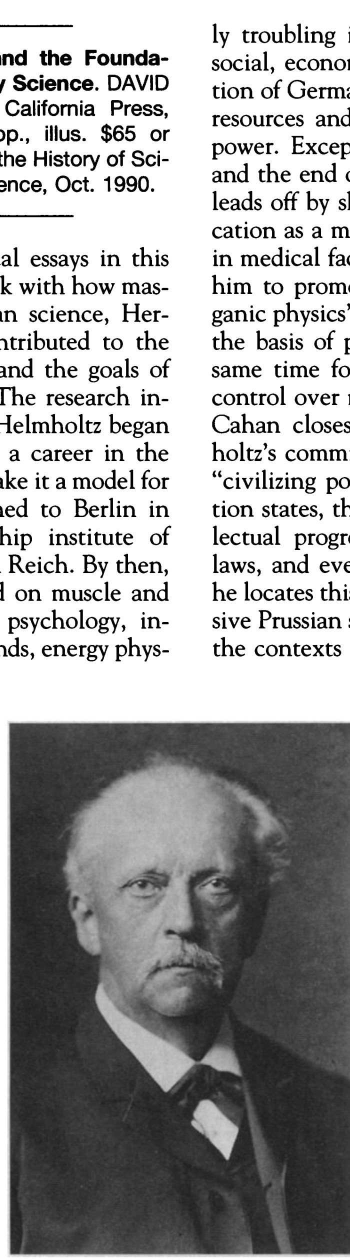
BOOK REVIEWS

The Helmholtz Program

Hermann von Helmholtz and the Foundations of Nineteenth-Century Science. DAVID CAHAN, Ed. University of California Press, Berkeley, 1994. xxx, 666 pp., illus. $65 or £47.50. California Studies in the History of Science, 12. Based on a conference, Oct. 1990.

Readers of the 15 historical essays in this fine collection will be struck with how massively that icon of German science, Hermann von Helmholtz, contributed to the content, the institutions, and the goals of modern research science. The research institute did not exist when Helmholtz began trying to make physiology a career in the 1840s. He had helped to make it a model for the world when he returned to Berlin in 1871 to establish a flagship institute of physics for the new Second Reich. By then, his fame could have rested on muscle and nerve physiology, sensory psychology, instrumentation of several kinds, energy physics, or electrodynamics. He had also become a leading exponent of a programmatic model that has often typified the natural sciences: that scientific knowledge consists in the explanation of phenomena at higher levels of organization by reducing them to summations of interactions between elements at a lower level (analytic reduction). Today this model is under severe attack from the computer-based sciences of complexity. Thus the present volume, which explores the content and development of Helmholtz's reductionist program, provides a timely critical memorial for the hundredth anniversary of his death in 1894.



Hermann von Helmholtz, 1886. [From the dust jacket of *Hermann von Helmholtz and the Foundations of Nineteenth-Century Science*; Siemens Aktiengesellschaft]

To be sure, the collection consists primarily of intellectual history, of the sort in which Helmholtz is "influenced" by previous individuals and their texts and in turn "influences" subsequent science. Particularly troubling is that so little shows of the social, economic, and political transformation of Germany that provided many of the resources and opportunities for his rise to power. Exceptions come at the beginning and the end of the book. Arleen Tuchman leads off by showing how Helmholtz's education as a medical doctor and his 22 years in medical faculties provided a platform for him to promote the independence of "organic physics" (experimental physiology) as the basis of practical medicine and at the same time for academic doctors to secure control over medical training and practice. Cahan closes with a discussion of Helmholtz's commitment to science as the great "civilizing power" of liberal, industrial nation states, the basis of material as of intellectual progress, of societies governed by laws, and even of aesthetic judgment, and he locates this ideology nicely in the expansive Prussian state. Between these bookends the contexts are intellectual.

As intellectual history, however, the book is a delight. Particularly illuminating are the many chapters that draw out the technical practices and instruments that grounded Helmholtz's research. Frederic L. Holmes and Kathryn M. Olesko pair up to study the graphical recording instruments he developed in the early 1850s to investigate the temporal character of work done by contracting frog muscles and to establish that nerve impulses propagate with a finite velocity. In a subtle interpretation of Helmholtz's use of error analysis (least squares), they show how he employed this minimization of uncertainty to establish the certainty of his results and thereby the reality of the objects of his investigation. Although this strategy may seem familiar enough today, it was fundamental to Helmholtz's innovative empiricist methodology, on which I will focus my comments, for it constitutes a major theme.

