that the government permitted civilian radio tubes to be used in military devices.²³ Moreover, it was only during the second half of the war, once it had been recognized that Germany's radar technology

21 See Gerhard Simonsohn's contribution in HOFMANN/WALKER 2007, pp. 294–295; and EPPLE 2002a.

22 See Section 2.3.1.

23 This information is related in a report on the history of research at Telefunken that was submitted on July 24, 1945 (see [DTMB] 7779, pp. 104–106).

was obsolete, that researchers were forced to concentrate on magnetrons and magnetic field tubes.

Because Karl Steimel had been appointed by the government to coordinate the nationwide development and production of electron tubes, all of the researchers in his employ – Iris Runge included – were at least tenuously involved with the military apparatus. The ineluctability of such involvement is evidenced, for instance, by a scientific report that Iris Runge was requested to supply to a research consortium of the Association of German Engineers, an organization known to have promoted and facilitated military research (see Appendix 5.6). Iris Runge's own research methods did not differ from those of the male mathematical experts employed at other laboratories, both in Germany and abroad, that were associated with the electrical industry. Because the importance or unimportance of mathematical contributions could be evaluated rather objectively, gender bias had little influence over the hiring process and laboratory assignments in this area of research.²⁴

Techno-science, which has recently come under an increasing amount of feminist criticism, was in its nascent stages during the (pre-computer) years investigated in this book. The critiques of modern techno-sciences – as well as of the entwinement of industry, science, and technology – have been somewhat redolent, however, of Luddism.²⁵ We are currently able to describe economic, engineering, physical, and biological processes with mathematical models and to simulate these processes on computers. Such scientific progress can be put to many worthy uses, of course, and it also cannot be stopped: “What was once thought can never be unthought,” in the words of the playwright Friedrich Dürrenmatt.²⁶ Whatever is capable of being thought will eventually be thought, and in a society in which money is the governing force, everything that might yield a profit will undoubtedly come to fruition.

Although electron tube researchers were able to make the post-war transition to academia on account of their distinguished professional achievements, their political behavior during the period of National Socialism, as the case of Iris Runge makes clear, was also an influential factor in their career change.²⁷ Having applied to conduct her *Habilitation* research at the University of Berlin on January 31, 1947, Iris Runge was soon exempted from the typical requirements of having to complete a post-doctoral dissertation and from having to present her research at a scientific colloquium. On account of her previous publications, all that was required of her to be awarded this academic rank – along with the concomitant permission to teach at the university level (the so-called *venia legendi*) – was to deli-

24 See HEINTZ 2003; DASTON 2003; and DASTON/SIBUM 2003.

25 For a philosophical perspective, see the critique and analysis in WEBER 2003.

26 Friedrich Dürrenmatt, *The Physicists*, trans. James Kirkup (New York: Grove, 1964), p. 92.

27 Klaus HENTSCHEL (2007) has shown that, as regards physicists, the careers of Nazi sympathizers were not necessarily hindered after the war if the latter had acquired a certificate of de-Nazification (*Persilschein*).

ver a satisfactory sample lecture. This she did on February 15, 1947, and as her theme she chose what had been a central concern at Osram and Telefunken, namely the noise produced by electron tubes.²⁸ One week after this lecture, Friedrich Möglich filed an application for Iris Runge to be awarded a teaching position devoted to “the mathematical principles of theoretical physics,”²⁹ in response to which she was ultimately assigned to teach courses as of the summer semester of 1947 (see Appendix 11).

As early as December 15, 1947, the university faculty of science and mathematics endorsed Iris Runge’s nomination to become a *Dozentin*, a position that is roughly equivalent to that of an assistant professor in America or that of a senior lecturer in the United Kingdom.³⁰ According to the university records, however, it is apparent that the administration took a considerable amount of time to process her application, and in this respect it is possible to speculate about the political factors that had come into play. Iris Runge continued to live in western side of Berlin, and the university was in the east. She also remained a member of the Social Democratic Party, whereas the latter had already united with the German Communist Party in Soviet-controlled Germany to form the Socialist Unity Party of Germany (*Sozialistische Einheitspartei Deutschlands*). Members of this latter party had a far easier time finding employment in eastern Berlin. Although there is no documentation to prove that party politics might have exercised a degree of influence over Iris Runge’s candidacy for the position, this is still a factor that ought to be kept in mind.

On February 18, 1949, Friedrich Möglich mailed a letter to the administrative director of the (now) Humboldt University in which he insinuated that Iris Runge had been entertaining the idea of returning to Telefunken.³¹ It did not come to that, however. Rather, the faculty once again endorsed Iris Runge’s candidacy to remain among their ranks as a *Dozentin* and filed a new application on her behalf. Unlike their first endorsement, this renewed effort was processed by the administration without delay. It also included memoranda concerning her professional achievements and her political position during the Nazi era, one of which read as follows:

For several decades, Dr. Runge has distinguished herself with her numerous contributions to the fields of theoretical physics and applied mathematics. In this way, she has earned a strong reputation in academic and professional circles. Her achievements have been such that she was exempted from completing a professorial dissertation (*Habilitation*) on account of her many previous publications. For several semesters, moreover, she has already held a teaching position in the field of physics. Political liabilities are also nonexistent. The nomination of Dr. Runge to serve as a *Dozentin* of theoretical physics is herewith endorsed.³²

28 See [UAB] R 387, vol. 2, p. 22.

29 Ibid., vol. 2, p. 2.

30 Ibid., vol. 1, p. 30.

31 Ibid., vol. 1, pp. 36–37.

32 Ibid., vol. 3, p. 17.

A similar memorandum was filed by a member of the scientific administration in eastern Berlin on September 12, 1949, during the foundational stages of the Federal Republic of Germany and nearly a month before the founding of the German Democratic Republic (October 7, 1949). Here, too, political reasons are given in support of Iris Runge's candidacy for the position:

To supplement the professional opinions that have already been provided, the following valid arguments can be made on behalf of the candidate's suitability for the lectureship: Dr. Runge has distinguished herself most clearly through her extensive and longstanding work in the professional world. Regarding her politics, I should remark that I have found her to have been decidedly against the Nazi regime, and this attitude corresponds with that of her family as a whole. Her sister, for instance, is married to the Jewish mathematician Richard Courant, who emigrated from Germany in 1933. An additional example is that of her brother, who holds an executive post at Telefunken and who is likewise devoid of any political liability. We should attempt to expedite her appointment as quickly as possible, for Dr. Runge's original application for the position, which was apparently misplaced in the office, had been submitted two years ago. On this account, Dr. Runge is currently in a highly unpleasant predicament.³³

It was not unusual at this time for employers to request political evaluations of potential employees. Just as her fellow women mathematicians and Nazi opponents Minna Specht, Margarete Hermann, Erna Blencke, and Adelheid and Marie Torhorst were able to receive new positions within the post-war education system, Iris Runge was likewise able to obtain a secure position in a professional environment that was new to her.

Raised in a household characterized by its Huguenot roots, she was openly encouraged to pursue both intellectual and physical activities and to develop into an independent thinker. With this background, she not only took a philosophical interest in the social and ethical problems of her day, but she became actively engaged to alleviate them. Although she had participated in socially critical groups and although she had been inspired to engage in political activism by Leonard Nelson, Iris Runge was nevertheless able to maintain and further develop her own way of thinking. For example, she neither abandoned her interests in science and mathematics nor did she fully lose herself – as did Margarete Hermann and Minna Specht – in Leonard Nelson's philosophy. Independent of Nelson and influenced by the events of the First World War, she forged her own path to the Social Democratic Party, a commitment that she would continue to honor through thick and thin. Even though she had ascribed for some time to the nationalistic politics that were rampant during the First World War – in which regard the influence of the media should not be discounted – she could nevertheless find few like-minded acquaintances, while working at rather conservative secondary schools, who shared her support for more revolutionary educational reforms. Toward the end of the war, at any rate, she adopted a decidedly independent and pro-democratic po-

33 Ibid., vol. 3, p. 18. This memorandum is signed by a certain Dr. Karl, who is known to have been a former industrial researcher at Telefunken (see Appendix 10).

sition. For the sake of a better society, one fashioned by parliamentary means, she campaigned for the Social Democrats during the elections of 1919, the first in which German women were allowed to participate. In this regard, Iris Runge's behavior can be compared to that of the British mathematician and electrical engineer Hertha Marks Ayrton, who had similarly worked on behalf of women's suffrage.

The sources consulted, especially letters from the period 1918–1919, confirm the hypothesis proposed by the historian Eberhard Kolb that a *Räterepublik* ("soviet republic") will not necessarily result in an anti-democratic social system.³⁴ Throughout her career as an industrial researcher Iris Runge's attitude toward matters of social justice were only sharpened. Despite being a member of the educated middle class, her political sympathies rested firmly on the side of the working people (such support was characteristic of the so-called "new bourgeoisie").³⁵ Her activity with the Workers' Samaritan Federation and for the Children's Friends movement, along with her critical and editorial efforts to refine the publications of the Belgian Social Democrat Hendrik de Man, were all conducted in the name of achieving democratic socialism in Germany. Such a goal led to her unequivocal rejection of National Socialism and to her critical stance toward the violence and anti-democratic nature of bolshevism in Russia, both of which political movements clashed with her conception of socialism and social democracy.

Iris Runge maintained a critical attitude toward the politics of the Weimar Republic and especially toward that of the Nazi era, during which she remained in contact with her many Jewish friends, who had either emigrated or were living at great risk in Germany. That she herself, inspired by George Sarton, considered leaving the country to pursue a new career in the history of science suggests that she no longer derived such great satisfaction from her professional life. The main reason for this, as can be surmised, was the overall political climate during the period of National Socialism.

In the end, she opted to study and contribute to the history of science in her spare time, and this can be seen as an effort to retreat from her intensive work at Telefunken, where her time was confined to making calculations, and also as an effort to find a new outlet for her formerly robust political activism, which was now more or less confined to clandestine oppositional gatherings. She did, however, make use of her historical research to maintain or cultivate politically innocuous contacts with men and women who had fallen into disrepute with the governing party. In 1939, she sent her first article on the history of science, which concerned the history of spectroscopy, to a number of people who had been either dismissed from their positions or forced to emigrate during the Nazi era. In this regard it should be noted that her circle of acquaintances included not only Fried-

34 See KOLB 1978/2005; and Section 2.6.7.

35 The existence of such political sympathies among the middle class contradicts the thesis presented in GALL 2009, namely that the members of this class were almost universally concerned with distancing themselves from the workers (see Sections 2.5.2, 4.1.3, and 4.1.4).

rich Paschen, the president of the Imperial Institute of Technical Physics, and the secondary school principal Elisabeth (Klein) Staiger, both of whom had suffered professionally on account of their “incompliant” behavior. She was also close to Karl Willy Wagner, the director of the Heinrich Hertz Institute for Oscillation Research in Berlin; Wolfgang Gaede, a pioneer of vacuum technology; and Friedrich Adolf Willers, a former student of Carl Runge and a leading expert in the field of practical analysis. Each of the latter lost his prestigious position – again, on account of “incompliant” behavior – and was ordered to work elsewhere within the educational system.³⁶

Iris Runge remained critical and incompliant even after 1945. In contrast to the majority of her fellow industrial researchers and physicists, who had hardly greeted the arrival of the Allied troops as a liberation,³⁷ Iris Runge had felt greatly relieved to be rid of the Nazi leadership, so much so that she composed poems about this very feeling. Unwilling to be restrained intellectually, professionally, or privately, she remained an independent thinker both with respect to science and mathematics as well as to her social and political environment. The self-assurance of her approach to work, politics, and her private life was grounded in a scientific world view and further supported by the pillars of her cosmopolitan extended family, her father’s style of thinking, her association with theoretical physicists, and her faith in social democracy. Needless to say, this self-confident and rational aspect of her persona cannot be separated from her emotional and artistic disposition, which manifested itself in poems, stories, and her participation in choirs.

During the period of National Socialism, Iris Runge retained her “insider” position as a mathematical expert in an industrial laboratory, but at the same time she became an “outsider” with respect to the political system. It was this outlying political position, in fact, that later enabled her to receive a new “insider” position within the university system after the war, a position that had largely been inaccessible to women before 1945. Her appointment as a *Dozentin* was finally made on November 1, 1949,³⁸ and it was only five months later that Friedrich Möglich nominated her for a professorship. On April 18, 1950, he wrote the following to the dean of his faculty:

36 Karl Willy Wagner was released from his position at the Heinrich Hertz Institute for reasons that were remarkably specious even for that political environment (see FRÄNZ 1986, pp. 6–7). Wolfgang Gaede, who had many inventions to his name, lost his professorship at the Technical University in Karlsruhe for having denounced the Nazi regime; he ran a private laboratory after the war. A Nazi detractor, Friedrich Adolf Willers lost his professorship at the Mining Academy in Freiberg in 1934, after which he was supported at the Technical University in Dresden by Erich Trefftz, who was likewise opposed to the Nazi government. During the late stages of the war, in 1944, Willers was reappointed to a professorship because of a lack of qualified candidates (see KÜCHLER 1983, p. 48).

37 On the different reactions of physicists to the Allied invasion, see HENTSCHEL 2007.

38 Issued on November 22, 1949, the official certificate of her appointment which was signed by Paul Wandel (the Minister of Education) is archived in [UAB] R 387, vol. 1, p. 39.

Your Honor!

Allow me herewith to nominate Dr. Iris Runge, a *Dozentin* at the Humboldt University, for a professorship with teaching responsibilities in the field of physics. I submit the following as justification for this nomination.

For many years, Dr. Runge has been an active researcher at the intersection of physics, mathematics, and engineering. She has numerous scientific publications of the highest quality to her name. Since completing her *Habilitation*, she has devoted herself to her students' education in an exemplary manner, especially by assuming the duties of lecturing on theoretical mechanics and the mechanics of deformable bodies. It has also been arranged, moreover, that she is to be responsible for addressing the problems of statistical mechanics in her lectures. In the meantime, Dr. Runge has dedicated her research to the extremely complex problems presented by the statistics of solid state physics, and she has already published two significant scientific articles on the order-disorder problems in related fields.

Given these circumstances, it would only be proper for Dr. Runge to be distinguished with a professorship. I therefore request your leave to submit the aforementioned nomination.

Respectfully yours,
Möglich (signed)³⁹

Iris Runge celebrated her sixty-second birthday on June 1, 1950. Exactly one month later she was made a professor of physics at the Humboldt University, where she thus became, at least for a time, the lone female professor on the faculty of science and mathematics.⁴⁰ In fact, she became the first female professor in this field in all of Germany, and in this respect her career can be likened to that of Edith Clarke (see Section 1.1).

Having worked at the General Electric Company from 1919 to 1945, Clarke, who was five years older than Iris Runge, joined the faculty of the University of Texas at Austin in 1947 and thus became the first female professor of electrical engineering in the United States. Similar, too, was the career of the German-Jewish mathematician Cecile Froehlich. After working as a mathematical consultant at various electrical companies, she became the first woman faculty member in the Department of Electrical Engineering at the City College in New York (1941). Here she was promoted to the rank of full professor (1950) and even served as the department chair (1953–1957). While working as a professor, she also continued to serve as a consultant for the Telecommunications Labs in New

39 Ibid., vol. 2, p. 23. The two articles by Iris Runge mentioned in this letter were published in the *Annalen der Physik* (Iris RUNGE 1950a, 1950b). In terms of their content, these studies share much in common with the research of Eleonore Trefftz – the daughter of her cousin Erich Trefftz – who, in 1945, had been awarded a doctoral degree from the Technical University in Dresden for a dissertation entitled “Curie-Umwandlung von Mischkristallen auf Grund klassischer Statistik” [The Curie Transformation of Solid Solutions on the Basis of Classical Statistics].

40 Ibid., vol. 2, pp. 48–49. She received a basic monthly salary of 500 Marks, which was supplemented by a housing allowance of 96 Marks. Because the stipulated retirement age for women was sixty, Iris Runge had to apply for an extension each semester (see *ibid.*, vol. 2, p. 22).

Jersey. Her membership in a number of societies, moreover, evinces her commitment to mathematics, electrical engineering, education, and women's interests. In addition to being a senior member of the IEEE, she also belonged to the American Society for Engineering Education, the Society for Industrial and Applied Mathematics, and the American Association of University Women.⁴¹

Iris Runge worked as a professor until the end of summer semester 1952. Her lectures and tutorials reflected yet again the broad spectrum of her expertise – from industrial mathematics to theoretical mechanics, from theoretical optics to the application of statistics to physical and biological problems. She retired from academia on August 31, 1952, but her retirement did not mark an end to her work. She continued to contribute to the history of science, both as a member of the History of Science Society and as a translator of English works into German.⁴² As a doctoral student, as an industrial mathematician, as a professor, and as a professor emerita, Iris Runge was able to work according to a creed of her own. Expressed in clever and concise terms, her guiding principle ought to be quoted once again:

New and significant findings are nearly always made when a successful bridge has been built between two or more branches of science that have hitherto been kept apart. The established methods and conclusions of one individual field will often result in unexpected applications when adopted by another, and these new applications will often, in turn, lead to the development of novel and fruitful methods of research.⁴³

41 For a biographical sketch of Cecile Froehlich, see JÄGER/HEILBRONNER 2010, pp. 148–149. For more on the careers of women scientists in America, see ROSSITER 1982, 1995; and SCHIEBINGER 2008. The case in Germany is discussed in TOBIES 2008a.

