from experiments. For example, he deduced Snell's law of refraction through an analogy with the motion of particles striking a racket, rather than from careful experiments on light itself. One shortcoming of such an approach is that any error in the fundamental postulates infects the entire theoretical framework. Descartes realized this when he wrote of his doctrine of light's instantaneous transmission, "light moves in an instant, . . . it reaches our eyes from the luminous object in an instant; and I even added that for me this was so certain, that if it could be proved false, I should be ready to confess that I know absolutely nothing in philosophy."

Fermat was less extreme, though he too stressed deduction. Motivated by a metaphysical idea of the economy of nature, he formulated his principle of least time, with which he deduced Snell's law. Later, Huygens proposed his principle, that the propagation of a wave can be considered the result of an infinite number of wavelets produced along the wavefront, and then used it to derive Fermat's principle. Optics was advancing through the reinterpretation and rederivation of laws, rather than from the discovery of new phenomena.

At the other end of the conceptual spectrum was Newton, who favored experiments, careful observation and induction. Hypotheses were for him far more tentative than they were for Descartes, Fermat and Huygens. He used principles to suggest further experiments, and these, in turn, suggested new principles or revisions of old ones. A. I. Sabra points out that Newton's first observations in his famous prism experiment concerned the *shape* of the spot on the wall, not the spectrum of colors. Through the methods illustrated in his *Opticks*, Newton advanced the field by expanding the scope of the phenomena for study.

Sabra also analyzes the development of ideas through single scientists, for example, Huygens. The son of a seafarer, Huygens had ample opportunity in his youth to observe and ponder elementary wave phenomena. Later, he explicitly formulated the germinal problems he tackled, such as the speed of light. If, as Descartes believed, light was a tendency toward motion—a secondary property of an ether—Huygens saw a paradox: How could light pass simultaneously in opposite directions through a given point? Huygens argued that the passage of light was analogous to the motion of a billiard ball striking one end of a long chain of balls; as a ball strikes the left end of the chain, a different ball reacts and leaves the right end. Moreover, if two balls strike opposite ends simultaneously, they bounce off, just as if the "light beams" had passed through each other.

For this to happen, though, a central ball must have been compressed and then expanded. Because this takes time, light must propagate at a finite velocity, and Descartes was wrong to believe its velocity was infinite. Further, the concept of chain reaction led Huygens to his famous principle, and ultimately to the derivation of Snell's law in most optics texts today.

Sabra comments upon the works of other philosophers and historians of science who have dealt with this period. When he disagrees with them, he presents clear, persuasive arguments why. The bibliography in this reissue is expanded from that of the original (1967) and could serve as a starting point for anyone addressing the philosophical and historical aspects of the origin of modern optics.

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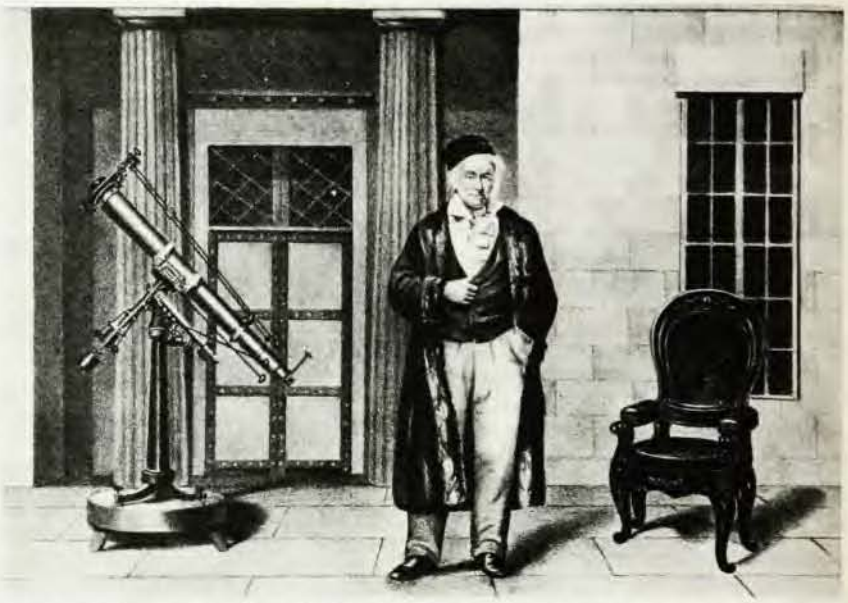

Gauss, astronomer and physicist as well as mathematician, on the terrace of the Göttingen Observatory, from *The Discovery of Nature* by Albert Bettex. (AIP Niels Bohr Library.)

