A Theorist of (Not Quite) Everything

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Helmholtz: A Life in Science
by David Cahan
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Alte Nationalgalerie, Berlin

Hermann von Helmholtz with several of his inventions, including a Helmholtz resonator, an ophthalmometer, and an ophthalmoscope; painting by Ludwig Knaus, 1881

In academic scientific biography, it's the biggest names that justify the biggest books. It helps if the subject is reckoned to have "made the modern world." Darwin's modernity-making idea was evolution by natural selection, and Janet Browne's magnificent two-volume biography accordingly weighed in at 1,200 pages. Newton's world-changing discoveries included calculus, the laws of motion, the inverse-square law of gravitational attraction, and the compound nature of white light, which Richard Westfall treated (along with much else) in 908 pages. Albrecht Fölsing did Einstein (special and general relativity) in 928 pages. But academic gigantism has now become epidemic, lowering the reputational bar for the biographical door-stopper. Daniel Todes took 860 pages to write his outstanding life of the Russian psychologist Ivan Pavlov (who originated *only* the psychology of classical conditioning).

David Cahan's new biography of the German physiologist and physicist Hermann von Helmholtz (1821–1894), thirty years in the making, is enormous: 937 pages, including 168 of notes, index, and bibliography. Cahan advertises his account as "comprehensive," and it doesn't leave much out. The biographer tells us that in 1853, before visiting Britain for the first time, Helmholtz ordered a black top-coat and a white vest from his Berlin tailor: "Both turned out very well." On arrival, he found Scottish accents easier to understand than English ones. He once sat at the wrong place at a dinner table and was obliged to cut slices of ham for everyone else. Disembarking in New York in 1893, Helmholtz viewed the city from the fifteenth floor of the Lloyd newspaper building; the train ride to Chicago took nineteen hours, and the trip from Chicago to Denver, where he stayed in a "luxury eight-story hotel," took thirty.

This sort of stuff might be pertinent if the subject's personality and manner of life were in any way remarkable, but in this case they were not: Helmholtz was thoroughly *bürgerlich*—a nonsmoking, practically nondrinking, broadly liberal but mainly apolitical family man, an uncharismatic lecturer, not well endowed with the eccentricities that biographers often use to illustrate what's commonly called the "human side" of a scientific life. But a biography of Helmholtz has to overcome a problem not attached to books about Newton, Darwin, or Einstein. Helmholtz isn't widely recognized as a maker of the modern world, nor is there a single major scientific breakthrough that can be attributed to him alone. His name isn't well known among a general readership, even in Germany (where there are research centers and streets named after him), though he was hugely respected by many of his contemporaries and followers, including the young Einstein. To his admiring biographer, Helmholtz was, "by any measure, an intellectually off-scale individual, a scientific genius."

The challenge for the Helmholtz biographer is the immense range of his interests, but that same intellectual sweep helps justify both the size of the biography and the claim for Helmholtz's importance.[1] Helmholtz did not simply achieve a lot, he also worked to establish proper relationships between a range of scientific and cultural domains—for example, between physics, physiology, and psychology; between the aesthetic and the scientific; between philosophy and natural science. He developed an early version of what became known as the conservation of energy. He determined the finite speed of the nervous impulse (previously thought to be unmeasurably fast); he worked extensively on the physics and physiology of human sensation; he conducted research on physiological and psychological aspects of responses to music and art; he contributed to meteorology and atmospheric physics; he wrote about the philosophical foundations of both science and mathematics; he was one of Germany's most energetic popularizers and advocates of science, building up some of the country's most important scientific and technological institutions; and he invented the crucial tool of modern ophthalmology, the ophthalmoscope, which allows doctors to view patients' retinas. This last achievement secured him more contemporary celebrity than his researches in pure science, an odd circumstance for a man who offered one of the nineteenth century's most confident assertions of scientific uselessness: "Whoever, in the pursuit of science, seeks after immediate practical utility, may generally rest assured that he will seek in vain."