42 Her retirement was officially confirmed in a letter to her by Gerhard Harig, the Secretary of Higher Education. Dated July 17, 1952, this letter is archived in [UAB] R 387, vol. 1, p. 56. According to the university pension system that had been ratified by the East German government in July of 1951, Iris Runge was eligible to receive the highest possible state pension. However, Iris Runge continued to reside in West Berlin, where another currency was in use. Regarding her academic work after her retirement, especially noteworthy is her translation of Richard Courant and Herbert Robbins's *What is Mathematics?*, which first appeared in 1962 and has since seen several more German editions. Having suffered an accident shortly before her death, Iris Runge moved to her brother's household in Ulm, where she died on January 27, 1966.

43 IRIS RUNGE 1930a, p. 1.

APPENDIX

1 Statements on Applied Mathematics (1907)

Unanimously resolved at a conference attended by representatives and supporters of applied mathematics held on March 22–23, 1907 at the University of Göttingen.¹

Participants: Friedrich v. Dalwigk (Marburg), Hermann Ernst Graßmann (Gießen), August Gutzmer (Halle), Robert Haußner (Jena), Felix Klein (Göttingen), Heinrich Konen (Münster), Emil Lampe (Berlin-Charlottenburg), Hermann Minkowski (Göttingen), Ludwig Prandtl (Göttingen), Karl Rohn (Leipzig), Eduard Riecke (Göttingen), Carl Runge (Göttingen), Friedrich Schilling (Danzig), Karl Schwering (Cologne), Paul Stäckel (Hanover), Otto Staude (Rostock), Heinrich Emil Timerding (Strassburg), Woldemar Voigt (Göttingen), Heinrich Weber (Strassburg).

The Scope of the Subject. 1. The essence of applied mathematics lies in the development and application of methods for finding numerical and graphical solutions to mathematical problems.

2. Applied mathematics requires proper mathematical thinking and understanding with respect to the real conditions to which it is applied.

3. Instruction in applied mathematics should also incorporate the fields of astronomy and geonomy (geodesy, geophysics) as examples of practically-oriented sciences in which applied mathematics can most naturally be put to use.

Teaching the Subject. 1. Applied mathematics should be made a regular component of the mathematics curriculum for future secondary school teachers.

2. Beside the teaching of theory, instruction in applied mathematics attaches the greatest importance to the practice of its methods and thus requires a laboratory practicum in which students will be afforded the opportunity to exercise their skills in making calculations, graphs, and measurements.

3. In order to impart an understanding of the full scope of applied mathematics, the subject must be taught in conjunction with several other areas of study.

Necessary Facilities. 1. The laboratory practicum for applied mathematics requires facilities similar to those for physics and chemistry. In the case of high enrollments, teaching assistants ought to be appointed to support the instructor.

2. For purposes of instruction, every university must ensure the availability of seminar rooms – especially drawing rooms (*Zeichensäle*) – and a collection of models.

3. The physics departments should assist the programs in applied mathematics by assuming the duties of teaching technical physics and technical mechanics. The laboratory equipment at the institutes of physics should accordingly be supplemented to accommodate instruction in these fields.

4. In consideration of the requisite curricula in astronomy and geonomy, so-called instructional observatories (*Unterrichtssternwarten*) should be constructed at smaller institutions that happen to lack a professional observatory.

1 Quoted from the *Jahresbericht der Deutschen Mathematiker-Vereinigung* 16 (1907), p. 518.

2 Iris Runge: A Biographical Timeline²

1888, June 1	Born in Hanover as the eldest daughter of Carl and Aimée Runge
1893, as of Fall	Private Lessons
1897, Fall–1902, March	Attends the Secondary School for Girls (II) in Hanover
1902, Easter–1907, Easter (Interrupted 1905/06)	Attends special preparatory classes for girls in Hanover (Private lessons and self study in Göttingen)
1907, February 19	Examination for university admission (<i>Abitur</i>) taken at the Johanneum Secondary School in Lüneburg
1907, SS–1908, SS	Student at the University of Göttingen (auditor status)
1907/08, WS	Begins to work as Leonard Nelson's private assistant
1908/09, WS–1910, SS	Official student at the University of Göttingen
1910/11, WS	Student at the University and auditor at the Technical University in Munich
1911	First academic publication (co-authored with Arnold Sommerfeld)
1911, SS–1911/12, WS	Student at the University of Göttingen
1912, January 12	Registers for the secondary teaching examination
1912, SS	Completes two term papers: 1) "An Examination of Schiller's Ethical Positions in Light of Kantian Ethics"; 2) "The Application of Walter Ritz's Integration Method to the Problem of Measuring Parabolic Membrane Oscillations"
1912, July 12	Oral examination passed <i>cum laude</i> Major subjects: mathematics and physics. Minor subject: Geography Examiners: Both, Husserl, Landau, Riecke, Wagner
1912–1914	Seminar/probationary period at the Lyceum and secondary school in Göttingen
1914, as of August	Appointed as a replacement teacher at the Lyceum in Göttingen
1915, April 1–1918, Easter	Teacher (<i>Oberlehrerin</i>) at the August Kippenberg School in Bremen
1918, February	Joins the Association for Freedom and Fatherland
1918, Easter to Fall	Teacher at the Haubinda Boarding School
1918/19, WS; 1919, SS; 1919, Interim Semester	Graduate studies at the University of Göttingen
1918, Fall	Joins the Social Democratic Party; campaigns with Richard Courant
1920, January 28	Passes a supplementary qualifying examination in chemistry <i>with distinction</i>
1920	Works in Gustav Tammann's laboratory; seeks employment

2 SS = Summer Semester; WS = Winter Semester.

1920, Sep.–1923, Feb.	Teacher at the Salem Castle School in Bodensee
1921, October	Submits her dissertation: “Über Diffusion in festem Zustande” [On Diffusion in the Solid State]
1921, December 16	University of Göttingen: Oral doctoral examination taken in physical chemistry, applied mathematics, and physics Examiners: Gustav Tammann, Carl Runge; James Franck
1922, January 12	Doctoral degree officially conferred
1922, Summer Vacation	Volunteers as a social worker under Friedrich Siegmund- Schultze in Berlin
1923, March 1	Begins her employment at the Osram Corporation in Berlin Assigned to the experimental research laboratory at Osram’s Factory A
1924, November 14	Start of membership at the German Physical Society
1929, end of May	Transfers within Osram to the electron tube laboratory within Factory A
1929, end of June	Attends a lecture by Hendrik de Man in Berlin
1929	Rejoins the Social Democratic Party; volunteers for the Workers’ Samaritan Federation and Children’s Friends
1934, Fall	Meeting with George Sarton in London
1936, August–October	Trip to the United States
1938, June	Trip to Great Britain, Iris and Ella Runge
1939, July 1	Transfers to Telefunken’s developmental laboratory for electron tubes
1944, Fall–1945, January	Outposted to Liegnitz, Lower Silesia (Legnica today)
End of the War	Residing in Berlin-Spandau
1945, October–1946, December	Lectures at the adult education center (<i>Volkshochschule</i>) in Spandau and works as a private tutor
1946, April–August	Technical University in Berlin: Assistant under Ernst Mohr and Aloys Timpe
1946, May–1949, March	(Humboldt) University of Berlin: Research assistant at the Institute of Physics II
1947, February 15	<i>Habilitation</i> (<i>venia legendi</i> granted)
1947, May 23–1949, SS	Lecturer (<i>Lehrbeauftragte</i>) in theoretical physics
1949, November 1	University Lecturer (<i>Dozentin</i>) in theoretical physics
1950, July 1	Appointed Professor of Physics (<i>Professor mit Lehrauftrag</i>)
1952, August 31	Retirement from academia (<i>Emeritierung</i>)
1935, April–1966	Home address: Berlin-Spandau, Teltower Straße 12
1966, January 27	Dies in the city of Ulm, where her brother Wilhelm’s family resided

3 Dr. Iris Runge: Publications During Her Time at Osram and Telefunken

- 1923 RUNGE, Iris: "Über einen Weg zur Integration der Wärmeleitungsgleichung für stromgeheizte strahlende Drähte" [On a Method of Integrating the Heat Equation for Electrically Heated, Radiating Filaments]. *Zeitschrift für Physik* 18, pp. 228–231.
- 1924 PIRANI, Marcello; RUNGE, Iris: "Elektrizitätsleitung in metallischen Aggregaten" [The Conduction of Electricity in Metallic Aggregates]. *Zeitschrift für Metallkunde* 16, pp. 183–185.
- 1925 RUNGE, Iris: "Zur elektrischen Leitfähigkeit metallischer Aggregate" [On the Electrical Conductivity of Metallic Aggregates]. *Zeitschrift für technische Physik* 6, pp. 61–68.
- JACOBY, Richard; RUNGE, Iris: "Über das Glühen von laufenden Drähten mittels hindurchfließenden elektrischen Stromes" [On the Illumination of Filaments by Means of a Transfluent Electric Current]. In *Festschrift für Fritz Blau zum 60. Geburtstag* (unpublished). Eds. Marcello Pirani and Franz Skaupy; and abstracted in the *Zeitschrift für technische Physik* 6, p. 359.
- LAX, Ellen; RUNGE, Iris: "Einfluß der Strahlungsschwärzung auf die Lichtausbeute bei Leuchtkörpern aus Wendeldraht" [The Influence of Radiation Absorption on the Light Output of Coiled Filaments]. In *Festschrift (Ibid.)*; and *Zeitschrift für technische Physik* 6, pp. 317–322.
- 1927 RUNGE, Iris: "Grundlagen des Farbensehens" [The Principles of Color Vision]. *Licht und Lampe* 11, pp. 361–372.
- RUNGE, Iris: "Zur Farbenlehre" [On Color Theory]. *Zeitschrift für technische Physik* 8, pp. 289–299.
- BECKER, Richard; PLAUT, Hubert; RUNGE, Iris: *Anwendungen der mathematischen Statistik auf Probleme der Massenfabrikation* [Application of Mathematical Statistics to Problems of Mass Production]. Berlin: Julius Springer (2nd edition 1930).
- 1928 RUNGE, Iris: "Über die Ermittlung der Farbkoordinaten aus den Messungen am trichromatischen Kolorimeter" [On the Determination of Color Coordinates from the Measurements of a Trichromatic Colorimeter]. *Zeitschrift für Instrumentenkunde* 48, pp. 387–396; abridged in *Technisch-wissenschaftliche Abhandlungen aus dem Osram-Konzern* 2 (1931), pp. 324–329.
- RUNGE, Iris: "Ein optisches Mikrometer" [An Optical Micrometer]. *Zeitschrift für technische Physik* 9, pp. 484–486; revised and reprinted in *Technisch-wissenschaftliche Abhandlungen aus dem Osram-Konzern* 1 (1930), pp. 165–169.
- 1929 RUNGE, Iris: "Die Einheitsmengen im Maxwell-Helmholtz'schen Farbdreieck und die Bestimmung der Farbsättigung" [The Unit Amounts in the Maxwell-Helmholtz Color Triangle and the Determination of Color Saturation]. *Zeitschrift für Instrumentenkunde* 49, pp. 600–603; reprinted in *Technisch-wissenschaftliche Abhandlungen aus dem Osram-Konzern* 2 (1931), pp. 330–333.
- RUNGE, Iris: "Die Unterschiedsschwelle des Auges bei kleinen Schwinkeln" [The Differential Threshold of the Eye at Small Angles of Vision]. *Physikalische Zeitschrift* 30, pp. 76–77; reprinted in *Technisch-wissenschaftliche Abhandlungen aus dem Osram-Konzern* 2 (1931), pp. 334–335.
- 1930 RUNGE, Iris; SEWIG, Rudolf: "Über den inneren Photoeffekt in kristallinen Halbleitern" [On the Internal Photoelectric Effect in Crystalline Semiconductors]. *Zeitschrift für Physik* 62, pp. 726–729; revised and reprinted in *Technisch-wissenschaftliche Abhandlungen aus dem Osram-Konzern* 2 (1931), pp. 336–338.
- RUNGE, Iris: "Die Prüfung eines Massenartikels als statistisches Problem" [The Evaluation of a Mass-Produced Good as a Statistical Problem]. *Technisch-wissenschaftliche Abhandlungen aus dem Osram-Konzern* 1 (1930), pp. 1–5.
- RUNGE, Iris: "Die normale Häufigkeitskurve und ihre Bedeutung" [The Normal Frequency Distribution and Its Meaning]. In *Fabrikationskontrolle auf Grund statisti-*

- scher Methoden*. Ed. Hubert C. Plaut. Berlin: VDI-Verlag, pp. 20–27.
- RUNGE, Iris: “Querschnittsbestimmung aus Durchmessermessungen” [Determining Cross Sections on the Basis of Diameter Measurements]. *Technisch-wissenschaftliche Abhandlungen aus dem Osram-Konzern* 1 (1930), pp. 170–178.
- RUNGE, Iris: “Energietransport im Dunkelraum der Glimmentladung” [Energy Transport in the Dark Space of Glow Discharges]. *Zeitschrift für Physik* 61, pp. 174–184; reprinted in *Technisch-wissenschaftliche Abhandlungen aus dem Osram-Konzern* 2 (1931), pp. 55–59.
- 1931 PIRANI, Marcello: *Graphische Darstellungen in Wissenschaft und Technik* [Graphical Representation in Science and Engineering]. 2nd ed. Rev. I. RUNGE. Sammlung Göschel 728. Berlin/Leipzig: Walter de Gruyter. 179 pages; 79 illustrations.
- 1932 RUNGE, Iris: “Über Schwingungen von Systemen mit negativer Charakteristik” [On the Oscillations of Systems with Negative Current-Voltage Characteristics]. *Zeitschrift für technische Physik* 13, pp. 84–91; reprinted in *Technisch-wissenschaftliche Abhandlungen aus dem Osram-Konzern* 3 (1934), pp. 80–85.
- 1933 RUNGE, Iris: “Farbenmetrik” [Colorimetry]. In *Handwörterbuch der Naturwissenschaften*. 2nd ed. Jena: Gustav Fischer, vol. 3, pp. 989–1000.
- RUNGE, Iris; BECKENBACH, Heinz: “Ein Beitrag zur Berechnung des Parallelwechselrichters” [A Contribution to the Calculation of the Parallel Inverter]. *Zeitschrift für technische Physik* 14, pp. 377–385; abridged in *Technisch-wissenschaftliche Abhandlungen aus dem Osram-Konzern* 4 (1936), pp. 92–94.
- 1934 RUNGE, Iris: “Neue Erkenntnisse über Glasströmungen in Wannenöfen” [Recent Findings on the Flow of Glass in Melting Tank Furnaces]. *Fachausschussbericht der Deutschen Glastechnischen Gesellschaft* 30 (1934), pp. 118–119; reprinted as “Über die exakten Voraussetzungen der Untersuchungen von Glasströmungen in Modellwannen” [On the Precise Conditions for Testing Glass Flow in Model Tanks]. *Technisch-wissenschaftliche Abhandlungen aus dem Osram-Konzern* 4 (1936), pp. 137–140.
- 1935 RUNGE, Iris: “Über Vorströme und Zündbedingungen bei gasgefüllten Glühkathodenröhren” [On Bias Currents and Ignition Conditions in Gas-Filled Thermionic Cathode Tubes]. *Zeitschrift für technische Physik* 16, pp. 38–42; abridged in *Technisch-wissenschaftliche Abhandlungen aus dem Osram-Konzern* 4 (1936), pp. 89–92.
- 1936 RUNGE, Iris: “Die Beurteilung von Ausschußprozentsätzen nach Stichproben” [The Evaluation of Defect Rates on the Basis of Random Sampling]. *Zeitschrift für technische Physik* 17, pp. 134–138; reprinted in *Technisch-wissenschaftliche Abhandlungen aus dem Osram-Konzern* 4, pp. 149–151.
- RUNGE, Iris: “Fluchtlinientafel zur Stückzahlermittlung auf Grund einer kleineren Vorprobe” [An Alignment Chart for Determining Sample Sizes on the Basis of a Small Preliminary Sample]. *Technisch-wissenschaftliche Abhandlungen aus dem Osram-Konzern* 4, pp. 151–152.
- 1937 RUNGE, Iris: “Zur Berechnung des Verhaltens von Mehrgitterröhren bei hohen Frequenzen” [On Calculating the Performance of Multi-Grid Electron Tubes at High Frequencies]. *Die Telefunken-Röhre* 10, pp. 128–142; reprint: *Technisch-wissenschaftliche Abhandlungen aus dem Osram-Konzern* 5 (1943), pp. 224–234.
- RUNGE, Iris: “Laufzeiteinflüsse in Elektronenröhren” [The Effects of Transit Time in Electron Tubes]. *Zeitschrift für technische Physik* 18, pp. 438–441; reprint: *Technisch-wissenschaftliche Abhandlungen aus dem Osram-Konzern* 5 (1943), pp. 235–238.
- 1938 HERRMANN, Günther; RUNGE, Iris: “Vakuummessung an mittelbar geheizten Empfängeröhren” [Vacuum Measurement in Indirectly Heated Receiver Tubes]. *Zeitschrift für technische Physik* 19, pp. 12–19; abridged as “Vakuumbestimmung an mittelbar geheizten Empfängeröhren durch Ionenstrommessung” [Determining the Vacuum in Indirectly Heated Receiver Tubes by Means of Measuring Ion Currents] in *Technisch-wissenschaftliche Abhandlungen aus dem Osram-Konzern* 5 (1943), pp. 244–252.

