Departures from Symmetry

The Physics of Time Reversal. ROBERT G. SACHS. University of Chicago Press, Chicago, 1987. xvi, 309 pp., illus. $55; paper, $23.

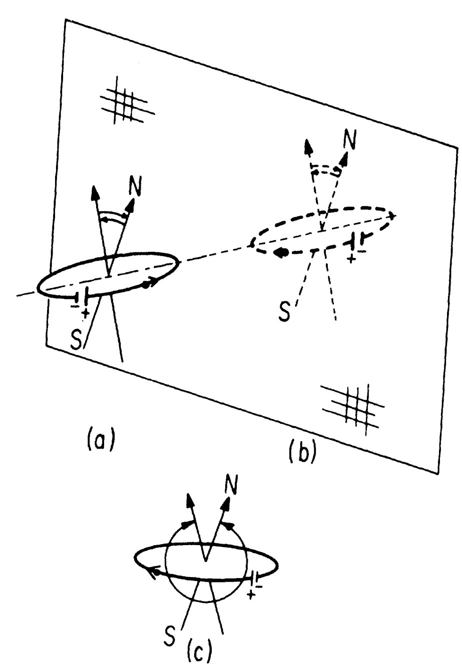
Until the astonishing discovery 30 years ago that the weak interactions responsible for beta-radioactivity can distinguish between right and left, it had been assumed that all physical laws should be invariant under space inversion, that is, that the mirror reflection of any physical phenomenon should also represent a possible physical process. This principle had been applied with great success by Wigner to explain and predict various "parity" selection rules in atomic and nuclear physics. Wigner developed similar considerations for time inversion and showed that the hypothesis of invariance with respect to reversal of the time coordinate (T) led to an explanation of the known Kramers degeneracy as well as to the prediction of other regularities.

The breakdown of space reflection symmetry, which led to spectacular advances in our knowledge and understanding of weak interactions, naturally stimulated questions about the possible failure of T invariance. Despite considerable experimental effort, however, there has not yet been *any* direct demonstration of departure from that symmetry in any phenomenon. At first this was consistent with theoretical prejudice, because an attractive theoretical suggestion linked the observed space asymmetry in beta-decay and related experiments to the asymmetry between matter and antimatter. According to the hypothesis of symmetry under the combined inversion of charge and parity (CP), the mirror image of any observed phenomenon represents the corresponding phenomenon, with each particle replaced by its corresponding antiparticle. Very general principles of relativistic quantum theory, which require invariance under the combined operation CPT of space-time inversion and particle-antiparticle interchange, then require that CP symmetry be accompanied by strict T invariance.

In 1964, the even more shocking discovery was reported, from a study of neutral K-meson decays, that CP cannot be an exact symmetry either. Within the framework of the usual theoretical description, we are forced to the conclusion that symmetry under time inversion must also be abandoned, despite the fact that there has not thus far been any direct evidence for its failure. In the absence of observed deviations from T invariance, and since the only known violations of CP symmetry are confined to neutral K-meson decays, we do not have any clear idea about the origin or cause of this lack of symmetry.

The major part of Sachs's book is devoted to this problem, although the author's declared objective is as much to expound the utility of T invariance, which is valid for all practical purposes in a wide variety of phenomena. To prepare the ground, Sachs begins with discussion of time reversal in classical mechanics and explains clearly that the statement of invariance refers to the equations of motion and not to the actual motions themselves. An amusing example is an adaptation of the demonstration by Painlevé in 1904 that a cat dropped from rest cannot during free fall change its orientation to one that differs from its original one by a simple rotation. The Loschmidt objection to Boltzmann's H theorem is explained; the irrelevance of time reversal symmetry for the validity of that theorem, as well as its associated definition of the entropic arrow of time, is described succinctly and well. But the real issue is the question of departures from time-reversal symmetry in the microscopic laws of physics.

