an intellectual turning point: "It was obvious that I would never catch up with Dirac to the point of being clearly ahead of him. Thus at this point I shifted my interest to the helium atom." Except for a war-induced interlude of intense effort on radar and microwaves, the remainder of Slater's research activity has been devoted to the theoretical study of the electronic energy levels of atoms, molecules, and solids.

Although Slater's immense respect for Dirac's intellect is clearly evident from this account, so also is the ideological difference concerning the approach to theoretical problems. Slater differentiates between two sorts of theoretical physicist, the "pragmatic, matter-of-fact sort" on the one hand, and the "magician, [who] waves his hands as if he were drawing rabbits out of a hat and . . . is not satisfied unless he can mystify his readers or hearers" on the other. It is interesting that Van Vleck used the same language in referring to Dirac's quantum theory of the electron, "one of the most brilliant intellectual achievements of all times," but in an entirely complimentary way: "All the properties of electron spin came out automatically, and almost magically, like rabbits out of a magician's hat" (*Pure Appl. Chem.* **24**, 235 [1970]).

Slater identifies himself (as well as Schrödinger and Heisenberg) strongly with the former group and Dirac with the latter. He expresses strong distaste for the use of what in his view are needlessly formal and general theoretical tools. The indiscriminate application of group theory (the "Gruppenpest" of 1929), second quantization, and diagram techniques all fall under this rubric. In his famous 1930 paper, which was the first to make use of what were subsequently called "Slater determinants," he showed that complex atomic spectra could indeed be adequately explained by simple theoretical means. He regards this as his most universally popular work, in part because it exorcised the "Gruppenpest." Its importance was in fact recognized very rapidly by Heisenberg, Hund, Wigner, Pauli (who claimed characteristically that "he couldn't understand a word of it"), and others, as Slater discovered during a half-year's stay in Europe on a Guggenheim fellowship.

In 1930 Karl Compton, the newly chosen president of the Massachusetts Institute of Technology, asked Slater to join that institution as head of its physics department. He accepted with enthusiasm and, together with Compton, greatly expanded the physics effort during the decade by attracting such first-rate people as F. Bitter, M. S. Livingston, P. M. Morse, J. A. Stratton, and B. E. Warren. Slater's view that the German institute concept was perhaps emulated in the United States more than was realized during this period of scientific immigration is of particular interest in the context of the organizational structure then being developed at MIT.

In the meantime the growth of solid state physics had been proceeding rapidly. In 1933 Sommerfeld and Bethe published a comprehensive review of the subject. According to Slater, that year marked a turning point in solid state theory because of the development of the Wigner-Seitz method for calculating electronic energy levels (or band structures) of solids. This was the first method to break away from the Bloch-Hückel "tight-binding" approach on the one hand and the Bethe-Peierls "nearly-free-electron approximation" on the other.

A number of other, more sophisticated methods have been suggested since, one of the most important being the augmented plane wave approach that Slater developed in 1937 during a stay at the Institute for Advanced Study. The full implementation of these methods had to await the development of large-scale digital computers after World War II. The Solid State and Molecular Theory Group, which Slater organized at MIT in 1951 largely for this purpose, furnished a wealth of information about the electronic energy levels of a large variety of molecules and solids. This proved to be very important in the interpretation of accurate experimental data on the newly available high-purity single crystals that were produced with the use of techniques developed in the late '40's as part of the technological effort following the invention of the transistor. The MIT group, however, seemed less interested in the detailed interpretation of experimental results than in the development of new theoretical techniques, the explanation of systematic trends in energy levels of related solids (for example, the transition metals), the improvement of calculational procedures, and the problem of constructing better crystal potentials. Much of the work appeared only in the form of quarterly progress reports, which, however, were widely read and quoted.

