until the early sixties. Arthur Eddington's confirmation of the third prediction, the light deflection, led to the dramatic acceptance of general relativity.

In spite of the newspapers' headlines, Eddington's observation as well as the perihelion shift (and, in fact, most of the current observations) only test some weak-field limit of general relativity. The uncertainty in Eddington's observations and the lack of conclusive observational evidence for strong fields has motivated many researchers to propose alternative gravitational theories. By now a few dozen such theories exist. In the early days a lack of observational data left a large margin for alternative theories. Similarly, a lack of computational tools led to proposals of theories whose predictions disagreed with existing data, the computations being too cumbersome to reveal inconsistencies.

In *Theory and Experiments in Gravitational Physics*, Clifford Will describes how this situation has drastically changed in the last 20 years. Technological advances have led to tighter limits on the old experiments and to new tests, some of which involve the most precise measurements ever made in physics. On the other hand, new theoretical formalisms, such as the parametric–post-Newtonian formalism, provide computational and conceptual tools for comparison of gravitational theories and experiments. Will, who contributed extensively to the theoretical developments in this field, describes the new confrontation between experiment and gravitational theory, which apparently leaves only general relativity and five other theories surviving.

The task of confronting theories with observations is fairly limited if one restricts oneself to existing theories or extremely ambitious if one wishes to include all possible theories. In the latter case one has to develop a theory of theories that should include all possible theories, including ones that have not yet been explicitly conceived, as well as (of course) the "real one." Will aims for the more ambitious goal in this book. He begins by a discussion of the Dicke framework. Examining the experimental evidence for the equivalence principle, he concludes that any theory of gravitation must be a metric theory. He proceeds with an extensive discussion of the parametric post-Newtonian formalism and its application to about a dozen gravitational theories and a half-dozen experiments. In the following section he describes the E(2) formalism for classification of gravitational theories according to the gravitational radiation that they contain (a purely theoretical discussion, of course, as gravitational radiation has not yet been detected). The rest of the book considers the structure of black holes and compact objects, the binary pulsar, and the implications of other cosmological matters on gravitational theories.

Although I enjoyed reading the book, I felt that the author emphasized the parametric post-Newtonian formalism at the expense of other topics. I would have liked to see a more detailed discussion of the experiments themselves. Will usually refers the reader to the original papers for such a discussion—an extensive reference list is indeed available—which I believe does not do justice to the book's title. After all, the same experiment may lead to a different conclusion when considered from the point of view of a radically different theory.

The validity of the Newtonian limit is another topic that deserves more detailed exposition. After he devotes one paragraph to the experimental status of Newtonian gravitation, Will stresses that all gravitation theories should yield Newtonian gravity as a limit. Considering the important impact of this restriction, one would desire a more careful discussion of the observational evidence supporting Newtonian gravity. After all, the inverse square law of gravity has been verified experimentally only in the range from a few centimeters to a few astronomical units; even within this range the question whether G is really a constant is not completely settled.

A potential danger in any text covering a large field is that the basic physical picture will be obscured by the fine details. Will avoids this danger successfully in the first chapter of the book in which he describes the Dicke framework. Unfortunately the connection between experiment and basic physical concepts becomes less clear in later chapters of the book, which overwhelm the reader with technical details.

After I read the book, curious colleagues asked me how well do general relativity and alternative theories pass the experimental tests. As is well known, general relativity passes all current tests with flying colors. Had there been a contradiction, we would have heard about it (probably prematurely) from the (front?) pages of *The New York Times*. The author shows that restricted versions of five competing theories (scalar–tensor, Will–Nordtvedt, Hellings–Nordtvedt, Rosen, and Rastall) pass all solar-system tests. However, the complete answer is left as an exercise to the reader. An additional chapter examining the experimental status of *all* current theories of gravitation and giving a complete up-to-date answer to this question would have served well as a conclusion for the book.

