Conservation Laws in Weak Interactions

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THE properties of K-particles have led to a difficult situation in present-day theoretical physics. The angular distribution of the τ-decay ($K^+ \to 2\pi^+ + \pi^-$) requires that the K^+-particle be in a 0^- state. But this state cannot then decay into two π-mesons ($K^+ \to \pi^+ + \pi^0$). We are faced with the dilemma, either to believe that there are two distinct K-particles, or to believe that conservation laws are violated in the K-particle decay. In the first case, we have to explain the equality of the masses (accurate to within 2 electron masses), and the approximate equality of the lifetimes, associated with the θ and τ decays. One may try to explain the equality of masses, as Lee and Yang[1] propose, by postulating an unknown symmetry property of the nuclear forces, under which the θ and τ states can be interchanged. However, if one supposes that the neutrino decay modes

$$(K^+ \to \mu^+ + \nu, \quad K^+ \to \mu^+ + \nu + \pi^0, \quad K^+ \to e^+ + \nu + \pi^0)$$

are equally probable for the two parity-states, one should expect a difference in the lifetimes arising from the different frequencies of the τ and θ decays (around 8% and 25% respectively). The difference in lifetimes should be 30–40% and is in conflict with recent experimental data.[2]

We are apparently forced to the conclusion that the two K-particle hypothesis disagrees with experiment, and the only alternative is to suppose that presently accepted conservation laws are violated in the K-particle decay. Since there is not the slightest reason to doubt the validity of the law of conservation of momentum, we have to envisage a direct violation of the law of conservation of parity.

At first glance it appears that non-conservation of parity would imply an asymmetry of space with respect to inversion. Such an asymmetry, in view of the complete isotropy of space (conservation of momentum), would be more than strange. In my opinion a simple denial of parity-conservation would place theoretical physics in an unhappy situation. I wish to point out that there exists a way out of this situation. We know that the strong interactions are invariant not only with respect to space-inversion but also with respect to charge-conjugation. We assume that in weak interactions these two invariance properties do not hold separately. But we can suppose that we still have invariance with respect to the product of the two operations, which we call combined inversion. Combined inversion consists of space reflection with interchange of particles and antiparticles. If all interactions are invariant with respect to combined inversion, space remains completely asymmetrical, and only electric charges are asymmetrical. This asymmetry destroys the symmetry of space just as little as the existence of chemical stereoisomers.

For charged particles there will not be any law of conservation of parity, since the combined inversion does not transform a charged particle into itself. It is also clear that all the constants (masses, lifetimes) characteristic of a particle are identical for particle and anti-particle. For the processes which are possible for particle and anti-particle differ only by a space-inversion, if the whole system is invariant under combined inversion. Speaking pictorially, a K^--particle is a K^+-particle reflected in a mirror.

Truly neutral particles, i.e., particles which are identical with their antiparticles, transform into themselves under combined inversion. For such particles the combined inversion becomes an ordinary space inversion, and so parity is conserved in all their interactions. It is to be emphasized that the conserved parity is the product of the ordinary parity and the charge-parity of these particles. In this sense the π^0-meson is an odd particle, the K_1^0 (θ^0) which decays into two pions is an even particle, and the K^0 which was predicted by Gell-Mann and Pais[3] and recently discovered experimentally[4] is an odd particle. For photons, combined inversion reverses the sign of the magnetic field and leaves the electric field invariant. The ordinary parities of electric and magnetic multipoles are just reversed under combined inversion. It is easy to show that in this scheme, in spite of the non-existence of ordinary parity, particles cannot possess dipole moments. In fact, the only vector which can be constructed from the wave-function of a particle at rest is the spin-vector, which is even under reflection and odd under charge conjugation. Thus the spin-vector is odd under combined inversion, and in view of what was said earlier about the electromagnetic field the spin-vector can carry only a magnetic and not an electric moment.

As Lee and Yang[5*] have shown, the non-conservation of parity would imply correlations in various hyperon creation and decay processes. One can prove that invariance under combined inversion requires that the coefficients multiplying the weak interaction terms in the Lagrangian are real. This does not however change the qualitative picture which appears in the general case of parity non-conservation. The asymmetry of hyperon decay with respect to the plane of production, which was predicted by Lee and Yang,[5] still occurs in our proposed scheme.

In conclusion I wish to express deep gratitude to L. Okun', B. Ioffe and A. Rudik, for the discussions in which the ideas of this letter originated.

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Possible Properties of the Neutrino Spin

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IF the law of conservation of parity is abandoned, then new properties of the neutrino become possible. In the case of zero mass, the Dirac equation separates into two uncoupled pairs of equations. In the usual theory it is impossible to restrict attention to one pair of equations, since the two pairs are interchanged by a space-inversion. But if we require only invariance under combined inversion[1], then we can suppose that the neutrino is described by a single pair of equations. In ordinary language, this implies that the neutrino is always polarized along (or always opposite to) the direction of its motion. The antineutrino is then polarized always in the opposite sense. In this scheme the neutrino is not a truly neutral particle, in agreement with the observed absence of double β-decay and especially with the experiments on induced β-decay. We call this kind of neutrino a longitudinally polarized neutrino, or a longitudinal neutrino for short.

In the usual theory the neutrino mass is zero "accidentally." And if one takes into account the neutrino interactions, a non-zero rest-mass appears automatically, although it is of negligible magnitude. The mass of a longitudinal neutrino is automatically zero, and this fact is not disturbed by any interactions.

If we assume the neutrino to be longitudinal, the number of possible types of weak interaction operator is greatly reduced. Consider the decay of a μ-meson into an electron and two neutrinos. We write the interaction operator in the usual way as a product of two factors, one composed of the μ-meson and electron field-operators, and the other composed of two neutrino field-operators. With longitudinal neutrinos, we can construct from two ψ-operators only a single combination, a scalar. It is a scalar under rotations only, the operation of ordinary inversion not being applicable to it. The tensor combination vanishes for two identical particles obeying Fermi statistics. From the μ-meson and electron fields we can construct two combinations, a scalar and a pseudoscalar (in the ordinary sense).

If the μ-decay produces a neutrino and an antineutrino, the situation is different. In this case, from the longitudinal neutrino and antineutrino fields, we can construct only a 4-vector. From the μ-meson and electron fields we can construct two combinations, a vector and a pseudovector. Thus in both cases, in spite of the lack of invariance under space-inversion, we have only two possible interaction operators.

It is easy to calculate the energy spectrum of the electron in μ-decay. The result agrees with the calculation of Michel.[2] In the case of two neutrinos we find the Michel parameter $\rho = 0$, and in the case of neutrino and antineutrino we find $\rho = 0.75$. The first alternative is contradicted by experiment, while the second agrees with the existing data,[3,4] which give $\rho = 0.64 \pm 0.10$. Thus the experiments on μ-decay do not contradict the longitudinal neutrino hypothesis, and they further lead to the unambiguous conclusion that the μ-decay involves one neutrino and one antineutrino.

Next we consider the decay $\pi \to \mu + \nu$. Since the pion has spin zero, the operator responsible for the $\pi \to \mu + \nu$ decay must contain a scalar combination of the μ and ν fields. This automatically implies that, in a $\pi \to \mu + \nu$ decay with a longitudinal neutrino, the μ-meson will be completely polarized along its direction of motion (or in the opposite direction). As Lee and Yang[5] observed, the non-conservation of parity can lead to a correlation between the directions of the μ-meson and electron in a $\pi \to \mu \to e$ cascade. In our scheme, a simple