At last—a sane look at the "arrow of time"

The Physics of Time Asymmetry

P. C. W. Davies
214 pp. Surrey U. P., London, 1974. £6.50

Reviewed by John Archibald Wheeler

Never has a saner book been written on a more insane subject. In every other part of physics there is reasonable concensus as to the lay of the land; but this is not so when it comes to the "arrow of time." One has only to question a dozen responsible and thoughtful physicists to find that there are two camps on the matter. No one doubts that entropy increases, stars pour out energy, evolution moves forward in time and memory contains only the past—and that all this development goes on while the universe is expanding. But the evidence is powerful that the expansion of the universe is slowing down and that there is truth in Einstein's views that this expansion will come to a halt and be followed by a phase of contraction.

As dynamic time marches forward, what will happen then to statistical and biological time? Will they continue to point in the same direction or will they point in opposite directions? In the one case, to a person alive in the second phase of the universe, the universe will appear to be contracting. In the other case, it will appear to be expanding, simply because a moving picture of contraction run backwards looks like expansion. Many colleagues agree that the question is open and that the answer is one of the great puzzles of our day; but others are strongly convinced that the one answer or the other is the only right answer and that the answer is perfectly obvious and should be accepted without question. This is the insanity of the subject.

No one has done more to give a forum to this diversity of views than Thomas Gold (Cornell) who organized there some years ago a fascinating conference on the "arrow of time," the proceedings of which were subsequently published (*The Nature of Time*, T. Gold, ed., Cornell U. P., 1967). Those discussions were productive, but the student could well feel at a loss in going through the proceedings because of the wide range of topics, including cosmology and elementary-particle physics, statistical mechanics and the mechanism of brain action.

With this book by P. C. W. Davies, the physics of time asymmetry becomes, for the first time, something approaching a single well-defined subject rather than "a collection of consistency problems that arise in almost all branches of physics when confronted with a choice of boundary conditions compatible with the real world." As Davies puts it, "... different authors have approached the subject from widely varying standpoints, employing almost nonintersecting explanation schemes and terminology for what should really be the common ground of much of 20th-century physics. The first purpose of this book is to collect together all these essentially related strands of research, and to combine them into a single subject matter with a uniform terminology and careful attention to definitions." In so doing, the author has created what would appear to be a pioneering textbook suitable for a part-year or full-year course, either in the senior or graduate-student level, a text on the "arrow of time" that takes a new cut through physics and furnishes a new perspective to those participating.

The first chapter deals with time as a fourth dimension and the meaning of time asymmetry. The second deals with thermodynamics and statistical mechanics, carrying the reader through the generalized H theorem and the meaning of entropy. Chapter 3 takes up the objections that arose in earlier years to the idea of entropy out of considerations of reversibility. To give an indication of the flavor of the discussion in this part of the book, I quote: "A reversal of the molecular velocities would certainly carry the system back to its initial state (time reversed) again, proving that it had not 'forgotten' the initial conditions. The conventional counter is that such a reversal cannot in practice be effected (in the words of Boltzmann: 'Go ahead, reverse them'). It must be admitted that this appears somewhat evasive, and is actually invalidated in the case of the spin–echo experiments of Hahn that indeed bring about a kind of reversal."

Chapter 4 is concerned with thermodynamics and cosmology. To make the discussion more accessible to the student, "General relativity is kept to a minimum, much of the cosmological discussion being referred to local neighborhoods of the comoving frame, in which ordinary language and definitions suffice." The physics reader of today is well acquainted with the limerick about the encounter on the beach between Mr Teller, made of matter, and Mr Antiteller, made of antimatter; but neither this encounter nor the encounter between Mr Time and Mr Antitime, as described so vividly by Boltzmann and (separately) by Norbert Wiener finds a place—perhaps one more indication of Davies's effectiveness in preserving sanity in an otherwise insane subject! This chapter concludes "We have reached a remarkable conclusion. The origin of all thermodynamic irre-

versibility in the real universe depends ultimately on gravitation. *Any* gravitating universe that can exist and contains more than one type of interaction material *must* be asymmetric in time, both globally in its motion, and locally in its thermodynamics." In this chapter black holes are discussed briefly and clearly though the subject has undergone new developments since the book went to press, not least in the new evidence that Cygnus X-1 is a black hole and in the revolutionary arguments of Bekenstein and Hawking that a black hole is endowed with a temperature and a "quantum radiance."

