

Portrait of Helmholtz by
Ludwig Knaus (1881).



HERMANN VON HELMHOLTZ

A 19th Century Renaissance Man

Barry R. Masters

Hermann von Helmholtz was many things to many people: physicist, teacher, medical doctor, aesthete and much more. The German polymath drew on his extensive knowledge of many fields to invent the ophthalmoscope—a device that revolutionized ophthalmology—when he was just 29 years old. He went on to conduct critical investigations into nerve conduction, physiological optics and the sensations of tone, and he worked to foster public understanding of science and to improve science education.

If any life exemplifies the value of interdisciplinary education and good mentoring, it is that of Hermann Ludwig Ferdinand von Helmholtz. From the time he was a boy, Helmholtz was encouraged to follow his curiosity and to cultivate an appreciation for both science and the arts.

The first of five children, he was born on August 31, 1821, in Potsdam, Germany. His father Ferdinand studied philology and philosophy and taught in a Prussian Gymnasium in Potsdam. At the age of nine, Helmholtz began his own studies in a Gymnasium. His interest in natural science and physics contrasted sharply with his abhorrence of memorizing facts.

Early on, Helmholtz's parents fostered in him a belief in the value of education and a love of music and the arts. While at the Gymnasium, he studied several languages, including Greek, Latin, Hebrew, Arabic, English, French, German and Italian, as well as subjects in the humanities, the natural sciences and mathematics.

Although he was interested in physics from an early age, his family's economic situation precluded him from furthering his academic study of the subject at that time. As an alternative, he applied for a scholarship to the Royal Medical-Surgical Friedrich-Wilhelms Institute in Berlin—a medical school designed to train military physicians to study medicine while minoring in physics. A stipulation of the scholarship was that the candidate, upon completing his or her medical studies, would be required to work for several years as a Prussian military physician.

As a medical student from 1838 to 1842, Helmholtz developed his desire to combine physiology and physics—an interest he maintained throughout his life, and one that followed from the strong influence of his physiology professor, Johannes Müller, and his friendship with Emil Du Bois-Reymond. At age 21, Helmholtz earned a doctor's degree with his thesis, which described his original discovery that nerve fibers originate in ganglion cells. After one year as a resident at the Charité hospital in Berlin, he joined the regiment of the royal guards at Potsdam and worked as a military surgeon.

During this time, he also investigated the heat produced by muscle contraction. Helmholtz strived to establish a general law for the conservation of energy that could be derived from fundamental

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physical principles. On July 23, 1847, he presented his accomplishment in a lecture to the members of the Physical Society of Berlin: He introduced the concept of potential energy and derived the law for the conservation of energy. He made the assumptions that matter is constituted of mass particles that

interact by central forces (i.e., those along the lines connecting two particles). This work propelled him forward in his academic career.

A year later, he became a teacher of anatomy at the Academy of Fine Arts in Berlin and worked as an assistant to Johannes Müller, a professor of anatomy and physiology and the director of the Anatomisches Museum in Berlin. Helmholtz acknowledged that this mentorship had a major impact on his professional life. (See sidebar on p. 37.)

After working for a year with Müller, Helmholtz became an associate professor of physiology at the University of Königsberg in 1849. He remained there for the next six years, during which he continued his studies on nerve physiology and initiated new investigations into the fields of physiological optics and acoustics. With a stable academic position, he married a young woman named Olga von Velten. His research focused on assessing the speed of nerve impulses, which at the time were thought to be so rapid as to defy measurement. Helmholtz succeeded in measuring the speed of propagation of an impulse in frog nerves as 30 m/s.

