he and Alexander had lost the physical strength necessary to repolish the mirror.

Much more is now known about the wealth that Mary Pitt brought to their marriage in 1788. Her inheritance from her late husband, and subsequent legacies from her mother and other members of her family, rendered Herschel's annual "pension" from the crown insignificant. Why then did he continue to make telescopes for sale? Part of the reason seems to lie in the delight he took at his international eminence in work so far removed from his profession of music—ambassadors were reduced to writing what were, in effect, begging letters, for if Herschel refused them, there was no one else to whom they might turn. But it has been argued that some of his production was destined for fellow observers who might, he hoped, confirm observations that hitherto he alone had been able to make.

BIBLIOGRAPHY

Brown, Frank. *William Herschel, Musician and Composer.* Bath, U.K.: William Herschel Society, 1990.

Caroline Herschel's Autobiographies. Edited by Michael Hoskin. Cambridge, U.K.: Science History Publications, 2003. Contains the two incomplete autobiographies that Caroline wrote when she was in her seventies and her nineties, respectively, and much of the information concerns William.

Hoskin, Michael. "Herschel's 40ft Reflector: Funding and Functions." *Journal for the History of Astronomy* 34 (2003): 1–32.

———. *The Herschel Partnership: As Viewed by Caroline.* Cambridge, U.K.: Science History Publications, 2003. A biography of Caroline that focuses on her relationship with William. Mary Herschel's finances are discussed in pp. 92, 95–96.

———. "Vocations in Conflict: William Herschel in Bath, 1766–1782." *History of Science* 41 (2003): 315–333. Discusses Herschel's musical activities.

———. "Alexander Herschel: The Forgotten Partner." *Journal for the History of Astronomy* 35 (2004): 387–420.

———. "Unfinished Business: William Herschel's Sweeps for Nebulae." *History of Science* 43 (2005): 305–320.

———. *The Herschels of Hanover.* Cambridge, U.K.: Science History Publications, 2007.

James, Kenneth. "Concert Life in 18th Century Bath." PhD diss., University of London, 1987.

Maurer, Andreas. "A Compendium of All Known William Herschel Telescopes." *Journal of the Antique Telescope Society,* no. 14 (1998): 4–15.

Spaight, John Tracy. "'For the Good of Astronomy': The Manufacture, Sale, and Distant Use of William Herschel's Telescopes." *Journal for the History of Astronomy* 35 (2004): 45–69.

Michael Hoskin

HERTZ, HEINRICH RUDOLF

(*b.* Hamburg, Germany, 22 February 1857; *d.* Bonn, Germany, 1 January 1894), *physics, philosophy.* For the original article on Hertz see *DSB,* vol. 6.

The centenaries of Hertz's discovery of radio waves, of his death, and of the publication of *The Principles of Mechanics* served to invigorate scholarship on the life and work of Heinrich Hertz. While it was true until 1994 that there was no book-length study, the next dozen years produced a 600-page biography, two highly focused monographs, and a collection of essays on Hertz as classical physicist and modern philosopher. These books appeared alongside numerous articles and the discovery of new biographical sources, laboratory notes, correspondence, and manuscripts.

Close scrutiny of Hertz's experimental and conceptual procedures produced uncertainty on some biographical questions, new insights on others. In particular, Hertz's "conversion" to a Maxwellian conception of electrodynamics has come to appear as an ever more intriguing problem. The publication of his 1884 lectures on the constitution of matter laid bare the continuity of his philosophical interests. This, in turn, prompted richly nuanced views of the *Principles of Mechanics* and yet another puzzle regarding the ether.

Between Helmholtz and Maxwell. The question of Hertz's "conversion" arises from his 1884 paper "On the Relations between Maxwell's Fundamental Electromagnetic Equations and the Fundamental Equations of the Opposing Electromagnetics." It concluded that "if the choice rests only between the usual system of electromagnetics and Maxwell's, the latter is certainly to be preferred" (1896, p. 289). This statement underwrites the view that in his decisive experiments of 1887 and 1888 Hertz set out to prove Maxwell's theory. However, it is odd not only that Hertz never again referred to this paper but also that he freed himself only very gradually from a Helmholtzian idiom. The publication of his 1884 lectures and 1887 laboratory notes did not settle the issue. On the one hand, they underscore his general distrust of action-at-a-distance theories and thus his sympathy for Maxwell's approach. On the other hand, they indicate that he was exploring the limiting case of Helmholtz's electrodynamics which leads to Maxwell's equations.