Helmholtz's father, a *Gymnasium* teacher in Potsdam, belonged to Prussia's cultured middle class, the *Bildungsbürgertum*. He valued his acquaintance with academic philosophers, and he transferred many of his own aspirations to his eldest son. Hermann wanted to be a physicist; his father wanted him to be a doctor (a more sensible and secure occupation). So the dutiful son trained as a physician in Berlin. What might seem an unfortunate concession to paternal authority delivered the young Helmholtz to one of the hot spots of nineteenth-century scientific and cultural change. Despite early struggles to achieve recognition within the German academic world, he eventually won a series of prestigious posts: following an initial exile to the provincial University of Königsberg in East Prussia (where Immanuel Kant had taught), Helmholtz moved on to chairs of physiology at the University of Bonn and then Heidelberg, before ending his academic career at the Humboldt University of Berlin, where, as a professor of physics, he returned to his first scientific love. (In 1883 the Kaiser ennobled the now world-famous Helmholtz, elevating him to *von* Helmholtz—an exceptionally rare honor for any Prussian scientist or scholar.)

Helmholtz was never greatly interested in treating the sick, but he was very much concerned with the general question of how human bodies worked and experienced the world. In mid-century Berlin, he was surrounded by some of the leading lights in what became known as the "organic physics" movement, including physiologists Carl Ludwig, Emil du Bois-Reymond, and Ernst von Brücke. The last two, like Helmholtz himself, had been students of the great elder statesman of German physiology, Johannes Müller. Their shared project was to firmly ground the processes of life in chemistry and physics. In 1847 Ludwig visited Berlin and, as he recalled, the four younger physiologists "imagined that we should constitute Physiology on a chemico-physical foundation, and give it equal scientific rank with Physics." These efforts attracted various labels—naturalism, physicalism, materialism—depending on which aspects of life they took in and how aggressively they aimed to account for vital phenomena.

In physics, demonstrating the impossibility of a perpetual motion machine was taken as an imperative for scientists seeking to give mechanical accounts of natural phenomena. To organic physicists like Helmholtz, that same endeavor was central to showing the wrongheadedness of vitalism, the idea that there was some special living force (*Lebenskraft*) that was unique to plants and animals and that could not be accounted for by physics or chemistry. To Helmholtz, as Cahan says, "*Lebenskraft* was simply another form of a *perpetuum mobile*," because vitalism supposed that living forms could draw on an unnatural, and presumably infinite, force to power their activities. There was no experimental evidence that such a thing existed or could be made to exist.

Early in his career Helmholtz joined with other contemporary physicists in asserting that while different kinds of energies could be converted into each other, energy could be neither created nor destroyed, a principle that emerged later in the century as the first law of thermodynamics. Helmholtz also advanced the idea, with physicists Sadi Carnot, James Prescott Joule, and William Thomson, that heat spontaneously flows from hotter to colder bodies, a version of the second law of thermodynamics. Such a flow implies the eventual "'heat death' of the universe," an equilibrium in which all objects in nature would be the same temperature and the whole universe would be at "eternal rest." "Some say the world will end in fire,/Some say in ice," wrote Robert Frost, and while Helmholtzian eschatology technically referred to *thermodynamic equilibrium*, the idea of the Big Freeze ultimately captured the public imagination.

Vitalism was a position closely linked to religion and also to German *Naturphilosophie*—a species of Romantic, idealistic, speculative philosophizing that inspired some natural scientists in their quest for unifying theories and irritated others with its cavalier disregard of empirical work and cautious inductive inference. Helmholtz was one of many young German researchers repelled by *Naturphilosophie*. "Doesn't one generally know," Helmholtz wrote in 1855, "that at present the natural scientist and the philosopher are not exactly good friends?" The struggle between scientist and philosopher continued, Helmholtz thought, not because one side was trying to convince the other but because they had agreed that there was no way to do so.