Sachs, who has made important contributions to nuclear and particle physics, was one of the few to study the problems arising from possible CP noninvariance even before the shattering discovery of 1964. He informs us that he became aware of the importance of time-reversal arguments when Wigner pointed out the simplifications they brought in nuclear-structure calculations, and he gives a good account of the regularities in atomic and nuclear physics imposed by such considerations. This requires a careful discussion of how time-reversal invariance is incorporated into quantum mechanics, which is done in a manner that should be useful to students encountering this subject for the first time. The author states that whereas in classical mechanics "motion reversal acts as the surrogate for time reversal . . . there are additional implications of time reversal in quantum mechanics." Unfortunately, this interesting suggestion—that time-reversal invariance in quantum mechanics implies more than reversibility of all motions—is neither developed nor substantiated later. The description of improper transformations (space and time inversion and particle-antiparticle conjugation) for relativistic fields is introduced in a way that is not so novel as the author implies; it is simply a rather old-fashioned way of defining the transformations for the free-field case. These are used to give a proof of the CPT theorem, which is then applied to derive various important relations between the behavior of particles and antiparticles. Using his own particular viewpoint, Sachs uses the standard phenomenological analysis of neutral K-meson decays to reach the generally accepted conclusion that the data on K° decays cannot be easily reconciled with T invariance. This is followed by a rather complete discussion of attempts (up to 1986) to accommodate CP and T noninvariance in quark models of the weak interactions, and corresponding estimates of CP-noninvariant effects in heavier homologs like B° mesons.



"(*a*) Small oscillations in a plane parallel to the mirror of an infinitely thin (one-dimensional) magnetic needle about an axis on the diameter of the loop. (*b*) The image in the mirror perpendicular to the axis of oscillation. (*c*) The motion in the laboratory when conditions are those seen in the mirror." [From *The Physics of Time Reversal*]

Somewhat surprisingly, Sachs's discussion of T noninvariance in K-meson decays makes no attempt to connect it with any departure from reversibility, although this can be easily done; for the heavier mesons, T invariance is hardly mentioned at all. A similarly surprising omission is the failure to describe, except in a footnote and without mention of his name, the intriguing suggestion by Sakharov that the observed preponderance of matter over antimatter could arise from CP- and T-noninvariant processes in the early universe, requiring also that baryons not be absolutely conserved. Instead, Sachs concludes with a series of what can only be described as extremely speculative remarks about the origin of violation of CP and T symmetry. In his opinion, "It is sometimes useful to start an argument without knowing the end of it." The book should be useful to students entering the field. Much work remains to be done, and there will undoubtedly be more books on this subject.

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Newton Tercentenary

Three Hundred Years of Gravitation. S. W. HAWKING AND W. ISRAEL, Eds. Cambridge University Press, New York, 1987. xiv, 684 pp., illus. $69.50.

This volume is a collection of 16 solicited contributions published in association with a Newton Tercentenary Conference held last summer at Trinity College, Cambridge, and summarizing the state of gravitation 300 years after the publication of Isaac Newton's *Principia*. The initial essays by Stephen W. Hawking and Steven Weinberg discuss Newton's greatest achievements. These include his development of the laws of mechanics, the universal inverse square law of gravitation, and the calculus. Weinberg feels that at the heart of the greatness of the Newtonian achievement is the fact that "mankind for the first time saw the glimpse of a possibility of a comprehensive quantitative understanding of all of nature." Hawking points out that the Newtonian universal law of gravitation is inconsistent with the idea held in Newton's time that the universe is filled with a static and nearly uniform distribution of stars extending infinitely in all directions. As Hawking shows, Newton used a fallacious argument to justify a static universe. When Einstein first published his theory of general relativity (which includes Newtonian gravitation as an important limit), his equations did not permit a static universe. In order to allow a static universe, Einstein in 1917 modified them by introducing the cosmological constant. He later called this modification his worst blunder. It is remarkable that two such great minds as Newton and Einstein missed an opportunity to predict a nonstatic universe.