Timothy Lenoir lucidly establishes this theme for Helmholtz's research on vision, especially on the coordination of eye and mind in the spatial location of objects, centered on the use of Helmholtz's renowned ophthalmoscope and on a mechanical simulator of eye muscles, the ophthalmotrope. The mind uses motions of the eye to locate objects, Helmholtz argued in 1863 (following Fick and Wundt), in a manner thoroughly analogous to an experimenter employing a measuring instrument, including the use of least squares to minimize error. Here the "errors" are a set of eye movements, so least squares gives a principle of "least orientation," analogous to Gauss's principle of least constraint in mechanics and more broadly to the principle of least action. Thus the unconscious practices of the mind mirror both physical principle and the conscious practices of experimental science, properly conducted.

In other areas of sensory physiology Helmholtz produced similar explanations. Each sense organ is a set of analyzers, which through their "specific energies" send a definite set of component sensations ("signs" or signals) to the mind. The mind in turn is a mathematical synthesizer, producing a composite perception of an external object or quality from the signs. With respect to color vision, Richard L. Kremer shows how Helmholtz combined the views, experiments, and mathematical work of a number of his contemporaries with some ingenious experiments and mathematics of his own to work out a sophisticated version of Young's three-color theory. Three color sensors in the eye deliver signals of varying amplitude, which the mind adds vectorially to infer a color in the source. Similarly, Stephan Vogel recounts how Helmholtz joined sides in an acoustics debate, again deploying new instrumentation with great virtuosity, to show that the ear acts like a Fourier analyzer, decomposing sound into a large number of sinusoidal vibrations and sending corresponding signals to the mind, which operates on them algebraically to produce the qualities of sound. Beginning in the mid-1850s Helmholtz became increasingly committed to two features of the analyzer-synthesizer scheme: the front end (as Kremer puts it) is passive; and the active but unconscious calculations of the mind are not innate but learned in the course of purposive action in the world, as practical or functional inferences. These beliefs defined Helmholtz's brand of sensory empiricism and set him in sharp opposition to two sorts of intuitionists, Kantians and nativists (R. Steven Turner and Robert DiSalle give illuminating discussions of these issues), involving him in a variety of controversies from the 1850s to the '70s. Several authors use the controversies to reconstruct the means through which Helmholtz articulated his position and gained his power. Turner especially, in an account of Helmholtz's work on spatial vision that differs from Lenoir's with regard to timing, emphasis, and instruments, reveals Helmholtz as a master rhetorician and polemicist who constructed and named the "nativist-empiricist" dispute in order to advance his own position as against that of Ewald Hering (a process developed more fully in Turner's recently published *In the Mind's Eye: Vision and the Helmholtz-Hering Controversy* [Princeton University Press]).

By the late 1860s Helmholtz's mature empiricism appeared at every level, from sensory psychology to the mathematics of space and time (DiSalle), to the methodology of experimental and theoretical practice in physics (Jed Z. Buchwald), to general epistemology of science (Michael Heidelberger). Most of the authors recognize also a turning point in his methodological stance by 1870, when he moved from Heidelberg to Berlin and, having just published a stunning new electromagnetic theory, from physiology to physics. But here agreement breaks down and explanations diverge.

To differentiate Helmholtz's electromagnetic investigations from the traditional Weberian and Maxwellian genres, Buchwald invents "Helmholtzianism." Noting that Helmholtz had now given up his youthful enthusiasm for reducing all physical systems to atoms and forces, he argues that Helmholtz had embraced a more phenomenological reduction to the interaction energies specific to particular object states directly available in the laboratory, meaning current densities, electromagnetic forces, velocities, and the like. And the principle of least action now replaced force as the foundation of dynamics. (Some author should have correlated these specific energies, object states, and extremum principles with those in sensory psychology.) A "Helmholtzian" researcher—Heinrich Hertz makes a plausible example—gets to know the laws of the objects by actively manipulating them: changing, varying, moving, modifying—like the eye exploring objects of vision—and always analyzing them into elements and their interaction energies. Buchwald's proximate source for this methodological change is Thomson and Tait's *Treatise on Natural Philosophy* (1867), which Helmholtz helped to translate.

