ON THE CONSERVATION LAWS FOR WEAK INTERACTIONS

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Abstract: A variant of the theory is proposed in which non-conservation of parity can be introduced without assuming asymmetry of space with respect to inversion. Various possible consequences of non-conservation of parity are considered which pertain to the properties of the neutrino and in this connection some processes involving neutrinos are examined on the assumption that the neutrino mass is exactly zero.

1. Combined Parity

As is well known, the unusual properties of K-mesons have created a perplexing situation in modern physics. The correlation between π-mesons in τ-decay (K⁺ → 2π⁺ + π⁻) leads to the necessity of assigning a 0⁻ state to K⁺-mesons. This kind of system, however, cannot decay into two π-mesons (K⁺ → π⁺ + π⁰). We are thus faced with the dilemma of either assuming that two different K-mesons exist or that the conservation laws are violated in K-meson decay. In the first case one must then explain the identity of masses (which are equal to within two electron masses) and the near coincidence in lifetime of the θ and τ-decays. One may attempt to explain the equality of K-meson masses by postulating, as Lee and Yang¹) have done, the existence of some hitherto unknown symmetry property of nuclear forces which transforms the θ-meson into a τ-meson. If, however, decay involving a neutrino (K⁺ → μ⁺ + ν, K⁺ → μ⁺ + ν + π⁰, K⁺ → e⁺ + π⁰ + ν) is considered to be essentially the same for particles of various parity a difference in lifetime related to the different rate of τ and θ-decay (≈ 8 % and ≈ 25 %) should be anticipated. This discrepancy should be not less than 30—40 %, a result which seems to be inconsistent with experiment²).

Thus we come to the conclusion that the hypothesis of the existence of two different K⁺-mesons is contrary to the experimental facts and the only alternative is to assume that the generally accepted conservation laws are violated in K-decay. Since there is no reason to think that the law of conservation of angular momentum is untenable, we are apparently dealing here with a direct violation of the law of conservation of parity.

It might seem at first glance that non-conservation of parity implies asymmetry of space with respect to inversion. If, however, complete isotropy of space (conservation of angular momentum) is taken into account this
type of asymmetry would seem to be extremely strange and in my opinion a simple rejection of parity conservation would create a difficult situation in theoretical physics. I would like to point out a solution of this problem which consists in the following. As is well known, both the law of conservation of parity and charge conjugation invariance undoubtedly hold in strong interactions. Let us now assume that each of these conservation laws does not hold separately in weak interactions. However, invariance with respect to the set of both operations (which we shall call combined inversion) will be assumed to exist. In combined inversion, space inversion and transformation of a particle into an antiparticle occur simultaneously.

It is easy to see that invariance of the interactions with respect to combined inversion leaves space completely symmetrical, and only the electrical charges will be asymmetrical. The effect of this asymmetry on the symmetry of space is no greater than that due to chemical stereo-isomerism.

On the other hand the law of conservation of parity of charged particles will not hold as the operator of combined inversion does not transform charged particles into themselves.

Furthermore, it is easy to see that the constants characterizing the particles and antiparticles (masses, lifetimes) should be identical since, as a result of invariance with respect to combined inversion, all processes involving particles and antiparticles should differ from each other only in regard to space inversion. Graphically speaking, a \( K^- \)-meson is a mirror reflected \( K^+ \)-meson.

Truly neutral particles, that is, particles which are identical to their antiparticles, transform into themselves in combined inversion. Consequently, with respect to these particles combined inversion leads to a law of conservation of combined parity. It should be emphasized that conservable parity is the product of ordinary parity and charge parity of the particles. Evidently, in this sense the \( \pi^0 \)-meson is an odd particle; the \( K_s^0(\theta^0) \)-meson which decays into 2 \( \pi^- \)-mesons is an even particle and the \( K_s^0 \)-meson predicted by Gell-Mann and Pais \(^3\) and recently discovered experimentally \(^4\) is an odd particle. Combined inversion changes the sign of the magnetic field of a photon but does not change that of the electric field. The ordinary parities of electric and magnetic multipoles are reversed for combined inversion.

It is easy to show from the foregoing that despite the absence of ordinary parity the particles cannot possess dipole moments. Indeed, the only vector which can be constructed from \( \eta \)-operators for a particle at rest is its spin vector which is even with respect to inversion and odd with respect to charge. It is consequently odd with respect to combined inversion and, in accord with the foregoing regarding the electromagnetic field, it defines only a magnetic but not an electric moment.
Lee and Yang have shown that non-conservation of parity leads to correlations in a number of hyperon production and decay processes. It can be shown that a consequence of invariance with respect to combined inversion is that the weak interaction operators in the Lagrangian contain real coefficients. This circumstance, however, does not appreciably modify the qualitative picture which is obtained in the general case of non-conservation of parity. Therefore asymmetry of hyperon decay with respect to the plane of their creation, which has been predicted by Lee and Yang, will also hold in this case.

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2. Properties of the Neutrino

Rejection of the law of conservation of parity entails the possibility of existence of new properties of the neutrino. The Dirac equation for the case of zero mass splits into two independent pairs of equations. It will be recalled that in the usual theory one cannot confine oneself to a single pair of equations since both pairs transform into each other as a result of space inversion. If, however, we restrict our attention to combined inversion we arrive at the possibility of describing the neutrino by a single pair of equations. In the sense of the usual scheme this would signify that the neutrino is always polarized in the direction of its motion (or in the opposite direction). The polarization of the antineutrino is correspondingly reversed. According to this model the neutrino is not a truly neutral particle and this agrees with the fact that double \( \beta \)-decay has not been observed experimentally and especially with the results of experiments on induced \( \beta \)-decay. We shall call this kind of neutrino a longitudinally polarized neutrino or briefly a longitudinal neutrino.