To Helmholtz and his colleagues, Cahan writes, "the natural and the social worlds were seen as the objects of detailed empirical, ever-more-specialized study, not of general philosophical speculation," and Helmholtz set out to show the power and scope of experimental methods in accounting for the phenomena of life, focusing on just those areas that had historically seemed most resistant to physico-chemical explanation, notably sensation and subjective experience. Philosophy would eventually either be left to treat matters that natural science had not yet sorted out or, from time to time, enlisted to help clarify scientific concepts and methods. (Helmholtz's main targets here were Friedrich Schelling and, especially, Hegel, whom he despised, though some of Goethe's scientific speculations also came in for sharp criticism.)

For physiologists, the expansion of natural science into domains previously owned by philosophy meant engagement, first, with the structure and working of the nervous system; second, with the relation of human sensations to the external world; and, last, with the perception of things that elicited aesthetic responses, notably art and music. A scientific position that Helmholtz inherited from his teacher Müller—one whose enormous significance he said he was "inclined to equate with the discovery of the law of gravitation"—was "the law of specific nerve energies": each type of sensory system responds in its unique mode, no matter the nature of the stimulus affecting it. So, for instance, you see stars if you rub your eyes hard and also if the optic nerve is electrically stimulated, and each of the other sensory systems has its own particular mode of response to stimulation.

That's a scientific claim, but it's also one that bears on philosophical positions. According to the law of specific nerve energies, sensations can only be indirect testimony of external reality: the different types of sensory nerves have their own distinct grammar, and each type speaks with its special vocabulary. The reality we sense is not innately divided up into its visual bits, acoustic bits, haptic bits, and so on. Rather, the body actively channels and sorts reality into these different modes. Philosophers had long debated the relationship between reality and what the senses deliver to the mind, but those who embraced variants of the doctrine of specific nerve energies now possessed experimental evidence that allowed them, if they wished, to replace philosophical dispute with scientific certainty.

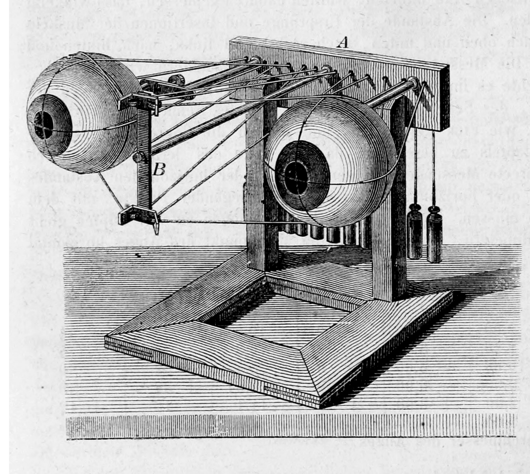
Where Helmholtz departed from Müller was in his important claim that the correspondence between our sensations and the objects perceived occurs not through the innate properties of nerves but through the accumulation of learned behavior, a process he called "unconscious inference." The sense organs, Cahan writes, become "educated"; the relationship between sensations and external objects is one of sign or symbol, not of image; and the perceptions that the mind constructs from sensations do not simply mirror the world but actively interpret it, drawing on the accumulated knowledge, learned expectations, and customs in the historically specific cultures that human beings inhabit. So there is a double disjunction between external reality and our perceptions—the first, through the working of specific nerve energies, is between sensations and their physical causes; the second, through the effect of unconscious inference, occurs as the mind makes perceptions out of sensations.

Helmholtz's stunning measurement of the speed of nervous conduction, which had recently been identified as an electrical impulse, similarly showed a disjunction between event and experience. We believe that we experience things, as it were, "in real time," but Helmholtz established that the speed of conduction was around 24–38 meters per second, so it was scientifically determined that "real time" has a time lag.