The amount of ingenuity, effort, and organization required to produce these results and advances must not be underestimated. Slater devotes half the book to a description of these theoretical developments. Much of the account is very technical. Suffice it to say here that the work has culminated in the $X\alpha$-SCF (self-consistent field) method and that the characterization and intellectual history of the method represent its raison d'être. As Slater quite properly suggests, this method may be of considerable importance in leading to a better understanding of small-particle catalysts, molecules of biological importance, and surfaces.

In 1964 Slater left MIT to join the physics department at the University of Florida in Gainesville. He no longer felt comfortable at MIT: "During the 1960s so many faculty appointments were made in nuclear and high energy theory that the department became unbalanced, in a way I would never have allowed while I was department head." Times change.

The image of the 50 years in which Slater often has been a leading contributor to physics and chemistry that is given in this book is somewhat distorted. It cannot be otherwise because of the intensely personal, even self-centered, though always straightforwardly expressed, viewpoint. For example, the connection between the $X\alpha$ method and the more fundamental Landau theory of Fermi liquids is never alluded to, despite its scientific importance. In fact, there is no reference to Landau or to many other important scientific figures of the period in the index. There is also no glimpse given of other very important ways of getting at the electronic structure of solids besides those with which Slater has been connected at some point in his career. The pseudopotential method is the most notable of these. Its simplicity and close connection with experimental results have made it one of the most widely used approaches to band theory.

This book is the first extended essay on the history of solid state and molecular physics. Despite some flaws, this account by one of its founders and most notable contributors will be an invaluable resource to the historian and fascinating to anyone who has had any contact with the field or with some of the institutions where it developed.

HENRY EHRENREICH
Division of Engineering and Applied Physics, Harvard University, Cambridge, Massachusetts

Tests of Gravitation

Experimental Gravitation. Proceedings of a school, Varenna, Italy, July 1972. B. BERTOTTI, Ed. Academic Press, New York, 1974. xx, 576 pp., illus. $42.50. Proceedings of the International School of Physics "Enrico Fermi," Course 56.

Gravitation is a realm of science in which each new experimental result is eagerly awaited, because the weakness of the gravitational interaction makes the battle for each new bit of information long and arduous, and because most physicists and astronomers would like their confidence in general relativity (or their own favorite theory of gravitation) to be based upon more than esthetic arguments. This volume admirably communicates to the reader the importance and difficulty of gravitational measurements, and describes many of the recent technological advances that have resurrected this field from dormancy.

In the past few years, a welcome degree of coherence has been brought to the subject by the development of theoretical frameworks for analyzing the increasing variety of experimental tests. This work, done chiefly by Kenneth Nordtvedt and Clifford Will, is beautifully presented in its most complete form by Will in the first lecture in the book. Such frameworks encompass virtually all currently viable theories of gravitation, which are each characterized by a set of parameters. They have also led to the proposal of new tests, such as that which employs lunar laser ranging, and have demonstrated the invalidity of many theories that were long considered viable.

What might be called "local" experiments essentially test the principle of equivalence, the foundation of most theories of gravitation. The most precise measurement to date of one of the consequences of this principle, the composition-independence of gravitational acceleration, is described by Braginsky, and plans for more accurate measurements using low-temperature techniques are described by Worden and Everitt. In another lecture in this volume, Vessot describes the planned use in a rocket flight of a hydrogen maser clock stable enough to measure the gravitational redshift, another prediction of the principle of equivalence, to an accuracy significantly better than the present value.

Another class of experiments includes those that make use of both man-made and natural bodies in solar system orbits. Anderson presents a useful summary of all factors involved in using spacecraft tracking data to test gravitation. Ways of dealing with the major limitation to the accuracy of such experiments, nongravitational forces, are also considered by Juillerat and Bertotti. The use of planetary orbits does not present this problem, but is limited by knowledge of the planet's topography. It is unfortunate that the recent progress in this area could not be included.

