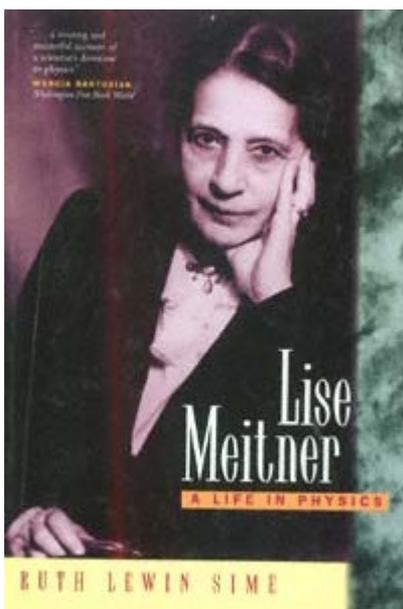

Preferred Citation: Sime, Ruth Lewin. *Lise Meitner: A Life in Physics*. Berkeley: University of California Press, c1996 1996.
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Lise Meitner

A Life in Physics

Ruth Lewin Sime

UNIVERSITY OF CALIFORNIA PRESS

Berkeley · Los Angeles · Oxford

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Preferred Citation: Sime, Ruth Lewin. *Lise Meitner: A Life in Physics*. Berkeley: University of California Press, c1996 1996.
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Preface and Acknowledgments

It seems to me that I have always known of Lise Meitner. As a child I must have seen her picture in *Life*, or in *The New York Times*, or perhaps in the *Aufbau*, the German refugees' newspaper that my parents and grandmother often read. In America just after World War II, Lise Meitner was a celebrity: the tiny woman who barely escaped the Nazis, the physicist responsible for nuclear fission, "the Jewish mother of the atomic bomb"—although she was a Jew by birth, not affiliation, and she had refused to work on the bomb. When I was six, the details didn't matter. To me, she was a hero, like Eleanor Roosevelt.

I came back to Meitner thirty years later, in the 1970s, by way of a class I taught at California State University, Sacramento. Then, as now, I was on the chemistry faculty at Sacramento City College, a community college. At the university, I was known as the woman the all-male chemistry department did not want to hire; under such circumstances one becomes, and remains, a

feminist. When the women's studies board asked me to put together a "Women in Science" course, I accepted right away, although at that moment I could think of only two: Marie Curie (of course) and Lise Meitner. So successful was feminist scholarship, however, that I was sure I would find more women in science and perhaps even begin to answer the question, Why so few?

As it turns out, they were not so few. Throughout history, everywhere, women have been active in science and mathematics and medicine. What these women shared, over the centuries, was the irregularity of their

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education and a determined undervaluation at the hands of historians. The great exceptions, from Hypatia to Laura Bassi to Sofia Kovalevskaja, were so recognized by their contemporaries that later historians, try as they might, could not make them disappear entirely. Among the less famous but still well known—Caroline Herschel and Marie-Anne Lavoisier, for example—are women who worked with male collaborators, an arrangement that gave them a chance to work but tended to obscure their contributions. There have been other women whose contributions are barely recorded, still others we know only from private correspondence or incidental references, and many more, surely, of whose existence and work we will never know. On the whole it is clear, however, that women have always done science and that the accomplishments of women, like men, have ranged from minor to extraordinary.

Historically, however, women scientists are far less visible than men, a "Matthew effect" in which the already famous attract repeated study and the lesser known are neglected. Although women's studies (like ethnic studies) has brought forth great treasures from neglected history, many historians, even today, are reluctant to bring women in from the cold. (Recently, when one historian of science decided to omit women physicists, including Lise Meitner, from his edited volume, he explained that women and gender questions have always fallen below a certain "historiographic threshold"—a tradition he was evidently content to perpetuate.) The result is a persistent double exclusion: of women from history, of their work from the scientific record. The neglect has been anything but benign. Over the centuries, the apparent paucity of women in science has been used to deny women equitable access to education and the professions. And although many more women are scientists today, sociologists note that as a group they are still, to a significant extent, at the margins.

Lise Meitner almost broke that pattern. She was born in 1878 (eleven years after Marie Curie), her timing just about right to begin cracking open the doors that were still closed to women. Her schooling in Vienna ended when she was fourteen, but a few years later, the university admitted women, and she studied physics under the charismatic Ludwig Boltzmann. As a young woman she went to Berlin without the slightest prospects for a future in physics, but again she was fortunate, finding a mentor and friend in Max Planck and a collaborator in Otto Hahn, a chemist just her age. Together Meitner and Hahn made names for themselves in radioactivity,

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and then in the 1920s Meitner went on, independent of Hahn, into nuclear

physics, an emerging field in which she was a pioneer. In the Berlin physics community she was, as Einstein liked to say, "our Marie Curie"; among physicists everywhere, she was regarded as one of the great experimentalists of her day. Her career was a string of firsts for the inclusion of women in science and academia. The painfully shy young woman had become an assertive professor—"short, dark, and bossy," her nephew would tease—and although at times she was haunted by the insecurity of her youth, she never doubted that physics was worth it. She never married, or even, as far as one can tell, had a serious love affair, but her capacity for friendship was very great. To the end, she was grateful to physics for bringing joy and meaning to her life and for surrounding her with friends and colleagues who were "great and lovable personalities." In the end, these were the only things she did not lose. Everything else—work, position, even, to a great degree, her scientific reputation—was taken from her when she fled Germany in the summer of 1938. Had she stayed longer, she would have lost her life as well.

When I began this study, less than ten years after her death in 1968, Lise Meitner was curiously in and out of view—odd, I thought, for someone who had been so well known. In the autobiographies of Otto Hahn, for thirty years her best friend and closest colleague, there was almost nothing of her personality and very little of her science; in the general literature, her pioneering work in nuclear physics was hardly mentioned. When her name appeared at all, it was for the discovery of nuclear fission, but then only at the margins. Like many of the women scientists I had recently studied, Lise Meitner seemed about to vanish.

Fission seemed to hold clues to her near-disappearance. Seen from Meitner's perspective, the story was fragmented, like torn-up snapshots thrown together. Here are Meitner, Hahn, and the chemist Fritz Strassmann, working as a team in Berlin from 1934 to 1938; there, in December 1938, is the discovery of nuclear fission, published under the names Hahn and Strassmann only; here we have Meitner again, in Sweden with her nephew, Otto Robert Frisch, providing the first theoretical interpretation for the fission process; there, finally, is the Nobel Prize, to Hahn alone.

For the rest of his life, Hahn provided a standard explanation: fission was a discovery that relied on chemistry only and took place after Meitner left Berlin; she and physics had nothing to do with it, except to prevent it

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from happening sooner. Hahn was believed: he was a Nobel laureate, and a very famous man. Strassmann, very much in his shadow, saw it differently. Lise Meitner had been the intellectual leader of their team, he insisted, and she remained one of them, through her correspondence with Hahn, even after she left. Meitner herself said little, other than to point to the essential interdependence of physics and chemistry throughout the long investigation. Privately, she described Hahn's behavior as "simply suppressing the past." And, she added, "I am part of that suppressed past."