Gauss: A Biographical Study

W. K. Bühler
208 pp. Springer, New York, 1981. $16.80

What is the value of publishing a comprehensive scholarly edition of the writings of a great scientist, such as Albert Einstein? We may get some idea of the answer to this question, which, applied to Einstein, is currently under discussion at the National Science Foundation and elsewhere, by examining a recent biography of Carl Friedrich Gauss (1777–1855). Gauss's place in the history of mathematics is comparable to that of Einstein in the history of physics—he is usually ranked with Archimedes and Isaac Newton as one of the three greatest mathematicians of all time. His collected works, including unpublished manuscripts and selected correspondence, were published in twelve volumes between 1863 and 1929; several additional volumes of correspondence with various scientists are also available. With many scholars having collected, transcribed and synthesized everything that Gauss wrote on mathematics and science, someone who wishes to interpret Gauss's achievements for readers with some technical knowledge will have extensive resources. The publication of Gauss's writings makes possible not merely a single "definitive" biography but rather a variety of studies, such as those Aristotle, Shakespeare, Bach and other giants continue to inspire.

W. K. Bühler states that his book "is addressed to the contemporary mathematician and scientist, not to the historian of science or the psychologist collecting the scalps of great men." He admits that he has included little not already known to the specialist. We must evaluate it on this basis: as an interpretation of Gauss's life and work for those who already have some idea of its significance, but neither as a popularization nor as a contribution to scholarship.

Buhler does succeed in giving a fascinating account of Gauss's personal and professional life. He makes effective use of quotations from letters to illuminate Gauss's personality and his

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view of contemporary events. His attempts to place Gauss in historical context are helpful though rather self-conscious—he frequently points out how it would be unfair to judge Gauss's behavior by the norms of later periods.

His book will probably interest mathematicians more than physicists. It gives a detailed account of Gauss's contributions to number theory, which Gauss in effect established as a separate field of mathematics. His treatment of Gauss's contributions to physical science, however, is sketchy and fails to place them adequately in their 19th-century environment.

Nonetheless, Gauss's work should be of interest to nonmathematicians. He developed the theoretical basis for several important areas of science: analysis of data and determination of astronomical orbits (method of least squares), distribution of errors or random variations (exponential "law of errors"—the bell-shaped curve), geodesy (differential geometry, theory of surfaces), geomagnetism (measurement in absolute units), and potential theory. He was one of the first to work out the principles of non-Euclidean geometry, even though he refrained from publishing his results. With Wilhelm Weber he developed the electromagnetic telegraph. Bühler, however, treats these contributions to physical science as isolated incidents in Gauss's life; he fails to integrate them into a comprehensive account of 19th-century physics.

Thanks to those who devoted years of meticulous work to collecting and editing the writings of Gauss and other giants, the raw material is now available to probe the development of science and to describe this growth to both popular and scientific audiences. Bühler's book is a good example of the latter, even if it will not be of great value to most physicists.

STEPHEN G. BRUSH
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book notes

Exploratorium Cookbook II: A Construction Manual for Exploratorium Exhibits
R. Hipschman
Exploratorium, San Francisco, 1980. $40.00

With this volume, the Exploratorium, the museum of science in San Francisco, has added 52 "recipes" for its exhibits to the 84 published in a first volume. Each recipe contains a description of how the exhibit works and details of how it can be constructed. The exhibits are designed for high-school and college students and adults. The cookbook is also expected to stimulate teachers to come up with other ideas for exhibits and demonstrations. Most exhibits described here illustrate phenomena of light and visual perception, heat and temperature, electricity and magnetism, mechanics, and physics of sound. —DG

Physiological Optics
Y. Le Grand, S. G. El Hage
338 pp. Springer-Verlag, Heidelberg, 1980. $46.00

This is a translation of Volume I of Yves LeGrand's three-volume work *Optique Physiologique*, published in 1945. While the two later volumes were translated some time ago—Volume II as *Light, Colour and Vision* in 1957 and Volume III as *Form and Space Vision* in 1966—this is the first English version of *La dioptrique de l'oeil et sa correction*. The translation is based upon the revised, 1958, edition of the French, but it has been updated by LeGrand and Sami El Hage.

Intended for those concerned with the correction of refractive errors of the eye and related problems, this volume adopts the point of view of the physicist and optometrist. A brief introduction and review of geometrical optics (occasionally with novel and elegant derivations) provide a general background for the rest of the volume. Le Grand next considers the single eye at rest: the nature of the image, accommodation, defects of accommodation, and corneal astigmatism. In practice, of course, the eye moves in the head and, therefore, in relation to corrective lenses worn outside the eye. Corrective lenses also affect the combined functioning of the two eyes. The book examines both of these topics at considerable length. A final group of chapters discusses methods of examination and the tools of the opthalmologist's trade.

The book treats a great amount of detail—including such topics as continuous-gradient bifocals, bichrome tests for visual acuity, the photometry of Purkinje's images, and the theory and method of retinoscopy. The style is somewhat terse and mathematical. The book may serve well as a reference and handbook, but there are very few references to any material published since the early 1970s. A small set of problems (with solutions) may be useful if the book is used as a text. —TVF