In spite of these few shortcomings, the experienced reader will benefit from this book. I can definitely recommend it as an extensive source of valuable information to anyone who wishes to become familiar with the "tools of the trade" in this field. It will enable researchers interested in new alternative theories to general relativity to make clear and immediate comparisons of new theories to existing experiments. To researchers contemplating new gravitational experiments, the book will provide useful guidance in considering the implications of their measurements on the verification of general relativity and competing theories, provided, of course, that they can afford the unusually high price ($75) of the book.

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Methods of Statistical Physics

A. I. Akhiezer and S. V. Peletminskii
448 pp., Pergamon, New York, 1981. $54.00

Statistical mechanics is a field of sharp dichotomies, in which few attempts are made to strike a balance. Some writers show an exclusive preoccupation with minutiae of mathematical rigor to the neglect of physical considerations; others do the opposite. The same imbalances exist with regard to principles vs. applications, Boltzmannian distribution functions vs. Gibbsian canonical ensembles, stochastic models vs. correlation functions, philosophical interpretation vs. pragmatic prediction, and so on.

As noted in a foreword by N. N. Bogoliubov, *Methods of Statistical Physics* is unique in that the authors try to balance these many extremes. In my opinion, while they come closer than anyone else in accomplishing this, they miss a point of basic understanding needed to bridge the most fundamental dichotomy.

The many applications have a neat and elegant quality. As one would expect from other well-known works of A. I. Akhiezer, the treatment of macroscopic electrodynamics is particularly thorough. The derivation of macroscopic hydrodynamics extracts a surprising amount of information from Galilean invariance; some of the special properties of superfluids are then seen to result from failure of Galilean invariance. The Wigner distribution function, hitherto a rather mysterious and unwieldy item defined on the 6N-dimensional phase space, becomes—by use of quantized wave functions—a Wigner distribution operator in ordinary position–velocity space, a much simpler and more useful quantity.

The applications are so interesting, useful and well presented that it is a temptation to concentrate entirely on them and pass over the less happy discussion of fundamentals. To do so, however, would run counter to the book's explicit purpose. The authors provide applications, valuable as they may be, to explicate certain general principles that they adopt as fundamental to statistical mechanics. It is really these principles that are being expounded; and we owe it to the authors to examine the work in that light.

Indeed, the useful applications of statistical mechanics are connected rather loosely to those fundamentals the authors proposed. In any particular application, the important and undoubtedly correct results usually turn out to be derivable from many different viewpoints. The danger of a too-narrow viewpoint is not so much that it will lead to a wrong prediction, but rather that it will suggest that the validity of a result depends on extraneous assumptions. Therefore, instead of asking which viewpoint is "correct"—a matter of personal opinion—it is better to ask which viewpoint leads to the most general results with the fewest assumptions—a matter of demonstrable fact.

The authors expound three general principles: the "contraction of distribution functions," the "attenuation of correlations," and the "ergodic relation." According to the first, after a short initial "kinetic phase" a joint probability distribution for the positions and momenta of n particles becomes a functional of (that is, is determined by) the Boltzmann single-particle distribution $f(x,p,t)$. Bogoliubov advanced the principle in 1947 as a tentative conjecture; the intervening years seem to have brought, if not proof, at least confidence; for Akhiezer and Peletminskii it has become a general principle. (However, I do not intend this as a criticism; for generally by a "principle" of statistical mechanics is meant some proposition that one wants to adopt but cannot prove—for once it is proved, it becomes a result, not a principle. Of course, this strategy necessarily entails the risk that one's principles will be disproved.)

The second principle is that as the separation between particles increases, their probability distributions become independent (in particular, uncorrelated). The authors also seem to assume, at first glance quite plausibly, that the range of correlations is short, of the order of the range of forces or at most a few times the mean free path. However, some caution is needed in making this assumption. For example, from the theory of response functions given in Chapter 4, the acoustic Green's function is $(kT)^{-1}$ times the space–time correlation function of the air pressure fluctuations, $\langle \delta P(x,t)\, \delta P(x',t')\rangle$. It follows that a student in the back of a lecture hall is able to hear the teacher's voice only because thermal pressure fluctuations at the student's ear and the teacher's mouth are correlated, over a distance of perhaps 10^9 mean free paths. If the distance required for attenuation of correlations is larger than the size of the macroscopic system under study, then the principle does not seem to have much content.

