BOOK REVIEWS

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PENDULUM-Léon Foucault and the Triumph of Science Amir D. Aczel. 275 pp. Atria Books, New York, 2003. Price: $25.00. ISBN 0-7434-6478-8. (Robert H. Romer, Reviewer.)

We all know the story of Foucault and his pendulum, how he first tried the experiment in the privacy of his basement, then gave public demonstrations, and eventually hung a 67-m pendulum in the Pantheon and convinced any remaining skeptics that—in the words attributed to Galileo—"*e pur si muove*." And everyone knows of his ingenious demonstration that light travels more slowly in water than in air. But how many of us know, for instance, that after attending a lecture by Daguerre himself, he did early work on the photographic process, that he became a protegé of Napoleon III, that he had little formal education but was belatedly elected to the Académie des Sciences in 1865, that he died 3 years later at the regrettably early age of 48, or that his collected works were published by his mother?[1] (Everyone should have such a mother!) In this interesting but often careless and exasperating brief account of his life and work, with assertions about physics that will amuse and/or upset physicists, we learn many interesting details of his life, along with numerous (sometimes rather long) excursions into such matters as Napoleon's mistresses and the ancient history of Reims.

One can only applaud attempts to present serious science to a general audience. Yet on any writer's list of priorities, the highest should always be to get the science right, closely followed by getting the history right and by giving readers the opportunity to examine for themselves the evidence for statements made in the book. (The more surprising the claim, the stronger is the obligation to provide appropriate references.) This book fails in several important ways.

Aczel claims (pp. 28, 135) that "artillery engineers have always [sic] known that (in the northern hemisphere) cannonballs fired north tended to deviate east..." Really? Pardon my skepticism. The statement is intriguing and I naturally wanted to look at the evidence, but no references are given. On p. 29 he repeats a silly bit of folk physics, asserting that "the Coriolis effect... also explains why water generally drains in a counterclockwise rotation in the northern hemisphere and clockwise south of the equator." (105 pages later, having apparently forgotten that remark, he gets it right, observing correctly that almost any imperfection favoring one sense or the other will dominate the Coriolis effect. If he had only looked at his own index, which gives both page references under "water, rotation of drain of," he might have noticed that inconsistency.) On p. 38 he observes that Galileo is *reputed* to have dropped various objects from the tower at Pisa. Only a few lines later, the qualifying word is omitted: "For the objects Galileo dropped to the ground had to have deviated east of the vertical—but he was completely unaware of it." What Aczel seems to be unaware of is that the predicted eastward deflection is $\omega_0 \cos\theta(8h^3/9g)^{1/2}$, with ω_0 the angular velocity of the Earth and θ the latitude, only 6 mm for a 55-m tower at Pisa. The eastward deflection is famously difficult to observe reliably. Just think of the difficulty, even with 21st century technology, of determining the local vertical with sufficient precision and releasing an object with sufficiently little perturbation.[2]

Foucault wrote that his pendulum's plane of oscillation should precess at a rate given by $\omega=\omega_0 \sin\theta$, and Aczel makes much of this "stunning piece of mathematical deduction by the untrained Foucault," while France's most eminent mathematicians and theoretical physicists were floundering in their attempts to derive "Foucault's sine law." But "just how Foucault managed to do it was a great mystery," Aczel concludes (p. 108), implying that we still have no idea how Foucault came up with his result. In fact, Foucault *did* have a derivation (or at least an interesting hand-waving argument) for his sine law, which he described in a letter that is contained in his collected works (Ref. 1, pp. 382–384, my translation).

"I begin by boldly adopting as a postulate the following. When the vertical, always of course lying in the plane of oscillation, changes its direction in space, the successive positions of the plane of oscillation are determined by the condition that the angles between successive positions shall be minimized. To state this in ordinary language—when the vertical direction changes from its initial position, the plane of oscillation follows, while remaining *as parallel as possible* to the initial plane of oscillation."