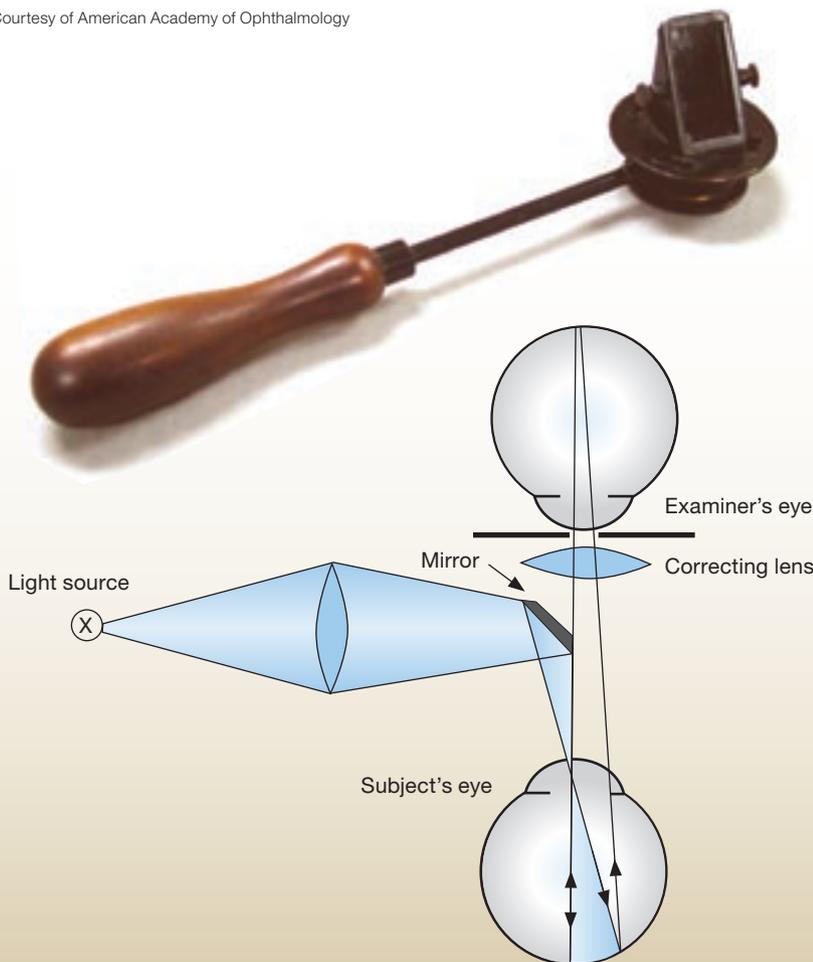
In the course of his investigations, Helmholtz developed precision instruments for his physiological and sensory studies. For his experiments in acoustics, he used an acoustic analyzer that consisted of a tuned set of spherical resonators. He also advanced the field of precision measurements with his use of techniques for error analysis based on probability. In addition, he employed physical models such as eye movements as demonstration devices.

Helmholtz's invention of the ophthalmoscope

In 1850—the same year he became the father of a daughter (Katharina)—he invented the ophthalmoscope—an optical instrument to observe the retina in the back of the eye. This invention brought him great renown in the medical world. The device, which was based on simple laws of geometrical optics, revolutionized diagnostic ophthalmology.

[Helmholtz's ophthalmoscope]

Courtesy of American Academy of Ophthalmology



Other scientists had established that, when a person's eye was illuminated in a dark room and the individual was adjacent to the light source, the eye seemed to give off a red glow. (Today we observe this as "red eye" in flash-photographic images.) Helmholtz used geometrical optics to analyze the refraction of the light rays that are reflected back from the illuminated eye. His analysis showed that the light rays entering the pupil and the reflected rays leaving the pupil follow identical paths. A point source of light (a candle or sunlight from a small hole in the window shutter) forms a point on the retina. The returning light rays traverse the same path, but in the opposite direction as the illumination rays from the point source of light. All the emerging rays return to the point source of illumination. This explains why an observer sees the interior of the eye as black. Clearly, a special instrument was needed to observe the retina.

In his initial experiments, he used a candle as the source of illumination. A glass plate was placed at an angle between the subject and the observer. The plate reflected the light from the candle into the subject's eye, and the emitted light passed along the same path as the illumination did, through the glass plate and into the observer's eye.

The problem with Helmholtz's early prototypes was that the resulting image was blurred. This occurred because the observer must be located very close to the subject's eye in order to see the retina through the small pupil, and the emitted light rays converge due to refraction in the subject's eye. Helmholtz's solution was to place a concave lens between the observer and the glass plate—an adjustment that completed the invention of the ophthalmoscope. Helmholtz called the device the *augenspiegel*, or eye mirror. Using it, he was able to see a sharp image of a person's retina.

Incidentally, Helmholtz was not the first scientist to image the anterior eye—but it was his design that turned out to be the most useful and practical. For example, in 1847, the British mathematician Charles Babbage, known as the

inventor of the computer, devised an instrument for imaging the back of the eye; it contained a silvered mirror with the silver removed in several spots for illumination and observation. However, Babbage could not correct the convergent rays from the subject's eye and therefore he dropped the project. And even earlier, in 1823, Jan Evangelista Purkinje, a professor of physiology at Breslau, had noticed that—under certain conditions of illumination—one could observe the back of the eye. However, because he published the finding in Latin, it remained unrecognized.

Later in his life, when Helmholtz reflected on the ophthalmoscope, he noted that his interdisciplinary education and training had enabled him to invent it; he understood more physics than physicians did, and he knew more physiology and medicine than physicists did. As a clinician, he was aware of the clinical problems that ophthalmologists faced, and he was inspired by new diagnostic techniques and instruments such as the use of the microscope in pathology and the use of the stethoscope to detect heart sounds. He understood that his invention—which he published in 1851—would reveal the anatomical and physiological details of the inner eye. Ophthalmologists quickly responded; in a few months, he received many orders for his instrument and, within several years, 16 books and many publications on the ophthalmoscope had emerged.