- 1939 RUNGE, Iris: "Zur Geschichte der Spektroskopie von Balmer bis Bohr" [On the History of Spectroscopy from Balmer to Bohr]. *Zeitschrift für physikalischen und chemischen Unterricht* 52, pp. 103–113.
- 1940 RUNGE, Iris: "Die Wirkungsweise der 4-Schlitz-Magnetfeldröhre" [The Mode of Operation of the Four-Split Magnetic Field Tube]. *Die Telefunken-Röhre* 18, pp. 33–49.
- 1941 RUNGE, Iris: "Die Berechnung des Durchgriffs auf Grund der Potentialverteilung" [Calculating the Penetration Factor on the Basis of the Potential Distribution]. *Die Telefunken-Röhre* 21/22, pp. 229–242.

4 Prof. Dr. Güntherschulze, R 10: Research Assignments at the Laboratory for Receiver and Transmitter Tubes Located in Osram's Factory A (1928–1929)

4.1 List of Laboratory Assignments (December 1928)³

I.) Dr. Statz

- 1.) Development of quiet azide tubes with impact resistance (an improvement of RE 084, RE 074 etc.).
- 2.) Clarification of unexplained emission oscillations in oxide filaments.
- 3.) Research on the nature of oxide emission in connection with Espe's experiments.⁴

II.) Dr. Hoepner

- 1.) Development of water-cooled receiver tubes.
- 2.) Basic research on secondary electron emission.
- 3.) Constructing facilities for high-frequency tungsten sintering
- 4.) Research on tubes to be sold on credit (Gutschriftsröhren).
- 5.) Filament quality control.
- 6.) Replacement of tantalum with molybdenum.

III.) Dr. Bingel

- 1.) Development of the carburizing process.⁵
- 2.) Introduction of a line of carburized tubes.
- 3.) Development of a one-kilowatt thoriated transmitter tube with a longer lifespan.
- 4.) Elimination of the chiming sound in RE 054.
- 5.) Doubling the emission of RE 154 at the same wattage.
- 6.) Explanation of the causes of ringing and chiming in tubes.
- 7.) Development of a high-voltage mercury vapor rectifier for a direct current of 20,000 volts.

IV.) Dr. Kniepen

- 1.) Development of the carburizing process.
- 2.) Development of a 500-watt transmitter tube.
- 3.) Development of an indirectly heated transmitter tube.
- 4.) Cathode-ray amplifier tubes.
- 5.) Bringing RV 218 to a dynamic range of 40 volts.

3 [DTMB] 6614, pp. 37–39.

4 Werner Espe was an employee of the Siemens Corporation. During the Nazi era he lived in exile in the United States and became a researcher at the Westinghouse Electric Co., where he attained several U.S. patents in the field of vacuum tube research.

5 Jakob Bingel earned his doctoral degree in physics at the University of Göttingen in 1925. – Carburizing is a heat treatment process for hardening iron and steel.

V.) Dipl. Ing. Bareiss

- 1.) Development of raytheon tubes for 1,000-volt direct currents.⁶
- 2.) Measurement of very small capacitances.
- 3.) Anode sputtering.
- 4.) Development of indirectly heated tubes for high-current filaments and high transconductance.
- 5.) Development of the oxide cathode rectifier for 2,500 volts.
- 6.) Development of a oxide transmitter tube for 15 watts.
- 7.) Improvement of tubes REN 1004 and 1104.
- 8.) Restructuring the load rectifiers G 4006 and G 4010 for tungsten baseplates.

VI.) Krüger (student intern)

- 1.) Research on the operations of various getter materials.

VII.) Keller (student intern)

- 1.) Research on the dielectric constants and dielectric breakdown of various types of glass at high frequency.

VIII.) Assignments that will have to be postponed for lack of staff

- 1.) De-gassing large transmitter tubes to the extent that thoriated filaments can be used.
- 2.) Creation of high-emission coatings by means of cathode sputtering.
- 3.) Replacement of platinum-iridium filaments with less expensive alternatives.
- 4.) The process of heating specific areas of a tube with concentrated radiation.
- 5.) Research on gas discharge during metal degassing and on the gas absorption of de-gassed metals.
- 6.) Development of a highly noise-free tube.
- 7.) Research on the diffusion of one metal into another at high temperatures.
- 8.) Clarifying whether the ionization energy (Ablösearbeit) of a metal can be reduced through the addition of a second metal with a higher ionization energy. (Emission catalysts.)
- 9.) Eliminating expensive tantalum from tubes.
- 10.) Development of a convenient high-vacuum measuring device with a direct display.
- 11.) Development of photocells.
- 12.) Development of thalofide cells.

Berlin – December 11, 1928
 Receiver/Transmitter Lab (stamped)
 Güntherschulze (signed)

*4.2 Questions to be Addressed in America by Dr. Meissner and Dr. Rothe
 (April 1929)⁷*

- 1.) With what manufacturing process and materials can flashovers be avoided in water-cooled transmitter tubes?
- 2.) Are getters used in water-cooled transmitter tubes?

6 Raytheon was a gaseous rectifier, developed by the Raytheon Company in Massachusetts that was used as a battery eliminator and a power supply for radio receivers.

7 [DTMB] 6614, pp. 25–28. The Austrian-born physicist Alexander Meissner had been working for Telefunken since 1907 and is known for being the first to use vacuum tube feedback for the amplification of high-frequency radio signals. Horst Rothe was the mentioned laboratory head at Telefunken, see [Table 12](#) in Section 3.2.4.

- 3.) What sizes are planned for their future water-cooled transmitter tubes?
- 4.) Are getters used in their large, air-cooled transmitter tubes?
- 5.) What types of gas-filled rectifiers with oxide cathodes have they already developed and what is anticipated with respect to the future development of these rectifiers? Which gases are used and at what temperatures? Is a getter used?
- 6.) Do they expect that thorium tubes will soon be taken off the American market?
- 7.) Are indirectly heated tubes with radiant heating already on the market, or do magnesia tubes still predominate?
- 8.) How do they go about making indirectly heated tubes noise-free?
- 9.) Are large transmitter tubes with oxide cathodes already in production there? If so, how high is their anode voltage and annealing temperature and how do they avoid secondary grid emission?
- 10.) For how many watts are their thorium transmitter tubes designed?
- 11.) Do they have high-grade noiseless tubes? If so, how is this achieved?
- 12.) How do the tube factories test their tubes?
- 13.) Are tubes tested on the assembly line and are faulty tubes removed automatically?
- 14.) How are amplification measurements tested?
- 15.) Do the tantalum-electrolytic rectifiers still have a large market presence?
- 16.) What experience have they had with various types of dry rectifiers?
- 17.) What pills (Pillen) are used for the production of cesium photocells and how long is the lifespan of these photocells?
- 18.) With respect to sensitivity and lifespan, what differences can be detected between cesium cells with a monomolecular cesium film in high-vacuum cells on the one hand, and in noble-gas cells on the other? If possible, acquire quantitative data on their respective sensitivities.
- 19.) What is their process for producing high-vacuum or gas-filled potassium photocells? (Bell Labs and General Electric, Dr. Dushman,⁸ Dr. Joes).
- 20.) Beyond hydrogenation, are there other known methods for activating potassium cells? In the case of cesium cells, have they applied a method analogous to hydrogenation?
- 21.) In the case of photocells, have they mixed barium with potassium or cesium in a manner analogous to that proposed in Telefunken's patent application?
- 22.) Have photoelectric cells been produced with molybdenum salts as a light-sensitive coating? Where?
- 23.) How do they produce thalofide cells? If possible, secure a sample (Case Research Laboratory, Auburn, NY).⁹

Berlin – April 19, 1929
 Receiver/Transmitter Lab (stamped)
 Güntherschulze (signed)

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- 8 Saul Dushman, a Russian-born physical chemist, moved to North America in 1891. He earned a doctoral degree from the University of Toronto in 1912 and was immediately employed by the Research Laboratory of the General Electric Company. For representative publications, see Saul Dushman, *Production and Measurement of High Vacuum* (Schenectady, NY: General Electric Review, 1922); and idem, "Electron Emission from Metals as a Function of Temperature," *Physical Review* 21 (1923), pp. 632–636 (Richardson-Dushman equation).
 - 9 See T. W. Case, "'Thalofide Cell': A New Photo-Electric Substance," *Physical Review* 15 (1920), pp. 289–292.

4.3 List of Laboratory Assignments (November 1929)¹⁰

I.) Dr. Statz and Dr. Daene

- 1.) Development of indirectly heated (noise-free) tubes.
- 2.) Development of indirectly heated tubes for direct current networks.
- 3.) Development of screen grid tubes for direct and indirect heating.
- 4.) Development of high-frequency screen grid tubes with very low capacitance (directly and indirectly heated).
- 5.) Development of an indirectly heated dual-grid tube.
- 6.) Improvement and redevelopment of high-vacuum rectifiers with oxide cathodes.
- 7.) Development of three prototypes with 100 milliamps series currents.
- 8.) Development of a highly-insulated special tube (for the Mekapion).¹¹
- 9.) Evaluation of the electron tubes of our competitors.
- 10.) Simplifying the production process of Albo-carbon lights.
- 11.) Development of coppered azide cathodes and cathodes with a nickel strip and a tungsten core.
- 12.) Systematic research on oxide emission.

II.) Dr. Hoepner

- 1.) Improvement of water-cooled transmitter tubes.
- 2.) Development of water-cooled transmitter tubes with oxide cathodes.
- 3.) Development of anodes with black-body radiation.
- 4.) Replacement of tantalum with molybdenum.

III.) Dr. Kniepen

- 1.) 110-watt thorium tubes: a) RS 234, b) RS 235, c) RV 236, d) SO 230.
- 2.) 500-watt tubes for 1,000 to 2,000 anode voltages.
- 3.) 1,000-watt tubes for 2,000 to 4,000 anode voltages.
- 4.) Air-cooled transmitter tubes with cold anodes for 1,000 to 4,000 watts with indirectly heated thorium-, oxide-, BaO-, CaO-, and SrO-cathodes.
- 5.) Replacement of tantalum anodes with blackened molybdenum and nickel anodes consisting of plates or gauze.
- 6.) Replacement of carburized, thoriated filaments either with a) filaments that are coated/fire-aluminized with paraffin-aluminum powder or b) filaments for which aluminum or magnesium powder is pressed before the sintering process.
- 7.) Improvement of thorium tubes.
- 8.) Methods for measuring the vacuum factor of tubes that are currently in production and researching the relevance of vacuum factors to the lifespan of tubes.
- 9.) Methods for measuring the emission of tubes that are currently in production.
- 10.) The introduction of sensitive ionization (or Pirani) manometers to the on-going vacuum measurements of tubes on the vacuum pump.

¹⁰ [DTMB] FA AEG-Telefunken, Bestand 1.2.060 C, Signatur 6614, pp. 22–24.

¹¹ The “Mekapion” was a measuring device for X-ray dosage that was used in medicine.

IV.) Dr. Sewig

- 1.) Development of photocells.
- 2.) Development of thalofide cells.
- 3.) Construction of a Charakterograph.¹²
- 4.) Construction of a manometer with a direct display.
- 5.) Organizing the calibration and control of measurement instruments within the laboratory.

V.) Dr. Meyer

- 1.) Improvement of the raytheon rectifier.
- 2.) Development of thermionic cathode rectifiers with mercury vapor for high voltage and weak currents.
- 3.) Development of thermionic cathode rectifiers with mercury vapor for stronger currents and medium voltage.

VI.) Dr. Runge

- 1.) Development of the theory of electron emission.
- 2.) Calculating the parameters of electron tubes.

VII.) Keller (student intern)

Research on the dielectric losses of a number of glass types at high frequency.

VIII.) Krüger (student intern)

Research on the operations of various getter materials.

IX.) Köppen (student intern)

Research on the correlation between current density and cathode fall in nearly pure mercury vapor.

Berlin – October 29, 1929

Receiver/Transmitter Tube Laboratory, Osram (stamped)

Güntherschulze (signed)

12 An apparatus that automatically recorded the characteristic curves of electron tubes (diodes and triodes).

5 Iris Runge: Laboratory Reports and Other Documents from the Electron Tube Laboratories of Osram and Telefunken

5.1 Dr. Runge, R 10: Titles of Laboratory Reports, Memoranda, Etc.¹³

1)	Report: Laboratory Experiments (#)	15.11.28
2)	Experiments on Ionization Manometers	20.02.30
3)	External Control and Glass Grid Control Tubes	05.05.31
4)	On the Possibility of Conducting Model Experiments for Studying the Flow Processes within a Glass Melting Tank	10.05.31
5)	Report: Oscillations of Bodies with Negative Current-Voltage Characteristics	Sept. 31
6)	Annual Report 1930/31, Dr. Runge: Measuring the Performance of Screen-Grid Tubes	09.09.31
7)	Oscillations of Bodies with Negative Current-Voltage Characteristics (*)	03.10.31
8)	Report: The Operational Demands of Thermionic Cathode Valves in Circuits with Non-Ohmic Resistance	Dec. 31
9)	Assignments: Circuits with Rectifiers and Non-Ohmic Resistance	04.01.32
10)	Van der Pol's Relaxation Oscillations ¹⁴	19.01.32
11)	Memorandum: On a Modified Circuit for Executing H. Schulz's Time-Bound Spot Welding Process (Equipment Design)	01.09.32
12)	Results of an Experiment on Bias Currents and on Current Erasure (<i>Löschen</i>) by Modifying the Grid Voltage in Thyatron Tubes	27.03.33
13)	A Contribution to the Engineering of Grid-Controlled Gas Discharges	28.04.33
14)	Powering a Welding Transformer by Means of a Capacitor Discharge	06.04.33
15)	Report: The Possibility of Conducting Model Experiments for Studying the Flow Processes within a Glass Melting Tank (*)	01.06.33
16)	A Contribution to the Calculation of a Parallel Inverter, Manuscript by H. Beckenbach and I. Runge (*)	08.06.33
17)	Memorandum on the Negative Current-Voltage Characteristics in Uranium Dioxide Resistance	10.02.34
18)	Memorandum on Triodes with High Transconductance and Low Capacitance	30.05.34
19)	Results of an Experiment on Gas-Filled Thermionic Cathode Tubes with Control Grids (*)	01.10.34
20)	A Diagram for Determining the Sample Size π that Yields the Percentage α with an Accuracy of $\pm \varepsilon$ for Desired Certainties of 95, 90, or 80%, with a Letter to Telefunken	16.10.34
21)	A Comparison of the Variance of RENS 1284 and CF 1	08.11.34
22)	A Comparison of the Variance of 1284 and CF 1 – A Comparison of the Variance of Transconductance at Three Different Heat Levels at Osram und Telefunken. CF 1	10.11.34
23)	The Variance of Transconductance and the Penetration Factor of RENS 1284 during its Four Stages of Development in 1934	04.12.34

13 [DTMB] 6603 and 6604. The symbol (#) designate a document known only by its title; an asterisk (*) follows the titles of reports that were later published. Dates are reproduced here in the Continental fashion of the original text (DD/MM/YY).

14 The reference is to the following study: Balthasar van der Pol, "Über Relaxationsschwingungen," *Zeitschrift für Hochfrequenztechnik* 28 (1927), pp. 178–184.

