RESEARCH FACILITIES AND PROGRAMS

Matter-antimatter asymmetry found in intermediate interaction

The symmetry of matter and antimatter in electromagnetic interactions is seriously in doubt. An experiment on the decay of the η^0 meson into a π^+, π^- and π^0 shows that, on the average, the π^+ comes off with more energy than the π^-. This result, reported in the 27 June issue of *Physical Review Letters,* implies that charge-conjugation invariance, believed valid in strong interactions, does not hold in interactions that have less strength. The discovery of this matter-antimatter asymmetry has intrigued such diverse beings as particle physicists, newspaper reporters and space-agency workers.

During the past decade three apparent symmetries of nature have come increasingly under suspicion and examination (see T. D. Lee, PHYSICS TODAY, March, page 23). Until ten years ago, invariance under charge conjugation (which reverses the signs of all charges) was unquestioned. Then Chen Ning Yang and Tsung Dao Lee, tormented by the theta-tau puzzle, suggested that parity P (which mirrors right into left) and C invariance might not be conserved in weak interactions. Experiments confirmed that, indeed, C and P were not conserved in weak interactions.

Symmetry was soon restored by theorists who suggested that the product of C and P was conserved instead. Then CP invariance in weak interactions was called into question, too, after a Princeton group (*Phys. Rev. Letters* **13**, 138, 1964) found that the K_2^0 meson occasionally decayed into two pions. CP-violating decay occurred once in 500 times. Violation of CP invariance implied that time-reversal invariance T was also violated in weak interactions since the CPT theorem (apparently required by special relativity) requires that the product of C, P and T be conserved in microscopic interactions.

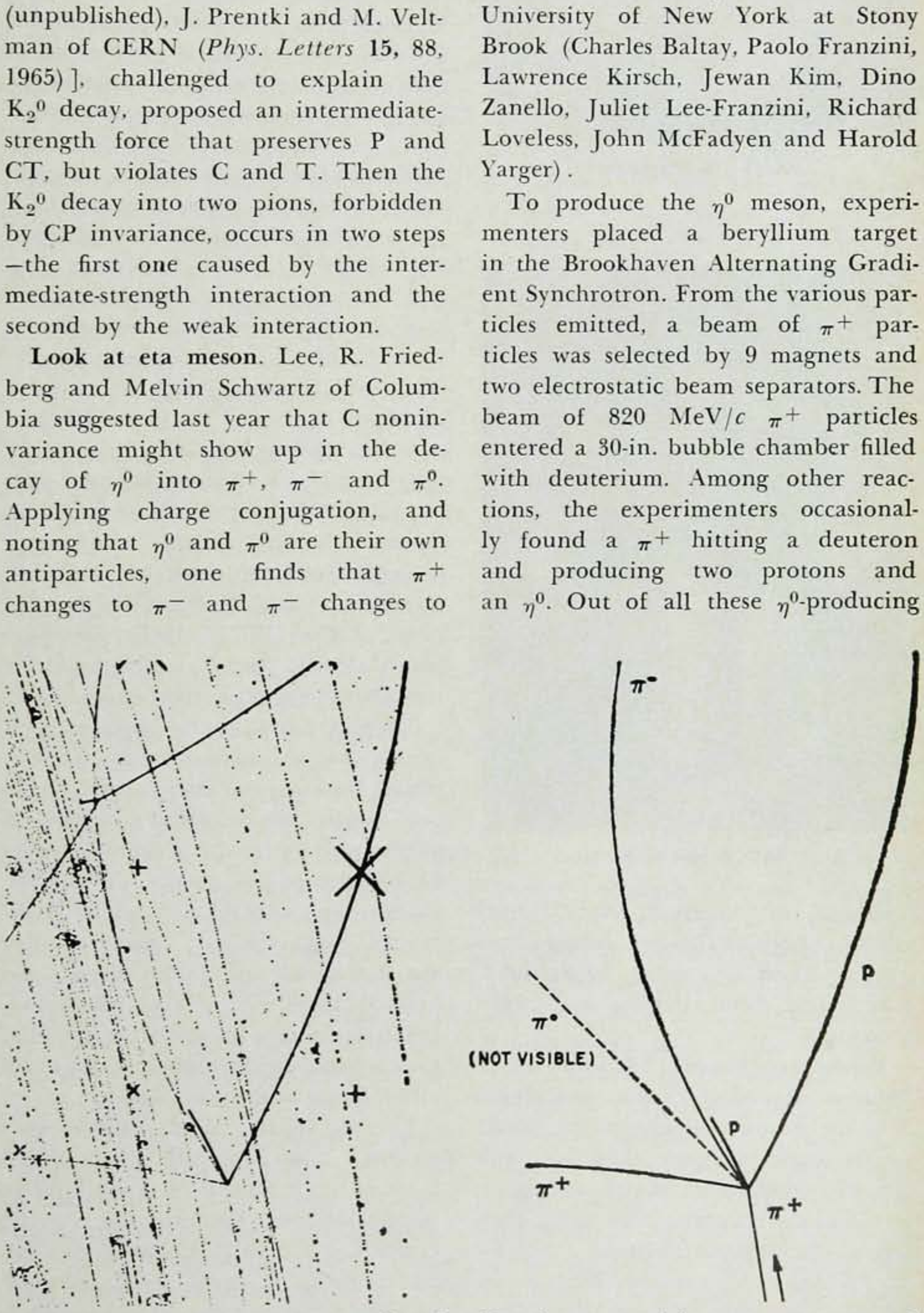
But interpretation of the K_2^0 experiment was controversial. Theorists entered a period of agonized questioning: Which symmetries *are* conserved? Is there another kind of force, aside from strong, electromagnetic, weak and gravitational, that we have not detected yet?