The third principle seeks to deal with a dilemma of interpretation that haunts us throughout the work, starting on page 1. Over and over again we find the statement that a system "makes a transition into a state of statistical equilibrium." Its quantum-mechanical version is easier to describe notationally. Given an initial "statistical operator" or density matrix $\rho(0)$, common teaching holds that its time development is given by the Schrödinger equation of motion:

$$\rho(t) = e^{-iHt}\rho(0)e^{iHt} \qquad (1)$$

On the other hand, equally common teaching holds that a system in thermal equilibrium at temperature T is described by a Gibbsian canonical distribution:

$$\rho_c \propto e^{-H/kT} \qquad (2)$$

Suppose, then, that a system with Hamiltonian H, in an initial nonequilibrium state described by $\rho(0)$, is left to itself and comes eventually to thermal equilibrium. Believing both of those common teachings, one seems forced to the conclusion that dynamical evolution of equation 1 must in the course of time lead to the "state of statistical equilibrium":

$$\rho(t) \rightarrow \rho_c \qquad (3)$$

But it is trivial to prove that this cannot, in general, be true. For equation 1 is a unitary transformation, and so not only is the information entropy $S_I = -k\,\mathrm{tr}(\rho \ln \rho)$ a constant, but also each individual eigenvalue of $\rho(t)$ is a constant of the motion. If the eigenvalues of the initial $\rho(0)$ are not the same as those of ρ_c, then no unitary transformation can carry $\rho(0)$ into ρ_c.

The difficulty was not seen so clearly in equilibrium theory, which simply postulated the canonical form and never paid much attention to the dynamical development. But any attempt to explain how a system manages to get into the equilibrium state presents the basic dilemma of irreversible statistical mechanics. Denying the validity of equation 1 denies that the system obeys the Schrödinger equation. Denying the validity of equation 2 denies experimental facts. Yet it is a mathematical theorem that in general equations 1 and 2 are incompatible. Each writer on the subject must find some way around this difficulty; most try simply to obscure it. Akhiezer and Peletminskii are refreshingly clear and forthright on this point; they simply ignore the mathematical theorem and assert the validity of equation 3 as an "ergodic relation." Equilibrium is achieved by fiat.

A point of understanding is missed here, one that was recognized clearly by Aleksandr Y. Khinchin about 40 years ago. In trying to bridge the dichotomy between equations 1 and 2, it would be far stronger than necessary and almost always untrue to assert that the distributions themselves become the same. It is sufficient to show that their physical predictions, for the particular macroscopic quantities of interest, become the same. It may well be that the authors' principles of contracted distributions and of attenuation of correlations would have helped in demonstrating this identity, but for intervention of their extraneous "ergodic relation."

In summary, the work has a beautiful and impressive collection of applications, which teachers of advanced statistical mechanics will want to use. The discussion of fundamentals is dated, however, and needs much revision before it would be suitable to use as a modern textbook.

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Bound for the Stars

S. J. Adelman, B. Adelman
335 pp. Prentice-Hall, Englewood Cliffs, N. J., 1981. $17.95 cloth, $8.95 paper

Bound for the Stars is an interesting book devoted, as the title indicates, to the feasibility of manned exploration of nearby stars. It contains essentially one equation (the so-called Drake equation, which simply estimates the unknown number of civilizations as a product of several equally unknown factors, such as L, the average lifetime of these civilizations) and a few versions of the coordinate sphere. I suspect it provides too little detail to satisfy readers of PHYSICS TODAY. My guess is that it is intended as general reading accessible to anyone having a high-school education. It might possibly serve as one of several books supporting a popular general course on space and space travel.

Bound for the Stars has a few nuggets for most everyone. The authors have done a good job of pulling together a wide variety of information, much of which the interested reader would find hard to locate in a library in such a coherent form. I personally enjoyed the critical assessment of the now-defunct President's Science Advisory Council's wishy-washy deliberations over what NASA should do after Apol-