The distortion of reality and the suppression of memory are recurrent themes in any study of Nazi Germany and its aftermath. By any normal standard of scientific attribution, there would have been no doubt about Meitner's role in the discovery of fission. For it is clear from the published record and from private correspondence that this was a discovery to which Meitner contributed from beginning to end—an inherently interdisciplinary discovery that would, without question, have been recognized as such, were it

not for the artifact of Meitner's forced emigration. But nothing about this discovery was untouched by the politics of Germany in 1938. The same racial policies that drove Meitner out of Germany made it impossible for her to be part of Hahn and Strassmann's publication, and dangerous for Hahn to acknowledge their continuing ties. A few weeks after the discovery was made, Hahn claimed it for chemistry alone; before long, he suppressed and denied not only his hidden collaboration with a "non-Aryan" in exile but the value of nearly everything she had done before as well. It was self-deception, brought on by fear. Hahn's dishonesty distorted the record of this discovery and almost cost Lise Meitner her place in its history. The unrecognized dishonesty, its careless acceptance, and deliberate perpetuation are among the most disturbing issues I address in this biography.

Given what is known about the systemic repression and "forgetting" of postwar Germany, it is, perhaps, not surprising that Hahn did not look back; he saw no need, and it was not to his advantage to correct the record with respect to Lise Meitner. A chorus of followers eagerly echoed his view, and a generation of journalists, writers, and casual historians of science uncritically propagated it. They may have been dazzled by Hahn's solo Nobel Prize (here, too, is an interesting issue), or motivated by nationalism. They also, apparently, found it entirely natural to suppose that a woman scientist would only be incompetent, or subordinate, or

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wrong. Or invisible: for thirty-five years Germany's leading science museum displayed the fission apparatus—the physical instruments Meitner used in her laboratory in Berlin—without mentioning her name at all. Were it not for her earlier achievements and her scientific reputation outside Germany, she might well have slipped permanently below the historiographic threshold.

Lise Meitner lived to be ninety years old; she knew what was taking place. Except for a few brief statements, she did not campaign on her own behalf; she did not write an autobiography, nor did she authorize a biography during her lifetime. Only seldom did she speak of her struggle for education and acceptance, although the insecurity and isolation of her formative years affected her deeply later on. And she almost never spoke of her forced emigration, shattered career, or broken friendships. She would have preferred that the essentials of her life be gleaned from her scientific publications, but she knew that in her case that would not suffice. Scientist that she was, she preserved her data. Her rich collection of personal papers, in addition to archival material from other sources, provides the basis for a detailed understanding of her work, her life, and the exceptionally difficult period in which she lived. In expressing my gratitude to those who have made this biography possible, I begin with Lise Meitner.

I have not worked in isolation. It is gratifying to note that in Germany, especially, a new generation of writers and historians of science has taken an interest in Lise Meitner; among the earliest were Fritz Krafft, Charlotte Kerner, Helga Königsdorf, and Renate Feyl. It may be, however, that Lise Meitner's greatest visibility lies just ahead. Recently, the Society for Heavy Ion Research (GSI) in Darmstadt has proposed that element 109, one of the heaviest yet, be named for her; in 1994, IUPAC, the commission that decides such things, approved the name (see Appendix fig. 4). It is not the first such proposal. In 1918, when Meitner and Hahn discovered element 91, her friend Stefan Meyer jokingly suggested the name "lisonium," or possibly

"isottonium"; the discoverers chose protactinium instead. It may take a while before a new periodic table makes its way into my classroom, but when it does, "meitnerium," Mt, will be there. I'm looking forward to it.

Many people have helped me. My first contact was Hahn's former secretary, the late Marie-Luise Rehder, Göttingen, who generously shared

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with me her knowledge of Otto Hahn and his papers and helped me contact others who were associated with Lise Meitner. I am indebted to the late Otto Robert Frisch for several interviews and for access to the Meitner Collection in the Churchill College Archives Centre, Cambridge, and to Ulla Frisch for interviews, family photographs, and continued access to the Meitner Collection. I am also deeply grateful to the late Fritz Strassmann and to Irmgard Strassmann, Mainz, for documents and photographs. Lilli Eppstein, Danderyd, Sweden, has made Meitner's Swedish experience accessible to me with her astute recollections of Meitner's personality and her friends in Sweden; she has generously permitted me to quote from her private correspondence with Meitner. I also wish to thank Sigvard Eklund, Vienna, for sharing with me his memories of his work and friendship with Meitner in Sweden. I am grateful to Hilde Levi, Copenhagen, for her assistance at the Niels Bohr Archive and for her memories of Lise Meitner's Copenhagen circle. Theodore Von Laue, Worcester, Massachusetts, shared childhood memories, photographs, and copies of his father's automobile guest book. Auguste Dick, Vienna, was an invaluable resource for documents and information about Meitner's education and family in Vienna. Franco Rasetti told me about his stay in Meitner's laboratory in the 1930s, and Emilio Segrè provided insight into the early neutron irradiation experiments in Rome and the discovery of technetium. Stephen Weininger interviewed Tikvah Alper, Sarisbury Green, England, for her memories of her student years with Meitner; Leslie G. Cook, Summit, New Jersey, recalled his experiences in Hahn's laboratory around the time of the fission discovery. I am grateful to Hans P. Coster, Belleaire, Texas, and Ada Klokke-Coster, Epse, Netherlands, for letters, photographs, and memories of their parents, Dirk and Miep Coster, and I owe special thanks to L. K. ter Veld, Groningen, for his interest in this project, for photographs, and for copies of Dirk Coster's correspondence from the University of Groningen.

The Office for History of Science and Technology, Berkeley, has been an invaluable resource; I wish to thank Bruce Wheaton for introducing me to the facility and John Heilbron for his ongoing advice and help. Ulla McDaniel and Eleonore Watrous translated letters for me from Danish, Swedish, and Dutch. Roger Stuewer has been a boundless source of encouragement and information. I am indebted to him and to David Cassidy and Susan Quinn for their extremely helpful reviews of the manuscript; they improved it greatly. Elizabeth Knoll, my editor at the Uni-

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versity of California Press, was the driving force in getting me to finish the book.

I have been generously assisted by the following institutions and individuals: Marion Stewart and Alan Kucia of the Churchill College Archives Centre, Cambridge; Marion Kazemi of the Archiv zur Geschichte der Max-Planck-Gesellschaft, Berlin; Finn Aaserud, of the Niels Bohr Archive,

Copenhagen; Wolfgang Kerber, Zentralbibliothek für Physik, Vienna; Elisabeth Vaupel and the staff of the Deutsches Museum, Munich; the Museum Boerhaave, Leiden; Urban Wråkberg, of the Royal Academy of Sciences, Stockholm; Spencer Weart of the American Institute of Physics; the Joseph Regenstein Library, University of Chicago; and the Bancroft Library, University of California, Berkeley.

