

EXPLORING CHAOTIC DYNAMICS THROUGH MODEL SYSTEMS

Chaotic Dynamics: An Introduction

Gregory L. Baker
and Jerry P. Gollub

Cambridge U. P., New York,
1990. 182 pp. \$17.95 pb ISBN
0-521-38897-X; \$49.50 hc ISBN
0-521-38258-0

Reviewed by Ronald Fox

This book was a pleasure to review. The authors' express purpose was to fill the void in the literature on chaotic dynamics between the readable and enjoyable but technically light books, best exemplified by James Gleick's *Chaos* (Viking, New York, 1987), and the technically difficult books, such as Michael Lichtenberg and Michael Lieberman's *Regular and Stochastic Motion* (Springer-Verlag, New York, 1983). Gregory Baker and Jerry Gollub have accomplished this superbly and provided us with a text, or text supplement, suitable for the advanced undergraduate.

The mode of presentation in *Chaotic Dynamics* is very pedagogical. Baker and Gollub have chosen one particular dynamical system as the vehicle for presenting nearly all of the useful concepts in chaotic dynamics. That paradigm is the damped, periodically driven pendulum. They successfully use this paradigm to discuss phase-space trajectories, Poincaré sections, time series, Fourier power-spectrum analysis, sensitivity to initial conditions, bifurcations, attractors, basins of attraction, period doubling, Lyapunov exponents, Kolmogorov entropy, mode locking, the Devil's staircase, intermittency, fractal dimension, information measures, Lyapunov-exponent connec-

tions to fractal dimension and more. Computer exercises are provided that demonstrate all these features for the damped, driven pendulum. (Appendix B contains 11 programs written in the readily accessible TRUE BASIC language.) The reader can learn much of the material in this book by executing these programs. In addition, each chapter ends with several informative problems to be solved by the reader.

In Chapter 4 even simpler paradigms are used to develop some of the concepts. The logistic map, the circle map and the horseshoe map are briefly introduced and discussed. Mitchell Feigenbaum's universal parameter δ is mentioned, and Vladimir Arnold's "tongues" are illustrated. Even Steven Smale's "heteroclinic tangle" is illuminated. The fractal nature of chaotic attractors is motivated by a presentation of the Cantor set. All of this gives the student a taste of some of the deeper aspects of chaotic dynamics.

My pleasure in reading this book was dampened just a little by two things. First the material in the final chapter, which addresses chaos in real physical systems, was far too brief. Gollub is one of the pioneers in research on chaos in real fluids, and I think students would benefit from his insights into the actual performance of chaos experiments—especially his expertise on the special problems such experiments pose. The coverage of the other experiments could have been fuller. As it stands, the reader will have to go to the cited literature for more.

The second problem is that the authors omitted one property of chaotic dynamics that I always like to emphasize: its connection to number theory and other areas of pure mathematics. Baker and Gollub could have included this connection without going into any more sophisticated mathematics. For example, they could have raised questions like: Why are the Arnold tongues on rational numbers and not on irrational

numbers? Why is the golden mean of the Greeks significant in mode locking? They could also have made observations such as the fact that the Devil's staircase contains steps of different sizes that can be described by Farey addition. Although the authors do show that a Cantor set has a fractal dimension less than one, they do not emphasize the equally significant fact that it is greater than zero. They could have easily included the ternary representation of the Cantor set and its isomorphism to the binary representation of the real numbers on the unit interval to show that the Cantor set is uncountable, is nowhere dense, has measure zero and yet has a fractal dimension greater than zero. This information could have been used to introduce the reader to symbolic dynamics (which is closely related to the Smale horseshoe).

These are just a few examples of the relationship between pure mathematics and chaotic dynamics that has surprised so many researchers. Fortunately, the references include some of the literature on this side of the story, and any student who becomes intrigued by this excellent book will naturally want to explore more.

Neutron Optics

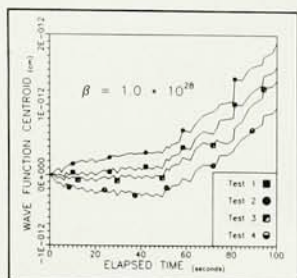
Varley F. Sears

Oxford U. P., New York,
1989. 317 pp. \$60.00 hc
ISBN 0-19-504601-3

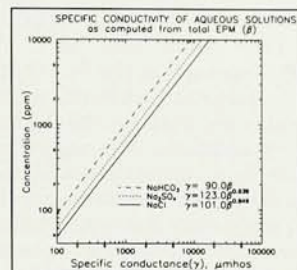
In the mid-1930s Enrico Fermi realized that thermal neutrons, which he discovered, are slow enough to be subject to the basic optical phenomena so well known for light. Yet at that time neutron sources were far too feeble to use in the experiments. Therefore, the experimental science of neutron optics had to wait for the advent of nuclear reactors, at which time sufficiently strong neutron beams became available. Eventually, as pointed out by Varley Sears in *Neutron Optics*, Fermi and Walter

Ronald Fox, a professor of physics at the Georgia Institute of Technology, does research on chaos in quantum systems and on the effects of chaotic dynamics on the description of molecular and thermal fluctuations in real physical systems.

