The Optical Revolution

The Rise of the Wave Theory of Light. Optical Theory and Experiment in the Early Nineteenth Century. JED Z. BUCHWALD. University of Chicago Press, Chicago, 1989. xxiv, 474 pp., illus. $75; paper, $24.95.

Jed Z. Buchwald has decisively rewritten the history of a scientific revolution. Received views of the early 19th-century "rise of the wave theory of light" still owe much to William Whewell's *History of the Inductive Sciences* (1837), written in the immediate wake of events. For Whewell, the experiments and theories of Thomas Young and Augustin Fresnel (together the "Newton of optics") unambiguously established the superiority of the wave theory to the emission theory of light. Light consisted of waves in an ether, not streams of particles.

Historians of science have already recognized Fresnel's greater importance to the revolution, and Buchwald underscores the fact by devoting over half of his book to him. Educated at the Ecole Polytechnique, Fresnel (1788–1827) approached questions in optics from a background in chemistry, and by 1814 both chemical and physical considerations had led him to prefer the wave theory and to speculate that a unifying ether underlay the phenomena of light, heat, and electricity. There followed the decade of highly precise experimental and theoretical research on diffraction, polarization, double refraction, and other such phenomena that constituted the optical revolution. The technical history of these researches is Buchwald's primary concern, and his book, copiously illustrated with optical diagrams, treats the mathematical and experimental aspects of Fresnel's work at length.

The course of the revolution was influenced in various ways by previous research on the emission theory. Fresnel, for example, found himself championed by François Arago, whose own qualitative development of the emission theory had been eclipsed by the more quantitative research of Jean-Baptiste Biot. Stung by Biot's insults, Arago was more receptive to Fresnel's ideas than he might otherwise have been, using them for revenge. But if Arago helped gain Fresnel a hearing, it was Biot's highly quantitative approach to optics that Fresnel followed. Buchwald strongly emphasizes this feature of Fresnel's research, recalculating some of his integrals by machine, for example, to verify "Fresnel's prodigious computational ability." Hence, the revolution in the precision of optical theories actually began in research with the emission theory and was continued by Fresnel. He required such accuracy if his theories were to compete with Biot's. The battle was not easily won.

Much of the difficulty arose from confusion created by the concept of a "ray" of light, a point stressed by Buchwald. He distinguishes between the "selectionist" and emission views of light, views that were generally though not necessarily linked. A selectionist regarded rays as the smallest physically real components of light. Though it was natural to think of rays as consisting of material particles, Biot, especially, sought to separate the concepts, developing a selectionist theory of light rays that did not depend on particles. Fresnel, to begin with, employed physically real rays in his wave theory but eventually dispensed with rays as well as particles. He thus reduced a ray to a mathematical abstraction, merely a line drawn from a source of light perpendicular to the wave fronts. Supporters of the wave theory did not fully realize the distinction between rays and particles. Conversely, supporters of the emission theory failed to understand that Fresnel's theory precluded the existence of physically real rays. Especially in debates about polarization, these misunderstandings often rendered straightforward communication impossible. The conceptual transformation from rays to wave fronts was thus both a deep part of the optical revolution and a principal obstacle to the disputants' comprehension of one another's ideas.

Buchwald's book is detailed and technical history of science at its most unapologetic. It is hard to see how it could have been otherwise and still have disclosed the essence of Fresnel's revolution. Buchwald successfully demonstrates that the revolution was not a clear-cut matter, not so easily effected as Whewell, for example, had supposed. He brings out both the continuity between wave and emission theories and the common context of the combatants. His book will undoubtedly be a standard account for some time, perhaps eventually matching the century-and-a-half lifetime of Whewell's.

