the book because taken out of context they will seem naïve or impertinent. But they are not, and they provide a leaven to this otherwise tough and demanding work.

There are some obvious problems with Cohen's book. As an immunologist, I am annoyed when the author reiterates that antibody-combining sites of high affinity are also of high specificity; the opposite is the general case, at least by my definition of specificity. But I would rather take such matters up personally with this humane and intelligent man. A more serious criticism is that Cohen's goal remains elusive. *Tending Adam's Garden* is full of interesting and suggestive notions that are expressed with enviable informality and clarity, but at the end, did I know what Cohen was really trying to do? Is there a falsifiable thesis? I do not think so. Cohen's remarkable book is an essay in interpretation, a personal exploration of possible contacts between disparate worlds. It is perhaps best seen as a manifesto for immunologists. The author is saying, try this way of looking and you will see our field very differently. Although I don't think Cohen has reformulated immunology, it is impossible not to admire the scale and scope of his insights.

These are not the right terms in which to judge or praise Mims's book. *The War Within Us* is a guide to infection and immunity for the general public. Its purpose is clear and also fulfilled. Unsurprisingly, considering Mims's own background, the infection aspects are presented better than the immunity. However, the facts of infectious disease are so breathtaking, so terrible, and so frightening that they have generated what amounts to a modern psychopathology of anxiety. Mims is really excellent here: calm, authoritative, and sensible. But beneath the calm lurks Mims's own more substantially grounded fear of the next great plague, whatever it may be, fuelled by global travel, population density, poverty, and stupidity. *The War Within Us* is an exciting book, despite Mims's ward-sister style. Who can fail to react to the knowledge that a Tanzanian coastal villager may receive 100,000 mosquito bites per year? Or to the affecting fact that Mims's own mother died of puerperal sepsis in 1930? Who is left unmoved by the colossal international effort of unselfish service that finally eliminated smallpox in 1974 and is now set to do the same with polio?

The public, as Mims stresses, is not of one mind over vaccination. For many common diseases, the consensus fails even before it reaches the public domain. I recently had personal experience of this when beginning a brief sabbatical in Paris from my home city of Cologne. To enter the French public school system, all children must be immunized against tuberculosis. On the other hand, in Germany no child is immunized against tuberculosis and a doctor who does so is not covered by malpractice insurance. Compare these two prosperous, adjacent, disease-conscious, public-spirited European countries: in France you must, in Germany you may not. Even here, with one of the oldest and trustiest of immunizations, we are still too close to the frontiers of knowledge to call the game. Those who are prepared to think for themselves on these complicated issues need a good book like Mims's to stimulate their intelligence.

BOOKS: PHYSICS

Explaining Time's Arrow

Jean Bricmont

Here is a problem that has confused philosophers and physicists from the 19th century to the present. Our most common experience of the world is that time has a certain direction. We are born, grow old, and die; eggs break; liquids mix; and our offices tend to get more disordered—not the other way round. A quantitative characterization of such one-way behavior is encoded in the second law of thermodynamics: the entropy of isolated systems usually increases and never decreases. However, in our most basic and most successful scientific theories, time has no such direction. For any motion that produces these effects, there is another motion obeying the laws of microscopic-scale physics that produces the reversed effect. In other words, the fundamental physical laws are reversible. Although a satisfactory answer to this puzzling state of affairs was offered a long time ago by Ludwig Boltzmann, it is often misunderstood even by physicists. One of the goals of David Albert's *Time and Chance* is to explain Boltzmann's ideas in a very pedagogical manner.

Time and Chance
by David Z. Albert
Harvard University Press, Cambridge, MA, 2001. 186 pp. $29.95, £20.50. ISBN 0-674-00317-9.

In a nutshell, Boltzmann's solution goes as follows: First, we must distinguish between the microstate and the macrostate of a system. The microstate is rather familiar to physicists (in classical physics, for example, it is given by the coordinates and the velocities of all the particles of the system), whereas the macrostate is rather familiar to everybody else (it is composed of the observable regularities like the density, the average distribution of velocities, and similar macroscopic variables). It is easy to demonstrate that a given value of the macrostate corresponds to a very large number of microstates. The equilibrium value of the macrostate is defined as the one that corresponds to the largest number of microstates. And for systems composed of many particles, the difference between the largest number and all others is enormous. The "problem" of convergence to equilibrium is then simple to solve. If a system starts in a microstate corresponding to a nonequilibrium macrostate, it will very likely evolve toward a microstate corresponding to the equilibrium value of the macrostate, simply because there are so many more of the latter.

The author is at the Unité de Physique Théorique et de Physique Mathématique, Université Catholique de Louvain, Chemin de Cyclotron 2, B-1348 Louvain la Neuve, Belgium. E-mail: bricmont@fyma.fyma.ucl.ac.be

Fortunato Depero's *Train Born from the Sun* (1924).

Objections were raised, even during Boltzmann's day (most notably by Poincaré and Zermelo), against this simple scheme, but they can be easily dealt with. However, the reversibility of the equations of motion leads immediately to a new worry: if physical systems are naturally expected to evolve toward equilibrium in the future, why don't they also do so in the past? We know that they don't, because we remember the past has having been more "ordered" (in the sense of being more out-of-equilibrium) than the present. But our explanation of the tendency of the entropy to increase in the future would lead us to expect the opposite. In other words, we are in the strange situation of being able to explain the future correctly, but not the past.

This puzzle is one of the main subjects discussed by Albert, a philosopher at

Columbia University. Its solution is based on an argument outlined by Feynman in *The Character of Physical Law* (MIT Press, Cambridge, MA, 1967). We have to make what Albert calls a "past hypothesis" and assume that the universe started out in a low entropy state; it is important to realize that nothing less than that will do. It is a strange-but-true fact that if we try to understand in depth why the water in the bathtub cools down, we are quickly led to assumptions going back to the Big Bang.