Early last year several theorists [Lee and Lincoln Wolfenstein of Carnegie Tech (*Phys. Rev.* **138**, B1490, 1965), L. B. Okun of the USSR (unpublished), J. Prentki and M. Veltman of CERN (*Phys. Letters* **15**, 88, 1965)], challenged to explain the K_2^0 decay, proposed an intermediate-strength force that preserves P and CT, but violates C and T. Then the K_2^0 decay into two pions, forbidden by CP invariance, occurs in two steps—the first one caused by the intermediate-strength interaction and the second by the weak interaction.

Look at eta meson. Lee, R. Friedberg and Melvin Schwartz of Columbia suggested last year that C noninvariance might show up in the decay of η^0 into π^+, π^- and π^0. Applying charge conjugation, and noting that η^0 and π^0 are their own antiparticles, one finds that π^+ changes to π^- and π^- changes to π^+. If C symmetry holds, the π^+ should carry off more energy than the π^- exactly as often as the inverse. If C symmetry does not hold, one kind of pion will come off, on the average, with more energy.

Several laboratories attempted to find an asymmetry in the η^0 decay. The most significant results, reported 27 June, were found by a group from Columbia University and the State University of New York at Stony Brook (Charles Baltay, Paolo Franzini, Lawrence Kirsch, Jewan Kim, Dino Zanello, Juliet Lee-Franzini, Richard Loveless, John McFadyen and Harold Yarger).

To produce the η^0 meson, experimenters placed a beryllium target in the Brookhaven Alternating Gradient Synchrotron. From the various particles emitted, a beam of π^+ particles was selected by 9 magnets and two electrostatic beam separators. The beam of $820\ \mathrm{MeV}/c$ π^+ particles entered a 30-in. bubble chamber filled with deuterium. Among other reactions, the experimenters occasionally found a π^+ hitting a deuteron and producing two protons and an η^0. Out of all these η^0-producing



ETA-ZERO DECAY. One of events found by Columbia—Stony Brook group. Pi-plus hits deuteron giving two protons and eta-zero, which goes to three pi's.

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reactions, they further selected only those in which the η^0 then decayed into π^+, π^- and π^0. After background events had been thrown out, 1441 remained.