24)	Memorandum Concerning the Work of Mr. Wagener on Calculating the Grid Temperature of Electron Tubes ¹⁵	12.02.35
25)	Report: A Variance Analysis and Statistical Evaluation of the Properties of Certain Types of Tubes, with Diagrams	27.04.35
26)	Report: The Evaluation of Defect Rates on the Basis of Random Sampling (*)	31.07.35
27)	Memorandum on the Current Load of Rectifiers with Capacitors	14.12.35
28)	An Alignment Chart for Determining Sample Sizes on the Basis of a Small Preliminary Sample (*)	17.02.36
29)	Report: On the Theory of the Split-Anode Magnetron (*)	01.08.36
30)	A Report on My Visits to the Tube Factories of Tung-Sol and the Radio Corporation of America (RCA) in September of 1936	19.10.36
31)	Report: On the Magnetron Experiments in the Laboratories of RCA	19.10.36
32)	A Letter to Telefunken Regarding Overvoltage in Series Connections on Account of Differences in Resistance	28.11.36
33)	Report: The Calculation of Diode Capacitances in the Junction to Saturation, with a Letter to H. Rothe at Telefunken	01.12.36
34)	A Summary of F. W. Gundlach's "Neuere Untersuchungen über Dezimeterwellensender mit Schlitzanodenmagnetrons" [Recent Research on Decimeter Wave Transmitters with Split-Anode Magnetrons], in <i>Zeitschrift für Hochfrequenztechnik</i> 48 (1936), p. 201	25.01.37
35)	A German Translation of Thomas H. Briggs, "Factors Influencing the Useful Life of Vacuum Tubes," <i>Electronics</i> 9 (1936), pp. 39–44	06.02.37
36)	Report: Deriving Equations for Electron Discharge in Time-Varying Fields in the Case of Planar Electrodes (*)	30.04.37
37)	Summary Analysis of C. E. Gould and W. M. Hampton, "Statistical Methods Applied to the Manufacture of Spectacle Glass," <i>Journal of the Society of Glass Technology</i> 21 (1937), pp. 235–246	29.05.37
38)	Report: The Effects of Transit Time in Electron Tubes (*)	09.09.37
39)	Report: Measuring the Vacuum of Directly Heated Receiver Tubes by Means of Ion Currents (*), by Günther Herrmann/I. Runge	16.09.37
40)	The Limiting Frequency for Oscillation Excitation	05.10.37
41)	A Letter to Prof. Dr. W. Hort Regarding Vacuum Measurements in the Case of Indirectly Heated Receiver Tubes	12.10.37
42)	A Letter to Johann Ambrosius Barth, Leipzig, Concerning a Lecture	20.10.37
43)	Report: The Evaluation of German All-Metal Tubes by RCA	08.11.37
44)	A Letter to Johann Ambrosius Barth, Leipzig, Concerning the Original Drawings that Accompanied "Measuring the Vacuum of Indirectly Heated Receiver Tubes"	20.11.37
45)	A Letter to Johann Ambrosius Barth, Leipzig, Concerning his Order for 200 Offprints of the Article on Vacuum Measurement	25.01.38
46)	An Offprint of the Article "Determining the Vacuum of Indirectly Heated Receiver Tubes by Means of Ion Current Measurements"	
47)	Report: The Measurement of Impedances in Decimeter Waves	17.05.38
48)	A Letter to the Army Technical Office Addressed to Dipl.-Ing. v. Weingrabner, Charlottenburg, Regarding an Offprint of the Article "The Evaluation of Defect Rates on the Basis of Random Sampling"	10.09.38
49)	Report: Observations on Back-Bombardment in Magnetrons	05.10.38

15 This document is reproduced in its entirety in Appendix 5.5.

50)	A Letter to Prof. Dr. Ing. Kienzle, ¹⁶ Charlottenburg, Concerning a Request	07.10.38
51)	A Letter to Dr. Rothe in Regards to Formulas for Electron Motion	06.10.39
52)	Report: The Mode of Operation of Four-Split Magnetic Field Tubes (*)	26.10.39
53)	On Oscillations in Gas-Filled Triodes	29.12.39
54)	A Letter to Dr. Steimel Regarding the Operations of Four-Split Magnetic Field Tubes	03.01.40
55)	A Letter to Dr. Rothe Regarding the Operations of Four-Split Magnetic Field Tubes	08.01.40
56)	A letter to Mr. Ratheiser, S.W. 61, Regarding the Operations of Four-Split Magnetic Field Tubes	22.02.40

5.2 Dr. Runge: Titles of RöE-Reports (Telefunken 1941–1944)¹⁷

57)	RöE No. 30/1941: The Calculation of Characteristic Curves (5065)	30.06.41
58)	RöE No. 50/1941: The Proportionality Factor of a Triode with a Non-Vanishing Space Charge between the Grid and the Anode (5092)	08.10.41
59)	RöE No. 74/1942: The Proportionality Factor and the Control Bias Voltage in a Non-Vanishing Space Charge (5124)	18.02.42
60)	RöE No. 78/1942: The Proportionality Factor and the Control Bias Voltage in a Non-Vanishing Space Charge (5132)	28.02.42
61)	RöE No. 97/1942: The Potential Near the Retarding Grid of a Pentode with Planar Electrodes (5157)	20.10.42
62)	RöE No. 139/1943: Magnetic Field Tubes with Feed-Forward Cathode Control (5213)	05.07.43
63)	RöE No. 171/1944: Electron Paths in a Magnetron with an Extended Cathode, with Space Charge Taken into Consideration (5264)	Berlin, 04.05.44
64)	RöE No. 188/1944: The Effect of Space Charge in the Matter of Velocity Modulation	Liegnitz, 07.11.44

16 Otto Kienzle was a student of Georg Schlesinger, whom he succeeded in 1934 as a professor of machine tools and industrial management at the Technical University in Berlin-Charlottenburg.

17 [DTMB] FA AEG-Telefunken, Bestand 1.2.060 C. The shelfmarks (*Signaturen*) of the individual reports are included in the table (in parentheses). The abbreviation “RöE” stands for *Röhrenentwicklung* ‘electron tube development’.

5.3 Dr. Runge, Laboratory Records: Annual Report 1930–1931¹⁸

1.) *Measuring the Performance of Screen-Grid Output Tubes.*

In order to answer the question of whether using a screen-grid tube as the output tube of an amplifier presents any advantage over using a triode, the output of these tubes should be compared at identical levels of nonlinear distortion.¹⁹ At the same time, the influence that a given distortion has on the sound effect should also be examined. In this regard, the distortion is defined as the square root of the sum of the squares of all harmonic amplitudes in relation to the total effective current at sinusoidal grid voltage. In order to measure this, a circuit was developed in which the fundamental oscillation of the output alternating current compensates away, at which point the residual current can be measured. Because the residual currents were very low, especially at low amplitudes, it was first of all necessary to eliminate numerous interferences, the zero-point fluctuations of the mirror galvanometer caused by mechanical and thermal effects, the interferences caused by high-frequency oscillations, and the asymmetry of the thermocouples. Finally, a tube voltmeter circuit was connected in place of a thermocouple and galvanometer. Even then, however, the interference remained very strong on account of undesired couplings. The experiments have been temporarily postponed.

2.) *Space-Charge Grid Tubes.*²⁰

Efforts were made toward developing a tube with an oxide cathode similar to that of RE 074d.²¹ Because the filament is longer than that of the thorium cathode, a planar arrangement with an N-shaped stretched filament was used instead of a cylindrical arrangement. This led initially to a decrease of transconductance and to an excess in the space-charge grid current, so that the intersection of the anode current curve and the space-charge grid current curve was too far in the positive grid voltage area. According to Schottky's theory of the space-charge grid, however, this was to be expected because the cylindrical system offers significant advantages. With the help of his theoretical concepts, it was nevertheless possible to push back the space-charge grid current in favor of the anode current by means of making structural modifications, so that the intersection of the two curves was still found at negative grid voltages.

Concerning these developmental experiments, the matters of the location of the space charge and its effects on the penetration factor were investigated both theoretically and experimentally. These investigations are still underway.

18 [DTMB] 6603, pp. 133–138.

19 The grid-screen tube, invented by Walter Schottky in 1916, is a tetrode that has a second grid (the screen grid) in addition to an anode, cathode, and (control) grid. The screen grid shields the control grid from the anode; it creates constant field conditions for the control grid and accelerates the electrons uniformly in the direction of the anode. All in all it yields more powerful amplifications, but it has disadvantages as well. If the anode voltage, limited by modulation, sinks below the voltage of the screen grid, secondary electrons – forced out of the anode by the main anode current – will be attracted by the screen grid and will not manage to return to the anode. The anode current will decrease even though the anode voltage is increasing. This phenomenon corresponds mathematically to a negative differential resistance. If the distance between the anode and the screen grid is kept as great as possible, however, this problem can be overcome. Grid-screen tubes were still being used as output tubes after 1945.

20 This was a tetrode in which a positively biased (space-charge) grid was located near the cathode in order to reduce the retarding effect that the space charge surrounding the cathode has on the electron current. The anode current and the transconductance are thereby increased.

21 This was a directly heated tetrode that was widely used (see RATHEISER 1941).

3.) *Tubes with External Control Grids and Glass Envelopes.*

Because, in these tubes, the transconductance and penetration factor cannot be measured at the measuring station, they were examined by means of a loop oscillograph in order to determine their characteristics. For the tube RE 201,²² this yielded transconductances of 0.12 mA/V and penetration factors of 3%, and for the investigated glass-grid tubes it yielded transconductances of 0.3 mA/V and penetration factors of 15%. In the case of overloaded rod-electrode tubes, the oscillogram demonstrated the typically flat forms that can be calculated by assuming a slow charge balance and that indicate that the vacuum has been impaired by the overload. A comprehensive report was prepared about these experiments.

4.) *High-Frequency Annealing.*

With an approximate calculation based on simplified assumptions, it was determined at which limiting frequencies a split anode receives more electrical power than an un-split anode. A comparison with Dr. Kniepen's experiments, however, revealed very little agreement, which was probably because the effects of scattering were not taken into account.

Further studies were carried out, moreover, for the Research Society for Electric Lighting that concerned the problem of the induction oven and the matter of tungsten sintering.

5.) *Oscillations in Gas-Filled Rectifiers.*²³

Because, in gas-filled rectifiers, tone burst signals had been observed at currents that caused the current-voltage characteristic of the tube to be negative, it seemed worthwhile to study the generation of oscillations in systems with negative characteristics.²⁴ Instead of gas discharge, we used Steimel's vacuum tube circuit, whose negative characteristic is constant, easily measurable, and controllable. It was established that, under defined and theoretically deducible conditions, relaxation oscillations occurred whose frequency was inversely proportional to the capacitance applied. These did not only occur in the normal oscillating circuit, in which the capacitor is parallel to the negative resistance, but also, analogously, when the capacitor was parallel to the positive series-connected resistor, as was the case in the rectifiers under consideration. Furthermore, the influence of self-inductance was also studied, and the transition of an oscillating circuit to sinusoidal oscillations was clarified. These results were presented in a comprehensive report.

6.) *The Magnetron Effect in Transmitter Tubes.*

Compared to Siemens's tubes of the same sort, Osram's transmitter tubes 255 0 had presented certain disadvantages regarding the transference of thermal hum.²⁵ It was investigated whether this might be associated with the planar arrangement of the four filaments in the Siemens tube as opposed to the prismatic arrangement in the Osram tube and whether this could be remedied somewhat by using another series connection.

A theoretical treatment of the matter revealed that the advantage of the planar arrangement over the prismatic cannot really be as great as our observations have led us to believe. It also

22 This was an external control tube that Telefunken had introduced to the market in 1930, but was both a technical and commercial failure. Karl Steimel referred to it as the "grossest developmental mistake" ([DTMB] 7845, p. 8).

23 A mercury vapor rectifier with a thermionic cathode.

24 Here the term "characteristic" denotes the current-voltage characteristic curve of a diode. Iris Runge's investigation concerned a condition that had been derived by Karl Steimel for the stability of a system. According to this condition, "the ballast resistance R must be greater than the differential quotient dV/di (presumed to be negative) in the negative region of the characteristic curve, which means that, represented with the abscissa V and the ordinate i , the resistance grade must be flatter than the characteristic curve that is cut from it" (IRIS RUNGE 1934, p. 81; see also Section 3.4.5.2).

25 She is referring to the water-cooled transmitter tube RS 255.

revealed that the closer proximity of the filaments under zigzag voltage can have a favorable effect on the observed values. The addition of another series circuit with parallel wires into the prismatic arrangement does not yield any advantages.

7.) *Bar Grids.*

If the grid of a tube is made of radial bars instead of wires, the penetration factor diminishes. By measuring three small experimental tubes – at the request of Dr. Hoepner – I determined to what extent the diameter of the grid wires would have to be increased in order to be equivalent to the variously sized grid bars that are used. After this, I calculated the bar width that would be required to achieve a particular penetration factor in a large tube.

8.) *Cathode Sputtering.*

In light of Dr. Meyer's cathode sputtering experiments, the number of sputtered atoms per incident ion was calculated, and correlations with the crystal structure of the cathode material were sought.

9.) *Flow Processes in a Glass Melting Tank.*

At the instigation of Dr. Thomas, it was examined theoretically whether the flow processes of melted glass in a melting tank could be analyzed more precisely by means of a model experiment and whether it would be possible to evaluate the extent to which these processes can be influenced. It turned out that this possibility depends on whether a substance can be found whose viscosity will change approximately 500% within an attainable temperature interval and whose density will be 1.3% during this same time frame. Also, its density change and thermal conductivity will have to be very low in comparison with the melted glass. In any case, it is necessary to be aware of the thermal conductivity of the glass at the temperatures prevailing in the tank.

10.) *Current and Voltage Curves of Rectifiers in Circuits with Non-Ohmic Resistances.*

With respect to the application of rectifiers, the quality of their performance depends on the correct measurement of the following four values: the attainable direct current, the alternating voltage to be expended, the existing maximum current of a tube, and the existing maximum voltage of the same. For circuits with purely ohmic resistances, the ratios of these four values were compiled by Dr. Meyer. However, as soon as there are capacitors and self-inductances in the circuits, the way in which these four values relate to one another changes, often to an appreciable extent. The path of the current within a given period was therefore calculated exactly for the most common single-phase and multi-phase circuits, and the four relevant values were derived for each case on the basis of these calculations. These latter derivations were then tested by means of an oscillogram. This showed that the calculated results did not yet correspond to the real conditions, because the self-inductivity of the transformer plays a role that was not taken into account. That is, when the rectifier is being ignited, circuit waves occur that can double the value of the maximum current. If the self inductance of the transformer is known, however, then even these waves can be calculated in advance. These circuit waves can also cause excess voltage, but this is hardly substantial so long as the scattering of the transformer and the capacitor is minimal. The calculated excess of voltage was experimentally confirmed with a measuring device controlled by a thyatron.²⁶ A comprehensive report is in preparation.

26 Thyatron, which is a Greek formation meaning 'current door', was the copyrighted name (by General Electric) for a controllable, gas-filled tube rectifier with a thermionic cathode, situated above a grid, the design of which resembled that of a triode. In 1902, the American electrical engineer Peter Copper Hewitt patented a mercury vapor rectifier for rotary currents. These gas-discharge tubes were later developed into the thyatron. During the war, thyatrons were ordered and built in large number for the automatic tracking of airplanes with floodlights (see STEENBECK 1977, pp. 61, 135). On the application of the thyatron to

11.) *A Thyatron Circuit for Regulating a Direct Current Motor.*

The theoretical conditions were explored under which the speed of a motor could be regulated by means of a thyatron. By means of oscillograms, the dependence of the anode current on the grid voltage phase was further investigated when loaded by the field coil of a motor. It was revealed that, in a single-phase circuit, a sufficient current could not be sent through the thyatron, but that the current could be made strong enough without difficulty if a two-phase circuit was used and by changing the grid voltage phase from 0 to 90°, as suggested by Hull and shown by the calculations. After this, it seemed practicable to regulate the speed with the help of a small alternating current generator and a two-way thyatron circuit.

Berlin – September 9, 1931
Runge (signed)

5.4 Dr. Runge, Laboratory Records: Annual Report (July 1931 to July 1932)²⁷

1.) *Circuits with Rectifiers and Non-Ohmic Resistances.*

Further investigations were made concerning the current-voltage ratios in circuits with inductors and capacitors. These were carried out in connection with the experiments of Dr. Prinz (Telefunken), who discovered significant excess voltage when using loop oscillographs with low inertia.²⁸ It was found that this was caused by the leakage inductance of the transformer (which, however, had been abnormally high in the experiments) in conjunction with the biased inductor, and that the excess voltage could be greatly reduced by connecting the transformer in the delta.

Sabbah's circuits (Gen.El.Co.), which supposedly reignite with great reliability, were calculated theoretically, and it was established that the effect claimed by Sabbah cannot be explained in terms of circuitry alone.²⁹ The possibility remains that the internal processes of ignition were influenced by Sabbah's circuit such that the development of arc discharge was hampered in a timely fashion and made to subside. However, the experiments conducted to confirm this effect produced only negative results.

The results of the calculations and experiments that were carried out last year concerning the current flux in the remaining circuits with inductors and capacitors were taken in their own direction. These results have been compiled and presented with graphs and tables in order to ensure that the correct tube and damping device are chosen for a given task. This study is still underway.

technologies designed for the long-distance transmission of electric power, see MAIER 1993, p. 128. On the role of the thyatron in the development of new converter circuits, see KLOSS 1990, pp. 188–191.

27 [DTMB] 6603, pp. 85–89.

28 In 1925 Dietrich G. Prinz had earned his doctoral degree under Arthur Wehnelt in Berlin with a dissertation entitled “Elektronenraumladung und ihre Beeinflussung durch positive Ionen” [The Impact of Positive Ions on Electrons Space Charge]. As a researcher at Telefunken since October 1, 1925, he acquired a number of electron tube patents. In 1935 he went into exile to Great Britain, where he joined the valve development laboratory of General Electric in Wembley. He began working at Ferranti Ltd in 1947, where he programmed the Manchester Mark I and the early Ferranti-Mark computers. He also wrote the first chess playing program for a general purpose computer in 1951.

