

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 multi-colored 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

Springer-Verlag, New York,
1992. 301 pp. \$39.95 hc
ISBN 0-387-97522-5

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

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regions of phase space is mediated by motion past equilibrium points and periodic orbits. Under these circumstances, stable and unstable manifolds of the equilibrium points and periodic orbits form the barriers dividing regions of the flow that separate. Portions of the stable and unstable manifolds isolate the regions of the fluid that form turnstiles. The primary goal of the theory Wiggins discusses is to describe the geometry of the intersections of these invariant manifolds and to develop a systematic accounting for the motion of phase-space regions into and out of turnstiles to predict rates of fluid mixing. For the simplest problems of this type, the geometry is intricate, but it can be reduced to the analysis of single area-preserving maps of the plane. Wiggins also describes other, more complex problems.

This book is a snapshot of a theory that is still new. Wiggins has brought together his own work of the past five years, but he has not gone to great lengths to provide additional background or perspective beyond that found in the original papers. On the other hand, there are many pictures in this book and they are superbly drawn: The patient reader can develop a great deal of geometric insight into the homoclinic tangles that lead to phase-space transport.

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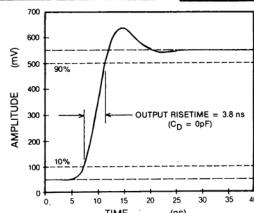
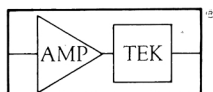
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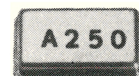
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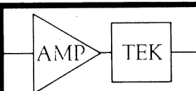
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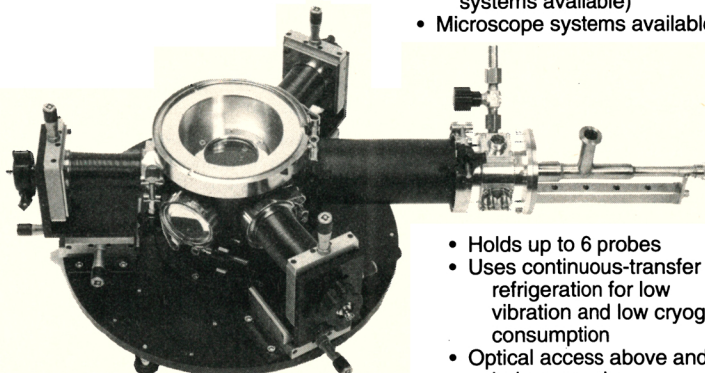
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