Asymmetry found. To look for a possible asymmetry, they calculated $N+$, the number of events for which π^+ is more energetic than π^-, and $N-$, the number of events for which π^- is more energetic than π^+. They found the asymmetry $A = (N+ - N-)/(N+ + N-)$ was 0.072 ± 0.028. That is, on the average, π^+'s have more energy 7% more often than π^-'s do.

Other groups have also seen indications of asymmetry, but with less certainty. A compilation of 1300 events (to be published) measured at Columbia, Berkeley, Purdue, Wisconsin and Yale, shows $A = 0.058 \pm 0.034$. Earle Fowler of Duke, at the April American Physical Society meeting, reported 355 events with $A = 0.087 \pm 0.053$.

Before these experiments were over, Lee, working with Jeremy Bernstein (New York University) and Gerald Feinberg (Columbia) (*Phys. Rev.* **139,** B1650, 1965) undertook a careful examination of experimental evidence for each of the particle symmetries in each of the interactions. Surprisingly, for some symmetries taken for granted over the years, there was almost no evidence. For electromagnetic interactions of strongly interacting particles, there was absolutely no evidence that either C or T is invariant (unlike electromagnetic interactions of leptons, which are C invariant to at least the fifth or sixth decimal place). They explained the K_2^0 decay as a violation of C (or T) in the electromagnetic interaction. Then the decay would occur in three steps—the first two caused by an electromagnetic interaction (emitting and absorbing a photon), and the third by the weak interaction. Saul Barshay of Rutgers (*Phys. Letters* **17,** 78, 1965) also proposed that C (or T) is violated in the electromagnetic interaction.

To find out if the η^0 asymmetry is caused by an electromagnetic force, rather than a new intermediate force, one should look at a decay that yields a photon. Since the Columbia-Stony Brook group has plenty of bubble-chamber photographs showing η^0 decaying into π^+, π^- and γ, they are now analyzing these events, and hope to learn if the C-invariance violation is indeed produced by an electromagnetic force. Other groups are also looking at the same decay.

Lee, in talking about particle symmetries, now carefully distinguishes between C, P and T for each kind of interaction. So, for example, he discusses C_{st}, C_γ, C_{wk}. Then he can ask whether C_{st} is equal to C_γ, instead of asking whether the electromagnetic interaction obeys C invariance (where plain C, without subscripts, denotes the customary particle-antiparticle conjugation operator).

The implications of asymmetry in eta decay are many. The question of which particle symmetries are good for what kind of interaction does not have a complete answer yet. And even when theorists and experimentalists alike finally feel they do know the answer, as the development of physics has shown in the past, the feeling is likely to be temporary.

Beyond its significance for particle physics, this violation of matter-antimatter symmetry has also excited physicists interested in space exploration. As Fowler remarked in his APS talk, "Since the asymmetry corresponds to observing the kinetic energy of charged particles, it can be used by observers remote from one another in the universe to tell whether or not their local regions are composed of matter and antimatter. Let us suppose that we are in communication with an observer at the other 'end' of the universe. We lead him to the point where he can observe well enough to perceive that pions of one charge have more kinetic energy than those of opposite charge. It is then suggested that he compare this charge with the charge of his nuclei. If they are the same, then we can plan to visit him."—GBL

Protostars

Recent observations have placed a very narrow bound on the extent of the celestial x-ray source in the constellation Scorpio (hereinafter designated "Sco X-1") and provoked a suggestion that it may represent a hitherto unseen class of objects, protostars. The observation, which placed a bound of 20 sec of arc on the angular diameter of Sco X-1, was made on 8 March with a rocket-borne experiment by Herbert Gursky, Riccardo Giacconi, Paul Gorenstein, John R. Waters of American Science and Engineering Corp.; Minoru Oda, Hale Bradt, Gordon Garmire and B. V. Sreekantan of MIT. It was published in the June issue of *The Astrophysical Journal* (**144,** 1249, 1966). The suggestion that Sco X-1 is a protostar is by Oscar P. Manley of American Science and Engineering and appeared in the