Chapter 5 deals with electromagnetic waves, retarded and advanced fields, preacceleration and the absorber theory of radiation. Chapter 6 takes up time asymmetry in quantum mechanics and includes a brief and clear discussion of T violation in elementary-particle physics. The final chapter is concerned with the old idea of the "heat death of the universe" and more recent cosmological models, including the steady-state theory, the oscillating universe, and time-symmetric cosmologies.

The book contains a most thoughtful brief discussion of the pioneering experiment of R. B. Partridge aimed at looking for reduced radiation reaction when a source of radiation is directed out into a region of space where absorption can be imagined to take place only so late in time that the universe is then contracting [Nature, **244,** (363) 1973]. As an indication of the balanced judgment of the author and his attempt to give absolutely fair treatment to varied points of view, it is appropriate to quote this paragraph from the conclusion:

> Philosophers will distinguish two prevailing schools of thought regarding the creation event (setting aside for the moment the models which do not have one). Traditionally, the present condition of the universe has been regarded as a highly specific one, requiring the creation to have been of a very particular nature to ensure the appropriate subsequent structure. In recent years, developments in modern cosmology have had a profound impact on this question. Many people now incline to the opposite point of view, i.e. that the present state of the cosmos is a *typical* one, which would almost certainly result from a very wide range of initial conditions. As a conclusion to this book, it is interesting to see how the subject of time asymmetry has provided material for both these points of view.

The precise, clear, exposition of this book, its breadth of vision, its up-to-dateness and the list of references to the literature and annotated notes on books for further reading, taken altogether make it a text for the undergraduate or graduate student and fascinating reading for every physicist concerned with the "arrow of time."

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Kinetic and Nonsteady-State Effects in Superconductors

B. T. Geilikman, V. Z. Kresin
155 pp. Wiley, New York, 1974. $19.75

Critical Currents in Superconductors

A. M. Campbell, J. E. Evetts
243 pp. Barnes & Noble, New York, 1973. $12.75

Developments in the technology of high current capacity wires using type II superconductors are quite innovative considering the lag in a good quantitative theoretical understanding in the crucial area of pinning of flux vortices. It is now well known that one needs to suppress dissipative flux movement by introducing pinning sites in the superconductor and by the addition of a normal conductor, like copper, for thermal and magnetic stability.

The book by A. M. Campbell and J. E. Evetts, of the department of metallurgy and materials science, University of Cambridge, is a reprint of their article originally titled "Flux Vortices and Transport Currents in Type II Superconductors" [Adv. in Physics **21,** 199 (1972)]. It reviews the authors' own work as well as that of others on the subject of vortex pinning, its relationship to metallurgical defects and the underlying physics of the homogeneous case. This subject does not lend itself to a general theoretical treatment, largely because of the varied ways in which a pinning effect can be realized. Moreover, conflicting theoretical viewpoints that often lead to similar results have not been resolved experimentally because of questionable applicability to specific experiments. Indeed, the technologically most interesting and useful materials have been the hardest ones to deal with theoretically.

Campbell and Evetts have detailed phenomenological models that consider the role of the elastic properties of the vortex lattice and local pinning forces of various kinds. These are well introduced by a rather complete review of relevant studies of the mixed state in the 1960's. Their book should be of particular interest to researchers active in this field, who presumably are already familiar with much of its content, both as a reference and as a presentation of the views of the authors on certain cases.

The short book by Boris Geilikman, of the Kurchatov Atomic Institute, and Vladimir Kresin, of the Moscow State Extention Pedagogic Institute, is in part a tutorial review of the theory of thermal conductivity and sound absorption in superconductors, the field of the authors' own contributions. Of the problems first tackled by the BCS theory, sound absorption got much attention because of the information on the electronic spectrum and the temperature dependence of the energy gap such studies provide. The book includes topics such as the effects of impurities, strong coupling, gap anisotropy and the intermediate state structure in varying detail. Mixed-state effects are treated briefly, and the more recent developments are omitted.

There is a short chapter on so-called thermal effects, reviewing theoretical speculations on unusual transport properties due to normal excitations, believed to occur near the transition temperature. As an example, a weak magnetic field can be produced by applying a temperature gradient to a uniaxial, pure superconductor.

A chapter on the influence of rf electromagnetic fields includes a discussion of non-linear effects. The authors