In his 1892 introduction to *Electric Waves* Hertz provided several cues as to how this puzzle might be resolved. On his own reconstruction of the course of experimentation, the competing theories of electrodynamics lacked physical meaning until Hertz's experiments. As long as Hertz could say no more about Maxwell's theory than that it is Maxwell's system of equations, all theories that mathematically coincide with Maxwell's equation were equivalent, including that of Helmholtz. In respect to electromagnetic theories, one cannot sensibly ask whether Hertz was a Maxwellian or still a Helmholtzian until the time of the "philosophical … and in a certain sense most important result" of his experiments, namely that they proved the "propagation in time of a supposed action-at-a-distance" (1893, p. 19). This finding simultaneously served to distinguish Helmholtz's and Maxwell's conceptions and to decide in favor of Maxwell's. To fully realize this may have taken Hertz well into 1889. At the same time, that Hertz was a Helmholtzian by training is evident from his laboratory practice, his style of experimentation, and his manner of developing a new phenomenon by literally unfolding and materially transforming a familiar laboratory device (the so-called Rieß spirals) into a sender and receiver of electric waves.

Philosophical Critique. Even before he studied with Helmholtz, Hertz had been exposed in Dresden to lectures on Immanuel Kant, and in January 1878 expressed in a letter to his parents that he was pondering conceptual issues, "and particularly the principles of mechanics (as the very words: force, time, space, motion indicate) can occupy one severely enough" (1977, p. 77). Towards the end of his life, in a letter dated November 23, 1893 Hertz encouraged his publisher to include among the potential readers of *The Principles of Mechanics* "the circle of philosophical readers" (in Fölsing, 1997, p. 509). The publication of his 1884 lectures on the constitution of matter establishes the continuity of Hertz's philosophical interest in conceptual critique. In the case of "force," he rejected it as a fundamental concept of mechanics since it lacked physical meaning but served only as part of its representational apparatus. In the case of "matter," he found the concept indispensable and struggled to determine its physical meaning, showing that on all available definitions it is an indissoluble mixture of a priori and empirical elements. In a highly suggestive passage he therefore compares it to paper money that is issued by the understanding to regulate its relation to things. All this has given rise to an appreciation of Hertz as a philosopher in his own right. He rigorously applies to the conceptual tools of physics a Kantian critique of how scientific experience becomes possible only within clearly specified limits of physical knowledge. He thus offers an original and parsimonious account of the metaphysical foundations of physics.

The Geometrization of Mechanics. In the context of a broadened appreciation of Hertz's concerns, it is no longer possible to divide *The Principles of Mechanics* into two parts, firstly a philosophical introduction that concerns the choice between empirically equivalent but conceptually distinct images of mechanics, and secondly the somewhat tedious articulation of a forceless mechanics.

Heinrich Hertz. © BETTMANN/CORBIS.

Instead, the book appears as a delicate and highly self-conscious exercise to relate physical content and mathematical form. Suspicious that the new mathematics and especially non-Euclidean geometry offer abstractions that are detached from reality, Hertz nevertheless developed a first geometrization of mechanics. The originality of *The Principles of Mechanics* does not consist in the elimination of force, which had been advocated already by one of Hertz's former teachers, Gustav Kirchhoff. Instead it arises from the way in which the new formalism suggests new ways of thinking about physical phenomena. Rather than build up mechanics from the motion of a single mass point, Hertz's geometrization yields a forceless mechanics by beginning with a system of points. Accordingly, forces are replaced by connections within and among systems of points, phenomena that unfold in time are referred to time-independent material systems, causal explanation is reduced to the correspondence between dynamic models, and intentionality is banished along with all phenomena of life from the domain of physics. The domain of physics, however, is to be unified by a single law of mechanics, giving rise to an unsolved biographical and scientific puzzle.

Hertz was clearly aware of the challenge to unify electrodynamics and mechanics and emphasized the need for a theory of the ether in his 1889 lecture on "Electricity and Light." However, while the 1884 lectures express Hertz's skepticism toward any material medium that cannot be isolated and rendered ponderable, *The Principles of Mechanics* hardly mentions the ether at all, except to point out that a clarification of the laws of mechanics is a prerequisite for any theory of the ether. In light of the broadened appreciation of Hertz's intellectual and experimental endeavors, it depends on his active interest or lack thereof in the ether and the unification of physics whether one should view the concern of his final years as primarily empirical or conceptual, as physical or philosophical.