Bold indeed, but why, after all, should the plane of oscillation have such a strong desire to stray so little from its initial orientation? We would now insist on a derivation based on Newton's laws of motion or a general extremum principle such as the least action principle—and no doubt mathematical physicists such as Liouville were trying, with mixed success, to produce such derivations. Nonetheless, once one grants Foucault's postulate, a bit of work with spherical triangles indeed leads quickly to the desired result: $\omega=\omega_0 \sin\theta$. And his sine law does seem to be the most obvious simple candidate for the dependence of ω on θ one can imagine that satisfies some obvious conditions: if $\omega=\omega_0 f(\theta)$, then $f(\theta)$ should be an odd function of θ, with $f(\pi/2)=1$, and $f'(\pi/2)=0$. With these restrictions, $f(\theta)=\sin\theta$ certainly looks like a pretty good guess. That, too, is of course only an argument and not by any means a derivation. Another unconvincing argument is simply to take the result at the pole and replace ω_0 with the *component* of $\boldsymbol{\omega}_0$ along the local vertical.

Anyone who builds a Foucault pendulum quickly realizes that—since no macroscopic device can be *perfectly* symmetric—one should strive to make both the suspension and the driving mechanism (if one plans to overcome friction and maintain the motion) so carefully that the dominant source of symmetry breaking is the rotation of the Earth. This is trivial if one's "Earth" is a rotating platform such as the one we built in Amherst ($0 \leq \omega_0 \lesssim 2\pi/2.4\ \mathrm{s}^{-1}$) but not so easy if one must rely on the real Earth ($\omega_0 = 2\pi/\mathrm{day}$). No matter how nearly symmetric one's apparatus, eventually a pendulum will develop some ellipticity in its motion, and then—largely oblivious to the rotation of the Earth—it will behave as a "spherical pendulum," its orbit precessing clockwise or counterclockwise at a rate that may well be far greater than the expected Foucault precession. If one intends to keep the pendulum swinging indefinitely, the driving mechanism must incorporate some device to keep any ellipticity in the pendulum's orbit at an acceptable level. (Other things being equal, long Foucault pendulums are not only more impressive but easier to coax into behaving properly. Consult two papers in this journal by Crane[3] for some especially valuable advice on the construction of short pendulums.)

Aczel refers (pp. 110, 161) to "a very important Foucault pendulum experiment" carried out in Brazil that "verified Foucault's sine law in the southern hemisphere." (Aczel's treatment of references is often careless or incomplete. In this case he tells us that the experiment was reported in the *Proceedings of the Academy of Sciences*—translating the title of a journal does no favor to the reader—but the footnote gives no indication of the actual volume or page.) He says that the pendulum "was kept going for two months without interruption." When I eventually tracked down the paper,[4] it was clear from the title of the article alone that "for two months" was inaccurate. But what had really intrigued me was the "without interruption" description. What, I wondered, was the driving mechanism? But there was none; the article clearly describes the frequent interruptions and restartings from various directions. And far from confirming expectations for the southern hemisphere, the article is almost exclusively devoted to describing the asymmetries and preferred directions of swing for that particular pendulum; why the Académie des Sciences should have been interested is beyond me.

I have always enjoyed this topic and loved teaching it. For many of us, Foucault is one of our heroes, though not, of course, up there with Newton, Maxwell, Einstein, and Feynman. Foucault's life and work deserve a more careful treatment.

Note added in proof. After completion of this review, I became aware of another very recent biography of Foucault: William Tobin, *The Life and Science of Léon Foucault* (Cambridge University Press, Cambridge, 2003). Although I have not yet had time to read Tobin's book with care, it appears to be superior to Aczel's, at least in it's treatment of Foucault's science, and anyone with a serious interest in Foucault and his pendulums should consult it.

[1] *Recueil des Travaux Scientifiques de Léon Foucault, Publié par Madame Veuve Foucault Sa Mère*, edited by C.-M. Gariel (Gauthier-Villars, Paris, 1878).

