BOOKS

Maxwell: Giant Shoulders to Stand Upon; A "Mysteriously Prescient" Intellect

The Natural Philosophy of James Clerk Maxwell

Peter M. Harman
Cambridge U.P., New York, 1998. 232 pp. $59.95 hc
ISBN 0-521-56102-7

Reviewed by C. W. Francis Everitt

Few people succeed in altering the nature of any science. We physicists are fortunate to be working in one in which the historical perspective is so long and clear that we can confidently recognize the giants on whose shoulders we stand.

James Clerk Maxwell brought about not one but two distinct revolutions in physics. The first was his introduction of statistical methods into the foundations of physics via the kinetic theory of gases. The second was the unification he effected between electricity, magnetism, and light. In *The Natural Philosophy of James Clerk Maxwell*, Peter Harman explores both and allows us to experience a mind so mysteriously prescient as to see truths decades before anyone else did and so incisive as to be incapable of writing a single dull sentence. Harman is the author of a notable book on 19th-century physics, entitled *Energy, Force and Matter* (Cambridge U. P., 1982), and the editor of a distinguished collection of Maxwell's unpublished writings. (*The Scientific Letters and Papers of James Clerk Maxwell*, Volumes 1 (1990) and 2 (1995); others in process; Cambridge U. P.) As such, he is well placed to help us in this encounter.

Natural philosophy is, as Maxwell said, "the good old English name for what is now called Physical Science." However, Harman rightly uses the term in another sense: Maxwell was a trained philosopher, and all his thinking about physical reality bears the stamp of his philosophical training.

Maxwell's education was rich. Brought up in Edinburgh, he enjoyed Scotland's traditional broad liberal-philosophical schooling. Then, at 19, he migrated to Cambridge University for the trial by ordeal of its famously ferocious mathematical *tripos* (Cambridge's final honors examination in mathematics). Thereafter, for the rest of his life, he oscillated between Scotland and England and, as the heir to a large country estate, he was able to retire from academic life for six years, beginning when he was 34, to write his *Treatise on Electricity and Magnetism*.

Maxwell's philosophical mentors were William Hamilton at Edinburgh and William Whewell at Cambridge. Harman gives a penetrating discussion of Whewell's deeply influential and too-little-appreciated notions of the "consilience of inductions" and "appropriate ideas." As for Hamilton, physicists may be surprised to learn that this half-forgotten philosopher (no relation to the Irish mathematician of the same name) is the man responsible for inventing the word "relativity." One of Hamilton's main doctrines was the "relativity of human knowledge," that is, the partly Kantian idea that we have knowledge not of objects in themselves but rather of relations between them. It is fascinating to see how that view affected Maxwell's thinking about electromagnetism and light. Through Maxwell's little masterpiece *Matter and Motion* (1876), this previously recondite philosophical term "relativity," suddenly entered physics. From there it flowed first to Henri Poincaré and to French and then German physics—and so to Albert Einstein.

As Harman points out, most writers on Maxwell have treated his two revolutions as intellectually independent events. In his most original chapter, "Dynamical and Statistical Explanation," Harman makes a valuable beginning on the difficult task of weaving the two together. In each, the key was a willingness to operate with incomplete knowledge. Maxwell found a way of describing the electromagnetic field dynamically in terms of a Lagrangian without any detailed hypothesis about the underlying mechanics, and he perceived that, in studying the dynamics of large numbers of molecules, one can formulate a method of treatment that is statistical and therefore incomplete but still enormously fruitful scientifically. It is curious that choosing the right thing to be ignorant about is the way to learn something. This philosophical dynamic has, as we know, continued to animate 20th-century physics.

Harman tells his tale skillfully, with an admirable use of quotations from Maxwell's published and unpublished writings. One characteristic of Maxwell that is not fully conveyed is the electric quality of his mind. Yet this is what impressed and sometimes intimidated those who met him. In this centennial year of the American Physical Society, it is nice to recall what Henry Augustus Rowland wrote in 1875 to Daniel Gilman, the president of Johns Hopkins University, after an extended visit to Europe, during which he spent several days with Maxwell at his home in Scotland. As for most of the professors, Rowland wrote, "They are men like the rest of us," but "after seeing Maxwell, I felt somewhat discouraged, for here I met a mind whose superiority was almost oppressive."

C. W. FRANCIS EVERITT, *who leads the NASA Gravity Probe B program at Stanford University, has written a scientific biography of Maxwell* (James Clerk Maxwell: Physicist and Natural Philosopher, *Scribner's, 1975*) *and on various topics in 19th- and 20th-century physics.*

Theoretical Global Seismology

F. A. Dahlen and Jeroen Tromp
Princeton U. P., Princeton, N.J., 1998. 1025 pp. $80.00 hc ($45.00 pb)
ISBN 0-691-00116-2 hc (0-691-00124-3 pb)

Seismology involves the analysis of vibrations of Earth that occur when energy is released by a variety of natural and human-induced sources. The vibrations, preserved as seismograms by ground-motion recording instruments, reveal many attributes of both the source excitation and the section of Earth through which the elastic waves have propagated.

As does any medium of finite dimensions with nearly elastic equations of internal motion, Earth has an infinite set of distinct normal modes of oscillation that sum, with appropriate linear weighting factors, to comprise any vibration of the system. Thus, one of the most elegant approaches to understanding seismic recordings involves their analysis in terms of normal modes of Earth. This approach underlies many techniques now in routine use for characterizing global earthquake faulting mechanisms, as well as for imaging three-dimensional material properties of the planet.