Along the way I have been helped by many other people as well. I wish to thank Helmuth Albrecht, Mitchell Ash, Lawrence Badash, Dan Bar-On, Ingmar Bergström, Alan Beyerchen, Peter Brix, Anna Borelius-Brodd, Joan Bromberg, H. B. G. Casimir, Ute Deichmann, T. De Vries-Kruyt, Steven Dickman, Inga Fischer-Hjalmars, Vincent Frank-Steiner, Robert Marc Friedman, Stanley Goldberg, Dietrich Hahn, Günter Herrmann, Erwin Hiebert, Darleane C. Hoffman, Dieter Hoffmann, Roald Hoffmann, Walter Höflechner, Teri Hopper, Thomas Kaiserfeld, Bettyann Kevles, Daniel Kevles, Christa Kirsten, Kerstin Klein, Lester R. Kleinberg, Fritz Krafft, Arnold Kramish, Svante Lindqvist, Evelies Mayer, Herbert Mehrstens, Anne Meitner, Barbara Orland, Diane Paul, Sir Rudolf Peierls, Max Perutz, Thomas Powers, Hildegard Pusch, Paul Lawrence Rose, Margaret Rossiter, Kurt Sauerwein, Elvira Scheich, Glenn T. Seaborg, M. D. Sturge, Lieselotte Templeton, Sheila Tobias, Pieter Van Assche, Angela Von Laue, Mark Walker, Sallie Watkins, Burghard Weiss, and Carl Friedrich von Weizsäcker. I apologize to anyone I may have inadvertently omitted.

I have received generous grants from the National Endowment for the Humanities, the National Science Foundation, and the Alfred P. Sloan Foundation, for which I am truly grateful.

During the years I worked on this project, my daughters, Karen and Jennifer, have grown from children to young women. I thank them for their love and patience; I think they understand that this book is, in many ways, for them. And finally my love and gratitude goes to my husband, Rod, without whose interest, understanding, kindness, and help I might not have started this book, and certainly would never have finished it.

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Chapter One

Girlhood in Vienna

And even today I am filled with deep gratitude for the unusual goodness of my parents, and the extraordinarily stimulating intellectual atmosphere in which my sisters and brothers and I grew up.

Lise Meitner was born in Vienna in 1878, the third child of Hedwig and Philipp Meitner. She would live in Vienna twenty-nine years, and then she would leave, not realizing how permanently, to make her professional home in Berlin. Part of her remained sentimentally, irreversibly Viennese. She gave in to it, laughing at herself each time she paid the special fee to maintain her Austrian residency. "Na ja," she would shrug. "Foolishness costs money." And

later still, after she fled Germany for Stockholm, after every member of her family was gone from Vienna, after the community from which she came was lost forever, even then she clung to her Austrian past, refusing to take Swedish citizenship until she could have both.^[1] Had she stayed longer in Vienna, she might not, perhaps, have remained so strongly bound.

Of Lise's childhood we have few details. Even her date of birth is not entirely certain. In the birth register^[2] of Vienna's Jewish community it is listed as 17 November 1878, but on all other documents it is 7 November, the day Lise herself observed. It may be that her parents, already ambivalent about their Jewish affiliations,^[3] somehow delayed the record, or perhaps the discrepancy was merely a case of *Schlamperei*, that well-known imprecision that contributed to Vienna's charm. Neither explanation is satisfactory. Lise's name also changed slightly, from its original Elise. In Berlin such things might have caused a flurry of paperwork; in Vienna it made no difference.

Like many of their generation, Lise's parents were recent arrivals in the capital, a move whose sense of future may explain their lack of attention

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to a detailed family history. The Meitners traced themselves back only a few generations,^[4] to the village of Meiethein in Moravia, the fertile region north of Vienna that is now part of the Czech Republic. Toward the end of the eighteenth century, not long before the Rights of Man began drifting toward Austria, Kaiser Josef II initiated a series of reforms designed to consolidate power and secure the loyalty of all his subjects: he made German the official language of government, curtailed the Church, gave peasants some relief from serfdom, and granted Jews their first very limited access to civic employment, military service, and education. The Kaiser's tolerance did not extend to his own environs—fewer than two hundred Jewish families were permitted to live in Vienna—but he cracked the ghetto walls, so that Jews flooded the schools, joined the military, and looked to German language and culture for its promise of emancipation, opportunity, and humanism.^[5]

Among Kaiser Josef's administrative reforms was the requirement of a family name. Lise's great-great-grandfather took the name Meietheiner, an indication that the family had lived in the village a long time; the name eventually shortened to Meitheiner, Meithner, Meitner. The family lived modestly;^[6] if some achieved special distinction, it was for their character and good deeds. Lise's great-grandfather, it was told, crept through the town after dark every Friday night to lay a loaf of challah, the Sabbath bread, at the door of every poor Jew. He did this as secretly as possible and did not permit anyone to thank him, but everyone knew it was the work of Reb Meitner. "Reb" did not mean "rabbi"—there were none in the Meitner family—but was a traditional title of respect.

Reb Meitner's son Moriz, Lise's grandfather, married Charlotte Kohn Lowy, a widow with two small boys who had inherited an inn, some property, and a guest house in the town of Wsechowitz. Her granddaughters would remember her as beautiful, well dressed, and as cheerful as she was self-disciplined. "The house might burn down," it was said, "and grandmother sings; there is cholera in the village, and still grandmother sings!" Moriz and Charlotte's son, Philipp, was blond and blue-eyed like his mother; like his grandfather, Reb Meitner, he would later be known for his integrity and kindness. In 1873 he married petite, dark-eyed Hedwig Skovran, whose grandfather had emigrated from Russia to Slovakia to escape the ongoing persecution of Jews.

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Philipp and Hedwig Meitner grew up with Austria's transition from late feudalism to a recognizably modern society. The liberal revolutions of 1848 were crushed in Austria, but the struggle for individual freedoms and national autonomy went on. Industrialization came to Vienna and with it, a great internal migration from throughout the empire. In 1858, the medieval fortifications ringing the old inner city were torn down; in their place came the imposing Ringstrasse, grand new public buildings, and a parliament with little real power whose Liberal majority pressed for a modern secular state and constitutional government. At a time when the old order was failing and the very notion of empire was threatened by nationalist dissensions, the Habsburg monarchy was humiliated by a string of unwise military ventures and diplomatic blunders. By 1867, Kaiser Franz Josef saved what he could by dividing the empire and letting Hungary go. He granted his people a number of constitutional laws: national and religious toleration, a laissez-faire economy, an impartial judiciary, greater individual freedoms of education, belief, speech, and press. For Jews, this meant full civic equality, including access to professions from which they had previously been barred.^[7] Philipp Meitner was among the first group of Jewish men who were free to study law and be admitted to its practice.