Readers who want to see the electrodynamics more concretely will find it in Walter Kaiser's contribution, which also gives an alternative account of Helmholtz's change in reductionist strategies. One difference is that Kaiser treats this change as part of a much broader turn to positivism among European scientists. This begins to show the scope of the problem. By contrast, Fabio Bevilacqua makes Helmholtz's turn the result of Clausius's criticisms, Heidelberger emphasizes Michael Faraday's influence, and the two papers by Helge Kragh and Günter Bierhalter seem to downplay the change. They continue to place Helmholtz within the atomist camp in the 1880s with respect to chemistry and thermodynamics, even while elaborating his macroscopic methodology in developing the "Helmholtz free energy" and in attempting to explain the entropy law in terms of the average behavior of abstract monocyclic systems. Some of the confusion is removed by Heidelberger's philosophical account, which succeeds in illuminating the subtle shifts in Helmholtz's view as he put the atoms and forces increasingly in the background as "hidden" realities (compare the "hidden" motions of monocyclic systems in Bierhalter's account) and stressed lawful regularity as the experiential meaning of force. Heidelberger invents another label, "experimental interactionism," and stresses the influence of the idealist philosophy of J. G. Fichte (which quite interestingly challenges the usual resources located in Helmholtz's critique of Kant). All these papers illuminate Helmholtz's scientific work. But by proliferating influences they reveal the inadequacy of such accounts: too many influences with too little attention to the multiply interacting activities and contexts in Helmholtz's life.

There remain two chapters at opposite ends of a spectrum, one by Bevilacqua treating Helmholtz's most famous paper, directed to physicists in 1847, "On Conservation of Force" (later reinterpreted as "conservation of energy"), and another by Gary Hatfield on his least famous later views, on aesthetics. Although specialists will certainly disagree with Bevilacqua about particulars regarding Helmholtz's paper, his thorough explication of its structure and content is valuable. It makes clear what an incredible command of diverse domains of mathematical and experimental research, completely outside his own specialty in physiology, Helmholtz had to have in order to enunciate a comprehensive conservation law in 1847. It also highlights the depth of his commitment at that time to reducing all physical phenomena to atoms and Newtonian forces and to deductive explanation of empirical laws from general principles. Of course the reductions never worked in the most critical subjects of electrodynamics and thermodynamics, as other chapters make clear. (Here is surely another reason that Helmholtz, along with many other practitioners, retreated to macroscopic energy physics in the 1870s.) But Helmholtz remained committed to analytic reductions to specific energies, both in physics and

Vignettes: Ascendancy

Aging 1960s radicals who now dominate the faculties of many universities have helped power the movement for political correctness, which punishes truth, penalizes merit, promotes faculty on the basis of quotas, and suffuses the campus with an atmosphere of abysmal, inflammatory ignorance.

—*Richard Nixon*, in *Beyond Peace* (Random House)

The notion that scientists and engineers will always accept as axiomatic the competence and indispensability for higher education of humanists and social scientists is altogether too smug. . . . How these matters play out in American intellectual life will depend, to some degree, on the ability of the non-scientists to rein in the most grotesque tendencies in their respective fields.

—*Paul R. Gross* and *Norman Levitt*, in *Higher Superstition: The Academic Left and Its Quarrels with Science* (Johns Hopkins University Press)

The popular image of the scientist as a breed apart, a cold, calculating person incapable of communicating in layman's language, content to remain aloof and preoccupied with research wherever it may lead, is only true in the minority. But it is this vocal minority that often prevails in university life.

—*Eric Chaisson*, in *The Hubble Wars: Astrophysics Meets Astropolitics in the Two-Billion-Dollar Struggle over the Hubble Space Telescope* (HarperCollins)

Many shall rise that now are fallen; and many shall fall that now are held in honor.

—*Horace*, in *Ars Poetica*, as quoted by William T. Golden in *Science and Technology Advice to the President, Congress, and Judiciary* (AAAS Press) physiology. His pursuit of that program, as he rose to the status of national symbol of science, helps illuminate one of the most far-reaching controversies of the late 19th century, between the natural sciences and the human sciences, epitomized as physics versus history.

In a masterly chapter, Hatfield probes Helmholtz's changing position on this divide. In sharply worded lectures of 1853 and 1862 he had lumped artistic with historical methods and differentiated them from natural science in terms of "artistic induction" versus "logical induction." The former, as an instinctive ordering of facts, yielded insight; the latter produced strict causal relations suitable for deductive explanation. By 1868, however, Helmholtz's view of aesthetics changed along with his view of science. The prominence of "unconscious inference" in the analyzer-synthesizer theory, Hatfield argues, led him to believe that "artistic intuition" has the same aim as unconscious inference and thus also as scientific reasoning, now in its much more inductive form. All three activities sought to abstract the lawlike from phenomena, the invariant forms or ideal types. But in thus assimilating art to science in the search for universal law, Helmholtz only reinforced the boundary he had articulated between natural science and history. Two points are noteworthy: Helmholtz provides a crucial marker for the modern two-cultures dichotomy; and he may be seen as a very early participant in the modernist movement in art, which so prominently abjured context, historical reference, and decoration in favor of abstraction, purity, and essences. Both developments continued for a hundred years. They are now in flux once again, along with analytic reduction as the goal of science. Is this the end of the Helmholtz era, or only an anomaly?

