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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*I wish to thank these authors for kindly sending me the manuscript of their paper before publication.

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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 calculation leads to the following distribution of the outgoing electrons in energy and angle,

$$dN / N = 2\varepsilon^2 [(3-2\varepsilon) + \lambda \cos\theta \, (2\varepsilon - 1)] \, d\varepsilon. \quad (1)$$

Here ϵ is the ratio of the electron energy to the maximum possible energy, θ is the angle between the directions of motion of the μ-meson and the electron, and λ is a constant depending on the ratio between the vector and pseudovector terms in the combination of μ-meson and electron field-operators. Explicitly we have

$$\lambda = 2ab / (a^2 + b^2), \quad (2)$$

where a and b are the coefficients of the two terms. In our earlier paper[1] we argued that a and b should be real. The quantity λ must lie between -1 and 1, and the value zero is not excluded. The integrated angular distribution of the electrons is proportional to $(1 + 1/3\ \lambda \cos\theta)$, so that the maximum possible forward-backward asymmetry is a factor of two. Even if λ should be markedly different from zero, the observation of the $\mu - e$ correlation may be very difficult because of the depolarization of the mesons in the course of their slowing down, and especially for μ^+-mesons because of the formation of muonium (the system $\mu^+ + e^-$).

Next we consider the effect of the longitudinal neutrino in β-decay. It is known from experiment that the β-decay interaction operator is a sum of scalar and tensor covariants. Either interaction term gives rise to a polarization of the electrons along the direction of their motion, of magnitude (v/c) (or $-v/c$), the ratio of the electron velocity to light velocity. The high-energy electrons are thus completely polarized in the direction of their motion.

Note added in proof.(February 21, 1957).

Very recently Wu, Ambler, Hayward, Hoppes and Hudson showed that in the β-decay of oriented Co^{60} nuclei there is actually a lack of mirror-symmetry. This definitely establishes the non-conservation of parity in β-decay. The experiments of Wu et al. agree with the theory of the longitudinal neutrino; however, the precision of the experiments does not seem high enough for a quantitative verification. The experiments of Wu et al. imply that the neutrino has its spin parallel to its direction of motion, while the antineutrino has its spin antiparallel.

Garwin, Lederman and Weinrich have observed a correlation in the $\pi \to \mu \to e$ decay. The magnitude of the correlation is large, which seems to imply a value of the parameter λ equal to unity. The energy-dependence of the correlation seen in this experiment does not agree with Eq. (1). It is difficult to say at present whether the discrepancy is within the limits of error of the measurements.

I am very much obliged to Professor Lederman for kindly sending me the manuscripts of both papers before publication.

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Concerning a Possible Method for the Polarization of a Proton Beam

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A BEAM of protons (likewise deuterons, tritons, He^3, etc.) passing through a thin ferromagnetic slab, magnetized to saturation, should become "magnetized" due to pick-up by the protons of the polarized ferromagnetic electrons. As a result of such electron pick-up, the atoms of hydrogen obtained will be polarized as regards their electron spin and if, outside the magnetic field, they are again ionized by passage through a thin foil (or a gas beam), then the protons will come out partly polarized.

The fraction of polarized protons coming out of the second foil (only atoms of hydrogen being considered entering the foil), will be equal to half the fraction of the neutral atoms polarized according to their electron spin. The degree of polarization of the hydrogen atoms is determined by the probability of the protons picking up the "ferromagnetic" electrons in comparison with the probability of picking up the unpolarized electrons. The magnitude of the polarization obviously will depend on the velocity of the protons and the type of the ferromagnet. If it is assumed that $3d$ and s electrons will be picked up with equal probability, then the degree of polarization of a proton beam passing through an iron foil should approach $\sim 15\%$.

The beam intensity of the polarized protons depends on the proton beam passing through the ferromagnetic slab. Experiments show that thin foils