BOOK REVIEWS

Shifts and Overthrows

Revolutions in Mathematics. DONALD GILLIES, Ed. Oxford University Press, New York, 1992. xii, 353 pp., illus. $98.

A revolution in the political sense of the word (like the French and Russian revolutions) may be said to have taken place when the locus of power and the grounds for legitimacy of rule are changed dramatically. To discuss scientific revolutions let us suppose there is a realm that is all of nature itself. Current science has subdivided this realm into countries each ruled by a scientific community determined by the explanatory power and the overall acceptance of its theories. The level of research activity in each land passes for a kind of currency. Revolutions occur when a new, unclaimed region is fought over by neighboring countries. The appropriation of this new region often entails a reassignment of boundaries and redistribution of wealth. For example, when the precession of the perihelion of Mercury was explained by Einstein's general theory of relativity, the Newtonian rule over the motion of the planets gave way to Einstein's new mechanics.

The "realm of nature" is a thumbnail sketch of Kuhn's approach to the history of science. The central notions of Kuhnian analysis are scientific communities, their disciplinary matrices (or paradigms), and the occurrences of revolutions. The disciplinary matrix for a given scientific community includes "symbolic generalizations" (like $f = ma$ that are legislative as well as definitional), "beliefs in particular models," "values" about the qualities of theories, predictions, and so on, and "exemplars" or "paradigms" that show how research should proceed. A revolution occurs when the elements in the disciplinary matrix are changed. This is usually brought on when anomalies arise in the course of the application of accepted theories. Examples of revolutions abound in the history of science: the Copernican revolution, the Einsteinian revolution.

Can the notion of revolution be applied to the history of mathematics? This question is the theme of this collection of essays. The appearance in 1962 of Kuhn's *The Structure of Scientific Revolutions* prompted some speculation on the question among historians of mathematics. The most notable response was Michael Crowe's 1975 essay "Ten 'laws' concerning patterns of change in the history of mathematics" (reprinted in the collection), which ends with his tenth law: Revolutions never occur in mathematics. Crowe requires of revolutions that "some previously existing entity (be it king, constitution, or theory) must be overthrown and irrevocably discarded." This simply does not happen in mathematics. The most recognizable example is Euclid's *Elements*. The discovery of non-Euclidean geometry and differential geometry did not diminish the stature of Euclid as exemplar. The term "geometry" simply took on a different meaning from what it had at the beginning of the 19th century, and "Euclidean" became one of many different instances of geometry.

Crowe's persuasive arguments were met by two critics: Herbert Mehrtens (1976) and Joseph Dauben (1984). In Mehrtens's essays in response to Crowe's ten laws, he makes a strong case that revolutionary activity is not what historians of mathematics should seek. The important aspects of Kuhn's work for mathematics are the ideas of a scientific community and the associated disciplinary matrix. This admits more details from without mathematics, for example, by considering the social structure of the mathematical community. Mehrtens suggests substituting the notion of "epistemological rupture" for revolution. The historian should "consider fundamental restructuring of scientific ways of knowing."

Dauben assumes another definition of revolution, one that arose in the wake of the French Revolution: "Revolutions, then, may be visualized as a series of discontinuities of such magnitude as to constitute definite breaks with the past. After such episodes, one might say that there is no returning to an older order." Mathematics is special because it does not discard its past. Dauben characterizes conceptual revolutions by a change in the interpretation of older mathematics after which the older mathematics is "relegated to a significantly lesser position." The discovery of incommensurable magnitudes, Cantor's theory of sets, Cauchy's introduction of rigor in analysis, and Robinson's non-standard analysis are Dauben's well-argued examples of revolutions in mathematics.

The discussions of the metaphor "revolution" in the book tell us what we can learn from its use. For example, Mehrtens's "epistemological rupture" and Boi's "mathematical hermeneutics" concern the nature of mathematical knowledge and changes in interpretation. Gray points to changes in the ontological status of mathematical objects as one locus of revolution in the 19th century: The meaning of "integer" changed significantly during the development of algebraic number theory.

Dauben considers counter-revolutionary activity as a measure of the occurrence of a revolution. Giorello takes up this idea in an analysis of a change in the "paradigm of legitimacy" represented by Newton's calculus. Bishop Berkeley plays the role of counter-revolutionary by demanding the precision of Euclid, and Maclaurin plays the role of apologist for Newton by restoring the "rigour of the Ancients."

It is clear that a precise definition of revolution is not apparent for the history of mathematics. A deeper problem with describing revolutions in mathematics is an inadequate description of mathematics itself: What exactly is the realm of mathematics? The accepted philosophies of mathematics, Platonism, formalism, intuitionism, and empiricism, tell us that mathematics is about intangibles, be they objects (forms), derivations, constructions, or generalizations. In each of these philosophies the meaning of the elements of a disciplinary matrix changes. It is one of the functions of history as described by Kuhn to give some direction in the problem of describing mathematics. The essays contributed to this volume offer some remarkable glimpses of the landscape of mathematics during periods of significant change, such as the introduction of the calculus, the discovery of non-Euclidean geometry, and the foundational crisis at the turn of the century.

