not the maker of this particular device, but he could have started the tradition. As is patent from the complexity of the Antikythera, this is probably not the first such mechanism ever made.

The luni-solar calendar has two subsidiary dials inside: one revolved once every 76 years (i.e., four Metonic cycles) and indicated when one day had to be skipped in the Metonic calendar (once every four cycles) in order to correct it. The second—one of the most amazing—revolved one revolution every 4 years and was divided into four cells: in them we can read the names of the Pan-Hellenic games, so that the arrow indicates what games would be played that year: the Olympics, the Nemean games, etc.

So in one device you can learn the position of the sun and moon (and probably also the planets) in the zodiac, and the day of the year; you have an eclipse predictor that tells you the time and kind of eclipse, and you also know whether you have to add 8 or 16 hours to the time indicated; you have a luni-solar calendar that tells you which years have 12 and which have 13 months, which months have 29 and which have 30 days, which day would be omitted in case you have a 29-day month, when you have to omit one day every 76 years for correcting the calendar; and, finally, you know which Pan-Hellenic games would take place that year. It was like a tablet PC of ancient times!

The research is still in progress, and every year new discoveries arise. The Antikythera Mechanism probably still has some mysteries to reveal, and the best way to be prepared to understand it is to read Jo Marchant's book.

Marchant invested several years in research, and the dedication and seriousness with which she directed that research is reflected in the book. She does not avoid technical issues when they are necessary and usually presents them clearly. It is a self-contained book: you have in it all the astronomical and historical knowledge that you need to understand the story of the Antikythera. Marchant documents her sources well and also provides a Further Reading section. Inevitably, the book contains some imprecisions. Nevertheless, it is, all in all, an excellent book that tells a fascinating story in a fascinating way. *Decoding the Heavens* is, I think, required initial reading for anyone seeking an introduction to the story of the research into the mysteries of the Antikythera Mechanism.

Book Review

Seduced by Logic

Reviewed by Judith V. Grabiner

Seduced by Logic: Émilie du Châtelet, Mary Somerville and the Newtonian Revolution
Robyn Arianrhod
Oxford University Press, 2012
US$34.95, hardcover, 338 pages
ISBN-13: 978-0-19-993161-3

In a world where over 30 percent of American Ph.D.'s in mathematics are earned by women, we forget how rare female mathematicians have been in the past. Counting the women with well-documented contributions to mathematics before the nineteenth century can be done on the fingers of one hand. Each of these women "made it" only because of highly unusual circumstances. For instance, in the case of Hypatia of Alexandria (c. 370–415 CE), her father was the mathematician Theon of Alexandria. Maria Gaetana Agnesi (1718–1799), who had an on-the-make father who showed her off as a prodigy, also benefited from liberal religious trends in eighteenth-century Italy. Sophie Germain (1776–1831) grew up in a Paris home that was a meeting place for intellectuals, and as mathematics in Revolutionary France became more widely accessible through lectures and notes from the École Polytechnique, adopted a male pseudonym to correspond with Lagrange and Gauss. The first actual European Ph.D., Sofya Kovalevskaya (1850–1891), came from an influential Russian family but had to contract a fictitious marriage in order to leave her home country to study mathematics in Germany. As Londa Schiebinger has documented in her magisterial *The Mind Has No Sex* (Harvard, 1989), various theories about the nonintellectual nature of women reinforced

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DOI: http://dx.doi.org/10.1090/noti1013

the legal and familial barriers. In modern society, where some people still say, "Math isn't for girls," the history of those who succeeded against such social forces remains instructive as well as fascinating.[1]