Helmholtz and others subsequently worked to improve the instrument. Helmholtz added a stack of thin glass plates to increase the illumination as compared to the initial single glass plate. In 1852, the scientist Christian Ruete replaced the glass plate with a silvered mirror that contained a central hole, and he added a wheel containing several different lenses to view eyes of different refraction.

In 1854, Albrecht von Graefe, an ophthalmologist in Berlin and founder of the journal *Archive für Ophthalmologie* (now called *Graefes Archive for Clinical and Experimental Ophthalmology*) attributed the great progress that had been made at

Müller inspires a generation of biologists

The Anatomisches Museum in Berlin—where Helmholtz worked for a year with anatomy professor Johannes Müller—trained a generation of future cell biologists and physiologists



Johannes Müller by Pasquale Baroni.

in microscopic techniques and offered its students a wide scope of intellectual freedom to pursue their research interests. Müller's students included Jacob Henle, Theodor Schwann and Robert Remak—all of whom contributed to cell theory—as well as Ernst Haeckel, Rudolph Virchow and Emil du Bois-Reymond.

Helmholtz's fellow students were to become leaders in cell biology and other areas within the biosciences, perhaps due in part to Müller's mentoring coupled with the intellectual freedom they were given to pursue their own curiosity-driven research. Remak discovered unmyelinated nerve fibers and the nerve cells in the heart, and he revealed that cells originated from other cells, thanks to cell division. Haeckel described many new species and proposed a controversial developmental theory. Virchow came to be known as the father of cellular pathology, and he was a great social reformer as well. In the 1840s, both Virchow and Henle were leaders in Germany's medical reform movement.

Du Bois-Reymond, a physician, physiologist and long-time friend of Helmholtz's, discovered the action potential in nerve fibers (i.e., the propagation of the nerve impulse); his research laid the groundwork for the field of experimental neurophysiology. Surrounded by so many fertile minds and the excellent mentorship of Müller, Helmholtz's own work thrived.

Helmholtz the aesthete

Helmholtz was a well-rounded person who enjoyed reading literature and making frequent visits to art museums, theaters and concerts. He was particularly interested in painting, sculpture and music. He played the piano



Hermann von Helmholtz
by Hans Schadow

from his boyhood to medical school and in his later life in Berlin—and that perhaps inspired his seminal investigations into physiological acoustics, the anatomy and physiology of the human voice, the human ear and the perception of sound.

While he did not paint himself, he had many friends who were painters, and he taught anatomy at the Berlin Kunstakademie for one year. His profound interest in art paralleled his investigations of physical and physiological optics, and he was a leader in the field of experimental optics and human vision.

As David Cahan wrote in the book he edited—*Hermann von Helmholtz and the Foundations of Nineteenth Century Science*—Helmholtz elucidated several aspects of the civilizing power of science. He pointed out that the process of science provides the foundation for an aesthetic life, and that science could unite people into a cohesive community that would work for the common social benefit to help build a nation-state. He also noted that science presents humanity with a path toward understanding the natural world and our place in it.

that time in retinal diagnostics to Helmholtz's invention.

Helmholtz also invented the ophthalmometer, an instrument that measures the curvature of the cornea and the anterior and posterior surface of the ocular lens. This instrument was used in his studies of changes in the shape of the ocular lens and its role in accommodation (change of the eye's focus).

Around the same time that Helmholtz invented the ophthalmoscope, he met William Thomson (later Lord Kelvin). They remained lifelong friends. In 1852, his second child, Richard Wilhelm Ferdinand, was born. A year later, Helmholtz embarked on his first trip abroad, in which he attended the meeting of the British Association for the Advancement of Science in London.

Anatomy, acoustics and physiological optics

Then, in 1855, Helmholtz accepted an offer to become a full professor of anatomy and physiology at the University of Bonn. In the three years that he taught anatomy, he also completed important work in acoustics: He derived laws for the combination of separate tones and beats. He posited that the nonlinear response of the ear drum or other sound detectors could explain the phenomena. A year later—at the age of 37—he published the physical and mathematical principles that explained musical harmony. At that time, Helmholtz moved to the University of Heidelberg and accepted the position of professor of physiology. He remained there from 1858 to 1871, during which he published his seminal papers on the mathematical theory of air vibrations in open pipes and the organ.

In 1859, Helmholtz experienced two devastating losses: Both his father and his wife died. In the wake of this double blow, he took a hiatus of several months in his scientific work. When he recovered, he began his fundamental investigations into physiological optics. His monumental body of work on this topic was published in the three volumes of Helmholtz's *Physiological Optics*. Helmholtz's early experimental work

was focused on a broad program aimed to help people understand physiological processes in terms of the chemical and physical laws that were their foundation as well as the physical and the philosophical basis of sensory physiology.

