written when Newton was in his late 20's they convey his excellent command of the subject and provide insight into his masterly treatment of problems in optics. An appreciation of Newton's mastery must take account of the details of his work as much as the broader themes in these lectures, but I will concentrate here on the latter.

Near the beginning of these lectures Newton reported having discovered that the rays of the sun's light "differ from one another with respect to the quantity of refraction." This discovery not only controverted other theories of light and accounted for the imperfection of refracting telescopes, it provided Newton with his point of departure for two different, though related, investigations. One of these lines of investigation concerned color; Newton discovered a correspondence between color and refrangibility, demonstrated the immutability of color, and showed that color is innate to unrefracted rays of sunlight and is thus not a product of refraction. In this part of the text, which is largely concerned with experiment, Newton investigated a host of related phenomena, including the decomposition and recomposition of white light and the colors of natural bodies. In the *Optica* this dissertation on color was extended to include the musical division of the spectrum, boundary colors, and those obtained from curved refracting surfaces.

Newton's other line of investigation concerned the mathematization of the phenomena of refraction. Starting with experiments to measure refractions at a prism set at the position of minimum deviation, Newton soon proceeded to calculate refractive indices and to construct a law of dispersion. With the aid of these relationships he then made an extensive mathematical analysis of refraction at plane surfaces and in the *Optica* extended this discussion to include curved surfaces. Of the many important results Newton obtained, his calculation of spherical aberration and chromatic aberration at a curved surface—which relates to the problem of the telescope's imperfection—are among the most impressive.

The increased availability of these texts will make them the subject of much close historical analysis. Even a cursory study of them, however, reveals a deep problem concerning Newton's proclaimed intentions. In the third of the *Lectiones opticae* Newton challenged the view in which colors "are thought not to pertain to mathematics" and then proceeded to argue that just as astronomy, geometrical optics, and mechanics belong to mixed mathematics, so the science of colors "must be considered mathematical, in so far as they [colors] are treated by mathematical reasoning." This program of bringing natural phenomena within the domain of mathematics provides a framework within which to read large parts of Newton's science, including, of course, the *Principia*. The historical importance of this highly successful program has been rightly emphasized, and some historians have even called it the "Newtonian style."

Though it is undeniable that Newton developed optics considerably by bringing the study of color within mixed mathematics, there is an intrinsic problem whether color can be mathematized in the same way as, say, positional astronomy. Whereas the positions of planets can be measured colors cannot. Certainly numbers can be attached to colors, but there are many possible (and usually inconsistent) color scales ranging from the codes used by paint manufacturers to the associated measure of frequency as generally employed by physicists. There was thus a philosophical problem underlying Newton's project, but Newton also encountered another type of problem.

In many of these lectures Newton utilized refrangibility as the mathematically expressible parameter connected with different color-making rays. The major difference between the structure of the *Lectiones opticae* and that of the *Optica* pertains to this relationship. In both of these texts Newton began by discussing his discovery that rays of light differ in their degree of refrangibility. In the first text he then proceeded to his dissertation on color, only subsequently turning to the mathematical analysis of refraction. In the latter text the order was reversed. This change is significant since it indicates that by 1672 Newton had recognized that in his program to mathematize colors the mathematization of refraction had logical priority.

Although Newton was successful in forging a mathematical theory of refraction this should not be interpreted as the sole axis of his program to mathematize color. Though most of his dissertation on color was directed to establishing nonquantitative propositions concerning the nature of colored light—and thus is not directly subsumable under the label "Newtonian style"—Newton attempted in the *Optica* (part II, lecture 11) to assign numbers *directly* to the divisions between the seven colors of a solar spectrum obtained by refraction through a glass prism: "Everything appeared just as if the parts of the image occupied by the colors were proportional to a string divided so it would cause the individual degrees of the octave to sound." Newton's preference for dividing the spectrum according to musical intervals is revealing with respect to his metaphysical presuppositions, but it—like the similar strategy he elsewhere adopted when discussing the color circle and the colors produced by thin and thick plates—can be interpreted as part of his "mathematical way of reasoning" (to quote a relevant section in the *Opticks*).

Thus in the *Optica* Newton offered two ways of mathematizing color—by means of refrangibility and by dividing the length of the spectrum. His next move was to combine the two into a dispersive law so as to assign numbers to the sines of the angles of refraction for each color interval. Having discussed refraction through a glass prism he then utilized the same procedure to calculate refractions from air into water, but in this latter case he noted that "those determinations are not precisely geometric." There is thus a strong sense in which Newton failed to achieve his aim of creating an exact science of colors in these optical lectures, and, as Shapiro has shown (*Archive for History of Exact Sciences* **21**, 91–128 [1979]), the problem of discovering the law of dispersion subsequently exercised Newton considerably but was never satisfactorily resolved.

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Earlier Explorations

Certain Philosophical Questions. Newton's Trinity Notebook. J. E. McGuire and Martin Tamny. Cambridge University Press, New York, 1983. xii, 519 pp., illus. $84.50.

With the publication of editions of the correspondence, the mathematical papers, the optical papers, the papers on dynamics, variant readings of the *Principia*, and other texts, the growing body of published manuscripts of Newton's is beginning to resemble a "Collected Papers." McGuire and Tamny's volume constitutes a measurable stride in that direction by bringing out two manuscripts that everyone familiar with Newtonian scholarship agrees are of immense importance.

