Time's Arrow: The Origins of Thermodynamic Behavior

Michael C. Mackey
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The conceptual conflict between the apparent noninvertibility of the direction of time in the macroscopic physical world of human experience and the fundamental invertiblity of the direction of time in the underlying laws of dynamics is perhaps the most basic problem of modern science. Its resolution has implications for biological evolution, the fate of the universe and the functioning of microelectronic devices. Val Fitch and James Cronin's Nobel-prize winning experiment on CPT violation in K^0 meson decays (1964), still unexplained nearly 30 years later, may one day force us to accept the fundamental noninvertibility of time in the most basic elementary-particle processes. The other possiblity is that the apparent noninvertibility at the macroscopic level may instead reflect the highly contracted nature of the macroscopic description as compared with the underlying many-particle description of all the constituent atoms and molecules. This dichotomy is the focus of Michael Mackey's stimulating new book.

This book is a compact, elegant account of a modern mathematical approach to dynamics. Some of the theorems quoted are only a few years old, and in chapter 1 the reader is reminded of σ algebras, measure spaces and what a rigorous mathematical argument is like. I was immediately reminded of Vladimir Arnold's remark in the preface to *Geometrical Methods in the Theory of Ordinary Differential Equations* (Springer-Verlag, New York, 1983): "The axiomatization and algebrazation of mathematics, after more than 50 years, has led to the illegibility of such a large number of mathematical texts that the threat of complete loss of contact with physics and the natural sciences has been realized."

Like Arnold, Mackey uses just enough formal definitions and techniques to sharpen reasoning without causing obfuscation. This enables Mackey to make precise statements such as, "Thus, in spite of this weak convergence and the decay of correlations, mixing by itself is not sufficient to ensure the convergence of the system entropy to a maximum" and "ergodicity of P [the Frobenius–Perron operator] guarantees that the uniform density of the microcanonical ensemble is the unique state of thermodynamic equilibrium, while the uniform exactness of P guarantees that the entropy will approach its maximum value of zero regardless of the way in which the system is prepared."

Having developed the ideas and mathematical tools associated with the time invertibility of dynamics and the evolution of the entropy, Mackey presents his case as an unfolding mystery. By the end of chapter 7, the dichotomy is finally posed, and the author clearly declares himself to be on the side of the second choice. The solution, he says, is the idea of the "trace." Chapter 9 contains the heart of the argument.

I enjoyed this book, and I agree with the general thinking of the author. But I was not enlightened by his conclusion or his solution. The trace idea is called "contraction of the description" in the predominantly Dutch statistical mechanics tradition (I am thinking mainly of Paul Ehrenfest and George Uhlenbeck, but there are also Ludwig Boltzmann, J. Willard Gibbs, Masaji Kubo and Lars Onsager). As a student of this school, I was taught, nearly 30 years ago, Mackey's solution in somewhat different language. Even the dissatisfaction with the naive idea of coarse graining (see chapter 8 of Mackey) was emphasized. Mackey's coverage does not include the work of these thinkers, and its absence in his otherwise splendid volume is unfortunate. Curiously, the explicit physics of many-particle systems is missing from this book as well. The book is not written from the perspective of a physicist, as is perhaps most succinctly illustrated by the choice of the symbol ω for temporal period.

The arrow of time is an alluring concept. Mackey's new book affords a constructive rethinking of this mystery that will benefit anyone who pursues it.

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New Perspectives in Turbulence

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Although dynamical systems theory is perhaps the best known of the recent "new perspectives" in turbulence, it is not the only one. This book, which grew out of a workshop held in 1989, offers the reader a comprehensive and incisive account of many of the new, and some of the older, paradigms for understanding and analyzing turbulent fluid motions. The reader will find articles on the direct interaction approximation, an older theory resurfacing with renewed vigor; rapid distortion theory; proper orthogonal decomposition; analysis of coherent structures; vortex dynamics; nonlinear dynamical systems, including their fractal and multifractal properties; and chaos. Experimental results are discussed primarily in the context of these theories.

Because many of the newer theories, at this stage and perhaps for some time to come, provide at best a conceptual framework for our understanding of turbulence and experimental data and are not predictive, the practitioner will still have need of the more traditional approaches, some of which are themselves quite new. Thus, the book also contains discussions, in the context of turbulence in compressible fluids, of large eddy simulation, Reynolds stress modeling and direct numerical simulation. The last approach involves the direct numerical solution, generally by spectral or finite-difference techniques of the complete Navier–Stokes equations. The revolutionary impact of this exact solution technique (made possible by the advent of large-scale computing) on the calculation of turbulent motion and the evaluation of various approximation theories and models has been only somewhat muted by the limitation to relatively small Reynolds numbers.

To an unprecedented degree recent studies of turbulence have attracted physicists and mathematicians. The participants in the workshop and contributors to the volume come from these groups as well as from engineering. Each of the topics is discussed by a person uniquely qualified to do so. The possible disadvantages of such a collection of articles by experts, in contrast to a monograph, are that there may be less integration of the various theories, and the authors may be less critical in their presentation than would be a more neutral commentator; such traits occasionally hamper this volume. Also, because of the diversity of the contributors' backgrounds and the knowledge they assume of the reader, all of the articles may not be equally accessible. Nonetheless, this work is not in any sense a proceedings; the articles in most cases are not the latest pieces of work by the authors but rather reasonably comprehensive reviews of the states of the art.

While the field of turbulence is too fluid—in the other sense of the word—for these articles to represent for very long what we understand of the field, they do provide an excellent picture, painted by many major artists, of where we are now. The reader who wishes to see this picture in all its richness and complexity could do no better than to begin with this volume.

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Prisoner's Dilemma: John von Neumann, Game Theory, and the Puzzle of the Bomb

William Poundstone
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This is a very strange book. The potpourri suggested by the subtitle, *John von Neumann, Game Theory and the Puzzle of the Bomb*, is unfortunate. The author, a seasoned writer, approaches the prisoner's dilemma, but wanders into the life of von Neumann, discusses game theory and describes the activity of Oskar Morgenstern in his collaboration in 1944 with von Neumann on *Theory Games and Economic Behavior* (Princeton U. P., Princeton, N. J., 1944), which Poundstone describes as "one of the most influential and least-read books of the 20th century." Poundstone gives a brief discussion of the role of Emile Borel to game theory. More evidence of the author's skill at popular writing is that he also works in the story of the fission bomb, and in due course, that of the hydrogen bomb.

The prisoner's dilemma has its origins in game theory. There are two versions of the game: a one-shot version and another involving many plays; both are based on the basic assumption of rationality of play. According to Albert Tucker, the scenario for the prisoner's dilemma is as follows: Two men, both charged with a joint violation of the law, are held separately by the police. Each is told that if one confesses and the other does not, the former will receive a lighter sentence while the latter will receive the maximum penalty. If both confess, they will both receive lighter sentences, but if neither confesses, both go free. The rules force the prisoners, who are unable to communicate and develop a strategy,