29 Born in Lebanon, the physicist Hassan Kamel Al-Sabbah worked, as of 1923, in the vacuum tube division of General Electric's engineering laboratory in Schenectady, New York. He obtained forty-three patents.

2.) *Calculations for Identifying the Most Favorable Configuration of a Water-Cooled X-Ray Anode Composed of Two Metals (inspired by Dr. Traub).*

Both for line focus and circular focus, the temperature distribution was calculated in the case of a cooled, stationary (constant load) anode. The practical value of these results, however, depends on knowing the highest possible heat capacity at which the inner surface of the anode can be kept at the temperature of the cooling water. Having consulted with the X-ray laboratory, I was told that there is as yet no promising way to determine this value experimentally.

3.) *Calculating the Field Distribution in a Braun Tube.*

The field distribution was calculated approximately for a Braun tube with a weakly positive ring-shaped grid between the cathode and the anode. This brought to light why a change in the positive voltage at the grid will shift the pinch point of the electron beam either nearer or farther away from the electron system.

4.) *A Nomogram for Calculating the Penetration Factor.*

For a planar electrode system, the correlation of the penetration factor, the grid slope, the grid-anode distance, and the radius of the grid wires was represented in the form of a nomogram. This was done to make it easier to choose the correct parameters when redesigning or modifying tubes. The mathematical preparations were also made for producing a nomogram for a cylindrical system, but first it will be necessary to test the practical applicability of the planar arrangement.

5.) *Relaxation Oscillations: Experiments and Theoretical Considerations.*

In connection with the earlier experiments on the oscillations of systems with negative current-voltage characteristics, the "multivibrator" was investigated according to the methods of Abraham and Broch,³⁰ and the dual-grid tube was investigated in regard to relaxation oscillations. Theoretical considerations were also extended to these cases. In particular, B. van der Pol's ideas were invalidated concerning the necessity of conductor wires to have rest conductance in order to generate oscillations. This was done by developing a theoretical derivation that does not presuppose rest inductance and yet better reflects the empirical observations in its details.

6.) *Experiments on Inverters (Together with Dr. Meyer).*

Inverter circuits were built with separate excitation and self excitation and with various types of grid switches. It was immediately shown that our tubes could comfortably achieve a degree of efficiency between 65% and 85% and frequencies of several thousand Hertz. In collaboration with the Research Society and with Dr. Wiegand (fluorescent tube division), experiments were conducted on the operations of fluorescent tubes with such inverters. These revealed that, by means of the appropriate auxiliary coiling on the transformer that is already required in the fluorescent tube, the costs of the inverter could be reduced to such an extent that it would thus be economical to operate fluorescent tubes with direct current networks. Other arrangements of this sort were put into operation for the purpose of testing their durability. Further efforts were made, moreover, to generate high frequencies and 14,000 Hz were achieved. Experiments on the value of high frequencies to the performance of fluorescent tubes are underway.

One configuration has been provisionally assembled and tested. Depending upon the load, this arrangement would allow for energy to be supplied from an alternating current network to a direct current network and vice versa; it would thus enable, for example, energy to be returned that had been used in a rectifier system. These experiments, however, have been temporarily postponed until higher voltage tubes, which are important in such installations, have been developed.

30 H. Abraham and E. Bloch, "Sur la mesure en valeur absolue des périodes des oscillations électriques de haute fréquence," *Comptes Rendus de l'Académie des sciences* 168 (1919), p. 1105. See also DENNHARDT 2009, pp. 90–96.

7.) *Experiments on Various Applications of Thyatron Tubes.*

As a further development of the circuit provided by Dr. Meyer, which was designed for operating a welding machine by using each half-cycle of an alternating current, a new circuit was developed that allows for the use of any given part of a half-cycle and has the added advantage of allowing for the replacement of the formerly necessary mechanical high-voltage switch with an electrical control and a low-voltage switch. Additional experiments on circuits for single-point welding machines are currently underway.

8.) *Space-Charge Grid Tubes and Jobst's Pentode.*³¹

Experiments were conducted in an effort to increase the transconductance of space-charge grid tubes. In the case of Dr. Jobst's pentode, measurements were taken and the influence of various technical modifications was examined.

Berlin – September 13, 1932

Runge (signed)

5.5 Dr. Runge, R1: *A Memorandum Concerning the Work of Mr. Wagener on Calculating the Grid Temperature of Receiver Tubes (February 12, 1935)*³²

Memorandum.

The study by Mr. Wagener on calculating the grid temperature of receiver tubes displays a great deal of diligence, knowledge, and methodological soundness. However, the overall organization of the study and the execution of particular calculations leave me highly hesitant to endorse its publication as it currently stands.

Throughout the work as a whole it is questionable that the tremendously comprehensive calculation of the mutual irradiation of electrodes was entirely carried out under the assumption that heat conductance has no effect – that the temperature is thus constant along the surface of each electrode. This is not the case, as the author also mentions several times. Only after the energy irradiated to a grid is calculated by solving a system of $3n - 2$ equations – under the assumption, again, that there is no heat conductance – does he go on to determine the value of heat conductance by integrating the heat equation, a value with which he then retroactively adjusts the calculated irradiation. This yields the rather surprising result that, by considering the conducted heat, the temperature of the grid changes by only 2%, even though, according to his calculation, the conducted heat is greater than the radiated heat. If this were really the case, then his initial disregard of heat conductance would certainly be justified. However, this contradicts other findings regarding the influence of changes in heat conductance on the temperature of electrodes. One is forced to suspect that there is an error in his reasoning somewhere, the discovery of which might jeopardize the value his entire endeavor.

31 In 1926, Günther Jobst and Bernhard Tellegen introduced the first pentode, which they referred to as a *Regelkathodenröhre* 'regulating cathode tube'. The tube contains a third suppressor grid – attached to the cathode – between the screen grid and the anode.

32 [DTMB] 6603, pp. 36–38 (Report No. 24). Though the name encountered in the document is "Wagner," it is undoubtedly concerned with Siegfried Wagener, who submitted a dissertation on this topic in 1935 to the University of Berlin, where he had been a student since 1927. Moreover, Wagener had worked at Osram as a student intern and was hired to join Richard Jacoby's research laboratory in 1932. It is clear that Jacoby had asked Iris Runge for her opinion of Wagener's academic work (see Section 3.5).

Because of time constraints, it has not been possible for me to test all of his calculations. However, my suspicion that there might indeed be a rather detrimental error was confirmed by the fact that I encountered several mistakes that work to undermine, or at least cast into doubt, the validity of his findings. In any case, even the correction of these errors, as far as I can tell, would still not eliminate the more general problem that he has far underestimated the influence of heat conductance.

The errors that I have been able to identify are as follows:

1.) In his consideration of heat conductance, he proceeds with the initial assumption that the entire length of the grid is irradiated by a uniform amount of heat, and then he shows that the actual deviations from this uniform amount of heat are negligible. However, in his assertion of the actual non-uniformity of the irradiation, he maintains that this deviation is the same if one calculates what is irradiated by the entire cathode to the element dr of the grid or, inversely, if one calculates what is irradiated by the element of the grid to the entire cathode, increased only in proportion to the two surfaces. In the latter case, however, it is clear that he has made no effort to calculate the differences in temperature along the cathode. This therefore yields curves for the value of the irradiation along the grid that, on account of the open front sides, drop quickly at the ends but otherwise remain constant (see [fig. 16](#) on p. 170). However, had he calculated – as he should have – the irradiation of the entire cathode at individual points along the grid, he would have obtained curves that almost perfectly reflect the radiation distribution along the cathode and that, even for the case of $s = 0.1$, would run a course that is far beneath that of his curve for $s = 0.4$.

2.) In his calculation of the influence of this non-uniformity on the solution of the heat equation, he maintains on page 183 (as he does earlier) that the function $D(t)$ is defined by his equation numbered (84). Here he fails to consider that the denominator of this formula can no longer be obtained by equation (76), but rather by the corresponding formula (108), which takes into account the influence of the non-uniformity of irradiation. Thus the statement on page 183 is incorrect that an equation identical to (87) is valid for the auxiliary temperature, but rather that this equation, too, would have to be changed to reflect the non-uniformity.

3.) In his evidence that the remainder of the formula for e_{ik} will diminish (Part I, p. 83f.), the indefinite integral of the bracket term from (48) has to be placed under the integral sign. Instead, the definite integral is taken between the boundaries 0 and 1, and 1 is replaced by z . When differentiated, however, this expression does not yield the bracket term from (48).

Regarding the presentation and form of the study as a whole, it remains to be noted that the great length of 262 pages could have been drastically reduced, in my opinion, had many needless repetitions and unessential observations been avoided. In general, the author takes far too many unnecessary detours. The essential argument on pages 105 to 118, for instance, could have been made in two pages, which also would have spared him from introducing five new values. The reading is made somewhat difficult, moreover, by the fact that part of the theoretical development (§ 30) recurs in the chapter on the experimental tests.

In sum, I should say that the study, although it clearly represents a great deal of hard work, has not consistently inspired my confidence that its results could withstand a thorough critique.

Berlin – February 12, 1935³³
Dr. Runge

33 The text of this memorandum was prepared with a typewriter. Regarding the date, it should be noted that the month was originally given as “3” (March), a typographical error that was corrected to read “2.” This is not unimportant, for Wagener submitted his dissertation on March 31, 1935 (see [UAB] Phil. Fak. No. 790).

*5.6 A Response from Iris Runge to the Research Consortium
“Measuring Large Quantities” (April 1, 1940)³⁴*

Association of German Engineers
Office of the Research Consortium
for Industrial Metrology
Berlin NW 7
Ingenieurhaus
Herman-Göring-Str. 27

March 13, 1940 (sent April 1, 1940)

Research Consortium – “Measuring Large Quantities”:

Please find enclosed the copy of Mr. Leinweber’s study from the Army Weapons Agency that you kindly sent me. As requested, I have also enclosed a few remarks and suggestions that might be taken into account before the text is published.

Heil Hitler!

Enclosure

Dr. Runge
March 30, 1940

Re: A technical report by the Army Weapons Agency on the evaluation of a large quantity of military products on the basis of random sampling.

I am essentially in agreement with the findings presented in this study, but I would like to take the liberty to make the following remarks:

1. Because the study, as far as I can tell, is mainly based on one of my own articles (“The Evaluation of Defect Rates on the Basis of Random Sampling,” *Zeitschrift für technische Physik* 17, pp. 134–138), I feel especially responsible for its content. Therefore I would like to direct your attention to a certain misgiving I have regarding my work that only dawned upon me after the article had been published. The propositions in my study – and therefore also in the report in hand – are based on the presupposition that the so-called *a priori* probability of the defect rates of the entire product run, about which nothing is known, can be assumed to be equal throughout. Even if this were so, which is doubtful, the question remains whether the assumption is tenable with respect to the quality control of manufactured goods. For it can hardly be presupposed, for instance, that a very high defect rate, such as 100%, would be just as probable as one that is very low. In the case of a mass-produced good, we know that the defect rate of the entire product run will not be 0, even though we are unable to determine the precise value of p . The question concerns the extent to which this uncertain knowledge of p , namely that high defect rates are simply improbable, influences our calculations. It is possible that this influence is very small, but – strictly speaking – this would have to be demonstrated, possibly by testing a great number of sample sets and comparing the product deficiencies with the calculated probabilities. In any event, it would be recommendable for the published report to state clearly that this presupposition has been made, so that subsequent studies might restrict themselves to testing its validity.

2. Illustration 2 in the report, which seems to have been taken directly from another study of mine (“The Normal Frequency Distribution and Its Significance,” in *Fabrikationskontrolle auf Grund statistischer Methoden*, Berlin 1930, pp. 20–27), is not entirely applicable to the case in question, for the chart represents examples for Poisson’s formula and not for the formulas used in the report to determine limited sample sizes.

34 [DTMB] 6604, pp. 5–8. The text was prepared with a typewriter, and a personal signature is lacking.

3. It is not entirely clear to me what it is that justifies the statement, made on pages 6 and 8, that the conclusions drawn from at least 40 defective products will “generally be sufficiently accurate.” The desired accuracy may in fact depend on the conditions pertaining to the case at hand, so that such a statement should not be made in the absence of some additional data.

4. I would like to suggest a few revisions to the titles and annotations of the graphs, which are partly misleading and partly difficult to understand.

Graphs 1–3. Title: A Table for Determining an Upper Limit for the Defect Rate p in the Total Quantity ... Change to: “... the Number of Defective Products in a Control Sample.”

Text accompanying Example 2: In the total quantity, $p = \dots\%$ deficient products are allowed for. The number of products that will have to be tested if, during the examination ... Change to: “In the total quantity, deficient products will be allowed for, and such deficiencies can be expected to occur with a probability of $\dots\%$.”

Graph 7. Change the title to: “A Table for Determining an Upper Limit for the Defect Rate p in the Total Quantity with a Probability of 90%.”

Change the text accompanying Example 1 to: “ $q = 2\%$ deficient products have been found in the control sample. This corresponds to the defect rate of the total quantity and has a 90% probability of not being exceeded.”

Graph 8. Change the text accompanying Example 1 to: “In the factory test of $n = 350$ products, $q = 2\%$ defective products have been discovered. In the quality inspection, this is the control sample’s defect rate p that will not be exceeded if the risk of product rejection is 10%.

6 A Report by Dr. Karl Steimel (Telefunken) to the Technical University in Karlsruhe (November 16, 1937)

Berlin – November 16, 1937

A report on the work of Dr. J. E. Scheel at the tube laboratory of the Telefunken Corporation and on his position within the laboratory.

Various rumors about the nature of Dr. Scheel’s work and his position within the tube laboratory, which are currently circulating at the Technical University in Karlsruhe, make it seem necessary to address these issues briefly in a report. Here my essential focus will not be on the rumors themselves, but rather on providing a clear and useful presentation of the facts.

For a long time, Dr. Scheel has directed the division of our tube laboratory concerned with the new development of all of our radio tubes. It is incumbent upon him and his laboratory to attend to our requests for new tube developments and new tube concepts. Moreover, he and his staff are expected to do this in such a way that, first of all, the significance and technical feasibility of the new ideas are evaluated. The tubes are subsequently calculated to suit our desired parameters, and prototypes are constructed and handed over to the manufacturing department to be put into mass production.

In this role, Dr. Scheel has had the opportunity – especially in recent years – to showcase his extraordinary talents by making a series of developments that are of fundamental importance to the field of electron tube engineering. Because the nature of these developments has not yet been made public, I will have to ask you to keep the following information confidential.

A large part of Dr. Scheel’s work has concerned the creation of new types of tubes with linear-logarithmic current-voltage characteristics. His recent assignment, to be precise, was to develop high-frequency pentodes, with exact linear-logarithmic characteristics, that function according to a new principle involving floating screen grid voltage, as it is called. Contrary to previous tubes, which function along a defined control curve, these new tubes operate in a tri-

parametric characteristic curve field, which allows for the elimination of a number of complications, most notably the effects of distortion, that were typical of the other tubes to date.

A second component of his recent work involved the application of the concepts outlined above to a controllable hybrid tube of the hexode-triode sort. This tube presented a number of problems, most of which concerned the issue of current distribution: improving the control with the third grid of the hexode, finding the optimal properties of the current transfer between the fourth screen grid and the anode to create a higher internal resistance, and so on. Because of certain additional conditions, especially a very minimal heat output from the cathode, it was extraordinarily difficult to develop this type of tube, but these problems were nevertheless solved by Dr. Scheel in a remarkably effective way.

A third aspect of his work consisted in developing a low-frequency pentode, by means of altering the grid bias that has a low and constant distortion gain control. In this regard he solved a problem that had never been encountered before. Dr. Scheel was able both to establish the theoretical conditions that would be necessary to solve it and to find, in a rather ingenious manner, a way to present the solution that was technically simple enough to be of practical use. The demand for low distortion led, first of all, to the seemingly paradoxical condition – from a technical point of view – of having to maintain a constant anode current during the control process. This ostensible paradox was solved by utilizing the principle of floating screen grid voltage and by simultaneously creating a functional dependence between the screen grid voltage and the control grid voltage. This made it possible to achieve, at all operating conditions, both the desired constant current as well as the low distortion factor.

In his work on electron tubes with linear-logarithmic characteristics and with various boundary conditions and variations, Dr. Scheel was afforded the best of all possible opportunities to test the utility of the calculation methods that he had developed earlier in Karlsruhe. The success of these methods was simply astounding. The practical results agreed with his calculations so closely that we had never seen anything like it, not even in the simplest calculations for electron tubes with constant penetration factors. The practical significance of his calculation methods can be illustrated by relating a single episode: One type of electron tube had been developed to the extent that it was sent over to the factory, where a larger number of samples were produced. The sample created by the factory indicated a deviant result in its characteristic curve. By recalculating this result and comparing it to that of the original curve, it was revealed that the diameter of its grid had to be 3.0 mm instead of 2.7 mm. A subsequent control test confirmed, in fact, that the factory had accidentally used a 2.7 mm grid instead of the 3.0 mm grid that had been prescribed.

