Heinrich Hertz: A Short Life

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(Invited Paper)

HEINRICH RUDOLF HERTZ was born in Hamburg on 22 February 1857, the 125th anniversary of the birth of George Washington. His grandfather, Heinrich David Hertz (1797–1863), was a scion of a wealthy Jewish family that had been resident in Hamburg since the 1780's; his grandmother, Betty Auguste Oppenheim (1802–1872), was a daughter of the estimable Cologne banking family. In 1834, when their oldest child, Gustav Ferdinand Hertz (1827–1914), was not quite seven, they were all converted to the Lutheran faith. Heinrich David Hertz was thereupon admitted to the full rights of a Hamburg citizen and presently became one of the city-state's 192 burgesses. His son Gustav (the physicist's father) later received the same honor, was elected to Hamburg's senate, and ultimately became head of its judicature (in effect, minister of justice). He was the first of his clan to attend a university, at Göttingen; in 1856 he married a classmate's sister, Anna Elisabeth Pfefferkorn (1835–1910), the daughter of a Prussian army surgeon and descendant of a long line of Frankfurt burghers. They had five children, of whom Heinrich Hertz was the oldest.

He was an exceptionally gifted child and excelled in every way except music (he was tone deaf), not only in school but also as a mechanic, sculptor, draftsman, linguist, and athlete. After completing his secondary education he determined to become a structural engineer. He first served a year as an apprentice in a civil engineer's office in Frankfurt. His duties were light and he was soon spending most of his time in the city's excellent art galleries and libraries, modeling in clay, and reading everything he could lay his hands on, from economics and physiology to physics and wire telegraphy. In attempting to devise an improved self-registering telegraph, he became aware of the already extensive technical literature on telegraphy (the oldest branch of electrical engineering), and decided to enroll in the Technical University where the first lectures on the subject were being offered—Dresden. He found the level of instruction too low to suit him and after a semester opted out by embarking on his year of compulsory military service. The signals service would have been the most logical assignment, but he was sent to train with a railway regiment instead, and at the end of the year was given a reserve assignment—in the infantry.

Manuscript received January 14, 1988; revised January 14, 1988.

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IEEE Log Number 8821078.

In view of his disillusionment with Dresden, he next enrolled at the Technical University of Munich, but changed his mind before the semester even began and switched to the University of Munich and to physics, though he managed to attend some lectures at the Technical University as well. He stayed for two semesters, but in the end this regime also proved to be inadequate and he transferred to the University of Berlin, where physics was taught by the likes of Gustav Kirchhoff (1824–1887) and Hermann Helmholtz (1821–1894). His talents were quickly recognized and before long he was working as an assistant to Helmholtz, while still an undergraduate—an almost unheard of distinction. He was allowed to graduate the following year, even though he had completed only six of the regulation eight semesters: one in Dresden, two in Munich, and three in Berlin. He had distinguished himself in every way. The work he had done for Helmholtz—an experimental determination of whether the moving charges that constitute a current in a conductor have an inertial mass—had been concluded to the professor's satisfaction when Hertz showed that the mass was at the most vanishingly small; as a result, Hertz had been awarded a departmental prize. A paper based on the experiment had been accepted for *Annalen der Physik und Chemie* and had appeared in a volume that also contained papers by Kirchhoff, Weber, Wiedemann, Kundt, Röntgen, Siemens, and Clausius—not bad company for a 22-year-old student! The oral examination for his degree had gone off smoothly and Hertz had been passed *summa cum laude*, a distinction almost never awarded by the tough Berlin examiners. Helmholtz, Germany's greatest living physicist, thought the world of his brilliant pupil. The only cloud that had cast a shadow over a relationship of mutual respect and admiration was Hertz's reluctance to accept Helmholtz's suggestion for a dissertation topic.