Although Helmholtz sought to displace philosophy as the means of understanding the relationships between sensory experience and reality, there was one major German philosophical tradition with which he could find common cause. In maintaining that our perceptions have as much to do with our sensory organs as they do with the external causes of sensation, he loosely identified with his Königsberg predecessor, Kant; only now, what had once been a contested philosophical position could be securely and scientifically demonstrated. Yet Helmholtz did not think, as Kant had, that our ability to perceive spatial relations was innate: this too was dependent on experience, including empirical facts about our eyes' motions, some of which were actively under the control of the human will.

In the mid-1850s Helmholtz's interests turned overwhelmingly toward sensory physiology (or the physics of perception), and it was this research that established his global reputation. His three-volume *Handbook of Physiological Optics* (1856–1866) aimed, Helmholtz announced, to "re-work the entire field," and was notable partly for its extension of the law of specific nerve energies to the notion that the eye had three different sorts of nerve receptors, each sensitive to a different color (blue, green, and red). His treatise *On the Sensations of Tone* (1863) radically changed musical culture—to some extent how music was made but, more fundamentally, how music was listened to, encouraging a new and focused attentiveness to aural sensation. The book was read by musicians and instrument-makers as well as many scholars outside the specialty of sensory physiology (including Nietzsche, George Eliot, and Gerard Manley Hopkins, whose poetry, Cahan says, was influenced by Helmholtz's understanding of meter).[2]

Helmholtz worked on the mathematical, physical, and physiological principles governing the production and perception of vibrations, analyzing apparently simple musical tones into their component vibrational parts and describing the excitation of auditory nerves. (Again, the principle of specific nerve energies was invoked: different nerve fibers in the ear resonated in response to different frequencies.) There was now a physics and a physiology of musical harmony and disharmony, and musical instruments could be treated both scientifically and aesthetically—as creating aesthetic responses and embodying scientific principles.[3] The great Darwin was impressed: in *The Descent of Man* (1871), he admiringly wrote that Helmholtz had satisfactorily explained "on physiological principles" why tonal concords are pleasing and discords are displeasing to the ear. Helmholtz had, again, brought human sensation into the realm of experimental science, and a significant number of Victorian artists, musicians, and lovers of art and music found that achievement inspiring.



An ophthalmotrope; from Helmholtz's 1867 Handbuch der physiologischen Optik

Helmholtz was one of many researchers introducing natural scientific methods and concepts into disciplines that had previously been the domain of humanistic studies, but, at the same time, he and other practitioners worried about the challenge presented by scientific progress to the universities' charge of instilling and maintaining *Bildung*, a hard-to-translate notion of refinement or cultivation, never to be identified with narrowly technical or professional pursuits. Intellectual specialization was presented as a problem for *Bildung*, and its effects were seen as pathological.

A *Methodenstreit*—or dispute over the sort of knowledge one could have about nature and the sort one could have about human beings and their cultural products—erupted passionately in the last decades of the nineteenth century, but already in the 1850s and 1860s Helmholtz was confronting related issues in both popular lectures and technical writings on music and art. In nineteenth-century Germany, both philology and chemistry, for example, counted as *Wissenschaften*—that is, as rational, rigorous, and systematic forms of inquiry, while scholars disputed the nature of their respective methods and products. (The Anglophone notion of "science" doesn't adequately capture German cultural categories and sensibilities: in English "science" came to stand largely for systematic studies of *nature*; chemistry counts as a "science," philology does not.) The natural sciences (*Naturwissenschaften*) had made stunning advances, and they had spectacularly pushed their understandings into some of the domains occupied by the human sciences (*Geisteswissenschaften*). People like Helmholtz had no doubt that this should be celebrated, but the nineteenth-century German "Two Cultures" problem was configured differently from its twentieth-century form—it referenced a fault line *within* the category of *Wissenschaft*—and the way that Helmholtz addressed the problem was also historically specific.

