duced and the concept of elastic strain energy was created. Benvenuto does not dwell on the birth of continuum mechanics, but moves quickly to a discussion of the development of energy methods for elastic structures. During the latter half of the 19th century much exciting work in this field was done by Italian engineers and mathematicians, most notably Luigi Federico Menabrea and Alberto Castigliano. Castigliano's lasting contribution was his theorem that for a linearly elastic structure, by taking the partial derivative of the strain energy with respect to a load, one can obtain the component of displacement along the load at its point of application. Benvenuto also discusses other contributions to structural mechanics, including those of Alfred Clebsch, James Clerk Maxwell and Otto Mohr.

In the closing paragraphs of this fine history, Benvenuto expresses a note of disappointment. Modern engineers, he writes, know only the formulas of their profession: The circumstances of their derivations have been forgotten. In reply, I would suggest that the principles of mechanics are themselves monuments that may outlast the domes of the Renaissance. Like other monuments, these too have a fascinating history, and as long as there are dedicated scholars like Benvenuto, that history will be accurately recounted.

The Maxwellians

Bruce J. Hunt
Cornell U. P., Ithaca, N. Y., 1991. 266 pp. $34.95 hc
ISBN 0-9814-2614-3

The theory of electromagnetic phenomena presented in James Clerk Maxwell's culminating work on the subject, *A Treatise on Electricity and Magnetism* (1873), differs significantly from the theory that appears in modern textbooks on classical electromagnetic theory. In *The Maxwellians* Bruce Hunt presents a fascinating account of a central episode in the recasting and further development of Maxwell's theory, focusing on the work of his British followers—especially George Francis FitzGerald, Oliver Lodge and Oliver Heaviside—in the last quarter of the 19th century. FitzGerald, a graduate and later a professor of natural and experimental philosophy at Trinity College, Dublin, was the major architect of the broad intellectual vision of this group of three. Lodge, a graduate of University College, London, who became a professor of physics at University College, Liverpool, was the chief experimenter, interlocutor and propagandist. Heaviside, a self-educated telegrapher who was for the most part isolated from the academic community, was the mathematical brains of the outfit and the one who made the important technological connections.

The central theme in Hunt's story is the shift from Maxwell's own emphasis on the vector and scalar potentials A and ψ as the central field variables of the theory—with the basic equations phrased in terms of them—to the familiar modern form of the theory, in which the electric and magnetic field vectors are the basic variables, the fundamental equations are the four symmetrical "Maxwell's equations" and the potentials are demoted to an auxiliary role. Heaviside is eponymously honored in this connection in that the four equations are sometimes referred to as the Heaviside–Hertz form of Maxwell's equations. (Heinrich Hertz's work on the reformulation of the equations was in part independent and in part influenced by Heaviside.)

FitzGerald, however, also played a central role in recasting the equations: Among the British interpreters of Maxwell he gave the most thought to the element of arbitrariness in the potentials and the related problem of potentials that are propagated instantaneously—as is ψ in the Coulomb gauge. These problems motivated what FitzGerald referred to as "the murder of ψ" and the attendant rephrasing of the equations. Also associated with this rephrasing was the work of Heaviside and John Henry Poynting on energy localization and transfer in the electromagnetic field, as expressed in terms of the electric and magnetic field vectors.

Branching off from the main theme of the book is a variety of interesting episodes and developments. A detailed account of the origins of the FitzGerald contraction hypothesis serves to show that this was something more—something deeper—than a mere *ad hoc* response to the Michelson–Morley experiment. In connection with the issue of the propagation of potentials and fields, as investigated by Fitzgerald and others, Heaviside developed in 1888 a formula for the field around a rapidly moving electric charge, exhibiting contraction along the direction of motion by $\sqrt{1 - v^2/c^2}$. Knowing this and assuming that intermolecular forces behaved in the same way, FitzGerald early in 1889, during a conversation with Lodge concerning the 1887 Michelson–Morley experiment, first formulated the contraction hypothesis. Turning to the more immediately practical connections of electromagnetic theory, Hunt shows how concerns with telegraphy and telephony motivated many of Heaviside's theoretical advances and how in turn Heaviside made important contributions to the technology of transmission lines, such as the practice of inductive loading to reduce distortion of the signal, "now recognized," according to Hunt, "as the most important technical innovation in telephone transmission between [Alexander Graham] Bell's original invention in 1876 and the development of the first electronic amplifiers in 1912."

Throughout, the book is a good read—clear, cogent and interesting, with a good balance between the coverage of personalities and their interactions and that of technical issues. Extensive use of archival materials—correspondence, notebooks and working papers—enriches the narrative so that it is concrete, lively and convincing. One might have wished for a bit more engagement with the existing historical literature on the subject for the purpose of making stronger connections with the broader history of electromagnetic theory. This single caveat notwithstanding, *The Maxwellians* makes an important contribution to our understanding of the history of electromagnetic theory, and I highly recommend it to both physicists and historians.

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Quantum Signatures of Chaos

Fritz Haake
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The Transition to Chaos in Conservative Classical Systems: Quantum Manifestations

Linda Reichl
Springer-Verlag, New York, 1992. 551 pp. $45.00 hc
ISBN 0-387-97753-8

Most physicists have grown up with the belief that elementary mechanics is represented by the well-worn standard examples of regular, or integrable, systems, such as a few linearly coupled pendula or a lone planet circling the Sun. This naive faith in the ultimate simplicity of nature extends even to the atomic and subatomic realm, where the Schrödinger equation replaces Newton's equations of motion. The disturbing influence of third bodies can then be taken into account by applying one form or another of perturbation theory.