In the twenty years from revolution to constitution (so the saying went), Austria had been dragged into the nineteenth century. By the time Lise Meitner was born in 1878, imperial Vienna was mostly theater, set with palaces of impossible opulence and a Kaiser, the popular and long-lived Franz Josef. It hardly mattered any more. The new Vienna was bursting with life of its own, sprawling into the countryside, its population doubling and doubling again with an influx so constant that for generations most Viennese would be born somewhere else: overwhelmingly Catholic with some Jews and virtually no Protestants, mostly German-speaking with large contingents of Czechs, Hungarians, Italians, Poles, Croats, Ukrainians, and others who retained their languages and national identities in newspapers and ethnic associations. To many of the new arrivals, Vienna was a place of marginal work and much unemployment, water shortages, and summer cholera, with congestion so severe that even the wealthy lived in apartments and the very poor shared beds and slept in shifts. The most heterogeneous city in Europe, it was among the most crowded and un-

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sanitary; it had the highest rate of suicide. Still people came: conditions in the provinces were not better. Vienna at least promised improvement and pleasure: music of every sort, opera and theater, newspapers by the dozens, a renowned university, famous physicians and scientists, good food, vineyards at the edge of town, and blue hills shimmering hazily in the distance. If the Danube seemed muddy or the waltz overrated, Vienna was beguiling nonetheless, drawing from every stream of European culture, layered with history and beauty every newcomer could aspire to make his own. The intellectual ferment was very great. By the end of the century, Vienna had given birth to Viktor Adler's democratic socialism and Theodor Herzl's Zionism; it was the home Sigmund Freud loved to hate and the political base for Karl Lueger, the city's longtime mayor, whose heady mix of populism and

anti-Semitism drew the rapt attention of the young Adolf Hitler. If the nineteenth century came late to this society, the twentieth arrived early.^[8]

When Philipp Meitner entered the legal profession in the early 1870s, it was possible not only to practice law but to have a hand in the creation of a new political order. The new constitution called for sweeping reforms of Austria's entire legal system, and in Vienna, after years of neglect by Crown and Church, the Liberal city council built an ample water supply and provided flood control and improved public health, hospitals, and schools.^[9] It was a time when progress seemed the natural order of things, each decade a noticeable improvement on the one before. As an attorney, "freethinker," and humanist, Philipp Meitner was committed to the Liberal ideals of reason and civic progress, sympathetic to the Social Democratic goals of justice and individual improvement. He immersed himself in Vienna's political life. Although he never sought elective office, he and Hedwig made their home a gathering place for interesting people—legislators, writers, chess players, lawyers. The children stayed up and listened. Years later, when Lise was asked about her childhood, she remembered most of all "the unusual goodness of my parents, and the extraordinarily stimulating intellectual atmosphere in which my brothers and sisters and I grew up."^[10]

During Lise's childhood the family lived in the second district, known as Leopoldstadt, just north across the Danube canal from the old city. Originally a ghetto, the community was named for Leopold I, who expelled Vienna's Jews in the 1600s, then grudgingly permitted them to return. For

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the next two centuries, the number of Jews in the capital remained small, but in the 1860s, when residence restrictions were abolished and Jews from throughout the empire converged on Vienna, Leopoldstadt grew.^[11] Crowded and run-down in some areas, it was pleasant, even somewhat prosperous, in others.

Lise was born in the family apartment at 27 Kaiser Josefstrasse,^[12] a tree-lined avenue that traversed Leopoldstadt from a commercial district at one end to the Prater, Vienna's huge park, at the other. There on a Sunday the family could enjoy amusements and cafés, wooded paths and open fields, and even on occasion glimpse the Kaiser riding by. On the whole Leopoldstadt was a comfortable place to raise a family. The first three Meitner children, Gisela, Auguste (Gusti), and Lise, were born only a year apart, followed not quite so rapidly by five more: Moriz (Fritz), Carola (Lola), another boy, Frida, and finally Walter, the baby brother Lise adored, who was born in 1891.^[13] The large family could afford few luxuries, but Philipp Meitner's law practice did provide the middle-class essentials: books, a few summer weeks in the mountains, and—virtually a necessity in Vienna—music lessons.^[14] Gusti was the family's most talented musician, a child prodigy who became a composer and pianist of concert rank.^[15] Lise played the piano too; all her life music would be a passion for her, as necessary as food. But she was especially curious about mathematics and science, an eight-year-old who kept a math book under her pillow and would ask about the colors of an oil slick and remember what she was told about thin films and the interference effects of reflected light.^[16] In this family children were seen and heard—and expected to think for themselves. Once, when Lise was still very young, her grandmother warned her never to sew on the Sabbath, or the heavens would come tumbling down. Lise was doing some embroidery at the time and

decided to make a test. Placing her needle on the embroidery, she stuck just the tip of it in and glanced anxiously at the sky, took a stitch, waited again, and then, satisfied that there would be no objections from above, contentedly went on with her work.^[17] Along with books, summer hikes, and music, a certain rational skepticism was a constant of Lise's childhood years.

Judaism was not one of those constants. In Leopoldstadt the Meitner children lived among Jews, in a neighborhood dotted with synagogues and shuls, fully aware that they too were of Jewish origin. And yet it is clear that the family distanced itself from its Jewish past. One of Lise's nephews,

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Gusti's son, Otto Robert Frisch, would later have the firm impression that his mother and all the Meitner children had been baptized and raised as Protestants.^[18] In fact, this was not so: the children were all registered with the Jewish community at birth and accepted baptism only as adults—Lola and Gisela as Catholics in 1908, Lise as Protestant the same year.^[19] But Frisch's impression was in essence true: the Meitners did leave the old religion for the new.

Their reasons were never explicitly stated. Opportunism was apparently not one of them: Philipp and Hedwig Meitner never baptized their children or themselves and thus derived none of the advantages conversion would have offered, particularly in the legal profession where discrimination remained strong and conversion was still a passport to judgeships and other civil service positions.^[20] One can only assume that the Meitner couple lost interest in Judaism, regarding it as a ghetto relic perhaps, or an undesirable ethnic division; they surely felt little kinship with Leopoldstadt's many *Ostjuden*, Jews from Galicia and other Austrian-held Polish provinces whose language, dress, and orthodoxy set them apart.^[21] Enlightened and progressive, Hedwig and Philipp Meitner were drawn to German culture; freshly emancipated, with optimism bordering on faith, they embraced the culture that freed them.^[22] By the turn of the century, such optimism must have dimmed somewhat, as the most charismatic Viennese mayor of all time, the handsome Karl Lueger (*der schöne Karl*), rallied his voters by appealing to their Catholicism, nationalism, and anti-Semitism. It is worth noting that none of the Meitner children followed their father into politics, or even law. But their parents' idealism influenced them nonetheless. It was part of the "unusual goodness" Lise remembered, the basis for the extraordinary intellectual atmosphere that nurtured Lise and the other children in their parents' home.