A series of lectures by Fairbank and his collaborators illustrates clearly how the use of low temperatures can make possible measurements of incredibly small effects in a wide variety of experiments, from gravitational-wave detection to the precession of an orbiting gyroscope. The two major advantages of low temperatures are the reduction of thermal noise and the existence of macroscopic quantum effects that can be employed in detectors, magnetic shielding and support, and many other ways.

At the time the summer school of which this volume is the proceedings was held, 1972, the only gravitational-wave experiments that were producing data were those of Weber and Braginsky, both of which are briefly described. These lectures can only provide a limited background for evaluating the conflicting results that now exist.

Among the other contributions, ones that are particularly relevant today are the presentations of opposing viewpoints on the significance of the solar oblateness experiment by Dicke and Roxburgh, and Sramek's presentation of his early results for the gravitational deflection of radio waves.

Two problems with this book are the delay in publication and the evident lack of care in typesetting. The lectures were not intended to survey the entire field of experimental gravitation, but what ground they cover has been covered well.

ROBERT V. WAGONER
Department of Physics, Stanford University, Stanford, California

The Time Problem

The Physics of Time Asymmetry. P. C. W. DAVIES. University of California Press, Berkeley, 1974. xviii, 214 pp., illus. $15.75.

How does time asymmetry come to be everywhere in the natural world (the milk bottle shatters irreversibly, the birth-to-death pattern of a biological organism is never reversed) even though the elementary natural processes of mechanics and electromagnetism are described by equations that are indubitably time-reversible (the motion of a particle will occur with a given initial direction or its reverse)? With the current concern for an overall, cosmic characterization of the universe, a parallel key question has come to be asked: What great natural process gives us a measure of the past, and future, of the universe? It is a merit of Davies's book that to a degree both questions are brought into a common investigation.

The customary Boltzmann's *H*-theorem approach to irreversibility is pursued in detail; and we learn how in a way it solves the problem, and yet in another does not do so at all, because the inherent statistical aspects of the theorem always allow, if one can wait long enough, the recurrence that is an effective reversibility. Davies has recourse to Reichenbach's *branch systems* as a method of bringing theory into accord with the observed irreversibility and entropy increase of nature. Any quasi-isolated system which we consider is in effect broken off in a state of relatively low entropy; hence, it does not share with the universe a long past history which would give it equal probability for entropy increase or decrease. Of course, in fact the total universe does not seem to be even close to an equilibrium state, and the solution to the question of its past and future must involve substantial questions about the cosmic processes. Ultimately, Davies proposes, these are problems relating to gravitation, which he sees as the origin of thermodynamic irreversibility. For, he notes, there are no true equilibrium states under gravity. The problems of choice of cosmological models, which seem largely to be determined by gravity, are naturally identified, then, with the problems of finding the universe's time characterization.

Davies fully uses the basic content of current theoretical physics: relativity and electromagnetic theory, statistical mechanics, thermodynamics, and quantum theory. Formally his treatment is self-contained, but its conciseness is such that I think the reader will want to have a fairly good background in physics.

The completeness of treatment in a relatively small volume is commendable. The discovery in elementary-particle interactions of a component of time irreversibility and its apparently nonsignificant role in macroscopic asymmetry is discussed. Also, Davies treats of the peculiar property that observation in quantum physics introduces a time asymmetry into natural process. He avoids such exotic solutions as an existence dependence of macrophysical state on awareness or formation of an entire universe for each substate in a superposition, in favor of a reasonable discarding of interference among macrostates. (But perhaps he does not adequately warn the reader that for his solution, too, there are formal objections.) There is an extended discussion of the Wheeler-Feynman electromagnetic absorber theory. One may question the importance of this speculative theory for time asymmetry, but the author's up-to-date account of it (it being one of his own research specialties) may be useful.

Davies's approach is directed toward time asymmetry as manifested in differences between the past (existence shown by physical traces) and future structures of physical systems. He disclaims any concern with "flow of time," and indeed asserts that time has no intrinsic properties whatsoever: there is no dubious "becoming," in contrast with the "objective, legitimate physical concept of time asymme-