Some modern neuroscientists like to call Helmholtz a "reductionist" and have recruited him as a founder of the current enthusiasm for reducing such cultural modes as music or art to bits of nervous physiology, or even to the evolutionary and genetic foundations of neural processes. It's an understandable temptation, but it overlooks what Helmholtz himself thought about the relationship between the physical and the psychological. With respect to music, though Helmholtz had discovered lawful relations between the physical and physiological facts of the matter, and though he believed that those facts were pertinent to the nature of aesthetic responses, he also believed that the psychological domain had its own laws, and that the reduction of psychological phenomena to physiological circumstances was a scientific mistake. The physical and physiological circumstances that bore upon hearing and making music weren't sufficient to explain aesthetic responses.

He had hoped, nevertheless, to discover universal laws of aesthetics comparable to the laws of nature—but he did not find these laws and was eventually satisfied that he could not. The anatomy of the human nervous system might be more or less constant, but aesthetic responses were historically and culturally variable. There were "historical and national differences of taste," he noted, and "the same properties of the human ear could serve as the foundation of very different musical systems."

A *Kulturträger*—a "bearer of high culture," like so many contemporary German scientists—Helmholtz loved art, theater, poetry, and especially music, and he and his second wife hosted regular musical evenings for colleagues and friends, at which the great man played the piano and other musical instruments, some of which he had designed or modified on scientific principles.[4] Helmholtz, according to an earlier biographer, "was not…a good performer on any instrument, but knew something of all, having paid so much attention to them, while his ear had become very acute from his constant preoccupation with tones."

He had definite tastes, and he was confident and fluent in his aesthetic judgments. He loved Bach, Mozart, and, above all, Beethoven, "the most powerful and deeply affecting of all composers." His understanding of the physical properties of tones and the acoustic responses of the ear was almost certainly more sensitive than those of people who lacked his scientific expertise. But as Helmholtz listened to music, his responses probably overlapped with those of many others of his class, age, experiences, and interests.[5] In 1873 Steinway shipped him an experimental new baby grand piano from New York, because, the company wrote, "you have done so many useful things for us concerning the phenomena of tone." It's tempting to think of him, seated at the Steinway, performing a kind of duet: one part played by Helmholtz the scientist, and the other by Helmholtz the *Kulturträger* and music-lover. But it was, of course, a solo performance, and Helmholtz, possibly better than anyone else in the nineteenth century, understood why—different cultural modes, one experiencing body.

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1 Before Cahan's book, the most recent Helmholtz biography aiming at definitiveness was Leo Koenigsberger's *Hermann von Helmholtz*, translated by Frances A. Welby (Oxford: Clarendon Press, 1906). A less thorough recent celebration is Michel Meulders, *Helmholtz: From Enlightenment to Neuroscience*, translated by Laurence Garey (MIT Press, 2005). ↩

2 Helmholtz's encouragement of novel modes of sensory attention, and his role in producing a new type of listener, are discussed in Benjamin Steege, *Helmholtz and the Modern Listener* (Cambridge University Press, 2012), chapter 3. Poets' responses to Helmholtz are described in Gillian Beer, *Open Fields: Science in Cultural Encounter* (Oxford University Press, 1996, especially pp. 242–272). ↩

3 Here see Alexandra Hui, *The Psychophysical Ear: Musical Experiments, Experimental Sounds, 1840–1910* (MIT Press, 2012), Chapter 3. ↩

4 Music-making, as well as music appreciation, was of special importance in the nineteenth-century German physics community—a subject beautifully treated in Myles W. Jackson, *Harmonious Triads: Physicists, Musicians, and Instrument Makers in Nineteenth-Century Germany* (MIT Press, 2006). ↩

5 For a marvelous recent study of Helmholtz's aesthetics in the context of German technology and politics, see M. Norton Wise, *Aesthetics, Industry, and Science: Hermann von Helmholtz and the Berlin Physical Society* (University of Chicago Press, 2018). ↩