In this atmosphere all the Meitner children, including the five daughters, pursued an advanced education. Even today such a family record would be notable, but at the time it was truly extraordinary, for until the end of the nineteenth century women were by law excluded from Austrian universities and, by the same logic, from rigorous secondary schools as well. While a bright boy might attend a *Gymnasium* and take the *Matura*, a leaving examination that was required before entering the university, public school for girls was over at age fourteen, and it was poor. Lise attended the Mädchen-Bürgerschule at Czerninplatz, a crowded inter-

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section not far from home. On 15 July 1892, she received her final *Jahres-Zeugnis*, a report card that was also an *Entlassungs-Zeugnis*, a completion

certificate.^[23] She had learned bookkeeping arithmetic but not algebra, a smattering of history, geography, and science, the requisite drawing, singing, and "feminine handwork," a little French and gymnastics. Although her grades were all good and her behavior "entirely appropriate" (*vollkommen entsprechend*), her diligence was rated only "satisfactory" (*befriedigend*) rather than "industrious" (*ausdauernd*), an indication that she did not find school very challenging. Inked at the bottom of her Jahres-Zeugnis was the line: "*vom weiteren Schulbesuch befreit*" (released from further schooling). Lise had gone as far in public school as an Austrian girl could go.

Not yet fourteen, her choices were few. Most girls would spend the next few years helping at home, sewing, and daydreaming of marriage. The only way for a girl to go on was to attend a private *höhere Töchterschule* for young ladies of the middle class; the only profession she could seek was teaching a subject that did not require university education. Lise chose French. Nothing in her contemporary records or later memoirs indicates that she ever had a real interest in it. Instead, she lavished her energy and love on her baby brother, Walter; he would always be her closest sibling. She also tutored younger girls to help pay for Gusti's advanced music lessons and volunteered with the poor in relief organizations and schools.^[24]

Of these years Lise would remember little but a sense of loss. "Although I had a very marked bent for mathematics and physics from my early years, I did not begin a life of study immediately," she wrote later.^[25] "Thinking back to ... the time of my youth, one realizes with some astonishment how many problems then existed in the lives of ordinary young girls, which now seem almost unimaginable. Among the most difficult of these problems was the possibility of normal intellectual training."^[26]

In Austria the issue of higher education for women had been simmering for a generation, certainly since 1867 when universities were first opened to men without regard to economic class, religion, or national origin. Over the years a small number of women had approached the universities, petitioned professors, begged to attend a class or two. At best they were permitted to sit in as unofficial auditors, not expecting and certainly never receiving any credit or documentation. Most of these women were teachers whose prior education did not qualify them for university admission. But

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even the few who did qualify—occasionally a young woman from Bohemia or Austrian Poland would somehow manage to attend her local Gymnasium and pass the Matura—were also denied admission. Daughters of the wealthy and the aristocracy were routinely educated in Switzerland. The rest were trapped in a cycle willed by the state: since the universities (all public institutions) excluded women, the government did not see fit to establish schools that would prepare women for university admission. In Europe, only Germany and Turkey offered more resistance to women's education.^[27]

Toward the end of the nineteenth century, however, the resistance began to falter. Women's groups, often led by headmistresses of girls' schools, regularly petitioned for improved secondary education; a private *Mädchengymnasium* was established in Vienna in 1891 even though its graduates were not permitted to take the Matura; the government itself, urgently needing female physicians for Moslem women in occupied Bosnia and Herzegovina, recruited foreign women for many years, hired the first Austrian (Swiss-trained) in 1892, but still denied medical certification to other Swiss-

trained Austrian women physicians who wished to enter private practice, although, at the same time, a highly competent eye surgeon who was born in Russia and trained in Zurich received special permission from the Kaiser to establish a clinic with her husband in Salzburg. Publicity accompanied each case, and opinion gradually softened. It seemed plausible, finally, to suppose that in Austria—as in America, France, and Switzerland—women could be educated without suffering mental illness or infertility or social catastrophe. By the mid-1890s, even conservative university professors regarded women students as a flood that could no longer be held back. In 1897 the government granted women access to the philosophical faculties (letters and sciences) of Austrian universities; a few years later women were admitted to medical schools as well.^[28]

With this, the cycle of exclusion was thrown into reverse. Justice, and the need for university educated women teachers, required that universities admit women at once, even without Gymnasium preparation. For the interim women would be required only to pass the Matura, any way they could. This came as good news—late, but not too late—for Lise and her sisters.

Gisela, already twenty-one, came first. After two years of intensive private lessons, Gisela passed the Matura and entered medical school in

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1900. Lise meanwhile completed her teacher training (as insurance, her father advised) and in 1899 began her own lessons in a group with two other young women. Together they compressed eight missing school years into two: Greek and Latin, mathematics and physics, botany, zoology, mineralogy, psychology, logic, religion, German literature, history. Lise studied night and day. "You'll fail," her younger brothers and sisters would tease. "You've just walked across the room without picking up a book."^[29] A photograph shows a pale young woman with dark circles under her eyes.

For physics and mathematics, Lise's group was tutored by Arthur Szarvassy, a young physicist who had just completed his doctorate at the University of Vienna.^[30]

Dr. Szarvassy [*sic*] had a real gift for presenting the subject matter of mathematics and physics in an extraordinarily stimulating manner. Sometimes he was able to show us apparatus in the Vienna University [Physics] Institute, a rarity in private coaching—usually all one was given were figures and diagrams of apparatus. I must confess that I did not always get correct ideas from these, and today it amuses me to think of the astonishment with which I saw certain apparatus for the first time.^[31]

Lise took the Matura in July 1901 at the Akademisches Gymnasium, a distinguished boys' school on Beethovenplatz in the old city.^[32] The course of study had been so intense and the examination conditions so terrifying—as *Externisten* (outside students), Lise and the other women were examined in strange surroundings by teachers they had never met—that Lise never failed to mention it in her later remembrances. Of fourteen who took the exam, only four passed;^[33] three were the students of Dr. Szarvassy. The fourth was Henriette Boltzmann,^[34] whose father would soon be a formative influence in Lise's life.

Lise would always think of Arthur Szarvassy as her first true teacher. And she was grateful to her parents, who made it possible for her to achieve what few other young women of her generation could.

Many parents shared the prejudice of the time against [women's] education, so that their daughters either had to forgo the education they desired, or fight for it. ... [I knew] a young woman who at age 24 wanted to be privately tutored by her cousin to prepare for the Matura; her parents—in other respects very loving, I'm sure—literally kept her prisoner in their apartment to keep her from carrying out her intentions. Only when she disappeared from the apartment one day and let her parents know that she would not return unless she had permission to study, did they give in.^[35]

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Although Lise herself had no such obstacles, she sensed that for her mother, at least, it was not always easy.

I had the feeling that in the beginning, when first my older sister, and then I passed the Matura, that my mother was inwardly somewhat depressed by it. But she was much too loving a mother ever to express it in any way.^[36]

From her father there was no such ambivalence. On the contrary, he was a steady source of support and advice.