Over time, after the soundness of his theory had become glaringly apparent, we felt confident on several urgent occasions to commission orders of tubes – valued at more than 5,000 Realm Marks – simply on the basis of Dr. Scheel's calculations and without even testing a single physical prototype in advance. This illustrates how highly we have come to value and trust his theoretical contributions.

It will be necessary to mention only a few additional aspects of Dr. Scheel's work. In tubes operating with a B-circuit, there was the complication that considerable distortion occurred in the region where the two characteristic curves overlap. Dr. Scheel succeeded in explaining the nature of this distortion and managed to develop characteristic curves for such tubes that did away with it. He was able to develop a novel method to improve the current distribution in the grid current region of B-Tubes and, what is more, he solved the problem of achieving a suitable current distribution in the case of their being an unfavorable ratio between the anode voltage and the control grid voltage. Furthermore, Dr. Scheel directed his attention to solving the problem of replacing a retarding grid with the space charge of the electron current. I should not fail to mention that he has also had surprising success in the practical area of tube design. Thus, for instance, he developed a new grid design that yields higher tube stability and a significantly higher load line.

Before bringing this report on Dr. Scheel to a close, I ought to mention one more point that might falsely be interpreted as something negative about him. Dr. Scheel's disposition is such

that he is, through and through, an engineer with a high degree of talent that is both theoretical as well as practical. He is not, however, entirely suited for working on the sales and marketing side of things. It is very rare for someone to possess the set of skills that is necessary for being both a stellar engineer and someone inclined to deal with matters of sales and marketing, even despite the fact such skills are highly desirable in certain industries. Originally we had hoped that Dr. Scheel might possibly be able to bridge the divide between engineering and sales. We relinquished that hope, however, as soon as we had become convinced of his remarkable abilities as an engineer, and we decided that it would be in our interest not to divide his time between two departments.

The extent to which we value Dr. Scheel's abilities and contributions is evident enough in the fact that we decided to expand his responsibilities by entrusting him with assignments concerning both radio tubes as well as the development of transmitter tubes.

In order to dispel the rumor that Dr. Scheel's work here has been more closely oriented to sales and marketing than to engineering, I have enclosed an excerpt of Telefunken's corporate structure that will make his position apparent to you.

Tube Division <i>Director:</i> Dr. Steimel				Radio Marketing Division <i>Director:</i> Dr. Engels			
Commercial Receiver & Transmitter Tubes	Research & Development: Radio & Transmitter Tubes	Fabrication & Test Bay for Radio Tubes	Technical Assistance & Sales Consulting	Radio Tube Sales & Licensing (Domestic)	General Radio Tube Sales & Marketing (Domestic)	Radio Tube Sales & Marketing (International)	Other Sales Groups
<i>Directors:</i> Dr. Rothe Dr. Hofer	<i>Director:</i> Dr. Scheel	<i>Director:</i> Dr. Wolf	<i>Director:</i> Dipl. Ing. Neulen	<i>Director:</i> Mr. Günther	<i>Director:</i> Mr. Drogies	<i>Director:</i> Mr. Mannhardt	

Steimel (signed)

7 A Letter from Iris Runge to Lise Meitner (November 26, 1938)³⁵

Spandau – November 26, 1938

Dear Miss Meitner,

A few days ago I read in the journal *Nature* that you have recently turned sixty,³⁶ and I would therefore like to take this opportunity to wish you all the best and a belated happy birthday. Unfortunately, these times are not exactly ripe for celebrations and congratulations. Here we are forced to live under the weight of horror and shame. But the feeling of paralysis that has resulted from these circumstances should not prevent me from expressing to you, in the most heartfelt of ways, how much I hope that you have found a space where you can feel content and where you can enjoy many more years of fruitful activity. Indeed, work is the only thing that can keep one alive; it somehow maintains its value no matter how insane the world has become.

At least this is how things are going for me, although my present work is only moderately technical. Much to my enjoyment, I have been granted the opportunity to conduct some experi-

³⁵ [Churchill Archives] MTNR 5/15.

³⁶ "Miss Lise Meitner," *Nature* 142 (1938), pp. 865–866.

ments of my own. Thus I have experienced anew how delightful it is to deal directly with the nature of a problem instead of having to contemplate the findings of others. My hobby of chronicling my father's life and scholarship has also been pleasant. A good part of this work is already behind me, and I live with my thoughts mired in the Berlin of the 1880s, rebounding between Weierstrass, Kronecker, and other famous names. Here I have even encountered Sonya Kovalevsky: Is her memory still alive in Stockholm? My father once visited her and Mittag-Leffler during a vacation; that was in September of 1884. – On another note, I was able to read the book on Mme Curie that you told me about during your last visit.³⁷ The book is truly outstanding, and her life was marvelous. I have to agree with you, however, that it is somewhat sad how naïve the Curies were in the matter applying for patents. In general, did they really have to live like such recluses at the time, in such opposition to their environment? In Marie's case it is understandable, given that she came from an downtrodden nation; but why couldn't Pierre, who was raised in free and happy France, act as an intermediary between her and the world? But he was even more reclusive than she was. Perhaps the France of that time was less free and happy than I imagined. All sorts of parallels come to mind when I think of certain events. But I think I should bring this letter to a close.

Yours truly and with warm regards, Iris Runge

8 A Letter from Iris Runge to Her Relatives in Göttingen (May 10, 12, and 27, 1945)³⁸

[...] Thus I have managed to survive in relatively good shape, though it was a horrendous time, and I still have no idea about the welfare of the others here in Berlin – Wilhelm, Anni Treffitz, Fanny, and the Bergs. Because there are no functioning telephones or trains, everyone is entirely isolated, unless of course one is inspired to wander around on foot. This I have not yet ventured to do, because it is impossible to know whether or not I will be accosted by soldiers. The complete closing down of all of communication, even regarding the most important news, is utterly astounding. I never imagined that something like this could be possible in the twentieth century. Even though I experienced the fall of Berlin first hand, I am only aware of what has happened on my own block; I have nothing but a vague idea about the decisive events of the attacks, and even this information is based mostly on contradictory oral reports.

Regarding the events themselves, on April 20th the municipal railway ceased working altogether, so that not a single train continued to run, and this must have been the result of the Russians cutting the power lines. There was still a little electricity, however, for another alarm was sounded in the evening, and the radio announced that the sirens could no longer be operated and that enemy planes would now be making themselves known with their own gunfire. Hearing that, we arranged for all of our bedding to be brought into the basement of the building, where we spent the nights to come. For myself I brought only a reclining chair from the deck, the pillows from the yard, and my blankets to keep warm; I slept in my day clothes. I have to say that spending the night in this way was not as bad as one might think; I actually managed to sleep quite well, except when the other people began to snore loudly. Having to remain in the same clothes was also less unpleasant than I imagined it would be, and I soon grew accustomed to it. During the first days I spent the daylight hours up in my apartment; the gas was still running, so it was possible for us to cook, and everything was relatively normal except, of course, for the fact that I couldn't go to work. On Wednesday, April 25th, the gas stopped working. In the boiler room –

37 Ève Curie, *Madame Curie: Leben und Wirken* (Vienna: Bermann-Fischer, 1937) [in English: *Madame Curie: A Biography*, trans. Sheean Vincent (New York: Doubleday, 1937)].

38 A letter to her Aunts Estelle (Dolly) and Rose du Bois-Reymond, and to her sister Aimée Louise in Göttingen [Private Estate].

acting on the advice of the caretaker – we built cooking stations out of bricks in front of the furnace's fire holes, where all the parties in the building (six in all) could prepare their meals. This was certainly the most unpleasant thing of all, for the fire smelled terribly and the pots became thick with soot, so that everyone's hands were perpetually black. Moreover, it was necessary to jostle with the others and to wait around, and only the most primitive meals could be made on account of the filth and darkness in the basement. We remained without gas for a long time, but two of the six households, at least, managed to acquire portable stoves, which they set up in their own apartments. So now there are only four households who have to cook down below, and last week the caretaker's son built us a somewhat better brick oven, with a genuine grate and hood, so that the matter of smoke and soot is far better than it was before.

On this same April 25th, the day that the basement cooking began, Russian planes arrived for the first time in large numbers, and we began to hear shots being fired. According to rumors, the Russians were supposed to attack from the north of Berlin, flying over Tegel en route to Spandau. On the next day they were still very close. We were warned at the military posts that as soon as the city limits were breached we would be ordered to retreat into our basements. Thus for a few hours we sat around a dim lamp in the basement, full of fear, but the planes never came and we were able to return upstairs. The following days passed with similar uncertainty; sometimes it was said that the Russians had been driven away, sometimes that they were still forging ahead. The gunfire was always nearby, however, and on the 27th a grenade exploded across the street from our building. The smithereens even landed in my kitchen; the last window pane was shattered and holes were blown through my cupboards. This same rain of debris wounded a husband and wife from our building who happened to be standing in the doorway – the man was hit only lightly on the arm, but the woman's hips and back were injured rather severely, so that she had to lie motionless and helpless in the basement for an entire week; she is now in the hospital. April 29th was the worst of all. On that day we endured five consecutive hours of heavy ground shelling on our block, behind which there was an entrenchment of German troops that made a desirable target. We sat still and terrified in the nearly total darkness of the basement, listening to the force of the blasts and hoping that the attack would soon come to an end. Many buildings were hit, but the shots managed only to blow a relatively large hole on our wall and to demolish our entryway. For the most part, the structure was left standing – things would have been far worse had there been an aerial bombardment. Beyond the few smithereens that struck my kitchen, my apartment was unscathed. – On that day, of course, we were unable to cook any lunch. I ate nothing but a little bread and sausage, and in the evening, once things had quieted down, I was able to cook something warm to eat. By this time, of course, the groceries were becoming sparse; the last set of supplies was received back on Sunday, April 22nd: noodles, semolina, yellow beans, sugar, and the like. I was last given a portion of bread on the 23rd, but only after standing in line for two hours. But during the last week of the 74th [rationing] period I failed to receive any meat or lard at all, because most stores no longer had any and those that do are so overwhelmed with crowds that I simply lost hope. In this regard I would have been in trouble even earlier had it not been for the kindness of the soldiers, who provided me with a variety of goods. At that time, a great many soldiers were passing through on account of the artillery battles that were taking place, some of them wounded, some discharged, and I welcomed several of them into my apartment for rest and coffee. For this they repaid me with bread, butter, and canned meats, of which one soldier in particular had taken along a hearty portion from the storehouse. In the final days of this battle, the mess officer left behind the remainder of his supplies to be used by the civilian population; these were rationed out individually and I was able to receive some flour, barley, sugar, and marmalade. –

But moving on: After the heavy gunfire of the 29th, things returned to being relatively still; shots could be heard only farther and farther away, and we were once again able to breathe freely. And yet there was still a great deal of uncertainty, and contradictory rumors could be heard about where the Russians were and how matters stood. On the evening of May 1st, approaching midnight, the landlady (who lives nearby) came into the basement and related the news that Hitler

had fallen; this she had heard around four in the afternoon from an officer who had just left an official meeting. The news was very dramatic indeed, for the other day it was said that the war was going on and that the soldiers were regrouping and heading westward to join the reserve army, about which there was always so much talk, but it was obvious that these were only empty words, for I never once believed in the existence of such a reserve army. The first Russians entered our basement around 4:30 AM on Thursday, May 5th. They were entirely well-mannered, spoke some German, asked about soldiers, cleared up a few matters, and told us that we could go back to sleep. Over the course of day, of course, others came who behaved less respectfully. At most they demanded our watches and rings, a great many of which were taken away from us. I had the foresight, however, to wear a wristwatch that no longer worked and to hide my good one away, and so my broken watch was taken from me and I managed to keep the functioning one. The worst adventure took place in the afternoon; two Russians entered my apartment, and while one of them was rummaging through my belongings, the other wanted to have his way with me. He advanced with an ungainly tenderness, smirked, stroked me, absolutely refused to be turned away, and stubbornly blocked the door. Remarkably enough, I was not at all afraid. I believed with some confidence that I would be able to dispose of him in one way or another, and finally, having been forced onto the sofa and with him looming over me, I figured out how I would do so. I began to groan and writhe and then I flopped limply onto my side; this behavior scared him – he threw the couch blanket over me and fled the apartment right away (the other Russian was already gone). – Nothing else of this sort happened in our building. We were sure to keep the front and back doors locked at all times, so nothing else was stolen from us beyond the watches on that first morning. It became known that the Russian soldiers were strongly forbidden, by their own authorities, from stealing anything, and also that no one had to be let in who lacked proper identification and who could not speak German. Nevertheless, we have heard that a great deal has been stolen from the neighboring apartment buildings and that women have also been raped. Everyone has to be careful not to let the Russians slip in unawares, but it is some comfort to know that they are unlikely to risk breaking down doors and making too much noise. The most dangerous event took place in the afternoon of May 3rd, when a fire broke out in one of the neighboring buildings. The fire originated in the apartment of a Nazi official, and so it is thought that it was started by Russians who probably came across pictures of Hitler and incriminating documents and so on. The fire was not noticed until the flames began to consume the roof of the building (the apartment was on the top floor) and had already spread to our own. We all had to work like dogs, both the volunteer firefighters from our block and the residents of the two buildings. Fortunately the fire was extinguished, or so we thought. I worked until half past nine in the evening, when everything seemed to be under control, and I ate some dinner and went to bed. But then flames began to rise again in the neighboring building, and they had to continue fighting the fire throughout the entire night. Our own roof was burning again the next morning, and once more I was called upon to help. The flames were finally extinguished by Friday afternoon.

May 12th. The main event of the following days was that the Russians demanded civilians to tidy up and clean the streets. If we did not obey, they threatened to burn down our houses. The street truly was in disarray, given all the debris that had been caused by bullets and fire – rubble, the remains of roofs and windows, charred wooden beams, and tin cans were strewn all around. The threat of arson was quite effective. In no time, all of the residents on the block were hard at work, and I must say that I was happy to participate. Symbolically, it felt like a liquidation of the war, and I was pleased that the first command issued to us by the Bolsheviks was so reasonable and even enjoyable. It was a pleasure to bring everything into order and to clear away all the rubbish. First we gathered everything into tall, long piles along the curb, and all that remained was swept up beautifully until everything looked quite orderly. The men were able to procure a vehicle, which we loaded up several times and drove to the corner of a dumping ground at Fa-ulensee. Then we had to repeat this whole process on Ruhlebenerstraße; one of our neighbors ran an inn there, the whole front of which was in shambles, and he could not be expected to clean everything up on his own. Here there was simply a monumental amount of scattered war debris:

helmets, leather scraps, spent ammunition, in addition to a terribly large amount of papers, rags, stockings, footwear – God knows where it all came from. In the midst of this mess were ruined, burnt cars and a large dead horse that was already beginning to smell of decay. We burned the papers and the rags on the spot; there were about ten of us, and after about three hours of work we managed to take care of nearly everything. The men had to return later on, however, to bury the dead horse themselves, even though we were told that it would be taken away by the authorities. But I was spared that experience.