Helmholtz was intent on an experiment that would demonstrate which of the two theories of electricity then contending for the attention of European physicists—Weber's or Maxwell's—was correct. He had persuaded the Prussian Academy of Sciences to set a prize for anyone who would "demonstrate experimentally any relationship between electrodynamic forces and the dielectric polarization of insulators." What the proposed experiment really came down to was showing whether a time-varying electric field would produce a measurable magnetic field in its vicinity. Hertz feared that a convincing experiment would be extremely difficult. Not only was the effect sought

0018-9480/88/0500-0802$01.00

exceedingly small, but to perceive it at all, one would have to use electric fields varying at a much higher rate than had yet been achieved; it could be years before anyone came up with a suitable oscillator. Instead, Hertz settled on another problem: what was the nature of induction in conductors that were not stationary but were rotating at a constant rate? That was a problem he thought could be solved in a few months; and so it proved. He started on it at the end of October 1879 and was finished by Christmas. Soon afterward he completed a paper based on this work, "On Induction in Rotating Spheres," which was also published in *Annalen*; so that he had two publications in his country's premier physics journal while he was still a student. But the Prussian Academy's prize problem—really, the problem of devising a high-frequency oscillator—remained ever after at the back of his mind. "It was scarcely possible," he wrote later, "that I should overlook any new form of such oscillations, in case a happy chance should bring such within my notice." He could not foresee that it would fall to him to fashion such an oscillator with his own hands, years later.

Despite this contretemps, Hertz remained in Berlin as Helmholtz's assistant for the next three years, helping with laboratory instruction and doing research with a view to building up a dossier of publications respectable enough to weigh in his favor in any application for a more permanent post; "publish or perish" loomed as the same imperative for aspiring academics a hundred years ago as it does today. His third and fourth publications derived from his dissertation project and dealt with moving conductors. Then he turned to an entirely different subject—elasticity.

The two papers that Hertz wrote on this subject are generally overlooked by all who consider his repute to be based entirely on his contributions to electromagnetism, but they are regarded as being of prime importance in the theory of contact mechanics and the measurement of hardness. The first appeared in a mathematics journal; the second, in a technical journal (the proceedings of a society for the advancement of the industrial arts). They continue to provide the basis for contact stress analysis and for hardness measurement to the present day. The apparatus has changed, and the theory has been generalized so that it also applies to bodies with anisotropic elastic properties. But at the 1983 International Symposium on Contact Mechanics and Wear, held in Vancouver, at which the centenary of this work was commemorated, Prof. L. E. Goodman of the University of Minnesota stated flatly, "The theory of normal frictionless contact left Hertz's hands in so perfect a state that the lapse of seventy years was to occur before major extensions would be effected." And this towering achievement was the result of a 25-year-old research assistant's curiosity to determine whether the classical theory of elasticity might be made to yield a mathematical expression that would describe the deformation that occurs when two solids are pressed together!

During the short time left to him in Berlin, Hertz completed twelve more papers, all ultimately published in major journals, so that he had a substantial *œuvre* to offer by the time he was ready to scale the next rung on the academic ladder. Although none of these contributions can compare in significance with the papers on elastic theory and hardness, two of them turned out to be of future importance, since they dealt with electric discharges in gaseous media, the subject that was to lead him to his major contribution and one to which he returned toward the end of his life.

A vacancy had opened up at the University of Kiel. The post would be that of a *Privatdozent*, normally an unsalaried appointment with a stipend proportional to the enrollment in the instructor's courses. Since Kiel was an unlikely venue for top candidates, the ministry in Berlin sought to sweeten the deal by providing a basic stipend and promising that the slot would be presently upgraded to an "extraordinary" (i.e., associate) professorship, although the upgrading would not necessarily benefit the incumbent. Hertz applied for the post with considerable misgivings, which were quickly justified. The facilities for research were virtually nonexistent, the community seemed dreadfully provincial after Berlin, and the young man was going through a personal crisis that left him wan and depressed. Of the three papers dating back to his time in Kiel, only one—a theoretical one, since he had no laboratory—is important: "On the Relations Between Maxwell's Fundamental Electromagnetic Equations and the Fundamental Equations of the Opposing Electromagnetics" (1884).