In *Theoretical Global Seismology*, two prominent theoretical seismologists, F. A. Dahlen and Jeroen Tromp, have contributed a major treatise that comprehensively develops the underlying mathematical theory of Earth's normal modes. This work is timely and of great value for seismologists and geophysicists as well as researchers interested in oscillations of other planets and stars.

In the span of 1000 pages, with 16 chapters and 4 appendices, *Theoretical Global Seismology* lays out the critical concepts and mathematics essential for a normal-mode theory of Earth, along with asymptotic treatments that connect the standing-wave approach to propagating body- and surface-wave perspectives of the wavefield. The introductory chapter touches on highlights of the century-and-a-half evolution of continuum mechanics and normal-mode theory, setting the stage for the main objective of the text: to treat the problem of computing normal modes for a self-gravitating, rotating, quasi-elliptical, anelastic, anisotropic, and heterogeneous medium such as Earth. Six chapters are used to lay the necessary foundations in continuum mechanics, anelasticity, and perturbational methods while developing the mathematical notation that can generalize to the complex problem at hand. The going is a bit slow, since many concepts are developed, including representations in Lagrangian and Eulerian reference frames, but one quickly comes to appreciate the thorough presentation.

By chapter 8, the text has progressed to consideration of a spherically symmetric, nonrotating model of Earth. This conveys the essence of the spheroidal and toroidal normal-mode displacements determined by the radial layering of the planet and its internal properties. Radially symmetric perturbations of elastic and anelastic properties are considered next, in a particularly insightful presentation of perturbation analysis that includes calculation of sensitivity functions, or Fréchet kernels, which underlie our ability to determine an average Earth model consistent with observations of normal-mode eigenfrequencies. The mode-summation process is addressed in chapter 10, with synthesis of ground-motion time series and corresponding spectra for the moment-tensor equivalent-body-force earthquake source model. Two further chapters address the connection between the normal-mode representation of ground-motion and traveling-wave representations of surface waves and body waves.

The last part of the treatise addresses the aspherical Earth, extending perturbation theory to explore the effects of departure from spherical symmetry that cause mode splitting and coupling. The theory developed here underlies the application of mode observations to retrieval of three-dimensional Earth structure. This presentation provides one of the best available surveys of mode-coupling matrices and the representation of heterogeneity effects on free oscillations. The final two chapters of this part develop body-wave and surface-wave asymptotic theory for aspherical Earth, using variational principles to develop theory that allows construction of synthetic ground-motion records. To some extent, this departure from the normal-mode development reflects the reality that traveling-wave analyses continue to play the dominant role in determining aspherical Earth structure at both short and long wavelengths, but the authors highlight the connections to normal-mode theory that have permitted rapid progress in global seismic tomography.

Theoretical Global Seismology is a masterful accomplishment for its rigor, completeness, and clarity of presentation. The material will be challenging, even for experienced seismologists, but therein lies the primary contribution of this treatise: It brings together for the first time a complete accounting of the theory for contemporary normal-mode analysis. This will be an enduring contribution that benefits not only experts in the field, but also geophysicists interested in the results extracted from seismology.

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Chaos, Scattering and Statistical Mechanics

Pierre Gaspard
Cambridge U. P., New York, 1998. 475 pp. $100.00 hc
ISBN 0-521-39511-9

Pierre Gaspard's *Chaos, Scattering and Statistical Mechanics* gives both the background and an overview of recent developments in nonequilibrium statistical mechanics, to which the author himself has made major contributions. The idea is to connect macroscopic quantities (like transport coefficients) to properties of the microscopic dynamics. To give an example: Consider independent particles of given mass and energy moving classically among fixed scatterers such as a Lorentz gas. For scatterers of a suitable shape (hard disks, for example), the dynamics will be "chaotic" and can be characterized by some (positive) Lyapunov exponents (measuring how fast initially close trajectories diverge in phase space) and a Kolmogorov–Sinai (K–S) entropy (measuring how fast the dynamics mixes up the phase space).

A theorem of Yakov Pesin asserts that, for closed systems, K–S entropy equals the sum of the positive Lyapunov exponents. Now consider an open system with the same dynamics: a slab of size L with absorbing boundaries, for example. Particles will be absorbed at those boundaries at an exponential rate with a coefficient proportional to L^{-2} times the (macroscopic) diffusion constant. But that coefficient can be shown, by analyzing the microscopic dynamics, to equal the difference between the sum of the positive Lyapunov exponents and the K–S entropy. The difference between those two quantities, which for open systems no longer vanishes, is also proportional to L^{-2}. Hence, a connection is established between the diffusion constant and quantities characterizing the chaotic microscopic dynamics.

This simple example illustrates the subject of Gaspard's book but by no means does justice to its rich content. Of the 10 chapters, the first four deal with the modern theory of dynamical systems at an advanced level, both from the point of view of deterministic dynamics (going from linear stability analysis to topological chaos) and from the probabilistic point of view (including Markov partitions, Sinai–Ruelle–Bowen measures, K–S entropy, and large-deviation formalisms). Although these chapters serve as an introduction to the rest of the book, such rather advanced topics as resonances, zeta functions, and trace formulas, are also covered.

Chapters 5 to 9 deal with the various connections between the microscopic dynamics and the macroscopic properties. The first dealt with is the so-called escape-rate formalism of which the Lorentz gas discussed above is an example; that formalism applies not only to the diffusion constant but also to general transport coefficients. Then we find a host of applications, for example, to hydrodynamics modes, nonequilibrium steady states, irreversible thermodynamics, and various noises. The final chapter gives a useful summary of the book and discusses perspectives in the field.

Because of the number of advanced topics covered in this book, complete arguments cannot be given, but the author does provide references to the latter. This is not an introductory text. It is, however, an important reference book as well as an ideal tool for ad-