[2] For some recent discussion of the physics and history of the eastward deflection, see Robert H. Romer, "Foucault, Reich, and the mines of Freiberg," Am. J. Phys. **51** (8), 683 (1983); Judit Brody, "Letter to the editor," *ibid.* **52** (2), 105–106 (1984); A. P. French, "The deflection of falling objects," *ibid.* **52** (3), 199 (1984); Edward A. Desloge, "Horizontal deflection of a falling object," *ibid.* **53** (6), 581–582 (1985). Desloges discusses some of the subtleties of the problem, e.g., the need to specify carefully what is meant by the local vertical. (Even for a hypothetical spherical Earth, it is clearly not simply a radial line from the center of the Earth.)

[3] H. Richard Crane, "Short Foucault pendulum: A way to eliminate the precession due to ellipticity," Am. J. Phys. **49** (11), 1004–1006 (1981); "Foucault pendulum 'wall clock,' " *ibid.* **63** (1), 33–39 (1995). See also Haym Kruglak, "A very short, portable Foucault pendulum," Phys. Teach. **21** (7), 477–479 (1983); Haym Kruglak and Stanley Steele, "A 25 cm continuously operating Foucault pendulum," Phys. Educ. **19**, 294–296 (1984).

[4] M. d'Oliveira, "Note des résultats obtenus dans les expériences faites à Rio de Janeiro, sur le mouvement du pendule pendant le mois de septembre et les premiers jours d'octobre de 1851, à la latitude australe de 22° 54′," Compte Rendu des Séances de l'Académie des Sciences **33** (21), 582–584 (1851). (This journal is sometimes cataloged as Comptes rendus hebdomadaires des séances de l'Académie des sciences.)

Robert H. Romer was editor of this journal from 1988 to 2001. During that entire period, while he was too busy to maintain his toys, a 75-cm Foucault pendulum—its design based in part on suggestions by H. R. Crane[3]—swung without interruption (except for the occasional power failure) in his Amherst College office ($\theta \simeq \sin^{-1}(2/3)$), *precessing steadily at approximately 10°/h.*

BOOKS RECEIVED

Advances in Condensed Matter and Materials Research, Vol. 4. Edited by Francois Gerard. 228 pp. Nova Science Publishers, Hauppauge, NY, 2003. Price: $98.00. ISBN 1-59033-476-0.

Advances in Neural Information Processing Systems 15. Edited by Suzanna Becker *et al.* 1687 pp. MIT Press, Cambridge, MA, 2003. Price: $95.00 ISBN 0-262-02550-7.

Advances in Plasma Physics Research, Vol. 4. Edited by Francois Gerard. 192 pp. Nova Science Publishers, Hauppauge, NY, 2003. Price: $89.00. ISBN 1-59033-629-1.

Biological Physics: Energy, Information, Life. Philip Nelson. 598 pp. W.H. Freeman, New York, 2004. Price: $95.15 ISBN 0-7167-4372-8.

The Cold Wars: A History of Superconductivity (translation). Jean Matricon and Georges Waysand. 272 pp. Rutgers U.P., New Brunswick, NJ, 2003. Price: $26.00 (paper) ISBN 0-8135-3295-7.

Electron-Phonon Interactions in Low-Dimensional Structures. Edited by Lawrence Challis. 285 pp. Oxford U.P., New York, 2003. Price: $144.50 ISBN 0-19-850732-1.

Entropy. Edited by Andreas Greven *et al.* 358 pp. Princeton U.P., Princeton, NJ, 2004. Price: $69.50 ISBN 0-691-11338-6.

Horizons in World Physics Vol. 240. Edited by Albert Reimer. 164 pp. Nova Science Publishers, Hauppauge, NY, 2003. Price: $98.00. ISBN 1-59033-597-X.

