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 advanced students in the expanding and important field of statistical physics.

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What Remains To Be Discovered: Mapping the Secrets of the Universe, the Origins of Life, and the Future of the Human Race

John Maddox
Free Press, New York, 1998. 434 pp. $26.00 hc
ISBN 0-684-82292-X

Although John Horgan's book *The End of Science* (Helix Books, 1996) is nowhere mentioned in John Maddox's *What Remains To Be Discovered*, the latter is clearly a reply to Horgan's contention that the most important scientific discoveries are behind us. Maddox summarizes many of the questions that will keep researchers busy for decades or centuries to come, and he is surely correct in saying that "the record of the past shows that novel conundrums are forever treading on the heels of those that still perplex." Maddox's book is engagingly written and clearly organized. But there are serious problems with it.

Maddox is amazingly opinionated about the directions in each field that are most and least ready for progress—a confidence in his own judgment that perhaps comes from his more than two decades as editor of *Nature*. The three parts of his book are titled Matter, Life, and Our World (the chapters of the third part are titled Thinking Machines, Mathematics, and The Avoidance of Calamity), but in this brief review I will concentrate on its discussion of physical science. I disagree with many of his predictions regarding the future of physics and astronomy. Among them:

> ▷ Einstein's hunch that a black hole is metaphysical (and thus intolerable) will be proved correct.
> ▷ By extension, the idea that the universe began in a single event, the big bang, will be found false. . . .
> ▷ [H]alf a century from now, cosmologists will have a much better idea of what kind of universe they are expected to explain. The once-and-for-all universe of Genesis, or of [Alan] Guth's [cosmic inflation] equivalent, is an improbable outcome.

I question whether Maddox understands enough about these subjects to render a thoughtful opinion. Consider, for example, his description of the Big Bang:

"What was the universe like at the very beginning? It was simply a tiny bubble of space-time packed with energy. . . . But energy is equivalent to mass, which means that space-time in the nascent universe would have been tightly curved, following Einstein's theory of gravitation. . . . The result is that, one microsecond after the big bang, the observable universe would have been just 300 meters in radius . . .but would have been embedded in a much larger structure, the parts of the larger universe that are permanently beyond our ken."

Every single statement cited here is wrong, or at best misleading: The energy of relativistic particles is not gravitationally equivalent to mass. Spacetime was not curved in the early universe but perfectly (or at least nearly) flat. At one microsecond, the radius of the presently observable universe was not 300 m, the distance light covers in a microsecond, but a hundred billion times larger. The mismatch between these two scales is known as the "horizon problem" in cosmology: Since the distance light could have covered in the early universe is so small, even after taking into account the expansion of the universe, how could different regions have come to the same temperature to within about a part in 10^5? The only answer that has yet been found is cosmic inflation, which also solves other problems concerning the initial conditions.

To be sure, Horgan's scientific understanding appears to be no deeper than Maddox's. For example, his book says that, "Astronomers may find that the cosmic microwave background stems not from the flash of the big bang, but from some more mundane source, such as dust in our own Milky Way. . . . We humans may never see directly into the dust-obscured heart of our own galaxy, let alone into any other galaxy, but we may learn enough to raise doubts about the black hole hypothesis."

That the cosmic microwave background originates inside the Milky Way has been rather convincingly ruled out, while increasing evidence is being found for black holes. Infrared light penetrates interstellar dust, and recent infrared observations of stars orbiting very close to the center of the Milky Way have not only confirmed that a black hole is lurking there but also given a fairly precise value for its mass.

Let us hope that scientists do not leave entirely to journalists and editors the debate over the future of science!

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Galactic Astronomy

James Binney and Michael Merrifield
Princeton U. P., Princeton, N.J., 1998. 796 pp. $99.50 hc ($35.00 pb)
ISBN 0-691-00402-1 hc (0-691-02565-7 pb)

James Binney and Michael Merrifield's *Galactic Astronomy* is one of the most important astronomy books of this decade. Within its nearly 800 pages it details almost every aspect of the nature and content of galaxies. Every astronomer will want to have it on his or her bookshelf as a reference work. As a textbook, however, it has severe shortcomings: many students will find it difficult and frustrating, and many instructors will find it unsatisfactory.

This is not a revision of a book of the same name by Dimitri Mihalas and Binney (W. H. Freeman, 1981); the authors describe it rather as a "replacement." What they mean by this is that they have drastically changed the point of view, aiming at the study of galaxies in general and touching on the Milky Way only as our local example. To support this aim, they have created an invaluable compendium of much of astronomy, not only detailing the facts about galaxies and the effort to understand them but also delving into related topics, such as nuclear astrophysics, radio-astronomy observations, and the physics of interstellar material.

It is this very wealth of factual detail that may render this book disappointing to teachers and students; the reader is presented with fact upon fact, but is not given the logical framework on which to hang them, a framework that would allow the facts to be remembered easily as parts of a coherent picture. Such a framework indeed exists in the form of our understanding of stellar structure, stellar evolution, and stellar populations. But these topics are not introduced until chapter 5; the properties of stars and the morphology of galaxies—introduced earlier—would have been so much more easily absorbed if the reader were first given the milieu in which so much about these topics is understood.

In a parallel way, the components of the Milky Way—disk, bulge, and halo—are held back until the tenth of the book's 11 chapters, thus passing by the possibility of interpreting corresponding components in other galaxies, rather than just cataloguing them and describing them. Strangely, interstellar material is discussed in earlier chapters, thus dividing the stellar inhabitants of chapter 10 from the material with which they share their lives. Fur-