The book under review aims to tell the story of two women from the eighteenth and nineteenth centuries, genuine contributors to the mathematical sciences. Gabrielle Émilie Le Tonnelier de Breteuil, Marquise du Châtelet (1706–1749), was the author of a state-of-the-art commentary on Newton's physics and made what is still the definitive French translation of Newton's *Principia*. Mary Fairfax Somerville (1780–1872) wrote the book *Mechanism of the Heavens*, which brought Laplace's ideas to English readers. She also wrote *Connexions of the Physical Sciences*, praised by James Clerk Maxwell for its clear communication of fundamental ideas of physics. It is Mary Somerville after whom Somerville College, Oxford (alma mater of Nobelist Dorothy Hodgkin, politicians Margaret Thatcher and Indira Gandhi, and author Dorothy Sayers), is named. Du Châtelet and Somerville are linked, according to the author, Dr. Robyn Arianrhod, by their common fascination with Newtonian science. As the main title, *Seduced by Logic*, may suggest, the approach here is that of popular biography. Both women, if not seduced, were in a metaphorical Newtonian sense "attracted" to a subject traditionally pursued by men. As popular biographies of women in the history of science go, *Seduced by Logic* is unusual in trying to put the science front and center. Readers of the *Notices* will not need many of the explanations (for instance, we're told that an inverse-square force, if the distance is tripled, is reduced to one-ninth the original value), but Arianrhod also frequently compares the science with modern points of view and explains scientific and mathematical ideas as understood not by us but in the style of the eighteenth and nineteenth centuries. As Arianrhod observes, Newtonian science has developed since the publication of Newton's *Principia* in 1687, and the work of Du Châtelet and Somerville can help explain that development. The goals of the volume under review, then, are admirable and ambitious. Although the book is flawed in a number of ways, it is interesting, and its subjects are worthy of serious study.

About two-thirds of the text is devoted to Madame du Châtelet and her work in science. First her early life is sketched. We learn that her father was the chief of protocol at Versailles under Louis XIV, and when she married the Marquis du Châtelet she continued to move in aristocratic circles. She found intellectual interests, especially in mathematics and science, and when she was twenty-six she and Voltaire fell in love. At this point Arianrhod switches gears to describe the major astronomical and physical discoveries, especially gravity, in Newton's *Principia*. Then we learn how Pierre-Louis de Maupertuis, a leading Newtonian scientist in France, instructed Madame du Châtelet in state-of-the-art mathematics. Meanwhile, Voltaire's politics led him to seek sanctuary with Madame du Châtelet at Cirey, on the estate of the Marquis du Châtelet—what a tolerant man the marquis must have been—and many leading intellectuals came to Cirey to enjoy the literary and scholarly atmosphere created by this unusual couple. We are also told what Voltaire and Madame du Châtelet thought about the science of Kepler and Newton and how they wrote an influential popularization of Newton's ideas, *Elements of Newton's Philosophy*. Arianrhod also relates how Maupertuis and Alexis-Claude Clairaut travelled to the Arctic to test Newton's prediction that the supposedly spherical earth was, because of its rotation, flattened at the poles. Madame du Châtelet wrote an essay (Voltaire wrote one too) for a contest of the Académie des Sciences on "the nature and propagation of fire", dealing with the nature of light and heat (neither won; Euler did), and we learn about Newton's theory of light along the way.

We then see Madame du Châtelet move in a different direction from the Newtonianism of Voltaire as she began to read Leibniz. She was now learning not only advanced mathematics but also philosophy from the Leibnizian Samuel König, as well as from Clairaut, author of a then-definitive book on the shape of the earth. At that time, a major issue, often called the "*vis viva* controversy", centered on whether momentum (mv), or "living force" (mv^2) as championed by Leibniz and his followers, was the key conserved quantity in physical interactions. In the light of modern physics, the experiments, philosophical background, and arguments in this dispute may seem much ado about nothing, but they were important in helping refine notions of energy and in encouraging the mathematization of classical mechanics. In describing the controversy, Arianrhod explains the influential Leibnizian ideas adopted by Du Châtelet, notably the principles of continuity and sufficient reason, and the belief that the universe obeys optimal principles. As an early adopter of the synthesis of Newtonian and Leibnizian ideas, Du Châtelet wrote an introductory book,

[1] *There are excellent books on these women. See, for instance, Maria Dzielska,* Hypatia of Alexandria *(Harvard, 1995); Michael Deakin,* Hypatia of Alexandria: Mathematician and Martyr *(Prometheus Books, 2007); Louis Bucciarelli and Nancy Dworsky,* Sophie Germain: An Essay in the History of the Theory of Elasticity *(Reidel, 1980); Ann Hibner Koblitz,* A Convergence of Lives: Sofia Kovaleskaia, Scientist, Writer, Revolutionary *(Birkhäuser, 1983). A very rapid overview may be found in the Mathematical Association of America's 2008 poster, "Women of Mathematics":* `http://www.maa.org/pubs/posterW.pdf`*, and there is a useful set of biographies maintained by Agnes Scott College online:* `http://www.agnesscott.edu/lriddle/women/women.htm`.