Information Theory, Inference, and Learning Algorithms. David J. C. MacKay. 628 pp. Cambridge U.P., New York, 2003. Price: $50.00 ISBN 0-521-64298-1.

Ink Sandwiches, Electric Worms, and 37 Other Experiments for Saturday Science. Neil A. Downie. 334 pp. Johns Hopkins U.P., Baltimore, 2003. Price: $45.00 (cloth) ISBN 0-8018-7409-2; $18.95 (paper) ISBN 0-8018-7410-6.

Introductory Physics: A Model Approach (second edition). Robert Karplus. 509 pp. Captain's Engineering Services, Buzzards Bay, MA 2003. Price: $54.95 (paper) ISBN 0-97217-261-0.

Kinetic Theory of Gases in Shear Flows. Vincente Garzó and Andrés Santos. 319 pp. Kluwer Adademic Publishers, Norwell, MA, 2003. Price: $163.00 ISBN 1-4020-1436-8.

Mathematical Perspectives on Theoretical Physics: A Journey from Black Holes to Superstrings (reprint). Nirmala Prakash. 835 pp. Imperial College Press, London, 2003. Price: $98.00 (cloth) ISBN 1-86094-364-0; $48.00 (paper) ISBN 1-86094-365-9.

Models and Methods of High-T_c Superconductivity: Some Frontal Aspects, Vol. 2. Edited by J. K. Srivastava and S. M. Rao. 418 pp. Nova Science Publishers, Hauppauge, NY, 2003. Price: $98.00. ISBN 1-59033-667-4.

Modern Problems in Classical Electrodynamics. Charles A. Brau. 594 pp. Oxford U.P., New York, 2004. Price: $96.00 ISBN 0-19-514665-4.

Nanotechnology Abstracts. Edited by Eugene V. Dirote. 154 pp. Nova Science Publishers, Hauppauge, NY, 2003. Price: $49.00. ISBN 1-59033-411-6.

The New Quantum Universe (revised edition of The Quantum Universe). Tony Hey and Patrick Walters. 357 pp. Cambridge U.P., New York,

2003. Price: $85.00 (cloth) ISBN 0-521-56418-2; $35.00 (paper) ISBN 0-521-56457-3.

Proceedings of the International Symposium on Frontiers of Science: In Celebration of the 80th Birthday of C. N. Yang. Edited by Hwa-Tung Nieh. 563 pp. World Scientific, River Edge, NJ, 2003. Price: $88.00 (cloth) ISBN 981-238-407-3; $46.00 (paper) ISBN 981-238-414-6.

Quantum Hall Systems: Braid Groups, Composite Fermions and Fractional Charge. Lucjan Jacak, *et al.* 224 pp. Oxford U.P., New York, 2003. Price: $89.50 ISBN 0-19-852870-1.

Spacetime and Geometry: An Introduction to General Relativity. Sean Carroll. 513 pp. Addison Wesley, San Francisco, 2004. Price: $80.00 ISBN 0-8053-8732-3.

Strange Curves, Counting Rabbits, and other Mathematical Explorations. Keith Ball. 251 pp. Princeton U.P., Princeton, NJ, 2004. Price: $29.95 ISBN 0-691-11321-1.

Studies of High Temperature Superconductors Vol. 46: Magnetic Superconductors. Edited by Anant Narlikar. 200 pp. Nova Science Publishers, Hauppauge, NY, 2003. Price: $98.00. ISBN 1-59033-797-2.

Symmetry & Modern Physics: Yang Retirement Symposium. Edited by A. Goldhaber *et al.* 291 pp. World Scientific, River Edge NJ, 2003. Price: $48.00 (cloth) ISBN 981-238-503-7; $28.00 (paper) ISBN 981-238-563-0.

Theoretical Physics 2002, Part 2. Edited by Thomas F. George and Henk F. Arnoldus. 252 pp. Nova Science Publishers, Hauppauge, NY, 2003. Price: $98.00. ISBN 1-59033-722-0.

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