In the usual theory the neutrino mass is zero, so to say, accidentally. Thus, account of neutrino interactions automatically leads to the appearance of a definite, albeit vanishingly small, rest mass. The mass of the longitudinal neutrino, on the other hand, vanishes automatically and this situation cannot be altered by the existence of any type of interaction.

The longitudinal neutrino concept appreciably reduces the possible number of types of weak interaction operators. Consider, for example, the decay of a \( \mu \)-meson into an electron and two neutrinos. In the usual manner we represent the interaction operator as the product of operators consisting of \( \mu \)-meson and electron \( \psi \)-operators on the one hand and \( \psi \)-operators of the two neutrinos on the other. For the longitudinal neutrino only one combination can be made from the two neutrino operators—a scalar (a

\( \dagger \) I would like to sincerely thank the authors for sending me a preprint of their paper.
scalar with respect to rotation; the operation of ordinary inversion is not applicable), as it is well known that the tensor combination of two identical operators obeying Fermi statistics is equal to zero. In this case two combinations, scalar and pseudo-scalar (in the usual sense of the word), can be constructed for a \( \mu \)-meson and electron.

If a neutrino and antineutrino are emitted in \( \mu \)-meson decay the situation changes. Only a four-dimensional vector can then be constructed from the longitudinal neutrino and antineutrino operators. In this case two combinations — vector and pseudo-vector—can be made from the \( \mu \)-meson and electron operators. Thus, despite the absence of invariance with respect to inversion in each of the two cases only two interaction operators are possible.

It is easy to calculate the energy spectrum of the \( \mu \)-meson decay electrons. It is found to be exactly the same as that calculated by Michel \(^6\). The two-neutrino case thus yields for Michel’s constant, \( \rho \), the value \( \rho = 0 \) and for a neutrino and antineutrino \( \rho = 0.75 \). The former case is apparently inconsistent with the experiments, whereas the latter agrees with the results obtained in ref. \(^7\), \(^8\), which yield \( \rho = 0.64 \pm 0.10 \) and \( \rho = 0.57 \pm 0.14 \). Thus \( \mu \)-meson disintegration experiments do not contradict the longitudinal neutrino concept and in this case lead to a unique result, namely, that a neutrino and antineutrino are involved in \( \mu \)-meson decay.

Consider now the reaction \( \pi \rightarrow \mu + \nu \). Since the \( \pi \)-meson is spinless we are obliged to set up a scalar expression for the \( \mu \)-meson and neutrino \( \nu \)-operators in the \( \pi \rightarrow \mu + \nu \) decay operator. This automatically yields that if the neutrino is longitudinal the \( \mu \)-mesons produced in \( \pi \rightarrow \mu + \nu \) decays will be completely polarized in the direction of their motion (or in the opposite direction).

As Lee and Yang \(^5\) have noted, a possible consequence of non-conservation of parity is the correlation between the directions of the \( \mu \)-meson and electron involved in the \( \pi \rightarrow \mu \rightarrow e \) decay. Simple calculations based on our scheme give the following energy and angular distribution for the emitted electrons:

\[
\frac{dN}{N} = 2e^2[(3-2e)+\lambda \cos \theta(2e-1)]de. \tag{1}
\]

Here \( e \) is the ratio of electron energy to the largest possible energy, \( \theta \) is the angle between the directions of motion of the \( \mu \)-meson and electron and \( \lambda \) is a constant which depends on the relation between the vector and pseudovector parts in the combination of the \( \mu \)-meson and electron \( \psi \)-operators,

\[
\lambda = \frac{2ab}{a^2+b^2}. \tag{2}
\]
where \( a \) and \( b \) are coefficients of the respective terms and, according to the foregoing, are real. Evidently, \( \lambda \) varies between \(-1\) and \(+1\). It is possible that \( \lambda \) is in fact equal to zero. The integral electron distribution is obviously proportional to \((1 + \frac{1}{3} \lambda \cos \theta)\) and this means that the largest possible value of the forward-backward asymmetry is \( 2 \). It should be noted that even if \( \lambda \) appreciably differs from zero it may be difficult to observe \( \mu \rightarrow e \) correlation because of depolarization of the slowed down mesons and in particular for \( \mu^+ \)-mesons because of formation of mesonium (\( \mu^+ + e^- \) system).

Consider now the effect of longitudinality of the neutrino on \( \beta \)-decay. According to experiment the decay operator should be represented as the sum of the scalar and tensor variants. It can be shown that in either case the same electron polarization in the direction of motion will arise, which is equal to \( \nu/c \) (or \(-\nu/c\)), the ratio of the electron velocity to that of light. Thus high energy electrons will be totally polarized in the direction of their motion.

**References**

1) T. Lee and C. Yang, Phys. Rev. 102 (1956) 290
2) Proceedings of the Sixth Annual Rochester Conference, April 1956
3) M. Gell-Mann and A. Pais, Phys. Rev. 97 (1955) 1387
5) T. Lee and C. Yang, Phys. Rev. 104 (1956) 254