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ON THE PROBLEM OF TESTING THE INVARIANCE OF AN INTERACTION UNDER TIME REVERSAL

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THE discovery of the noninvariance of the weak interactions under space inversion and charge conjugation has greatly increased interest in a more detailed study of the symmetry properties of the strong interactions. In the present note we point out the possibility of a direct experimental test of the invariance of various interactions under time reversal, based on the relations between polarization phenomena in inverse reactions.[1-5] Until recently such tests were based on the ratio of the cross-sections of inverse reactions averaged over the spins,[6] and for the weak interactions on a number of consequences arising from the reality (or purely imaginary nature) of the interaction constants. Very recently it has been proposed[7,8] that the symmetry of strong interactions under time reversal be studied by examining the equality of the polarization and asymmetry in elastic scattering.[9,10] On the basis of the results of references 1 to 5, analogous tests can be carried out with various nuclear reactions. For example, the polarization of the neutron in the reaction $d + d \rightarrow n + He^3$, with the deuterons unpolarized, agrees, within the usual factor appearing in the balance relations, with the asymmetry in the cross-section of the inverse reaction $n + He^3 \rightarrow d + d$ with polarized neutrons. An examination of the relation between the polarization and the asymmetry, and of more complicated relations, would be a test of the invariance of the interaction under time reversal, since it is known that parity is very precisely conserved in the strong interactions of ordinary particles.[11] For this same purpose one can also use the reaction $p + T \rightleftharpoons n + He^3$. And in general, by looking at a table of nuclear reactions, one can pick out many other reactions that can be used for this purpose.

For the reactions involving γ-ray quanta we can look at the photodisintegration of the deuteron and the radiative capture of a neutron by a proton:

$$n + p \rightleftarrows d + \gamma. \qquad (1)$$

Here, in addition to the relations that hold, for example, between the polarization of the neutron from the photodisintegration of the deuteron and the asymmetry in the cross-section for radiative capture of polarized neutrons by protons, one can make a comparison of the polarization of the photons from the radiative capture and the asymmetry of the photodisintegration cross section with polarized γ radiation.

For studying the time reversibility of processes of pion production we can take the reaction

$$p + p \leftrightarrows d + \pi^+, \qquad (2)$$

which has been studied in detail in reference 1. Recent experiments[12,13] can be regarded as the first stage of such a test. The results of Neganov and Parfenov show that the relations between the unpolarized cross-sections are satisfied to within 10 to 15 percent, which agrees with the estimates of Henley and Jacobsohn,[6] which were based on different experimental data.

For the study of the symmetry of interactions involving strange particles we can consider the reaction

$$K^- + d \rightleftarrows \Sigma^- + p, \qquad (3)$$

which Lee once proposed for the determination of the spins of the particles,[14] and also a number of similar reactions.[15] The polarization of the Σ^-, which one can hope to detect from the asymmetry of its decay, must agree with the asymmetry of the K^- in the reaction $\Sigma^- + p \rightarrow d + K^-$ with the Σ^- polarized (for example, by the process that produces it). The study of the polarization phenomena in the reaction (3) can also help to settle the question as to whether there is a connection between the small asymmetry in the decay of the Σ^- from the reaction $\pi + N \rightarrow \Sigma^- + K$ and threshold effects.

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THE UNIVERSAL FERMI INTERACTION AND THE CAPTURE OF MUONS IN HYDROGEN

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THE theory of the universal Fermi interaction with (V-A) coupling proposed by Marshak and Sudarshan[1] and by Feynman and Gell-Mann[2] is supported by all existing experimental evidence on β decay. To explain the equality of the Fermi β-decay constant and the constant for the μ decay, Feynman and Gell-Mann have put forward the hypothesis of a conserved vector current in the weak interactions. This hypothesis leads to the appearance of an anomalous magnetic-moment effect in the β decay ("β magnetism"). Calculations of the effect have been made by Gell-Mann and others[3-5] and have apparently already received experimental confirmation in β decay.[6]

The latest experimental data show that the probability of the β decay or (μ, ν) decay of hyperons is apparently considerably smaller than that given by the universal (V-A) theory.[7] But even if these data are confirmed and we are forced to abandon the universal interaction including the hyperons, nevertheless the universal interaction between (p, n), (e, ν), and (μ, ν) will remain an extremely probable hypothesis.

Since it already seems that the β decay and the decay of the μ meson can be explained within the framework of the (V-A) theory, it is of particular interest to examine the process of μ capture and test the idea of the universal (V-A) interaction in this case.

In the present note we present expressions for the probability of the capture, the angular distribution, and the polarization of the emerging neutrons in the case of capture of polarized μ^- mesons by protons, based on the assumption of the universal (V-A) coupling with conserved vector current as proposed by Gell-Mann and Feynman.

The capture probability and the angular distribution are (in units $\hbar = c = 1$):

$$w = (2\pi)^{-2} (\pi a_\mu^3)^{-1} 2^{-1} G^2 I \left[1 + \alpha P\, (\mathbf{n}\cdot\mathbf{s})\right] p^2\, d\Omega,$$

$$I = 1 + 3\lambda^2 + \beta(1 + \lambda^2) + \beta\mu(2\lambda + \beta\mu/2),$$

$$I\alpha = 1 - \lambda^2 + \beta(1 + \lambda^2) - \beta\mu(2\lambda + \beta\mu/2).$$

The total probability for capture is

$$\tau^{-1} = 2^{-1} G^2 \pi^{-2} a_\mu^{-3} p^2 I.$$

The polarization $\langle\sigma_n\rangle$ of the neutrons is given by the formula

$$I\left[1 + \alpha P(\mathbf{n}\cdot\mathbf{s})\right]\langle\sigma_n\rangle = \left[a + b\,(\mathbf{n}\cdot\mathbf{s})\right]\mathbf{n} + c\mathbf{s},$$

$$a = -2\left[\lambda(\lambda + 1) + \beta\lambda + \beta\mu(\lambda + \beta\mu/4)\right],$$

$$b = -\beta P\left[\lambda(\lambda + 1) - \mu(1 + \lambda + \beta\mu/2)\right],$$

$$c = 2P(\lambda - 1)\left[\lambda + \beta(\lambda + \mu)/2\right].$$

Here we have used the notations: $p\mathbf{n}$ is the momentum of the neutron, and $P\mathbf{s}$ is the polarization of the μ meson ($\mathbf{n}$ and $\mathbf{s}$ are unit vectors); $\lambda = -C_A/C_V$, $\beta = p/M$; $G \equiv 2^{1/2} C_V$ is the universal coupling constant; M is the nucleon mass; $\mu = \mu_p - \mu_n$ is the difference of the magnetic moments of the proton and neutron; $a_\mu = (m_\mu e^2)^{-1}$ is the radius of the mesonic K orbit in hydrogen.

Terms of the order $(v/c)^2$ have been neglected in the calculation (v is the speed of the neutron). In addition it has been assumed that in the pseudovector coupling the higher moments do not give an additional renormalization. A numerical computation (taking $G = (1.01 \pm 0.01) \times 10^{-5} M^{-2}$, $\mu = 4.7$, $\lambda = 1.24$, $\beta = 0.1$) shows that the effect of the anomalous magnetic moment increases the total