SUPPLEMENTARY BIBLIOGRAPHY

WORKS BY HERTZ

"Annual reviews for the years 1878–1883 of electrostatics, electrochemistry, electrodynamics, thermoelectricity, and related fields." *Die Fortschritte der Physik* 34–39 (1884–1889). Hertz's synoptic reports on altogether 230 papers and books include those of British scientists.

Die Constitution der Materie: Eine Vorlesung über die Grundlagen der Physik aus dem Jahre 1884. Edited by Albrecht Fölsing. Berlin: Springer, 1999. Hertz's 1884 lectures on the constitution of matter.

"An Unpublished Lecture by Heinrich Hertz: 'On the Energy Balance of the Earth.'" Edited by Joseph F. Mulligan and H. Gerhard Hertz. *American Journal of Physics*, 65 (1997): 36–45. Hertz's 1885 inaugural lecture in Karlsruhe.

"Heinrich Hertz's Laboratory Notes of 1887." Edited by H. Gerhard Hertz and Manuel Doncel. *Archive for History of Exact Sciences* 49 (1995): 197–270.

Electric Waves. London: Macmillan, 1893. Reprinted New York: Dover Publications, 1962.

Miscellaneous Papers. London: Macmillan, 1896.

Erinnerungen, Briefe, Tagebücher. Memoirs, Letters, Diaries / Heinrich Hertz. Edited by Johanna Hertz. Second enlarged edition prepared by M. Hertz and C. Susskind. Weinheim/San Francisco: Physik Verlag/San Francisco Press, 1977. This bilingual edition includes roughly a fifth of Hertz's weekly letters to his parents and excerpts from his diary, extensive quotes from the here unpublished material can be found in Fölsing's biography. The first edition appeared in 1927.

OTHER SOURCES

Baird, Davis, R. I. G. Hughes, and Alfred Nordmann, eds. *Heinrich Hertz: Classical Physicist, Modern Philosopher*. Dordrecht, Netherlands; Boston: Kluwer, 1998. Includes contributions by Jed Buchwald, Salvo D'Agostino, Manuel Doncel, Giora Hon, Jesper Lützen, Alfred Nordmann, and Simon Saunders; also a concordance of German and English editions of Hertz's main works; and a comprehensive annotated bibliography of original works and secondary sources.

Buchwald, Jed. *The Creation of Scientific Effects: Heinrich Hertz and Electric Waves*. Chicago: University of Chicago Press, 1994. Reconstructs how a known phenomenon is transformed to yield a novel effect; argues for Hertz's late adoption of a Maxwellian account.

———. "The Scholar's Seeing Eye." In *Reworking the Bench: Research Notebooks in the History of Science*, edited by Frederic Holmes, Jūrgen Renn, and Hans-Jōrg Rheinberger. Dordrecht, Netherlands; Boston: Kluwer, 2003.

D'Agostino, Salvo. "The Bild-Conception of Physical Theories from Boltzmann to Hertz." In *The Dawn of Cognitive Science: Early European Contributors,* edited by Liliana Albertazzi. Dordrecht, Netherlands; Boston: Kluwer, 2001.

Darrigol, Olivier. "The Electrodynamics of Moving Bodies from Faraday to Hertz." *Centaurus* 36 (1993): 245–360.

Doncel, Manuel. "On the Process of Hertz's Conversion to Hertzian Waves." *Archive for History of Exact Sciences* 43 (1991): 1–27. Includes as evidence for slow conversion a discussion of the differences between the first and final publications of Hertz's papers on electrodynamics.

Fölsing, Albrecht. *Heinrich Hertz: Eine Biographie.* Hamburg: Hoffmann und Campe, 1997. Draws on a vast amount of previously unconsidered source material, for the most part deriving from an otherwise unidentified *Nachlaß Mathilde Hertz*, including laboratory notes for 1886, official and scientific correspondence, documents, manuscripts, and Hertz's diary. Fölsing also identifies some of Hertz's contributions to the Karlsruhe newspaper.

Hon, Giora. "H. Hertz: 'The electrostatic and electromagnetic properties of the cathode rays are either *nil* or very feeble' (1883): A Case-Study of an Experimental Error." *Studies in History and Philosophy of Science* 18 (1987): 367–382.

Hüttemann, Andreas. "Heinrich Hertz and the Concept of a Symbol." In *Symbol and Physical Knowledge*, edited by Massimo Ferrari and I.-O Stamatescu. Berlin and New York: Springer, 2002.

Hyder, David. "Kantian Metaphysics and Hertzian Mechanics." In *The Vienna Circle and Logical Empiricism*, edited by Friedrich Stadler. Dordrecht, Netherlands; Boston: Kluwer, 2003.