Roger Penrose's essay is interesting because of his unconventional view of why Newton doggedly maintained his belief in his corpuscular theory of light and because of Penrose's conviction that the gravitational field is instrumental in the reduction of the wave packet—a profound idea. In any volume purporting to survey research in gravitation, a review of experiments is essential. A. H. Cook and Clifford M. Will admirably survey the status of current experimental and observational tests of theories of gravitation. Cook concentrates mainly on laboratory experiments, whereas Will's discussion also ranges over the motion of the planets, the moon, light, and stars in binary systems. One of the most important systems for testing general relativity is the binary pulsar PSR 1913 + 16, which consists of a pulsar in close orbit about an unseen companion. General relativity is essential for determining the orbital parameters of this system. As Will points out, the rate of loss of orbital energy can be attributed to gravitational radiation and is consistent with the quadrupole formula of general relativity and inconsistent with dipole formulas predicted by a class of alternative metric theories of gravitation. The discovery of the binary pulsar has encouraged much recent theoretical work on the general relativistic two-body problem. Thibault Damour reviews the current status of this problem.

Werner Israel gives a carefully researched and readable historical sketch of the development of the idea of black holes. He starts with the work of John Michell, who speculated in 1783 on the possibility that there might exist bodies so dense that "their light could not arrive at us," continues through the history of white dwarfs and neutron stars, the final states of gravitational collapse, and the thermodynamics of black holes, and ends with the discovery in 1974 by Hawking that black holes produce blackbody radiation through gravitational effects. This historical sketch is particularly good because of the author's insight as an important contributor to the field. He states that as the narrative "moves nearer to the present, the perspective inevitably becomes more subjective. Others, located at diverse research centres around the globe, will have experienced the events recounted here in their own very different ways." This reviewer is one case in point. The quantum field theoretical method of treating particle production in gravitational fields, which was applied in deriving the black-hole radiation, was originally developed by me in the 1960s to investigate particle production by the expanding universe. The method was further applied in 1971–72 by Stephen Fulling in his Ph.D. dissertation to a situation involving event horizons. My work and the work of Fulling played an important role in the development of the ideas that led to Hawking's definitive calculation of the spectrum of particles created by a black hole, although it is not included in this historical sketch. Furthermore, the assertion that skepticism about Hawking's 1974 paper was "prolonged and virtually unanimous" is not entirely correct. (I, for one, immediately recognized the result as correct.)

Astrophysical black holes occurring as the end state of stellar gravitational collapse are sufficiently massive that their temperature is negligible. However, they act as sources of energy through the heating of infalling matter, which radiates as it spirals gradually inward. R. D. Blandford gives an up-to-date survey of astrophysical black holes, including a good discussion of observational evidence for their existence, which appears strong in at least three cases. In the next one or two decades gravitational wave astronomy will open up a key new window on the universe. One of the most important contributions in this volume is a complete review of gravitational radiation research by Kip S. Thorne. This includes a particularly good discussion of astrophysical sources of gravitational waves and methods for detecting them. The Newtonian dynamics of bound groups of galaxies seems to imply that much of the matter in the universe is in a nonluminous, unobserved form. An interesting discussion of dark matter and the large-scale structure of the universe is given by Martin J. Rees. Alexander Vilenkin gives a clear exposition of the basic physics involved in deriving the gravitational properties of cosmic strings, one of the candidates for explaining the large-scale structure of the universe.

The cosmological constant introduced by Einstein has regained significance in recent work. Certain elementary particle theories imply that at very early times there may have been a large cosmological constant caused by vacuum energy, which would have produced a very rapid early expansion of the universe. These "inflationary" models are of considerable interest because they offer a possible explanation of several observed facts, such as the homogeneity of the cosmic background radiation and the near spatial flatness of the universe. Steven K. Blau and Alan H. Guth offer a well-written, comprehensive review of inflationary models. This is followed by Andrei Linde's discussion of chaotic inflation, in which inflation is produced by an initial nonequilibrium distribution of a scalar field. Some of the deepest issues in cosmology are addressed in the essay by Hawking on quantum cosmology. These include the choice of the initial quantum state of the universe and the question why the observed universe shows an asymmetry between the future and the past. The leading candidate for a unified theory that includes gravitation is superstring theory, in which the elementary constituents are strings rather than point particles. John H. Schwarz, one of the key developers of the theory, gives an overview. Finally, Cedomir Crnković and Edward Witten in a clearly