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An Unusual Planet

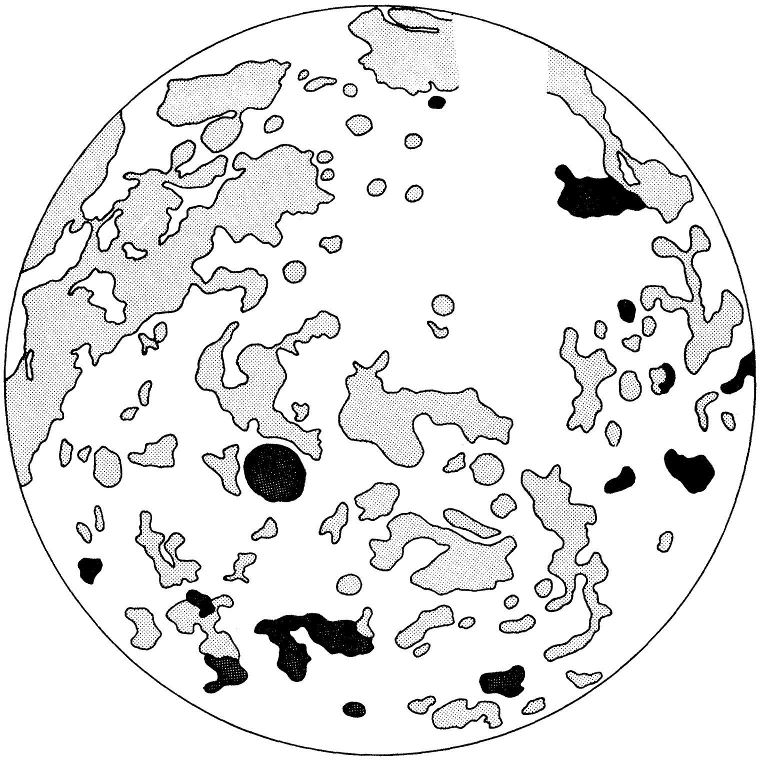
Mercury. FAITH VILAS, CLARK R. CHAPMAN, and MILDRED SHAPLEY MATTHEWS, Eds. University of Arizona Press, Tucson, 1988. x, 794 pp., illus. $45. From a conference, Tucson, AZ, Aug. 1986.

By many measures Mercury is an unusual planet. It is the closest planet to the sun and has the largest diurnal range in surface temperature. Because of the dissipation of large solar tides, Mercury is the only planet locked in a spin-orbit resonance. Mercury has the largest uncompressed density and, by inference, the greatest mass fraction of iron-nickel of any planet, with a ratio of metal to silicate at least twice that of the other terrestrial planets. A strong internal magnetic field and the absence of a significant atmosphere or ionosphere combine to produce a planetary magnetosphere with characteristics unique in the solar system.

Most of what is known about Mercury is the result of the three flybys by Mariner 10 in 1974 and 1975. Until a few years ago, placement of a spacecraft in orbit about Mercury was thought to be unattainable by conventional propulsion systems, so subsequent missions to Mercury did not figure prominently in the planning of solar system exploration. Ground-based observations of the planet continued at a modest rate nonetheless, with the 1985 discovery of sodium and potassium as components of the tenuous atmosphere being the most notable result. These observations, as well as new mission scenarios and new perspectives on planetary formation obtained from recent calculations of planetary accretion and solar nebula evolution, led Vilas and Chapman to convene a conference in 1986 devoted to Mercury. This book reports the proceedings of that conference.

The 23 chapters present overviews of all known aspects of the planet. Some papers include results of numerical modeling not published elsewhere. Particularly thorough summaries are given of the geological history by Spudis and Guest, the impact crater morphology by Pike, the properties of the magnetosphere by Russell, Baker, and Slavin, and the characteristics of the atmosphere by Hunten, Morgan, and Shemansky. Other chapters treat surface properties, rotational dynamics, tectonics, interior structure and evolution, bulk composition, and prospects for future observations.

Perhaps the most fundamental outstanding question regarding Mercury is the origin of its anomalously high bulk density. At one time, on the basis of work by Lewis, the high density was attributed to the slightly higher condensation temperature of iron



"Distribution of Calorian (light grey) and Calorian and/or Tolstojan (dark grey) smooth plains. Smooth plains cover about 10.4×10^6 km^2 or 40% of the part of Mercury photographed by Mariner 10." [From P. D. Spudis and J. E. Guest, "Stratigraphy and geologic history," in *Mercury*]

compared with magnesian silicates in the cooling solar nebula, in such a manner that at Mercury's distance from the protosun the ratio of metal to silicate was much higher than in the formation zones of the other terrestrial planets. Subsequent calculations of dynamically plausible accretion scenarios, however, have shown that the terrestrial planets probably formed from material originally condensed at a wide range in solar distance. Thus, the high metal fraction of Mercury cannot be primarily a result of condensation temperature.