Crowe admits the possibility of revolutions, not *in* mathematics *per se* but in "mathematical nomenclature, symbolism, metamathematics (e.g. the metaphysics of mathematics), methodology (e.g. standards of rigour), and perhaps even in the historiography of mathematics." In her essay, Dunmore gives an analysis of revolutions in metamathematics that illuminates the relationship between the belief structure of a scientific community and its paradigms. Breger's account of Finsler's failed theory of sets is an example of one mathematician's belief structure during a time of extraordinary change and its consequences.

Kuhn's book and Crowe's essay have drawn considerable criticism. What is at stake is our understanding of the process of discovery and the nature of new-found truths in science and mathematics. The insightful contributions found in this book prove that the tools of Kuhnian analysis, in particular the idea of a revolution, may be applied usefully to produce history of the sort that goes beyond description in the logical presentation of ideas, to reveal what is at the heart of the process of discovery. Crowe's second essay, which is last in the collection, ends with an appropriate summary: "A revolution is underway in the historiography of mathematics, a revolution that is enabling a discipline that dates back to Eudemus to attain new and unprecedented levels of insight and interest."

John McCleary
Department of Mathematics,
Vassar College,
Poughkeepsie, NY 12601

■

AEC and Critics

Containing the Atom. Nuclear Regulation in a Changing Environment, 1963–1971. J. SAMUEL WALKER. University of California Press, Berkeley, 1992. xiv, 533 pp., illus. $50.

"Demonstrators protest against Monticello nuclear plant at headquarters of Northern States Power in Minneapolis, 1971." [From *Containing the Atom*; © 1971 *Star Tribune*, Minneapolis–St. Paul]

In the 1970s nuclear reactors became one of the most controversial technologies in history, as enormous opposition movements developed around the globe. The conflict has differed from earlier controversies over new technologies, one difference being that other such technologies have usually been opposed—as was the case with the machine-smashing that occurred in the 19th century—as a threat to jobs, whereas nuclear energy was widely defended as creating them. A small library of books and articles has been generated in attempts to understand the battle, and the field of risk analysis was developed largely to explain antinuclear sentiments. It is crucial to understand this conflict, since it raises important issues of the role of experts in democratic countries.

"An ecologist at Oak Ridge National Laboratory uses a radiation-detecting instrument to measure radioactivity in the body of a live fish." [From *Containing the Atom*; National Archives]

In *Containing the Atom* J. Samuel Walker offers a wealth of raw materials for understanding the roots in the 1960s of the controversy that blossomed fully in the 1970s. Intended as a history of the Atomic Energy Commission from 1963 to 1971 (the period of Glenn Seaborg's reign as chairman), this beautifully written account provides more details concerning the civilian development of nuclear power in the United States during that period than any other work ever has—or perhaps ever will. As the official historian of the Nuclear Regulatory Commission, the AEC's successor, Walker had unprecedented access to internal memos and documents (as the 75 pages of notes demonstrate), a concern with covering all aspects of nuclear regulation, and the time to check his facts carefully. Because every aspect of nuclear development raised regulatory issues, his book approximates a general history of American nuclear energy rather than merely a history of the Atomic Energy Commission.

Walker organizes his book around a series of issues that regulators faced as they tried to balance their conflicting roles as promoters of the new technology and protectors of public health and safety. Despite the polite tone of the account, the evidence Walker presents is damning. Time after time, the promotional concerns won out, owing in some cases to the entreaties of the nuclear industry, in others to the coercion of Congress's powerful Joint Committee on Atomic Energy, and in others yet to the preferences of regulators themselves. I was struck by the number of controversies in this period, the golden age for American nuclear energy, the height of "the great bandwagon market" for reactors in the United States. Most of Walker's substantive chapters deal with debates and controversies: over proposals to put nuclear reactors in cities or near earthquake faults, over reactor safety and the odds for major accidents, over radiation standards and the effects of low doses of radiation. In many cases, the AEC and the nuclear industry treated nuclear critics brutally but learned from them in adopting new standards.

During the period from 1963 to 1971 nuclear fission seemed to achieve commercial success, with almost 80 reactors ordered from 1966 to 1968—representing almost half of all electrical generating capacity ordered in those three years. Virtually all the reactors ordered in this period were vastly larger than any then in operation. Only the contagious enthusiasm of nuclear energy's promoters, and some loss-leading plants sold by Westinghouse and General Electric, could persuade utilities to buy a technology about which so little (including its costs) was known. So the AEC was extremely successful in its promotional role. Unfortunately, expert understanding of nuclear plant operations and safety was not