Since then it's been reasonably quiet. The weather has become summery, and despite all the uncertainty I am beginning to enjoy my life quite a bit. I have slowly been cleaning my apartment and putting my closets in order; I've been reading and generally enjoying the fact that the war is over. It has now been three weeks since I've been to work, and two weeks since having to live in the basement. At that time everyone was so unhappy and fearful, and no one had any idea about how long it would all last and how things would come to an end. In fact, things turned out far better than we had expected. In themselves, these last eight days have truly been enjoyable, though they would have been far more so if I knew what has happened to the others. But even by this point there is no way of finding out any information about what they might have experienced. Two days ago, for instance, I walked to the post office to find it half-destroyed, and an employee at the entrance said that he had absolutely no idea when service would be up and running again. I have heard, however, that gas, water, and electricity are supposed to be restored next week. Now that would be nice indeed! But when will the trains be running again? As far as I can tell, the overhead power line on the Charlottenburger Chaussee is still torn down, and many of the poles themselves are no longer standing. And what about food? My own inventory is growing slim, to say the least. New provision cards were handed out yesterday, but the rations are extremely meager: 400 grams of potatoes a day, along with 200 grams of bread, 25 grams of meat, and no lard whatsoever. Even these few goods, however, have not yet been delivered. Maybe tomorrow I'll try to make a long march to visit the Bergs in Eichkamp. They are my only close acquaintances who live somewhat nearby, but to reach them on foot will still take over an hour. –

May 27th. Because it seems as though the possibility of using the postal service will never return, I have set this letter aside for quite a while. Now, however, I should relate something of what has happened in the meantime. Gas, water, and electricity are unfortunately still not available and they will probably not be coming any time soon. Although water and electricity have already been restored to some parts of town, the situation here in my neighborhood is rather more difficult. To reach us here in Spandau, that is, all of these services have to cross the Havel River, and the bridges are an absolute mess (the railway bridge is entirely demolished and lying in the river, where it's obstructing any sort of barge traffic, and Charlottenstraße bridge, though passable, has been damaged severely on the very side that contained water and gas pipes, which are now broken in two). And so the people here will have to manage to get by without these amenities in the foreseeable future. There is access to water through a pump behind my building, which is not so bad at all, and there is hardly any need for electricity anyway. By order of the Russians, the clocks have all been set back an additional hour, which is in fact very practical. By six in the morning it is already completely light outside, which is convenient, and in the evening it is still possible to read without a lamp until half past ten. – The most unpleasant thing of all has surely been the lack of gas. By now, however, three of the families in my building have acquired electric stoves, which they share with two others, so I am therefore the only person who still cooks in the basement. At least I managed to construct a little metal ring for myself, so I am now able to put a small pot over the cooking fire, and thus it has been possible to scrape by from day to day. During the last fourteen days I have restored my connection with the outside world. On Sunday, May 13th, I went as planned to visit the Bergs in Eichkamp. Maleen and I fell emotionally into each other's arms, which was very moving.³⁹ They have also survived everything in one piece. Although they experienced somewhat less direct gunfire than the rest of us, they nevertheless had

39 Maleen Berg (née Du Bois-Reymond), the daughter of René and Frieda du Bois-Reymond.

to endure an even stronger presence of prowling Russians, who devoted their time to harassing women and stealing things. That said, their situation with respect to groceries is quite favorable. This is because they happen to live near a large German storehouse, formerly run by Todt's organization,⁴⁰ in which many provisions were left behind after the retreat – the local residents simply helped themselves. On Sunday, of course, I had brought some potatoes and a few sausages along with me, but Maleen refused to take them; instead, she proceeded to treat me with such generous hospitality that I was left more satisfied after the meal than I had felt for a long time. Then, in the afternoon, an order was issued to stay off of the streets, so we decided that I would have to spend the night. So it happened after all that my potatoes were put to good use, for I had to eat dinner there, too, not to mention breakfast the next morning. I slept in Maleen's charming guest room. Although there was no glass in the windows at the time, this minor inconvenience was compensated for by the exquisite views; through one window it was possible to watch the sunset, and through another I was able to admire the sunrise and the songs of cuckoos and orioles. [...]

The postal service in the greater Berlin area remains, to quote the reports, "out of commission by order of the occupying authorities." In the meantime I have returned to work, at first entirely on foot, which took over two hours and was rather draining. Now the subway is running as far as Knie, and from there my walk is a manageable three quarters of an hour. Last week I went to work for three days before having a discussion with my supervisor in which we agreed that I could complete my current assignments at home. The state of Berlin is rather unsettling, and it is even more decimated than it should be because of that final and nonsensical defense of the city.⁴¹ On the way from Knie to the Kaiserplatz in Wilmersdorf there is literally nothing but ruins. I counted only about twenty buildings that still had intact floors and inhabitable rooms. Nevertheless, the people here are very active in removing the debris; stores are being opened again, and it is clear to see that progress is being made. Also, newspapers are even being printed again⁴² – that is, they are mostly available to be read on billboards around town, but yesterday I came across a newspaper vendor for the first time in ages; of course, I bought a paper right away to bring home to Spandau, where it was greedily read by everyone in my building. Thus it is finally possible to read something about the news. It is most reassuring to learn that most of the Nazi leaders are either dead or captured. Beyond that, the papers have focused on the local affairs of Berlin. Movie theaters and concert halls are opening their doors again, and various city officials are getting back to work. Soon it will be possible to rebuild a normal life, or at least to try. – I should also say that the first ration cards, which I mentioned toward the beginning of this letter, have since been exchanged for others, and that these are a bit more generous. These new cards come in two types, one for the employed and the other for the unemployed; for now I only have a card for the unemployed, and this is because I had not yet returned to work by the time they were issued. Although it is actually possible to receive what is allotted by these cards, the portions are truly paltry and include almost no lard at all. Everyone is surviving almost entirely on potatoes and bread and is therefore perpetually hungry. New cards will be issued next week, at which point I hope to receive a worker's ration. [...]

40 Founded in 1938, the *Organisation Todt* was an association of civil and military engineers that was responsible for many building projects during the war, for which forced labor was used from prisons and concentration camps. The founder of the organization, Fritz Todt, was appointed Imperial Minister of Armaments and Munitions (*Reichsminister für Bewaffnung und Munition*) in 1940. He died in an airplane crash in 1942.

41 The so-called Battle of Berlin, which was waged from April 20 to May 2, 1945.

42 The first post-war German newspaper, *Tägliche Rundschau* [The Daily Review], was published on May 15, 1945 under the editorship of the Red Army.

9 A Letter from Karl Steimel to the District Mayor of Berlin-Zehlendorf
(June 16, 1945)⁴³

Berlin – June 16, 1945
Berlin-Zehlendorf, Goethestr. 2a

To:
The Mayor of the Zehlendorf
Administrative District
Berlin-Zehlendorf

Re: A Reapplication for the Bestowal of a Worker's Ration Card

My dear Mr. Mayor,

Because my previous application for a worker's ration card was rejected, I find myself compelled to submit another application in order to present my case more persuasively. Having compared the way this issue is dealt with in other districts of the city, I am left with the impression that it is especially difficult in Zehlendorf for chief engineers and deserving scientists to receive a worker's ration card for food. Whereas a number of men in my employment, who neither occupy executive positions nor contribute anything of special importance to the field of engineering, have received such ration cards simply for having the good fortune of living in another district, it is the case in Zehlendorf that even engineers in executive positions, whose services are of the utmost value to their firms, have come away empty handed.

Thus it has seemed necessary to justify my reasons for deserving a worker's ration in a more comprehensive manner. I would be reluctant to make such an appeal if the matter were not absolutely imperative.

I am submitting this application for a worker's ration card on account of my position in industry and on account of my many years of internationally recognized service to German engineering.

I am the director of the research and development laboratories at the electron tube factory of the Telefunken Corporation. At the same time, I am also the executive director of the Telefunken factory in Schöneberg. In all, I oversee the work of nearly 800 employees. With respect to their scope and accomplishments, the laboratories under my direction were unique in all of Europe and had only one counterpart in the United States, namely the laboratories of the Radio Corporation of America.

The laboratories occupied a key position within Europe's radio industry, so much so that the success of this industry essentially depended upon their operations.

In addition to my work in private industry, I was personally appointed by the Government Research Council and by Minister Speer to supervise the nationwide research and development that was taking place in my area of work. This appointment represented an unambiguous testament to the quality of my technical leadership in the field. Given that I was neither a member nor an affiliate of the National Socialist Party, it is clear that my appointment to this position was made on the basis of my qualifications alone.

As of 1932, the year that I entered the radio industry, I have been responsible, as a scientist and design engineer, for a number of significant inventions. These are used on a daily basis by national and international specialists, and their practical value is evidenced by the fact that they have been reproduced by the millions to be used in products around the globe.

43 [DTMB] 03483, pp. 66–69. Some excerpts of this letter have been printed in BUSCH 1991.

My first major contribution to the radio industry was the invention and development of the so-called fading hybrid hexode, which enabled the development of the first practicable superhet receiver. Shortly after the appearance of this new tube, its design was reproduced in tube factories worldwide. At the same time, another technological innovation appeared in America for the same purpose, but after a three-year period of stiff competition, the product designed by me was recognized as the better one throughout the world and drove the American design off the market. Among my other technological achievements, I can also name the so-called oval cathode, which allowed for the improved and simplified design of high-frequency tubes. A few months after its introduction, this new design, too, was put to use in all of the world's tube factories.

As with the oval cathode, I was also successful in improving the so-called tuning indicator in radio receivers. By means of one of my own inventions, which proved to be a lucrative patent, this originally American invention was improved to such an extent that several of its most stubborn deficiencies were eliminated. This improvement, too, was immediately adopted by all of the tube factories in the world.

Throughout the war, of course, I was engaged in military research. During these years I executed a large-scale development project, whose initial importance had lain in its value to non-military communications engineering. I developed at that time a type of tube for very short wavelengths, by means of which a novel and very large range of wavelengths was made available for technical application, and this will be particularly valuable now that the war has ended. The significance of this contribution was not only widely recognized in Germany, but it has also attracted the interest of Russian researchers who intend to make use of the innovation in their home country (more will be said about this below).

In addition to the distinctive and well-known accomplishments just outlined, I have made several other scientific and technological contributions. It would take me too far afield, however, to discuss these in detail.

I should note, however, that there are likely more than 100 million tubes in the world that have been built according to my own proposals and patents, and that Germany, before the war, had earned a considerable amount of revenue from the licensing fees that were charged for the right to use my inventions.

In order not to create the impression that I am making this appeal strictly on the basis of my past accomplishments, I would like to provide a brief overview of my present activity. The following details are of significance in this regard:

1.) By order of the high command of the Russian army, I am serving as an advisor to a special commission of Russian scientists, the purpose of which is to reproduce my former laboratories at a corresponding institute in central Russia. As part of this enterprise, much of my essential laboratory equipment will be removed from Germany.

2.) By the same order as (1), I must supply the Russians with a contingent of approximately 15% to 20% of my professional staff – including physicists, engineers, foremen, and technicians – to serve as the foundational personnel at their new institute. This task will require me to interview nearly all of my remaining employees in order to identify qualified personnel for the new assignment.⁴⁴

44 Before being transferred to the institute in Russia, the researchers selected by Steimel for this assignment were first stationed at the Oberspree factory in the eastern part of Berlin, where they were given apartments. A group photograph of the leading German specialists employed at the laboratory and design of office in Oberspree was taken in the winter of 1945/46 (see [DTMB] 7813, pp. 3–4). The researchers pictured in this photograph, who moved with their families to Fryazino (some 25 km north-east from Moscow) in October of 1946, include a Mr. Jürgens, Mr. Grimm, Dr. Hülster, Mr. Palme, Dr. Bechmann, Dr. Fogy, Dr. Kaufmann, Dr. Fritz, Mr. Feußner, Mr. Schiffel, Dr. Hagen, Dr. Roosenstein, Mr. Herzog, Dr. Granitzka, Dr. Steimel, Mr. Spiegel, Mr. Gruner, Dr. Richter, and Dr. Kotowski.

3.) By the same order as (1), I am charged with preparing a comprehensive report on the state of the field that focuses on the latest tube research and on the development of tubes for the German military.⁴⁵

4.) By order of the high command of the Russian army, represented by Colonel Remmer under the command of Colonel General Bersarin,⁴⁶ I am overseeing the reconstruction of one larger and one smaller tube factory to meet the needs of German broadcasting stations. This is to ensure that the both the stations and the studio systems do not fail in the near future, given that replacement equipment has been unavailable to the stations ever since the evacuation of the German tube factories.

5.) By request of the factories associated with the radio industry in greater Berlin, I have been studying the possibility – and, whenever possible, facilitating its realization – of ensuring the ongoing production of radio devices in Berlin and preventing the complete shutdown of the existing radio tube factories. At stake in this endeavor is the employment of more than 10,000 qualified employees in the Berlin radio industry.

I hope that, having described the nature of my work, I have been able to provide you with an impression of the tasks that are currently being faced by executives in the industrial sector. Moreover, I hope to have exposed the invalidity of the currently popular notion that “German industry is busy with nothing but mere cleanup efforts.”

Respectfully yours,
Dr. Karl Steimel (signed)

(The names of these men are only included in the Index of Names if they feature elsewhere in the book.)

45 This report, which was submitted in June of 1946, is archived in [DTMB] 4416 and 7845.

46 N. E. Bersarin was the first Soviet commander of Berlin. He died in a motorcycle accident on June 16, 1945, the same day that this letter was written. The mention here of Colonel Otto Ernst Remer is somewhat puzzling. By this point, Remer – a general in the German army and later a holocaust denier – was already held in custody by the American military.

10 A List of Former Researchers at Telefunken (Compiled on July 4, 1947)⁴⁷

Questionnaire		Former employees of Telefunken	
Weth, Max	Dr. phil. Physiker	Daene, Herbert	Dr. phil.
Stats, Willy	Dr. phil. Physiker	Steinmetz, Karl	Dr. phil.
Wiegand, Erich	Dr.-Ing. Chemiker	Kleen, Werner	Dr. phil. nat. habil.
Berg, Walter	Chemiker	Biskamp, Helmut	Dr. Ing.
H.W. Wolff	Dr. phil. Physiker	Brück, Lothar	Dr. phil.
Wolf, Paul	Dr. phil. Physiker	Fritz, Karl	Dr. phil.
Zickermann, Karl	Dr. rer. nat. Physiker	Graffunder, Walter	Dr. rer. nat. habil.
Zerrmann, Günther	Dr. Ing. Physiker	Hülster, Fritz	Dr. phil.
Düsing, Werner	Dr. Phil. Physiko-Chemiker	Rzehulka, Rudolf	Director
Willner, Ernst	Dipl. Ing. Chemiker	Peters, Ernst	Director
Uredat, Eberhard	Dr. phil. Physiker	Knoblauch, Henning	Dr. Ing.
Wolf, Günther	Dipl. Ing.	Righetti, Ricardo	Dipl. Ing.
Pulfrich, Hans	Dr. phil. Physiker	Nickel, Gerd	Dr. phil.
Schriel, Maximilian	Dr. Ing.	Bischoff, Kurt	Obering.
Weber, Anton	Dr. phil.	Palme, Kurt	Obering.
Köppen, Fritz	Physiker	Engbert, Wilhelm	Dr. phil.
Langer, Kurt	Ingenieur	Kluge, Werner	Engineer
Schulz, Johannes	Ingenieur	Rohde, Wolfgang	Dr. phil.
Feldhege, Heinrich	Ingenieur	Selner, Paul	Dr. phil.
		Tschöpe, Georg	Dr. rer. nat.
		Lehmann, Josef	Chemiker
		Ricken, Karl Heinz	Dipl. Ing.
		Zichter, Kurt	Dr. Ing.
		Schiffel, Rudolf	Dipl. Ing.
		Wehnert, Waldemar	Dr. Ing.
		Huber, Harry	Dr. Ing.
		Karl, Fritz	Dr. Ing.
		Miss Runge, Iris	Dr. phil.
<u>Former employees of Telefunken</u>		<u>Employees of Telefunken, at present occupied in the firm's branches outside of the tubes factory at Berlin.</u>	
Kniepen, Peter	Dr. phil. et. nat.	Mey, Karl	Dr. phil.
Heinze, Walter	Dr. phil.	Beckenbach, Heinz	Dipl. Ing.
Mie, Kurt	Dr. phil.	Natalis, Herbert	Obering.
Schmidt, Alexander	Dipl. Ing.	Winkelmann, Arthur	Obering.
Widmann, Alfred	Dr. Ing.	Kraft, Hans	Dr. phil.
Wagener, Siegfried	Dr. phil.		

47 This list is excerpted from an enclosure that accompanied a letter by Dr. Zickermann (Telefunken). The letter was addressed to: Military Government, British Troops Berlin, Disarmament Branch, Berlin-Charlottenburg (archived in [DTMB] 6734, p. 21). The following names appear on the reverse side of the page reproduced here: Dr. Ing. Johannes Müller, Dipl. Ing. Ernst Woeckel, and Ing. Kurt Eberhardt. The list does not contain the names of all the researchers who were active at Telefunken; Erik Scheel, for instance, is not named. (It should be noted that the researchers mentioned on this list are not recorded in the Index of Names unless they are featured elsewhere in the book.)