Fundamentals of Physics, conventionally dedicated to her son but obviously of value for anyone wanting to learn the basics of what was going on in physics and astronomy. Later on, beginning in 1744, she undertook a much more important task: translating Newton's *Principia* into French. The translation included explanations and the use of Leibnizian calculus. This work, still used by scholars today and arguably her most important intellectual legacy, was published only after her death.

Meanwhile, her relationship with Voltaire and a return to Cirey after time in Belgium keep the personal part of the story interesting to readers. Voltaire saddened her by falling in love with Marie-Louise Denis, and Du Châtelet herself had an affair with the Marquis de Saint-Lambert, became pregnant, and died just days after the birth of her daughter. Arianrhod describes some events of the French Revolution, including the moving of Voltaire's remains to the Panthéon in Paris, the guillotining of Madame du Châtelet's son, and the scattering of the remains from Madame du Châtelet's grave. But from the standpoint of the history of science, as Arianrhod observes, what matters is that Madame du Châtelet lent a hand to the triumph of the physics of Newton in the mathematical language of Leibniz, Euler, D'Alembert, Lagrange, and especially Laplace throughout the eighteenth century. That observation serves as the book's transition from the life of Madame du Châtelet to that of Mary Fairfax Somerville, who would, Arianrhod says, explain Laplace as Du Châtelet had explained Newton.

Mary Fairfax grew up in semirural Scotland, but her father became an admiral. Britain was not immune to the revolutionary ideas of the eighteenth century. Arianrhod discusses the views of Rousseau, Mary Wollstonecraft, various anti-slavery writers, and the Marquis de Condorcet as part of Fairfax's intellectual background. But then Mary Fairfax became interested in mathematics by being shown a magazine with mathematical problems in it, so she asked her brother's tutor for some mathematics books. In 1804 she married a distant cousin, Samuel Grieg, who died after three years. During that time she was often alone and used the time to study higher mathematics. Upon returning to society after Grieg's death, she met various literary intellectuals in Edinburgh, including John Playfair, professor of mathematics and natural philosophy at Edinburgh, and his eventual successor, William Wallace, both of whom guided her studies in mathematics and physics. She soon met and married another cousin, William Somerville, a physician and diplomat. Meanwhile, starting with a tutor, she had begun the serious study of Laplace's *Mécanique celeste*. With her husband's support, she continued to study and met many famous scientists both in Britain and in France, including Thomas Young, Michael Faraday, Charles Babbage, François Arago, Jean-Baptiste Biot, Simon-Denis Poisson, and Laplace himself. At this point Arianrhod digresses to give a short account of the career of Sophie Germain, who never met Mary Somerville but whose life gives some sense of the situation of women in science in the early nineteenth century.

Aware of Mary Somerville's scientific understanding, Lord Brougham suggested that she write a popular account of the work of Laplace in English, and though Brougham later rejected the result as too advanced for the purpose, the Scottish publisher John Murray, after a favorable report from the astronomer John Herschel, published Somerville's book, *The Mechanism of the Heavens*, in 1831. *The Mechanism of the Heavens*, which covers the principle of least action, the planetary orbits, and the stability of the solar system, was quite successful and came to be used by students at Cambridge preparing for examinations. Somerville wrote an even more successful book, *On the Connexion of the Physical Sciences*, that treated not only mechanics but electricity, magnetism, chemistry, light, and heat. Arianrhod uses her discussion of the book to explain electromagnetism and the wave theory of light, briefly describing the work of Oersted (Ørsted), Faraday, Young, and Maxwell. Later, the Somervilles moved to Italy with their daughters, and Mary Somerville wrote two more books: *Physical Geography* and *On Molecular and Microscopic Sciences*. She actively supported the movement for the right to vote for women and advocated for women's access to higher education. As Arianrhod says, Mary Somerville was able to combine "a happy family life with intellectual challenge," and "gained the respect of the international scientific establishment" (p. 250). Finally, after concluding the twin stories of Du Châtelet and Somerville, the author adds a personal epilogue, arguing for the importance of "female heroines" for women in the sciences.