The issue is a subtle one, because one might be tempted to deny the existence of the past altogether and to regard our memories of it as mere illusions. Of course, such an attitude would violently contradict common sense. It is, however, important to understand how one may reconcile our commonsense view (the past did exist) with our best physical theories (in particular, the mechanical account of the second law of thermodynamics). This reconciliation is very carefully discussed in the book. Essentially, assuming the existence of the past allows us to make sense of presently observed correlations (for example, that my house is where I remember having left it before traveling abroad).

A good part of the book is devoted to criticisms of frequent misconceptions in the physics literature, such as those on the role of ergodicity. The last chapter concerns quantum mechanics. There, the discussion is quite interesting and nicely summarizes the foundational issues associated with that theory, but Albert's final argument in favor of an intrinsically stochastic theory does not seem very convincing to me.

Albert has an idiosyncratic style, but a very pleasant one. Although this sounds like a cliché, he really is able to write both for intelligent teenagers and for specialists in philosophy of science. The foundations of statistical mechanics are often presented in physics textbooks in a rather obscure and confused way. By challenging common ways of thinking about this subject, *Time and Chance* can do quite a lot to improve the situation.

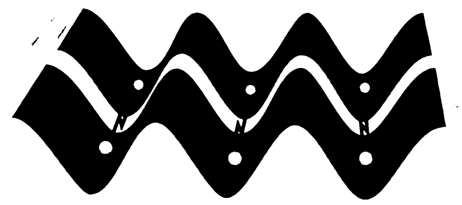
PERSPECTIVES: QUANTUM PHYSICS

No Mere Anarchy

Salman Habib

The study of quantum nonlinear systems is surprisingly young. Although Poincaré had understood key aspects of dynamical chaos (*1*) at the turn of the 20th century, and Einstein had realized its consequences for early quantum theory (*2*), quantum dynamics of nonlinear systems remained an obscure topic until the recent explosion of interest in quantum chaos. Sophisticated analysis (*3*, *4*) and greatly improved computational power have propelled many recent theoretical explorations of quantum chaos, and experimental progress has been no less rapid (*5*–*7*). In most cases, our intuition about quantum systems develops by thinking about them in classical terms, yet such intutions are hard to come by in systems that are chaotic. But it is just these systems that can produce surprising phenomena. A good example is chaos-assisted tunneling, the first experimental observation of which is presented by Steck *et al.* (*8*) on page 274 of this issue. Similar results have also been obtained recently by Hensinger *et al.* (*9*).

Quantum tunneling in the presence of an external barrier is theoretically well-understood in time-independent, one-dimensional systems. Classical physics may exclude particles from a spatial region, whereas quantum mechanically they are able to leak through. We can compute the magnitude of these effects by a variety of methods. However, as time dependence, or more dimensions, are added, the situation rapidly becomes more murky even in the case of integrable systems. Here, almost all classical trajectories live on n-dimensional surfaces in the $2n$-dimensional phase space. The isolation of classical trajectories on these invariant tori demonstrates that a potential barrier is no longer required to partition the classical phase space. According to the Kolmogorov-Arnold-Moser (KAM) theorem, small perturbations of integrable Hamiltonian systems will not destroy the tori but will leave most of them intact, albeit distorted and existing in a background of complex resonances and chaotic motion. As the size of the perturbation is increased, the generic case is that of a mixed phase space consisting of "regular islands" filled densely with tori and "stochastic seas," where no tori exist. A quantum initial state localized on one of the tori can evolve to another torus despite the fact that the corresponding classical trajectory cannot leave the original torus. This process is called dynamical tunneling (*10*). Direct dynamical tunneling occurs when the exact eigenstates are (approximate) linear combinations of the localized states, a situation analogous to a double-well system. Chaos-assisted tunneling (*11*), however, refers more specifically to the role of chaotic states near in energy to the localized states. Such states strongly influence the tunneling mechanism, leading to large and erratic variations in tunneling rates as an external parameter in the Hamiltonian is varied (in addition, there is no universal dependence on $\hbar$ for the tunneling amplitude).



Chaos-assisted tunneling. The potential felt by the atoms is a lattice of potential "wells," formed by a standing wave of laser light, in which the atoms can be confined. Because the intensity of the light is time-dependent, the wells become alternately shallower and deeper. Alternatively, the potential can be viewed as the sum of three lattices of constant amplitude: One of the lattices is stationary and does not participate in the tunneling, and the other two lattices move in opposite directions, as illustrated here (displaced for clarity). At the beginning of the experiment, atoms are trapped in the wells of the lattice moving to the right. The atoms then tunnel to the "mirror image" state, where they are trapped in the potential wells of the lattice moving to the left. The tunneling continues as the atoms oscillate between the two opposite motions.

Steck *et al.* studied the dynamics of cold cesium atoms in the presence of a time-dependent, cosine potential. There are essentially two regular islands, related by symmetry and surrounded by a large stochastic sea. With very precise velocity selection, the authors prepared an atomic ensemble in one of the islands and observed coherent oscillations between the islands by monitoring the momentum distribution of the atoms (see the figure).

To characterize the observed tunneling as chaos assisted, Steck *et al.* compare their results with the situation when chaos is absent. This they do by considering a time-averaged version of their potential, which is nothing but a quantum pendulum. In the case of the pendulum, the existence of a separatrix forbids classical transport across the $p =$

The author is in the Theoretical Division, Los Alamos National Laboratory, Los Alamos, NM 87545, USA. E-mail: habib@lanl.gov