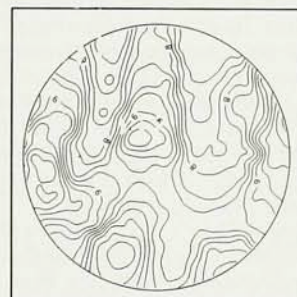
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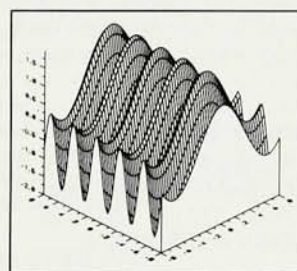
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Zinn performed the first experiment in neutron optics on 14 July 1944. They took a collimated thermal beam emerging from the Argonne CP-3 reactor and reflected it from flat metal surfaces at grazing angles of incidence. In that experiment they successfully demonstrated that neutrons suffer external total reflection by most materials, and they used the value of the critical angle to determine, via the neutron optical index of refraction, the coherent bound-neutron scattering length for various materials.

By now neutron optics has bloomed into an active field, and practitioners have gained a wide range of practical experience with many different types of neutron optical devices and instruments. The experimenter now has such devices as lenses, focusing mirrors, diffraction gratings and zone plates at hand. A notable present-day application of neutron optics follows directly from the work by Fermi and Zinn. At many modern high-flux research reactors, neutron-guide tubes operating on the principle of total reflection direct intense neutron beams away from the reactor. These guide tubes permit many more experiments to be done simultaneously than the old reactors, with which one could exploit only those beams that emerged directly from the reactor beam ports.

Central to the description of these phenomena is the concept of the neutron refractive index, which is directly related to the neutron optical potential: The neutron, entering the sample, interacts with the neutron optical potential and thus its direction of propagation is changed. If the component of the neutron momentum orthogonal to the surface is too small to overcome the neutron optical potential, the neutron suffers external total reflection. A certain experimental drawback stems from the fact that this neutron optical potential is very small, typically five orders of magnitude smaller than the energy of thermal neutrons. Thus some of the most beautiful neutron optical experiments have been performed with neutrons of low energies emerging from cold sources in some nuclear reactors.

A striking phenomenon occurs at very low energies: Neutrons can be too slow to overcome the neutron-optical potential barrier and thus they suffer external total reflection at all angles of incidence. This phenomenon, also predicted by Fermi, makes storage of neutrons in bottles possible. Such stored neutrons are then useful for a number of fundamental experiments, particularly those aiming at

precise determination of neutron properties such as lifetime and charge. One of the most interesting applications is the on-going search at the Institut Laue-Langevin in Grenoble and at the Leningrad Nuclear Physics Institute for an electric dipole moment of the neutron. An electron dipole moment, predicted by various unified theories, would be by its mere existence further evidence for the violation of time-reversal symmetry in nature.

The book by Sears is a comprehensive review of the theory of neutron optics. It puts particular emphasis on the rigorous theory of dispersion and on dynamical neutron diffraction and neutron interferometry. The book therefore complements the various existing texts that cover the crystallographic and materials science aspects of neutron scattering. Sears nicely illustrates the theoretical results with experimental findings. However, the reader might like an even broader illustration of experiments in neutron optics. The book is written on a level appropriate for the graduate students and it is a very useful introduction into the field of neutron optics. It is also a must for anybody working on the development of new facilities or new experimental methods with cold or thermal neutrons.

ANTON ZEILINGER

Technical University of Vienna

Beamtimes and Lifetimes: The World of High Energy Physicists

Sharon Traweek

Harvard U. P., Cambridge, Mass., 1988. 187 pp. \$20.00 hc
 ISBN 0-674-06347-3

This study by Sharon Traweek of the high-energy physics community belongs to the school of descriptive or anecdotal anthropology. The author's goal is to describe "how high-energy physicists see their own world, how they have forged a research community for themselves, how they turn novices into physicists and how their community works to produce knowledge." Traweek did her field work at the Stanford Linear Accelerator Center in California, the National Laboratory for High-Energy Physics (KEK) in Tsukuba, Japan, and Fermilab in Illinois over a five-year period starting in 1976; she had previously worked part-time in SLAC's public information office from 1972 to 1975. It is not clear how much time she spent at each laboratory, but the