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.

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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 asymmetry." And, he writes, his approach is "rooted in the real world," with no recourse to reduction of the time problem "to subjective concepts, such as language or psychology." These, and other comments, tell the reader that he will find no enlightenment in the book with respect to the genuine philosophical questions about the meaning and use of the time concept. Perhaps one should not cavil, for Davies has delivered well on the promise implied in the title. Yet, it is surprising: in his conclusion he rests the overall time pattern of the universe on cosmological problems which I would judge, difficult as they may be, are essentially physical; but, notwithstanding an attitude of scorn for philosophers, he in the end proposes that these last questions be left with them for solution.

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Archeoastronomy Advancing

The Place of Astronomy in the Ancient World. Proceedings of a symposium, London, Dec. 1972. F. R. HODSON, Ed. Published for the British Academy by Oxford University Press, New York, 1974. iv, 276 pp., illus. + plates. $41.75. Reprinted from *Philosophical Transactions* of the Royal Society of London, Series A, Vol. 276, No. 1257 (1974).

Science Awakening. Vol. 2, The Birth of Astronomy. BARTEL L. VAN DER WAERDEN. With contributions by Peter Huber. Noordhoff, Leyden, and Oxford University Press, New York, 1974. xvi, 348 pp., illus. $35.

Astronomy is reputedly the second oldest profession, but its origins were long ago lost in the mists of time. What was for millennia common knowledge, such as the way the ancient Egyptians mapped their fantastic animal constellations against the stars, has now been forgotten, perhaps irretrievably.

Modern scholars who would reconstruct the beginnings of astronomy have been mining the written records—from cuneiform tablets to Mayan codices—with admirable perspicacity and brilliant results. Other possible sources include those artifacts that more generally are in the province of the archeologists. Nowadays the most prominent of these are the megalithic circles that may have been prehistoric observatories.

Just over a decade ago, megalithic astronomy began to achieve international notice, somewhat to the annoyance of archeologists and of the students of "exact sciences" in antiquity. Meanwhile, the extensive measures of stone circles carried out by the indefatigable Alexander Thom have brought forth evidence that can no longer be ignored. Thus in 1972 the Royal Society and the British Academy convened a symposium on the place of astronomy in the ancient world. It is perhaps premature to say that archeoastronomy came of age with this conclave, but in the volume of proceedings the section on unwritten evidence occupies over half the pages.

Although it is the megalithic astronomy that has caught the popular fancy, this volume serves to remind us of the recent impressive progress in understanding Egyptian, Mayan, Chinese, and above all Babylonian astronomy. Many of these results are available elsewhere—Needham's material in volume 4 of his monumental *Science and Civilisation in China,* or R. A. Parker's in his monograph on the calendar of ancient Egypt plus the multivolume Neugebauer-Parker treatise, *Egyptian Astronomical Texts*—but nowhere else can one find such authoritative summaries in a single convenient place.

A. Aaboe's masterly brief review of ancient theoretical astronomy points out clearly how the Babylonian approach to planetary theory differs from Ptolemy's. J. E. S. Thompson stresses the importance of Venus in Mayan astronomy; he also expresses his doubts that the round tower at Chichen Itza served as an observatory. A. Thom's paper is an unexpected disappointment. Tersely written, it will make sense only to readers having a considerable familiarity with his earlier books and articles.

The climax of the symposium (from the point of view of the delicate balance between the "scientific" astronomy of antiquity and the more speculative interpretations of the great stone monuments) comes in the final paper, where statistician D. G. Kendall analyzes the diameters of the British stone circles to see if Thom's "megalithic yard" of 2.72 feet is a significant standard unit. Kendall's exemplary exposition makes his methods lucid even to the nonspecialist. He finds clear evidence for the megalithic yard, such that there is only a 1 percent chance that the diameters could be represented by a smooth, nonquantal distribution. Given the question "Does the analysis of the available data justify the expenditure of public monies on a costly and sophisticated aerial re-survey of the circular sites?" he answers affirmatively.

Thus megalithic numeracy has achieved a certain credibility, and Stone Age astronomy has ridden the coattails to a new respectability. Archeologist R. J. C. Atkinson, who greeted the early work with a scathing review entitled "Moonshine on Stonehenge," here cautiously points to the contradiction between "the positive evidence for prehistoric mathematics and astronomy on the one hand, and the negative evidence for recorded numeracy on the other." More recently, after further considering Thom's researches in both Britain and Brittany, Atkinson has said that he is prepared "to believe that my model of European prehistory is wrong rather than that the results presented by Thom are due to nothing but chance" (*J. Hist. Astron.* **6**, 51 [1975]).

A second important volume on ancient astronomy published in 1974 is the English translation of B. L. van der Waerden's *Anfänge der Astronomie.* A sequel to his *Science Awakening* volume on the early history of mathematics (Oxford University Press, 1961), *The Birth of Astronomy* describes Egyptian and Babylonian astronomy in substantial detail, thus furnishing the most readily accessible source for the mathematical methods of Mesopotamian astronomy.

The author's relaxed and personal style makes his book interesting to read, although English-speaking readers will be distracted by such names as "Platon," "Aristoteles," and "Apollon," an idiosyncrasy inconsistently practiced and not found in the first volume of the series. Although the typography is excellent, the 31 plates have generally been copied from halftones in the German edition rather than afresh from glossy photographs, the result being low-quality and inexcusably moiréed reproductions.

Van der Waerden's account provides a remarkable juxtaposition of the "hard" analysis of the exact sciences with "soft" speculation on the intertwining of astronomy, astrology, and astral religion. In this new version, the German original has been considerably rearranged to give greater prominence to his long chapter on cosmic religion. Briefly, he argues that the religious currents and ferment of the Middle East in the 1st millennium B.C. provided the cultural framework out of which astronomy arose. The astral aspects of the Mithraic cult and Greek Orphism furnished the background against which the zodiac became a significant astrological concept. Spurred by the collapse of the Assyrian empire in 612 B.C., these religions gained new adherents and influence; in van der Waerden's view, the fact that systematic planetary observations begin at about this same time is not accidental. In turn, the rapid development of computational