In 1861, Helmholtz married Anna von Mohl. He also began the most intense and productive period of his life. Their son Robert Julius was born in 1862, followed by a daughter—Ellen Ida Elisabeth—two years later.

The next year, he published all his acoustical investigations in his seminal book *On the Sensations of Tone as a Physiological Basis for the Theory of Music*. Helmholtz then began his theoretical studies on problems in hydrodynamics and electrodynamics, and he expanded his work into the theory of knowledge and the axioms of geometry. His genius was increasingly recognized by the wider physics and medical communities. As his reputation grew, he received numerous offers to visit and to lecture. He became prorektor (vice president) of the University of Heidelberg.

When the University of Berlin asked him to fill a vacancy in the department of physics in 1870, Helmholtz boldly stated his conditions for taking the position. He asked to be given the directorship of a new physics institute, his desired salary and living quarters in the institute. The university accepted—and in 1871 Helmholtz moved to Berlin. He was also elected to the Berlin Akademie der Wissenschaften.

Later years

His peripatetic academic lifestyle had come to an end; Helmholtz remained in Berlin until his death in 1894. The University of Berlin was funded by Wilhelm von Humboldt in 1810. From 1828, it was called the Frederick William University, and in 1949 it became the Humboldt University in honor of its founder Wilhelm and his brother Alexander von Humboldt—the great explorer and naturalist.

At the University of Berlin, his scientific investigations into electrodynamics, acoustics and thermodynamics continued

to bring him success and acclaim. His reputation grew both among scientists and the general public. He travelled to France, Italy, Spain and Switzerland and lectured widely in Germany. Helmholtz became the rektor (president) of the University of Berlin from 1877 to 1878. In 1888, the Physikalisch-Technische Reichsanstalt (PTR, the Physical and Technical Institute of the Reich) was founded and Helmholtz was named its first president. One section of the institute was to provide the precise spectroscopic data on black body radiation that stimulated the theoretical studies of Lord Rayleigh, James Jeans, Wilhelm Wien and Max Planck.

Helmholtz continued his research into disparate fields of physics: color theory and space perception, non-Euclidean geometry, the formation of clouds and thunderstorms, cohesion in liquids, the electrolysis of water, the energy of winds and waves, chemical thermodynamics (the concept of “free energy”), the least action principle in electrodynamics, electromagnetic theory of color dispersion and sensory physiology.

Perhaps less known is his important insights into the relationships between science and philosophy, art, culture and society. (See sidebar on the previous page.) In addition to his technical accomplishments, Helmholtz is remembered as someone who popularized science. From 1853 to 1892, he gave about 25 public lectures that addressed the nature and purpose of science; the optimal political and institutional conditions for promoting science; and the connections between civilization and science. These lectures and others on the lives and works of prominent scientists were reprinted in the *Vorträge und Reden*, which consisted of several volumes and appeared in five editions. Helmholtz envisioned that broad public awareness and understanding of science would help to counter what he perceived as the irrational aspects of German society—its mysticism and spiritualism.

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offer. He strived in these lectures to show the nuances of the process of knowledge generation that is called science. He understood that scientific progress depended on financial resources, and that researchers had a duty to explain their discoveries to their benefactors as well as to describe how their work had benefited society and the state.

For Helmholtz, science was not about accumulating disparate facts; it was a process of inductive logic that derives general laws of nature. Thus, the metric for scientific progress was the development of general laws—e.g., the law of conservation of energy.

Helmholtz did not get overly involved in state or university politics, but he did analyze the German university system. He appreciated that the state funded much research without interfering or controlling it. He also lauded the fact that professors were active researchers and that intellectual freedom applied to both students and professors. In fact, the title of his inaugural lecture when he became rektor at Berlin was: “On academic freedom in German universities.” On balance, it is important to state that he failed to notice or at least to communicate the negative aspects of the German university system, including its insidious authoritarian aspects and its pervasive discrimination against Catholics, Jews and women.

Helmholtz’s scientific contributions were widely recognized with many honors and awards. He received the first Graefe Medal (named after Albrecht

von Graefe, the famous Berlin ophthalmologist) from the Ophthalmologische Gesellschaft, the Copley Medal from the Royal Society of London and the Becquerel Medal of the Royal Society of Chemistry. In addition, he was granted an honorary doctor-of-law degree from Cambridge University. He was appointed an honorary member of the National Academy of Sciences in Washington, D.C., and an honorary member of the Imperial Russian Academy of Medicine.

Helmholtz visited and toured the United States in 1893 at the age of 72. The German government sent him as a delegate to the Electrical Congress in Chicago. He passed away the following year, on September 8, 1894. ▲

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