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Environmental Test Case

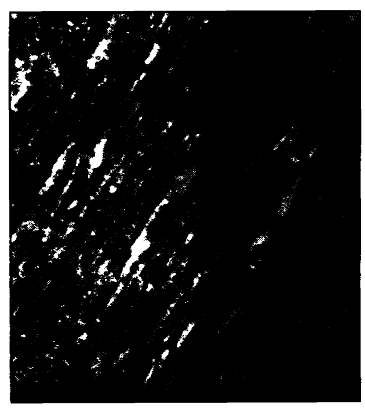
Everglades. The Ecosystem and Its Restoration. STEVEN M. DAVIS, JOHN C. OGDEN, and WINIFRED A. PARK, Eds. St. Lucie Press, Delray Beach, FL, 1994. xvi, 826 pp., illus., + plates + map. $97.50.

U.S. Secretary of the Interior Bruce Babbitt proposed to take an ecosystem approach to solving environmental problems and declared the Florida Everglades a test case. Though subsequent headlines focused on litigation and permits, the story was really about simultaneously achieving environmental and economic goals with scarce public and private funds. Everglades history suggests that endangered ecosystems threaten sustained economic development. Now a social experiment is under way to test this idea with new policies protecting the regional ecosystems on which the human economy depends. *Everglades* documents part of the scientific basis for such policies. It proposes restoration of ecosystem functions as the first step toward sustaining natural, agricultural, and urban subsystems of the regional landscape.

For a century, state and federal policies were to reclaim (drain) the Everglades for human habitation and agriculture. By 1917, four canals led the way for the U.S. Army Corps of Engineers' Central and Southern Florida Project for Flood Control, based on levees, water storage areas, canals, and large pumps. Flood protection spurred rapid urban and agricultural growth. But evidence accumulated that the diminished function of the Everglades and connected ecosystems threatened the human economy. First, the condition of the Everglades, Florida Bay, and perhaps the fringing coral reef deteriorated as a result of an insufficiency of fresh water, while the dumping of 80 percent of the system's fresh water into Atlantic coast estuaries caused damage of a converse sort. Second, overdrained organic soils have rapidly been depleted by oxidation, presaging farm abandonment or drastic change in farming methods in much of the Everglades Agricultural Area by the year 2000. Third, the urban water supply, stored in the surficial aquifer and Lake Okeechobee, is threatened by overpumping and deteriorating quality.


"Alligator pond surrounded by sawgrass (gray) and button bush (green). Photo extent ≈3 meters." [From *Everglades*]


"Plant communities of sawgrass marshes (gray), tree islands (green), and wet prairies. Note alligator trails. Photo extent ≈100 meters." [From *Everglades*]


"Satellite image showing plant communities: tree islands (red), sawgrass (gray), and wet prairie (black). Dark side of image is recent fire. Photo extent ≈10 kilometers." [From *Everglades*]

The original Everglades was a resilient system because it was large enough to tolerate flood and drought. Removing half the system and compartmentalizing the remainder has greatly reduced its resilience. Signs of degradation include an 80- to 90-percent decline in populations of wading birds, loss of peripheral marshes in which wading birds fed, abandonment of wading-bird rookeries in Everglades National Park, reduced hydroperiod with flow pattern changed from attenuated to pulsed, overdrainage and pooling near canals and levees, reversal from muck accretion to subsidence, and reduced flow of fresh water into Florida Bay. Economic sectors now threatened by the Everglades crisis include Everglades agriculture at $750 million a year, ecotourism of the Everglades at $300 million a year, and the downstream Florida Bay fishery at $104 million a year.

The Everglades case joins a handful of other resource-use crises being addressed by adaptive management, an approach developed in Canada and Europe and now gaining headway in the United States. Adaptive management seeks to formulate public policy in the face of system complexity and scientific shortcomings by stepwise implementation of policy changes accompanied by research, to make simultaneous progress in ecosystem science and application. The idea and previous cases are expounded in C. S. Holling's *Adaptive Environmental Assessment and Management* (Wiley, 1978), Carl Walters's *Adaptive Management of Renewable Resources* (Macmillan, 1986), and Kai Lee's *Compass and Gyroscope* (Island Press, 1993). In *Everglades*, 57 authors describe