As the ministry in Berlin seemed to be in no hurry to establish the associate professorship, Hertz was receptive to an offer from the Technical University of Karlsruhe, where an "ordinary" (i.e., full) professorship had become available when the incumbent, Ferdinand Braun (1850–1918), accepted a call to the University of Tübingen, starting in the spring of 1885. Belatedly, both Kiel and the ministry tried to make amends. The university had been told that the associate professorship would be in the budget for 1885–86; Hertz would certainly be the only candidate proposed for it. Friedrich Althoff, the section chief for higher education, summoned Hertz to Berlin in an effort to persuade him to stay in the Prussian system and not go to Karlsruhe, which was in Baden. An unspoken consideration was that Karlsruhe was a Technical University (really a college where engineers, architects, and foresters were trained), then not yet authorized to award doctorates; that was why Braun had heeded the call to the "real" University of Tübingen, even though it was not nearly as well equipped as Karlsruhe. On the other hand, the accelerated promotion from *Privatdozent* to full professor, at age 28, was not to be sneezed at. Hertz accepted.

With his move to Karlsruhe, his life changed in every way. He was "master in his own house" at last. His personal circumstances took a turn for the better. He met and married the pretty daughter of a colleague, Elisabeth Doll (1864–1941). The depression and lassitude that had marred his two years in Kiel vanished. (As often happens, Hertz's open dissatisfaction with his Kiel post served to make things easier for his successor, another promising young physicist, who became the beneficiary of the new associate professorship there: Max Planck.) Best of all, he could resume experimental work where he had left off in Berlin: on electric discharges in gaseous media. It was through this work that he was led to invent the spark oscillator and solve the Prussian Academy's prize problem at last, and to use the new device brilliantly to show that electromagnetic waves existed and behaved in accordance with Maxwell's theory—that is, like light waves. In the process, he also discovered photoelectricity, but after an initial paper on the subject left its elaboration to others, notably Wilhelm Hallwachs (1859–1922).

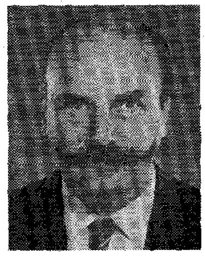
These researches, carried out during 1887 and 1888, made Hertz world famous. He received many offers from major universities, including Berlin, which he turned down on the grounds that the demands of the appointment (it was for a mathematical physicist) would take him away from the experimental physics he liked best; he chose Bonn instead, replacing the recently deceased Rudolf Clausius (1822–1888), whose house in Bonn he bought. (It still stands, reconstructed after heavy damage during World War II.) He was invited to come to London at the end of 1890 to accept the Royal Society's Rumford medal and met some of the British physicists with whom he had been corresponding, including Lodge, FitzGerald, and Sir William Thomson (the future Lord Kelvin). He was elected member or corresponding member of scientific societies in several countries, and saw his electromagnetic researches elaborated and carried forward all over the world. He never thought of their practical applications, with one exception.