11 Iris Runge: Courses Taught at the (Humboldt) University of Berlin,
1947–1952⁴⁸

Summer Semester 1947		
Lecture: Mechanics of Deformable Bodies	Mon 11:00–13:00	Fri 9:00–11:00
Tutorial	Wed	15:00–17:00
Winter Semester 1947/48		
Lecture: Mechanics I	Mon, Thu	11:00–13:00
Tutorial	Wed	15:00–17:00
Summer Semester 1948		
Lecture: Mechanics of Deformable Bodies	Mon, Thu	11:00–13:00
Tutorial	Wed	15:00–17:00
Winter Semester 1948/49		
Lecture: Statistical Mechanics	Mon, Thu	11:00–13:00
Tutorial	Fri	11:00–13:00
Summer Semester 1949		
Lecture: Mechanics	Mon, Thu	11:00–13:00
Tutorial	Fri	11:00–13:00
Winter Semester 1949/50		
Lecture: Mechanics of Deformable Bodies	Mon, Thu	11:00–13:00
Tutorial	Fri	11:00–13:00
Summer Semester 1950		
Lecture: Applied Probability and Statistics for Physicists and Biologists	Mon, Thu	9:00–11:00
Winter Semester 1950/51		
Lecture: Mechanics	Mon, Thu	9:00–11:00
Tutorial	Fri	9:00–11:00
Summer Semester 1951		
Lecture: Introduction to Theoretical Optics	Mon, Thu	9:00–11:00
Tutorial	Mon	13:00–15:00
Winter Semester 1951/52		
Lecture: Mechanics I	Mon, Thu	10:00–12:00
Tutorial	Tue	9:00–11:00
Summer Semester 1952		
Lecture: Theory of Classical Physics	Wed, Sun	11:00–13:00
Tutorial	Fri	9:00–11:00

48 Compiled from the university course catalogues.

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- [BBF] Deutsches Institut für Internationale Pädagogische Forschung, Bibliothek für bildungsgeschichtliche Forschung Berlin, Archiv. Personal profiles of Prussian teachers; Adolf Reichwein Estate; Adelheid und Marie Torhorst Estate.
- [Büchsel o.J.] The student years of Mareile Hoppe (later Mareile Büchsel). Manuscript transcribed from an audio tape by Ute Zimmermann and supplemented by Mareile Wallis. In the private possession of Dr. Elfriede Büchsel, moderated by Dr. Karin Ehrich of the office of historical records in Hanover.
- [Churchill Archives] Lise Meitner Estate, Cambridge, Great Britain, MTNR 5/15.
- [DTMB] Deutsches Technikmuseum Berlin, Historisches Archiv, Firmenarchiv AEG-Telefunken, Bestand 1.2.060 C; Geschäftsberichte, Vol. 1: 1918/19 to 1930/31, Vol. 2 1931/32 to 1939/40; Signaturen 0005, 0058, 0088, 0135, 0199, 3084, 3483, 4413, 4416, 4811, 5212, 5265, 5299, 5813, 6233, 6236, 6473, 6603, 6604, 6614, 6659, 6665, 6734; 7779, 7813, 7845; PD 1552, 2375; 3471, 3483; Photo album presented to Dr. Karl Mey by the employees of Osram GmbH (Factory A) in honor of his twenty-five years of service.
- [FES] Archiv der sozialen Demokratie der Friedrich-Ebert-Stiftung; Leonard Nelson Estate, Minna Specht Estate.
- [Geiger Private Estate] Personal documents of Mrs. Rosemarie Geiger, Kaiserslautern, a former secretary at Osram.
- [HATUM] Historisches Archiv der Technischen Universität München. StudA., FotoB. Porträts, Meyer, K., PromA. Hofer, R., PromA. Müller, J.
- [HUG] Harvard University Archives, Richard v. Mises's Papers, 4574.5. Correspondence (1903–1953) Box 2, Folder 1932.
- [IISH] International Institute of Social History, Amsterdam, Netherlands: Letters from Iris Runge to Hendrik de Man during the years 1929–1933.
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- Thomson, Joseph John 1856–1940, British physicist, Nobel Prize 1906: 29, 55, 265, 274
- Thürmel, Erich *1882, physicist: 136–138
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- Timpe, Aloys 1882–1959, math.: 221, 349, 363
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- Toeplitz, Otto 1881–1940, math.: vii, 75
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- Tolmé (née Penecke), Maria Eliza *1796: 28
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- Torhorst, Marie 1888–1889, math., teacher, politician: 101, 120, 342, 356
- Townsend, John Sealy 1868–1957, British physicist: 243
- Traub, Wilhelm *1893, physicist: 166, 167, 378
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- Treffitz (married Renner), Emilie (Ducca) 1895–1986: x, 77, Plate 1
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- Treuding, Albert *5.10.1848, teacher: 41
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- Tschoepe, Georg *18.8.1908, physicist: 167, 393
- Tucholsky, Kurt 1890–1935, author: 314
- Tyndall, John 1820–1893, British physicist: 27
- Uhrig, Robert 1903–1944, mechanic, resistance fighter: 323
- Upton, Francis Robins 1852–1921, American math., physicist: 144, 298, 314
- Uredat, Eberhard *8.1.1905, physicist: 164, 166, 323, 393
- Vaerting, Mathilde 1884–1977, professor of pedagogy: 285
- Van der Pol, Balthasar 1889–1959, Dutch physicist: 265, 371, 378
- Vandervelde, Emil 1866–1938, Belgian Social Democrat: 309
- Veithen, Cornelius *22.10.1884, math.: 65
- Vergil 70–19 BC, Roman poet: 37
- Vesper, Will 1882–1962, Nazi poet: 322
- Virchow, Miss, landlady: 294
- Völker, Johanna *4.7.1904, physicist: 252
- Voigt, Anna *7.10.1867, teacher: 37
- Voigt, Woldemar 1850–1919, physicist: 30, 56, 57, 59, 64, 74–78, 81, 134, 139, 227, 361
- Voisin, Charles 1882–1912, French airplane designer, pilot: 72
- Voisin, Gabriel 1880–1973, French aviation pioneer: 72
- Vreeland F. K., American electrical eng.: 251
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- Wagener, Siegfried 1908–1997, physicist: xiv, 165, 173, 187, 284, 323, 346, 352, 372, 379, 380, 393
- Wagner, Hermann 1840–1929, geographer: 75, 76, 362
- Wagner, Karl Willy 1883–1953, eng.: 19, 182, 183, 187, 283, 358

- Wallach, Otto 1847–1931, chem., Nobel Prize 1910: 59, 126
- Walther, Alwin 1898–1967, math.: 69, 290
- Warburg, Emil 1846–1931, physicist: 137, 152, 179
- Ward Leonard, Harry 1861–1915, electrical eng., inventor: 144
- Warrentrup (married Schwiemann), Hildgard *1905, physical chem.: 173, 292
- Weber, Anton *21.2.1895, physicist: 167, 173, 393
- Weber, Erna 1897–1988, statistician: 286
- Weber, Heinrich 1842–1913, math.: 47, 58, 86, 361
- Weber, Wilhelm 1804–1891, physicist: 43
- Wedde (married Jørgensen-Wedde), Dora, 1884–1966, physician: 34
- Wegener, Friedrich, manager: 338
- Wehage, Dora *1890, math.: 292
- Wehnelt, Arthur 1871–1944, physicist: 77, 164, 284, 377
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- Weierstraß, Karl 1815–1897, math.: 30, 44, 333, 385
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- Westman, Albert Ernest Roberts *1900, American statistician: 199, 212
- Weth, Max *1890, physicist, manager: 164, 323, 327, 393, Plate 14
- Wettstein, Friedrich (Fritz) von 1895–1945, Austrian botanist: 23
- Weyl, Hermann 1885–1955, math.: 349
- Whitney, Willis Rodney 1868–1958, American chem.: 45, 57
- Wiechert, Emil 1861–1928, geophysicist: 30, 55–57, 59, 64, 72, 89
- Wiegand, Erich *31.1.1900, chem.: 167, 327, 378, 393
- Wielandt, Helmut 1910–2001, math.: 287
- Wien, Max 1866–1938, physicist: 106, 148, 166, 252
- Wien, Wilhelm 1864–1928, physicist, Nobel Prize 1911: 106
- Wilamowitz-Möllendorf, Ulrich von 1848–1931, philologist: 43, 44, 48, 105
- Wilhelm II 1859–1941: 41, 43, 72, 114, 141
- Wilke, Wilhelm *1882, physicist: 77
- Willers, Friedrich-Adolf 1883–1959, math.: 19, 62, 65, 66, 70, 183, 195, 196, 277, 358
- Windaus, Adolf 1876–1959, chem., Nobel Prize 1928: 126
- Winkelmann, Max 1879–1946, math.: 197, 218
- Winschuh, Josef 1897–1970: journalist, politician: 300
- Winston (married Newson), Mary Frances 1869–1959, American math.: 49
- Wirtz, Karl 1861–1928, eng.: 148
- Woeckel, Ernst, eng.: 165, 173, 393
- Wolf, Günther *1.11.1912, eng., physicist: 176, 393
- Wolf, Paul *16.2.1904, physicist: 23, 173, 176, 384, 393
- Wolff, Theodor 1868–1943, journalist: 295, 314
- Wrangell von (married Andronikow), Margarete 1876–1932, chem., plant physiologist: 285
- Wright, Orville 1871–1948, American aviation pioneer, inventor: 72
- Wright, Wilbur 1867–1912, American aviation pioneer, inventor: 72
- Wundt, Wilhelm 1832–1920, psychol.: 308
- Wynecken, Gustav 1865–1964: 123
- Young, Thomas 1773–1829, British physicist, physician: 232
- Žáček, August 1886–1961, Czech physicist: 19, 252
- Zeeman, Pieter 1865–1943, Dutch physicist: 80
- Zenneck, Jonathan 1871–1959, physicist: 3, 137, 185, 253, 278
- Zepler, Erich (Eric Ernest) 1898–1980, German-British physicist: 148
- Zickermann, Carl (Karl) *1908, physicist: xvi, 172, 393
- Ziebarth (married Wiechert), Helene: 89
- Ziegenbein, Dr., eng.: 166
- Zielke, Margot, a young woman under Iris Runge's guardianship: 316
- Zsigmondy, Richard 1865–1929, chem.: 59
- Zuhrt, Harry, electrical eng.: 248
- Zweig, Arnold 1887–1968, novelist: 298, 341
- Zweiling, Klaus 1900–1968, math., philos.: 66

Plate 1: The Runge Family



Fanny Runge (née Tolmé) with Richard, Carl, and Lily in Bremen



*Aimée du Bois-Reymond and Carl Runge
as an engaged couple in Berlin (1887)*



Erich Treffitz with his sister Emilie (Ducca)

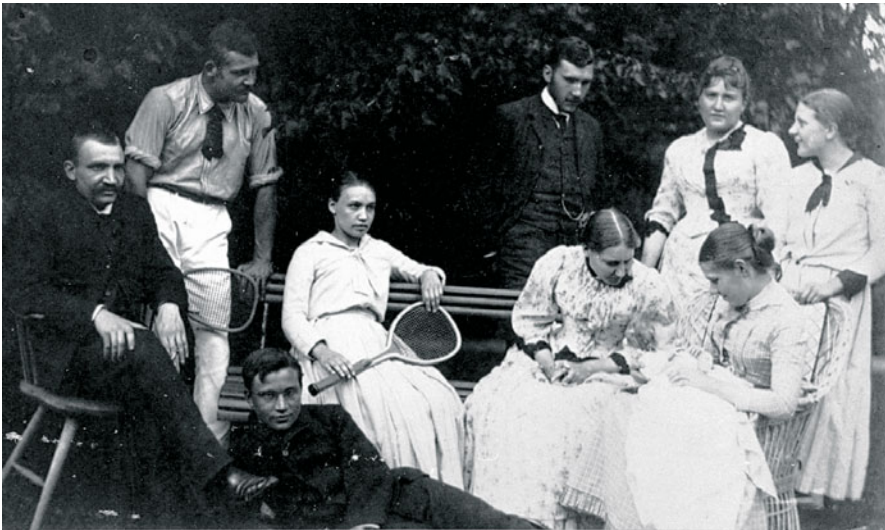
Plate 2: The Extended Du Bois-Reymond Family



Jeanette du Bois-Reymond (née Claude), Aimée Runge (née Du Bois-Reymond), Wilhelmine Claude (née Reklam) with Iris Runge



Aimée Runge with her daughter Iris in Potsdam (1888)



The children of Emile and Jeanette du Bois-Reymond and Iris (Summer 1888) Claude, René, Percy, Estelle (Dolly), Alard, Ellen, Lucy, Aimée with Iris, Rose

Plate 3: Children of Aimée and Carl Runge

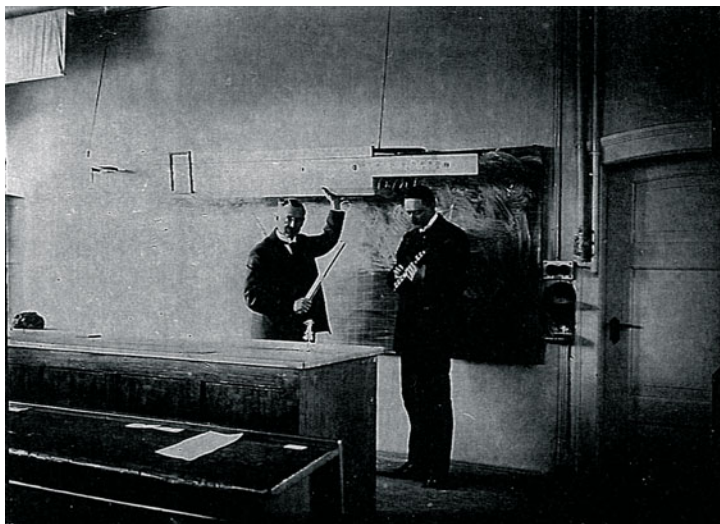


Nerina (Nina), Ella, and Iris



Aimée and Carl Runge with Iris, Ella, Nina, Wilhelm, Bernhard, and Aimée (1903)

Plate 4: Carl Runge at the University of Göttingen



Carl Runge and his assistant Horst von Sanden



Carl Runge in the lecture hall

Plate 5: Iris Runge



Iris Runge (1929)



Plate 6: School and University Years



Iris Runge and Hedwig (Hedi) Ehrenberg in math class



Elisabeth Klein



Erich Trefftz, (unknown), Iris Runge, Anni Trefftz, Albrecht Renner, Richard Courant (1907)



A theater scene at the Göttingen Lyceum, Iris Runge first from right (June 10, 1914)

Plate 7: The Circles of Sommerfeld and Tammann



Arnold Sommerfeld (ca. 1910)



Paul Ewald



Iris Runge (second from left) with Tammann (second from right) and others (1920)

Plate 8: Close Companions



Leonard Nelson



Wolfgang Kroug (ca. 1914)

Plate 9: Close Companions



The Wilmersdorf Samaritan Group (ca. 1931)



Dance class in 1929. Iris Runge (bottom right), Wilhelm (standing, 5th from right) and Maria Runge (bottom, 2nd from left)



The Wilmersdorf Samaritan Group

Plate 10: The Electron Tube and Light Bulb Factory



*Berlin-Moabit, Sickingenstraße 71
Main building of AEG's light bulb factory (constructed in 1905–06);
as of July 1, 1920 the headquarters of Osram's Factory A (light bulbs, electron tubes);
as of July 1, 1939 Telefunken's electron tube factory;
from 1952 to 1960 the headquarters of Telefunken*

Plate 11: Osram



Researchers at the experimental laboratory of Osram's Factory A. Sitting in the middle: Dr. Iris Runge, with laboratory assistants sitting to her left and right. Standing (from left to right): Dr. Walter Heinze, Dr. Magdalene Hüninger, (unknown), Dr. Ilse Müller, Dipl.-Ing. H. Lutterbeck (1924)



Richard Jacoby (1929)



Marcello Pirani (after 1945)

Plate 12: Osram



Magdalene Hüniger (1929)



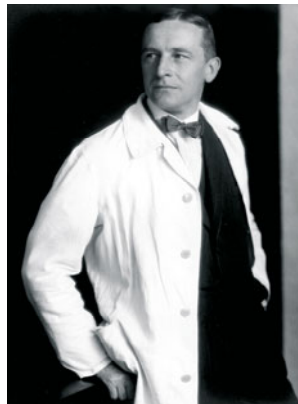
Ilse Müller (1929)



Otto Frenz (1929)



Walter Heinze (1929)



Erich Hoepner (1929)

Plate 13: Electron Tube Research at Osram



Adolf Güntherschulze (1929)



Willy Statz (1929)



Konrad Meyer as a student in Munich



Peter Kniepen (1929)

Plate 14: Telefunken



Wilhelm Runge



Wilhelm Runge, Conducting an Experiment at the Lighthouse in Friedrichsort (May 1937)



Karl Steimel



Max Weth (1929)

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Name	Vorname	Titel	Frühere Tätigkeit bei Telefunken	Gegenwärtige Adresse	Spezialkenntnisse
name	Christian-name	title	former occupation	present address	special knowledge
Wehnert	Waldemar	Dr. Ing.	Head of the testing field for small power and military valves	Berlin - Dahlem, Schorlemer Allee 13	extensive knowledge of testing small power and military valves, testing sets and the use of them
Ruber	Harry	Dr. Ing.	Head of the laboratory for developing metal-ceramic valves	Paris	comprehensive knowledge of developing and constructing metal-ceramic valves.
Karl	Fritz	Dr. Ing.	Head of a group in laboratory for developing velocity-modulation valves	unknown	comprehensive knowledge of mathematical treatment of valve problems.
Miss Runge	Iris	Dr. phil.	specialized in treating mathematical valve problems	Berlin - Spandau, Teiltower Str. 12	comprehensive knowledge of mathematical treatment of valve problems

TELEFUNKEN
 Gesellschaft für drahtlose Telegraphie m. b. H.
 Röhrenwerk Berlin

Deutsches Fachministerium
 Reichsministerium für wissenschaftliche Forschung
 Reichsministerium für Luftfahrt
 Reichsministerium für Kriegswirtschaft
 Reichsministerium für Wirtschaft

An excerpt from a post-war document describing Iris Runge's expertise at Telefunken (July 4, 1947). Prepared by Dr. Zickermann of Telefunken's electron tube factory and addressed to: Military Government, British Troops Berlin, Disarmament Branch, Berlin-Charlottenburg, Reichskanzlerplatz, Deutschlandhaus

Plate 16: Iris Runge's Residence



The apartment building in which Iris Runge resided from 1935 to 1966



A view of from the courtyard