The text is immediately followed by twenty-five pages of appendices, all accessible to a bright high school student, covering Kepler's second and third laws; the flattening of the earth, the period of pendulums, and triangulation; the laws of reflection and refraction; the calculus, using the concept of infinitesimal and Leibniz's notation; using calculus to derive the conservation of momentum and "*vis viva*" from Newton's Second Law; Newton's demonstration that, if the force of gravity on the earth's surface is inverse-square, the theory predicts the moon's acceleration (deviation from a straight path) to be the amount that is actually observed; a sketch of the proof that the net force of gravity (or any inverse-square force) within a spherical shell is zero; modern definitions of measures of distance and time; using calculus to minimize physical quantities; how the principle of least action produces Newton's laws of motion; discussions of various concepts of energy and Joule's discussion of its conservation; resonance; theories of light; and statistics about women in the sciences.

So there's a lot in this book. How is one to evaluate it, and who is the intended audience? Certainly anyone interested in Newtonian science and its progress in the eighteenth and nineteenth centuries and the role of women in science in the same period will want to give it a try. A woman science student looking for predecessors would be an ideal audience, and somebody with such interests who wants a good popular account of the elementary topics of mechanics could learn a lot from the appendices and in-text explanations: my favorite of these is the quantitative account of how, as Newton says he once mused while watching an apple fall, the force of gravity would act if it were extended as far as the moon.

However, the historical background is unevenly sketched, with nuances missed and sources sometimes haphazardly chosen. For example, although of course this book is not intended as the definitive account of the history of the time periods covered, the French Revolution was far more than the Terror, and the relationship between mechanics, chemistry, light, electricity, and magnetism has a much richer history than this book allows. Newton did say, concerning the cause of gravity, that he "did not feign hypotheses," but he certainly made hypotheses, though his British contemporaries often dogmatically denied it. It is hard to accept Arianrhod's explanation of Newton's antipathy for Hooke (who misunderstood what Newton experimentally showed about the composition of white light and who wanted credit for the inverse-square law whose properties he could not mathematically demonstrate) as "Newton never seemed to outgrow the insecurity of his abandoned childhood" (p. 140).

Arianrhod frequently looks at eighteenth-century ideas, such as those of energy or space, and says, in effect, "Yes, this is like, or unlike, what Einstein proposed" or "They didn't get modern results, but that's because they had other goals or lacked the right equipment." I find this ahistorical and not always adding insight. For example, after stating that "only in nuclear reactions [can] energy be converted into a detectable gain in 'rest' mass," Arianrhod says, "No wonder Voltaire could not come to a conclusive result in his experiments!" (p. 205). In a similar example, Arianrhod writes, "Émilie did not articulate such a modern position [as Einsteinian relativity]—partly because she wanted a philosophy that took account of the history of humanity as well as that of impassive celestial spheres" (p. 112).

The scholarly apparatus is both deficient and annoying, surprising for a book from the Oxford University Press. It's all right to have endnotes instead of footnotes, but instead of normal endnotes, where a number or asterisk in the text signals a reference, in this book you need to flip to the back (and you'd better know the number of the chapter you are in, since no page numbers are cited in the endnotes) and then find, instead of the page referred to, a topic heading that may or may not be what you're looking for. In one frustrating example, on p. 79 Arianrhod writes that *Elements of Newton's Philosophy* was influential in popularizing the theory of gravity on the Continent. She supports this conclusion with this statement: "'All Paris studies and learns Newton', wrote an enthusiastic reviewer." If you want the eighteenth-century source of that eighteenth-century quotation about "all Paris", what you'll find, buried in an endnote on p. 296 headed "On Voltaire's Academy memberships", is the phrase "'All Paris studies Newton': quoted in Johnson and Chandrasekhar, Part II, p. 537"—a reference to a journal article published in 1990. Furthermore, some controversial statements made in the text have no supporting endnote at all.

So what do we have? An attractive idea; very interesting material; appendices that can teach a student some important ideas in physics, calculus, and astronomy; and a most readable account of the lives of two quite different pioneering women in science, all in under three hundred pages of text. But Judith Zinsser's recent biography of Du Châtelet, Kathryn Neely's of Somerville, Londa Schiebinger's book on women in science, Mary Terrall's biography of Maupertuis in the context of the science of his day, and I. Bernard Cohen's *The Newtonian Revolution* would provide a better resource for those interested in the topics covered here. I enjoyed reading *Seduced by Logic*; I just wish its organization were tighter and its scholarship more robust and more helpfully documented.