In 1889 Hertz received an inquiry from a German engineer, Heinrich Huber, then employed by the new electric power station in The Hague: could not Hertzian waves be used to transmit electric power and telephone signals? Huber's letter contained a sketch of two facing parabolic mirrors, one with the top of an electromagnet at its focal point and the other, an air-core coil. Hertz replied that the wavelength corresponding to a typical audio frequency would be several hundred kilometers, so that the proposed scheme would only work with mirrors "as large as a continent." This reply cannot be faulted: Hertz could not be blamed for not thinking of the way the problem was solved after his death, low-frequency modulation of a high-frequency carrier wave. Nor can one argue that his negative reply delayed the advent of radiotelegraphy. For one thing, the correspondence received no circulation at the time. For another, at least three other proposals to use electromagnetic waves for communications were made during the subsequent three years: by Richard Threlfall (in the *Report* of the Australasian Association for the Advancement of Science for 1890), in an unsigned editorial in *The Electrician* (in 1891), and by William Crookes (in the *Fortnightly Review*, in 1892). But Hertz, despite his early training in engineering colleges and his extraordinary skill as an experimenter, stayed outside the realm of practical applications. In 1889, after an encounter with Thomas Edison at a meeting in Heidelberg, Hertz wrote to his parents that the great inventor had "wanted to make certain that I was the man 'who made the experiments about vibrations and sparks.' Then he told me that he had once tried something similar, and when I expressed my regret that he had not brought it to a conclusion, he said that his business was 'only inventions, not science.'" Well, Hertz's business was just the opposite; in fact he expressed some distaste for Edison's style in the letter, adding, "The phonograph is marvellously effective, but the manner in which it was presented there was advertisement and not very dignified by our lights."

Hertz undertook one more series of experiments in Bonn, working with his assistant Philipp Lenard (1862–1947), who joined the university in the spring of 1891. Together, they returned to the work on gaseous discharges, and in 1892 they succeeded in sending cathode rays through a vacuum-tight thin aluminum foil, now known as a "Lenard window." Hertz's report on this work, "On the Passage of Cathode Rays Through Thin Metallic Layers," was his last paper. For some years he had been troubled with a jaw infection, probably derived from a dental abscess, which proved to be intractable despite the best available medical advice. The illness took such a toll that Hertz had to give up lecturing altogether. During 1892 and 1893 he spent most of his time on a massive theoretical endeavor, a new theory of mechanics in which he explored the implications of Maxwell's electrodynamics for all physics. Force would no longer be a fundamental concept; only mass, space, and time would remain, and action at a distance would be altogether excluded. The theory found little favor with physicists, for all that it was perfectly self-consistent logically, since it was quite cumbersome in practice. However, the book Hertz based on this work, *The Principles of Mechanics, Presented in a New Form* (1894), is reckoned as a classic in the philosophy of science.

Heinrich Hertz died in Bonn on New Year's Day of 1894, a few weeks before his 37th birthday. Besides his young widow he left two small daughters, Johanna Hertz (1887–1966), who became a physician; and Mathilde Hertz (1891–1975), a future zoologist and ethologist. In 1927 Johanna published a selection of her father's letters and diaries, which remains the only book-length account of Heinrich Hertz. In 1935 Hertz's widow and daughters left Nazi Germany, where they felt uncomfortable because Hertz had been half-Jewish by ancestry, and settled in England. Just before her death Mathilde collaborated with the present author in a revised and enlarged edition of that book, which was brought out in 1977 in a bilingual edition by San Francisco Press: *Heinrich Hertz—Memoirs, Letters, Diaries*.

Philipp Lenard, who received the 1905 Nobel Prize for physics for the work he had initiated under Hertz, became his literary executor. Although personally devoted to Hertz, whose contributions he described in his 1929 compendium *Grosse Naturforscher*, Lenard never wrote the biography of his erstwhile mentor that he was uniquely equipped to write both as scientist and as historian of science, doubtless because he had meanwhile become one of Adolf Hitler's early adherents and a proponent of "German physics" (that is, a pragmatic, largely experimental physics —Lenard's strong suit); he characterized modern physics as "dogmatic Jewish physics." As a result, a book-length life of Hertz still remains to be written, a task the present author is currently undertaking.



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From 1951 to 1955 he was on the research and teaching staff of Stanford University, where he also served as assistant to the director of the Microwave Laboratory. In 1955 he joined the engineering faculty at Berkeley, where he is now Professor of Engineering Science. His specialties are microwave engineering and bioengineering, but he has also made numerous contributions to the sociology and history of engineering, subjects on which he has written several books.