Even as a child I was strongly interested in mathematics and physics, and as I grew up I also developed a very pronounced inclination for social responsibility. ... When I was 23 years old and about to enter the university, I entertained the idea of primarily pursuing medicine, for its social usefulness, and studying mathematics and physics only at the side. My father kept me from this incorrect choice by making it clear to me that such a course of study might be possible for a genius like Hermann Helmholtz, but not for another person.^[37]

Lise entered the University of Vienna in October 1901. Small and slender, with a faraway expression and serious dark eyes, she looked younger than her twenty-three years. A bluestocking, her nephew would judge later, a young woman who cared for nothing but study. He was probably right. Anxious to make up for lost time, Lise filled her university registration book with physics, calculus, chemistry, and botany—twenty-five hours a week of lectures, laboratories, demonstration and discussion sections.^[38]

No doubt, like many other young students, I began by attending too many lectures. ... I cannot say I have a very lively recollection of the lectures on experimental physics. These were delivered almost without experiments, between noon and one P.M. , when most of the students were already very tired. Sometimes I was really afraid I would slip off my chair.

But for calculus, at eight o'clock in the morning, she was awake.

My first term I studied differential and integral calculus with Professor Gegenbauer. In my second term he asked me to detect an error in the work of an Italian mathematician. However I needed his considerable assistance before I found the error, and when he kindly suggested to me that I might like to publish this work on my own, I felt it would be wrong to do so, and so unfortunately annoyed him forever.

Here was Lise, a first-year student, refusing to publish as her famous professor asked. Assertive in one way, self-deprecating in another—neither

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to her academic advantage. "This incident did make it clear to me, however, that I wanted to become a physicist, not a mathematician."^[39]

In fact, the physics course Lise attended, her drowsiness notwithstanding, had the reputation of being exceptionally well taught. It had been designed for pharmacy students, but Professor Franz Exner brought such clarity and perspective to the subject that students from all disciplines thronged to it.^[40] The laboratory was directed by Anton Lampa, a promising young physicist and teacher.^[41] Lise may have been drowsy in lecture, but she vividly remembered the laboratory: the somewhat aloof instructor, the primitive equipment, the experiments requiring ice that could be done only when there was snow in the courtyard below.^[42] For this young woman who had never had science in school, whose only previous encounter with apparatus was to view it with astonishment, the laboratory was of paramount interest. She would study physics after all.

The physics institute was on the Türkenstrasse, a short side street in Vienna's ninth district, on the same block as the institutes for pharmaceutical chemistry and medicinal chemistry, not far from the renowned medical school and its clinics. The university had no central campus; its buildings were interspersed among the residences and shops of the neighborhood. A photographer's studio and a coffee house stood on either side of Türkenstrasse 3; Sigmund Freud lived and worked on the steep Berggasse nearby. Originally the structure had been a small apartment house, already run-down when the university purchased it as a temporary building in 1875 (a permanent physics building opened in 1913). Its entrance reminded Lise Meitner of the door to a hen house. "I often thought, 'If a fire breaks out here, very few of us will get out alive.'"^[43] Inside were worn stairs and shaky floors, makeshift laboratories with untold amounts of mercury in the floor cracks, a lecture room with neither podium nor desks, ceiling beams so rotten they looked as though they had been chewed by termites.^[44]

The lecture halls in particular were downright life-threatening. This was so widely known that the Viennese newspaper *Arbeiterzeitung* once carried this notice: "Once again a student has registered at the Physics Institute on the Türkenstrasse; unhappiness in love is said to be the motive for the deed."^[45]

But in that shabby building the quality of teaching and research was very high. Exner, the first professor students encountered, was a multifaceted

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experimental physicist whose research included electrochemistry, atmospheric electricity, crystal physics, spectroscopy, and optics. A friend of Wilhelm Röntgen, Exner had introduced x-ray research and its medical applications to Vienna; one of the first to take an interest in radioactivity, Exner secured uranium ore residues for Marie and Pierre Curie, received an enriched radium sample in return, and made Vienna an early center for radioactivity research. Although Exner lectured only to first-year students, he directed the advanced physics laboratories and supervised a large number of doctoral candidates. One of Lise's fellow students, Karl Przibam, remembered Exner for his contagious enthusiasm and for the community spirit that went far beyond the usual relationship between teacher and students.^[46]

This sense of community was essential for Lise in finding her way. She had come to the university on her own, very conscious of how few women there were and how visible she was, how some of the men went out of their way to be pleasant and others, just as conspicuously, did the opposite. Never having

gone to a Gymnasium, she could only imagine that she had missed some vital aspect of normal student life, in academics, perhaps, or student friendships, or relationships with teachers. With Professor Gegenbauer she had apparently been awkward and then embarrassed by her awkwardness; not ready to be singled out, she needed first to be convinced that she could be a student like any other.

For Lise, this happened in the old building on the Türkenstrasse, in the cluttered laboratory, during the informal give-and-take of teachers and students. It helped that the subject was difficult, chosen only by a few. In Vienna, indeed worldwide, the number of physicists was small; nearly all were engaged in teaching and research, very few in business or industry. Physics was more a calling than a career.^[47] Students who committed themselves to physics did so because they could not imagine a more fascinating way to spend their lives. By 1902, Lise Meitner knew she was one of them.

In her second university year, she began studying physics in earnest. Over the next six semesters, her *Meldungsbuch* lists analytical mechanics, electricity and magnetism, elasticity and hydrodynamics, acoustics, optics, thermodynamics, and kinetic theory of gases as well as mathematical physics each semester and a course in philosophy of science. A fairly typical curriculum, it was highly unusual in one respect: all of it was taught by just one person, the theoretical physicist Ludwig Boltzmann.

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Fifty years later Lise Meitner would still remember Boltzmann's lectures as "the most beautiful and stimulating that I have ever heard. ... He himself was so enthusiastic about everything he taught us that one left every lecture with the feeling that a completely new and wonderful world had been revealed."^[48]

One can scarcely imagine a better teacher for the atomic world that lay ahead. In 1902, Boltzmann was fifty-eight years old, the famed theoretical physicist who had extended kinetic theory and established statistical mechanics, the leading "atomist" who tied the second law of thermodynamics to atomic theory by showing that the inherent irreversibility of natural processes arises from the statistical behavior of atoms in the aggregate. The notion of unseeable atoms with indeterminate behavior was more than some scientists could swallow. For years Boltzmann was forced to defend his work against the fairly widespread philosophy of scientific positivism that denied the value of scientific theory and the reality of anything that could not be directly observed.