Poincaré first noticed how the solutions of many ordinary differential equations show extremely complicated behavior. But the mathematicians who studied these problems lost contact with physics. Later, astronomers and astronauts found out that even simple problems in classical mechanics turn out to be more complex than anticipated. Now a beginning student can, with the help of a desktop computer, watch a complex dynamical system in real time. A plot of the surface of section shows dramatically how phase space breaks up into multicolored fractals.

In the last decade, numerous books at all levels of sophistication have been published to celebrate and help the reader enjoy the discovery of classical chaos. Our intuition seems well equipped to cope with classical chaos, and we can capture it in crisp mathematical language. But the smooth transition to quantum mechanics, specified by Bohr's correspondence principle and quantization rules, no longer works. Because Planck's quantum sets a lower limit on the resolution of position and momentum, the self-similar structures in phase space cannot be transferred to the quantum domain. Quantum chaos is the ambiguous name for this fundamental but largely unresolved problem. The two authors have dealt with this difficult subject in rather different ways.

Fritz Haake's book is a careful and complete monograph about the statistics of energy levels in quantum systems. This topic was first studied by nuclear physicists, not for the sake of chaos, but because they despaired of finding the appropriate Hamiltonian. The subtleties of time reversal, among other possible symmetries, are crucial in deriving the different types of correlation that result from different ensembles of "random matrices." The explanation of the correlations for regular systems is fairly straightforward in terms of Bohr's rules of quantization. For classically chaotic systems, however, Haake relies on "level dynamics," an ingenious model for the spectrum of energy levels as a function of the coupling strength. A rather different argument Haake uses comes from a special mechanical model, the "kicked rotator," for which one can establish a direct relation to Anderson localization in solid-state physics. The book closes with a very useful chapter on dissipation in quantum systems: A spin system in weak contact with a heat bath is a special example. In this system the essential input is an ensemble of matrices with complex eigenvalues.

Linda Reichl's book is closer to a standard textbook that tries to give the reader the tools for striking out on his or her own. First, Reichl presents classical mechanics, discussing important problems such as nonlinear resonances, the Kolmogorov–Arnold–Moser theory, measures of entropy, area-preserving maps, Arnold diffusion, self-similarity in phase space and various simple but externally driven systems. After a brush with the concept of quantum integrability, the reader gets a thorough treatment of random-matrix theory, including a detailed discussion of observed spectra. Because the semiclassical approach to quantum mechanics is the most natural way to connect classical chaos with its quantum manifestations, Reichl gives a rather complete account of the trace formula and the "scars" in eigenfunctions. The last two chapters cover her own work on driven quantum systems and their relation to stochastic systems, including the quantum standard map and the microwave-driven hydrogen atom of the experiments of Jim Bayfield and Peter Koch.

Both books manage to be both eminently readable (without requiring special background knowledge) and quite explicit in the detailed development of their ideas. Both provide a set of problems at the end of each chapter, so that either could serve as a text in a course for graduate students. There are, however, some striking contrasts between the approaches the authors have chosen.

Haake comes closer to an axiomatic treatment, in which all the mathematical consequences of the assumptions are worked out. In contrast, Reichl gives more of the intuitive motivation for and some of the history of each subject. Moreover, to explain her thinking in geometrical terms, she offers figures from the numerical results of related work and simple sketches. She covers a large variety of examples illustrating general principles, and she gives a fairly complete and up-to-date account of the literature—no mean achievement in a field that moves so rapidly in so many directions.

In conclusion, Haake's book gives a thorough account of a topic for a specialized course in the statistics of energy levels, while Reichl's could well serve as the basis for a general course that is concerned with the transition to chaos in both classical and quantum mechanics.

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Chaotic Transport in Dynamical Systems

Stephen Wiggins
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Hamiltonian dynamical systems have a natural invariant measure; nonetheless, regions of phase space can stretch, fold and intertwine in intricate ways. The relative motion, or transport, of regions in phase space has important consequences in physical problems. Similar problems occur for three-dimensional vector fields that describe the motion of steady incompressible fluid flows. Stephen Wiggins discusses the geometry of transport in phase spaces in his latest book, *Chaotic Transport in Dynamical Systems.* This theme is a modern one—most of the literature that specifically addresses the problem is less than a decade old. The work summarized in this book is primarily that of Wiggins, his students and his collaborators.

The physical examples that motivate the analysis described by Wiggins come from two directions: the mixing of fluids and molecular dynamics. Wiggins discusses examples from these two fields in the first chapter, and these examples reappear throughout the book. An example from fluid mixing illustrates the problems they study: Streamlines of a steady two-dimensional flow separate the plane and provide barriers to fluid mixing on the two sides of a streamline. In two-dimensional time-periodic flows or in three-dimensional steady flows, streamlines can form chaotic structures that lead to separation of nearby bits of fluid. In time-periodic Rayleigh–Bénard convection states with a well-defined roll structure, some fluid particles cross roll boundaries. In 1984 Robert Mackay, James Meiss and Ian Percival observed that this phenomenon of phase-space transport is localized and mediated by special geometric structures, which they called turnstiles. Their seminal work dealt with transport past boundaries in which there are remnants of the invariant tori described by the Kolmogorov–Arnold–Moser theory.

Wiggins's work concentrates on transport in which the separation of