There are currently three classes of alternative explanations, discussed in chapters by Lewis, Goettel, Wasson, Wetherill, and Cameron and others. One class of models invokes differences in the physical properties of iron and silicates to achieve fractionation during accretion. A second class, championed by Cameron and Fegley, attributes the high metal content of Mercury to preferential vaporization of silicates during the evolution of the solar nebula. In a third class of models, for which Wetherill is the most eloquent spokesman, selective removal of silicate occurred as a result of a giant impact on a previously differentiated protoplanet. These hypotheses could be distinguished by future measurements of the composition of Mercury's surface.

Clever gravity-assisted trajectories have recently been found which will permit, with current launch systems, the insertion of a spacecraft into a circular orbit around Mercury. A Mercury orbiter mission would provide the opportunity for a precise determination of the solar quadrupole moment and an important test of general relativity as well as for a host of measurements of the planet itself. This book provides ample arguments that such a mission is of the highest scientific priority.

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Monitoring Volcanism

Volcanic Hazards. Assessment and Monitoring. JOHN H. LATTER, Ed. Springer-Verlag, New York, 1989. xiv, 625 pp., illus. $98. Proceedings in Volcanology, vol. 1. From a congress, New Zealand, Feb. 1986.

This excellent book is an outgrowth of a trend that began in the mid-1970s, when events in several parts of the world sharpened the focus on volcanological hazards. In the early 1980s, eruptions of Mt. St. Helens and El Chichón whetted North American interest, and geophysical unrest at three heavily populated calderas drew further attention to the effects on humans of volcanic activity. Then in 1985, after a year of premonitory activity, Colombia's Nevado del Ruiz killed 22,000 people. A small group of volcanologists had prepared excellent hazard maps and warned authorities in October, but that gave little solace in November when news of the disaster rolled in. The effect of the experience on the volcanological community was palpable in the symposium on volcanic hazards, held three months later in New Zealand, that resulted in this book.

The volume contains a stimulating mix of regional reviews, case histories, and technique papers from most of the world's volcanic regions. The book is divided into two parts, with 15 papers under the heading Hazard Assessment, followed by 21 under the heading Monitoring and a 27-page subject index. All the papers read smoothly, regardless of the authors' native language.

A wide range of fine papers reflects the wide range of volcanic behavior. Contrast, for example, Réunion Island, where eruptions come, on the average, only 14 months apart, with Mexico's Popocatepetl, where activity is weak but risk, because of a large local population, is not. Excellent papers review both Papua New Guinea and the West Indies, with one on the latter forthrightly discussing the problems of hazard reports that do not tell tourist-oriented governments what they want to hear. The likelihood of fluid basalt eruptions from low fissures in Iceland belies the conventional wisdom that large, explosive strato-volcanoes are the main threat. Seismicity has been a reliable precursor of eruptions in Japan, Alaska, and elsewhere, but roughly three out of four West Indian seismic swarms turn out to be volcanological false alarms.

A wide spectrum of technology for monitoring volcanoes is described. An amazing tiltmeter at Japan's Sakura-jima regularly measures uplift of 0.01 microradians (equivalent to 1 mm uplift at one end of a carpenter's level 100 km long) and automatically sounds an alarm when the rate exceeds a critical value. A low-cost alternative in New Zealand involves careful measurement of lake-level changes on opposite sides of 25-km-wide Lake Taupo. At Rabaul caldera, however, 1.8 m of uplift was recorded between 1973 and 1985 with no resulting eruption. One paper describes computer-generated movies, showing theoretical eruptions at specific volcanoes for use in contingency planning and education, and another describes the use of vegetation mortality as an eruption warning in the Philippines. Geostationary Meteorological Satellites provide invaluable, hour-by-hour data on plume changes in large eruptions but are