Quaestiones quaedam Philosophicae, Certain Philosophical Questions, is the title Newton put at the head of an extended section of the notebook he kept for philosophical studies during his undergraduate days at Trinity College, Cambridge. Some 30 years ago, A. R. Hall first called attention to the *Quaestiones* as the opening chapter of Newton's career in science. His estimate of its importance has not been challenged; nearly every Newton scholar finds it necessary to explore the document. Now at last, with this fine edition, McGuire and Tamny place it before the public. To the *Quaestiones* they add another document of similar importance for Newton's work in optics, the short essay "Of Colours," composed (they argue, in agreement with most but not all students of his optics) in 1665–66. Anyone seriously interested in Newton will rejoice at the appearance of this volume.

In fact, the texts themselves form the lesser part of the book, the first two-thirds of which contains extensive essays introducing them. A footnote (p. 58) indicates that the authors have prepared a book-length study of "Philosophical Themes in the Early Thought of Isaac Newton." Some may think they have already presented such a study and wonder how much is left to be said on the subject. In any event the essays are themselves an important contribution, and they cannot fail to be the focus of great attention. Unless I am mistaken, the authors will need to answer some objections before their conclusions are universally accepted. Two of their points, which figure prominently in the interpretation as a whole, concern the influence of Epicurus's *Letter to Herodotus* and of the works of Hobbes on certain aspects of Newton's early thought. One is therefore surprised when one turns to the edited documents to see how few the passages traced to those two sources are and how hesitant the attributions. I found exactly two passages (pp. 340 and 352) ascribed to Epicurus, in each case represented as only possibly from him. I also found two ascribed to Hobbes. One of them (p. 376) is to me less obviously derived from Hobbes than it is to the authors; the other (p. 450) takes explicit exception to Hobbes's opinion. This leaves a rather slender foundation for the argument the editors build on it.

Probably the most important point in the introductory essays is a new interpretation of the origin of Newton's central insight in optics, the heterogeneity of light. No doubt McGuire and Tamny's argument, that Newton's work in optics flowed from speculations on the physiology of sight based on Hobbes, will require—and receive—the extended consideration of informed scholars before it is finally assessed. I will say that to me there appears to be a major gap, unfilled by any convincing argument I saw, between Newton's speculations on the physiology of sight, which are wholly compatible with the theory that colors arise from the modification of white light held to be homogeneous, and Newton's insight that colors arise from the analysis of white light, which is shown to be heterogeneous.

Much as I welcome the edition I will express one disappointment, and that is with the relative paucity of new sources that the editors identify. Scholars have been at work on the *Quaestiones* for three decades and have identified a number of Newton's sources. This is important information; it establishes the intellectual context from which Newton set out. In this edition the authors who appear in the footnotes as the sources of individual passages are the ones we have known for some years—Charleton, Descartes, More, Glanvill, Boyle, Wallis, Galileo, and a small number of others. Meanwhile the sources for quite a few passages clearly drawn from specific reading (see, for example, pp. 393 and 402) remain unidentified. The most important of these is the long essay on motion. Perhaps the editors are correct in their assertion that Newton was developing his own ideas here as he wove together reading from a number of sources. Some of those ideas appear to involve rather specific information, however, and it seems to me that a young student would have needed more explicit guidance in order to tackle a subject as difficult as motion. I continue to think there is a source for this discussion that no one has yet found. This is not grounds for serious censure of the editors. Nevertheless, a fuller identification of Newton's sources would have painted a more detailed picture of the scientific milieu that stimulated the greatest career in the annals of science. Such details are the essence of editorial work. Success in supplying them marks the difference between a good edition and a great one.

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A 19th-Century Mathematician

A Convergence of Lives. Sofia Kovalevskaia: Scientist, Writer, Revolutionary. ANN HIBNER KOBLITZ. Birkhäuser, Boston, 1984. xx, 305 pp. + plates. $19.95.

"You see how expensive I am. I went for two 'ordinaries'!" (p. 187). So the mathematician Sofia Kovalevskaia (1850–1891) wryly summarized Gösta Mittag-Leffler's tactic to assure her an extraordinary professorship (roughly equivalent to a modern assistant professorship) at Stockholm University. Kovalevskaia's professorship was not the result of universal recognition of her mathematical talent in spite of her gender, but rather of a deal according to which Mittag-Leffler, a fellow mathematician and shrewd politician, conceded promotions to ordinary (full) professorships to two protégés of Kovalevskaia's foes in exchange for her professorship.

The preceding is one of the many carefully sketched incidents in Ann Hibner Koblitz's biography that demystify the woman known in her lifetime as "a princess of science." Characterizing Kovalevskaia as "an extremely gifted but in some ways perfectly ordinary woman" (p. 7), Koblitz presents a realistic, popular biography of her subject, who was the first woman in modern times to obtain a doctorate in mathematics, hold a chair in the subject, and serve on the editorial board of a major scientific journal. Koblitz succeeds in reducing Kovalevskaia to human (rather than superwoman) stature primarily by viewing her from a broad sociocultural perspective. This perspective, that of Russian nihilist women of the 1860's, dominates the biography and accounts for its special allurement.

Koblitz argues that the three major roles assumed by Kovalevskaia—scientist (mathematician), literary writer, and revolutionary—were consistent in the matrix of Russian nihilism of the 1860's. Opposed to the tsarist regime, the young Russian intelligentsia coming of age in that decade pinned its hopes for reform on the natural sciences and education, believed in the equality of women, and sought to serve the common people. A product of this nihilist circle, Sofia Kovalevskaia determined in her late teens on a career of public service as a physician. Blocked by her gender from attending any Russian university and by law from emigrating without her father's consent, Kovalevskaia contracted in 1868 a "fictitious marriage." This ruse involved her legal (but supposedly Platonic) marriage to Vladimir Kovalevskii, who, according to nihilist theory, was obliged to escort her to the educational