Lützen, Jesper. *Mechanistic Images in Geometric Form: Heinrich Hertz's Principles of Mechanics.* Oxford: Oxford University Press, 2005. Establishes the significance of Hertz's geometrization of mechanics; considers the various drafts of the manuscript.

Mulligan, Joseph F., ed. *Heinrich Rudolf Hertz (1857–1894): A Collection of Articles and Addresses.* New York: Garland, 1994. Very useful comprehensive introduction to Hertz; a biographical essay is followed by eight papers from *Electric Waves* and *Miscellaneous Papers*, Hertz's lecture "On the Relations between Electricity and Light," his introductions to *Electric Waves* and the *Principles of Mechanics*, and texts on Hertz by George FitzGerald, Hermann von Helmholtz, Philipp Lenard, and Max Planck.

Nordmann, Alfred. "Heinrich Hertz: Scientific Biography and Experimental Life." *Studies in History and Philosophy of Science* 31 (2000): 537–549.

O'Hara, James, and Willibald Pricha. *Hertz and the Maxwellians: A Study and Documentation of the Discovery of Electromagnetic Wave Radiation, 1873–1894.* London: Peter Peregrinus, 1987. Includes Hertz's correspondence with the Maxwellians, the preamble to his 1879 manuscript on the demonstration

Hertz

of electrical effects in dielectricity, and a series of plates on Hertz's apparatus at the Deutsches Museum in Munich.

Alfred Nordmann

HERTZ, MATHILDE CARMEN (*b.* Bonn, Germany, 14 January 1891; *d.* Cambridge, United Kingdom, 20 November 1975), *Gestalt psychology, comparative psychology, sensory physiology.*

Hertz was a pioneering comparative psychologist. She fused psychological and biological perspectives in her research, and contemporary psychologists and biologists alike held her work in high esteem. She combined innovative experimental techniques and Gestalt principles to examine the visual perception of diverse animal species, including ravens, honeybees, butterflies, and hermit crabs. Time and again facing adversity, Hertz overcame various obstacles to pursue an academic career. She was prolific while her career lasted, but her scholarly work ended abruptly after she emigrated from Germany to England in 1936.

Short Biography. Mathilde Hertz was the youngest daughter of the physicist Heinrich Hertz, who died when Mathilde was three years old. After completing a nonclassical secondary education she began a career as a sculptor. To supplement her income she took a job at the library of the German Museum in Munich, where she drew and sculpted plastic reconstructions of fossilized teeth in the zoological collection. At this time her work came to the attention of Ludwig Döderlein, who was the director of the zoological collection. Overcoming barriers for a scientific career for women at that time, Hertz enrolled at the University of Munich from 1921 to 1922 and later completed her doctoral degree in 1925 with honors on a study about early mammalian jawbones under the supervision of Richard von Hertwig.

By 1925, and inspired by Wolfgang Köhler's research with anthropoid apes, Hertz began work in the field of animal psychology. In 1927 she moved to Berlin and worked in the Department for Genetics and Biology of Animals under the auspices of Richard Goldschmidt. Here she taught and conducted research until her authorization to teach was withdrawn in 1933 due to the implementation of the "Law for the Restoration of Professional Civil Service." According to this law, civil servants who were not of "Aryan descent" were to be retired, and those whose political stance did not guarantee loyalty to the Nazi regime to be dismissed. Hertz was presumably classified as "non-Aryan" according to this law because she had

Mathilde Hertz, 1918. **COURTESY OF DR. SIGFRIED JAEGER.**

one grandparent, Gustav Ferdinand Hertz, who had been Jewish prior to converting to Christianity.

Despite the intervention efforts of Max Planck, the president of the Kaiser Wilhelm Society at that time, she was no longer able to teach, although she continued her research until the end of 1935. Between 1925 and 1935 she published more than thirty articles. In 1936 Hertz immigrated to England, where, after publishing another article on color vision in bees (1939) and an article on vision in migratory locusts (1937b), her empirical work basically came to an abrupt end presumably due to an unfortunate combination of personal and professional factors. Various reasons for this are explored by Regina Siegfried Kressley-Mba and Jaeger (2003), including the fact that Hertz appears to have remained loyal to Germany despite the grave injustices she suffered as a result of Nazi racial policies. Furthermore, the growing popularity of ethology and an emphasis on instinctive behavior may have rendered the phenomenological orientation that was characteristic of Gestalt psychology and Hertz's work obsolete.

Problem-Solving Behavior in Animals. Hertz's first experiments with ravens were explicitly designed and