A big man, heavy, very nearsighted, with curly brown hair and a full reddish beard that framed his broad face,^[49] Boltzmann aroused admiration and affection in his students. He began his mechanics course in 1902 by offering his students "everything I have: myself, my entire way of thinking and feeling," and asking the same of them: "strict attention, iron discipline, tireless strength of mind. But forgive me if I [first] ask you for that which means most to me: for your trust, your affection, your love—in a word, for the most you have the power to give, yourself."^[50]

Like many of the others, Lise was swept away. He was immensely engaging, she remembered, this famous professor whose lectures were models of clarity, this warmhearted *Hofrat* (Excellency) who would shrug at his title and laugh, "Ach, how dumb of me!" at his blackboard errors.^[51]

Boltzmann had no inhibitions whatsoever about showing his enthusiasm when he spoke,

and this naturally carried his listeners along. He was fond of introducing remarks of an entirely personal character into his lectures. I particularly remember how, in describing the kinetic theory of gases, he told us how much difficulty and opposition he had encountered because he had been convinced of the real existence of atoms and how he had been attacked from the philosophical side without always understanding what the philosophers held against him. ... I wonder what he would say about our huge machines and teamwork [today], when I remember how bitterly he complained ... about the great extension of the subject matter of physics and

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the resulting overspecialization. He stated categorically that [Hermann] Helmholtz was the last physicist who had been able to have an overall view of the whole subject.^[52]

His relationship to students was very personal. ... He not only saw to their knowledge of physics, but tried to understand their character. Formalities meant nothing to him, and he had no reservations about expressing his feelings. The few students who took part in the advanced seminar were invited to his house from time to time. There he would play for us—he was a very good pianist—and tell us all sorts of personal experiences.^[53]

Boltzmann accepted women students as a matter of course. In 1872, long before women were admitted to Austrian universities, he met Henriette von Aigentler, an aspiring teacher of mathematics and physics in Graz. From their four-year correspondence we know of her desire to attend the university ("out of eagerness to learn and to qualify for teaching"), how she was refused permission to unofficially audit lectures (an administrator declared himself "delighted" to keep women out, since "the character of the university would be lost and the institution endangered" by their presence), that Boltzmann advised her to appeal (she did, successfully), and that when he proposed marriage, finally, he began, "It seems to me that a constant love cannot endure if the wife has no understanding, no enthusiasm for the endeavors of the husband, but is merely his housekeeper rather than the companion in his struggles."^[54]

Lise may have heard some of this; she came to know his wife and daughters and considered their family life harmonious.^[55] In any case, her university years were free of the obstacles she had encountered earlier and the difficulties that lay ahead. With his intellect and spirit, Boltzmann created a community to which she fully belonged. "He was in a way a 'pure soul,' full of goodness of heart, idealism, and reverence for the wonder of the natural order of things."^[56]

All who were close to Boltzmann were also aware of his bouts of severe depression and his suicide attempts.^[57] His students blamed it on the bitter controversy over whether atoms existed, in which Boltzmann gained many adherents among younger scientists but never the satisfaction of convincing his opponents. It was not that simple. Boltzmann himself jestingly attributed his rapid changes in temperament to the fact that he was born during the night between Shrove Tuesday and Ash Wednesday: he was, almost certainly, manic-depressive.^[58] But he was also very sensitive. As

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Meitner reflected, "[He] may have been wounded by many things a more robust person would have hardly noticed. ... I believe he was such a powerful teacher just because of his uncommon humanity."^[59]

Boltzmann's academic career was a series of wanderings. Born in Vienna in 1844, he graduated from the Akademisches Gymnasium, where Lise Meitner and also his daughter, Henriette, later took their Matura. At the University of Vienna, he was a student of Josef Loschmidt (1821–1895), who made reliable early estimates of molecular size and the number of molecules per mole,^[60] and he was assistant to Josef Stefan (1835–1893), who devised an empirical formula for black body radiation that Boltzmann subsequently gave a theoretical basis.^[61] Between 1869 and 1890, Boltzmann held appointments in Graz, then Vienna, then Graz again, a period during which he contributed to all branches of theoretical physics: electromagnetic theory, kinetic theory, the Maxwell-Boltzmann distribution, statistical mechanics. He went to Munich in 1890, returned to Vienna as Stefan's successor in 1894, left for Leipzig in 1900, and came back again in 1902. The university had kept his position open in the expectation that he would return.^[62]

Boltzmann was torn between his attachment to Austria, especially Vienna, and the attractions of German universities. Meitner recalled that Boltzmann would tell how in Munich there was "wonderful equipment, but far fewer good ideas" than in Vienna and then hastily add, "One must not let the Austrian [education] ministry know that good work can sometimes be done with inferior equipment."^[63] Of all universities, he most preferred Berlin, for its intense scientific atmosphere and the presence of Hermann Helmholtz, whom Boltzmann regarded as the greatest physicist of the nineteenth century. Yet in 1888 he refused the offer of a chair in Berlin, in part out of concern for his health,^[64] in part, it was said, because he disliked the formality of the Prussian capital.^[65] Later he would tell his students how much he regretted that decision. The position he refused went to a younger theoretical physicist, Max Planck.

A year after Boltzmann came to Vienna in 1894, he was joined on the faculty by one of his principal scientific adversaries, the formidable Ernst Mach. The leading proponent of the philosophy of scientific positivism, Mach argued that science can do no more than conduct positive—that is, direct—observations: while scientific theory may be of use for organizing such data, it must not create "pictures," as he called it, of underlying

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reality. Mach's impetus was antimetaphysical, a reaction against nineteenth-century attempts to reduce all of physics to mechanical principles; he opposed the kinetic theory of gases, based as it was on molecular motion, and dismissed the existence of atoms in broad Viennese, "'Ave y'seen one of 'em?"^[66] In the 1890s, according to Boltzmann, the attitude toward the gas theory was "malevolent,"^[67] complete with angry debates at meetings, struggles for the allegiance of young scientists, fights over appointments to faculties and journals.^[68] In central Europe especially, Mach attracted a sizable following, including "energeticists" led by the physical chemist Wilhelm Ostwald, for whom energy was the primary reality and the second law of thermodynamics superfluous. For his part, Boltzmann attacked positivism as a modern version of an "old aberration," going back to the philosophy of George Berkeley. In 1905 he visited a university in California whose campus he described as "the loveliest place one can imagine," except for its "philosophical aura":^[69] "The name Berkeley is that of a highly reputed English [*sic*] philosopher who is famous for the greatest foolishness ever hatched by the human brain, philosophical idealism, which denies the

existence of the material world."^[70]

In 1898 Mach suffered a stroke, and he retired from teaching in 1901. When Boltzmann returned to Vienna in 1902, he claimed the philosophy of science course that had been Mach's for many years. Boltzmann's inaugural philosophy lecture in 1903 was thronged by the press, students, including Lise Meitner, and six hundred "sensation-seekers." With his predecessor in mind, Boltzmann confessed to his "dislike, even hate of philosophy," comparing it to "a hallowed virgin ... [that] will remain eternally barren"^[71] as long as it denies the existence of physical reality. Thus the hostilities between the atomic theorists and the followers of Mach went on.

But the dispute over the reality of atoms was nearing an end. The discovery of radioactivity in 1896 and the electron in 1897 transformed atoms from disputed specks of mass to complex structures that were divisible, measurable, packed with amazing amounts of internal energy, and composed of fundamental particles of electric charge. "No physicist today believes atoms are indivisible,"^[72] Boltzmann told an audience at the World's Fair in St. Louis in 1904. That was probably true for those who believed in atoms, but not all physicists did, yet. The final blow came after Albert Einstein in 1905 and Jean Perrin in 1908 made detailed studies of

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Brownian motion, the random movement of particles suspended in a liquid, visible under the microscope. By relating the movement of the suspended particles to the number and energy of the molecules in the liquid that were hitting them from one side or another, Einstein and Perrin obtained a value for the number of molecules in a mole that was consistent with other, unrelated experiments. The direct relationship between the heat energy of atoms and the mechanical energy of visible Brownian particles gave complete credence to Boltzmann's interpretation of thermodynamic laws. And somehow it made atoms nearly visible and very real. Ostwald was convinced and in 1908 conceded; it is uncertain if Mach ever did before he died in 1916.^[73]

The controversy made plain to students that scientific endeavor is not coldly objective but relies on human judgment. From Boltzmann, Lise Meitner understood physics to be a passionate commitment of intellect, strength, and integrity. Many years later her nephew Otto Robert Frisch wrote, "Boltzmann gave her the vision of physics as a battle for ultimate truth, a vision she never lost."^[74]

Meitner's goal in physics would be theoretical understanding; her means, nearly always, would be experiment. In the summer of 1905, her coursework completed, she began her doctoral research. In Austrian and German universities the thesis research for a doctorate generally took no more than a few months to complete. She chose an experimental project, under Franz Exner and his assistant, Hans Benndorf, undoubtedly because she wanted the laboratory experience but also, perhaps, because Boltzmann was lecturing in California that summer and had been quite ill before he left.^[75]

In her research, Lise determined that Maxwell's formula for the conduction of electricity in an inhomogeneous solid also applies to the conduction of heat. Her inhomogeneous solid, an emulsion—a finely divided mixture—of mercury droplets embedded in fat, was layered between two horizontal copper plates, on which was laid a third copper plate that was insulated from the bottom two. The temperature of the bottom plate was kept constant by a stream of

running water; when the top plate was heated by steam, three strategically placed thermometers in the emulsion measured the temperature gradient as the heat flowed through. Exner was pleased, commending her for a "not entirely easy" investigation that was brought to completion "not without experimental skill." Her dissertation,

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"Test of a Formula of Maxwell's," was published under the title "Conduction of Heat in Inhomogeneous Solids" in the proceedings for the Vienna Physics Institute.^[76] Experiment close to theory, it typified her later approach to physics. Personally, however, Exner's influence seems to have been slight: in her later memoirs she mentions him only in passing, never with the affectionate term *Doktorvater* that German-speaking students often use. Most probably Boltzmann's personality eclipsed all others. Both men took part in her *Rigorosen*, the oral examinations that she took in December 1905 and passed summa cum laude. She was awarded her doctoral degree on 1 February 1906.^[77]

It was the middle of the academic year and Lise found herself somewhat at loose ends. At the time Paul Ehrenfest, a theoretical physicist her own age who had taken his doctorate under Boltzmann a few years before, was in Vienna. When he heard that Lise had taken detailed notes of all Boltzmann's lectures, he suggested they study his ideas as well as the work of others in analytical dynamics.^[78] Ehrenfest had a gift for explaining theoretical physics; he called Lise's attention to Lord Rayleigh's scientific papers, in particular an article on optics that described an experiment the British physicist could not explain. Meitner not only explained it but also predicted some consequences, proved them experimentally, and described them in her report, "Some Conclusions Derived from the Fresnel Reflection Formula."^[79] More than her thesis project, this investigation convinced her that she was capable of independent scientific work.^[80]

While engaged in the optics study, she also decided to learn something of the experimental procedures used in the new field of radioactivity. She had taken an advanced seminar on the subject from Egon von Schweidler the year before; now she became acquainted with Stefan Meyer, an assistant in Boltzmann's institute who was only six years her senior and already quite well known in the field. At Meyer's suggestion, Meitner measured the absorption of alpha and beta radiation in foils of various metals. By June she completed the study,^[81] having been introduced to several radioactive substances, the literature of radioactivity, and a new instrument, the leaf electroscope.

It was the summer of 1906, a time to assess her future. For the young woman who had just become Dr. Lise Meitner, the future was not much clearer than it had been at age fourteen. As the second woman to earn a doctorate in physics from the university, she knew of no prospects for a

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woman in physics;^[82] it seemed entirely possible she might never work as a scientist. In Austria there had as yet been no female *Assistent*, the first position on the academic ladder; there were no women's colleges like those in America with positions for a few women scientists,^[83] no great likelihood of a job in industry. Of course, Lise had heard of Marie Curie, who had won the 1903 Nobel Prize in physics with her husband, Pierre, and Henri Becquerel; if

she also knew of Curie's enormous professional difficulties in Paris and how little the prize had alleviated them, she would not have been encouraged. At one point she wrote to Marie Curie about working in her laboratory, but there was no position available.^[84] There seemed no choice but to follow her father's advice once again and obtain the credentials necessary to earn a living. She signed up for practice teaching at a girls' school.^[85] Teaching did not appeal to her. Great, perhaps insurmountable, obstacles stood in the way for a woman in science. There was no path to follow.

Late that summer, on 5 September 1906, the physics community was shocked by the news that Ludwig Boltzmann had taken his life. In a tribute to his friend and scientific opponent, Wilhelm Ostwald described Boltzmann as a victim of the immense sacrifices of health and strength demanded of those who struggle for scientific truth.^[86] Lise Meitner, more realistically, ascribed his suicide to "mental instability"; she never understood it.^[87] But it seems likely that Boltzmann's death strengthened her determination to remain in physics, so that the spark he had kindled in her would remain alive.

In the fall of 1906, therefore, she continued working with Stefan Meyer, who temporarily took over Boltzmann's institute. By day she taught school; in the evening she returned to Türkenstrasse 3. During that year she became familiar with radioactivity research, although she had no particular intention of specializing in it.^[88]

One of the earliest workers in the field, Meyer had been investigating the magnetic properties of various elements when polonium, radium, and then actinium were discovered in the Curies' laboratory in 1899.^[89] With von Schweidler, he investigated the radiation emitted by the new elements; using a magnetic field to deflect the radiation, they discovered that beta radiation consists of particles with negative charge,^[90] a discovery made at nearly the same time by Henri Becquerel in France and Friedrich Giesel in Germany. A year later Becquerel measured their charge-to-mass ratio

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and confirmed that beta rays—more correctly, beta particles—are identical to electrons. In a similar experiment, Meyer and von Schweidler studied the alpha radiation from polonium but were unable to observe a deflection; a few years later Ernest Rutherford would use stronger magnets to determine that alpha particles are positively charged.

Meyer remained in radioactivity. He recognized that the puzzling "induced activity" that early workers had found throughout their laboratories was due to radium, thorium, or actinium emitting a radioactive gas—Rutherford called it "emanation"—that diffused into the air and then decayed to a solid that coated objects all over the laboratory. The solid, also radioactive, was thereafter termed the "active deposit."^[91] (For the radioactive decay series, see Appendix fig. 1.) In those early years of radioactivity research, Meyer also studied the physical effects of radiation, such as color changes in minerals.

In 1900, four years after the discovery of radioactivity, the number of recognized radioactive species stood at five: the elements uranium, thorium, polonium, radium, and actinium. When Lise Meitner began research in 1906, the number was over twenty and rising—most confusing, since at first every new radioactive substance was thought to be a new element (the existence of isotopes was not fully appreciated until about 1913, when it became clear that it was possible for different radioactive species to be chemically identical). In