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Non-Conservation of Parity and Hyperon Decay

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THE NON-CONSERVATION of parity in weak decay interactions[1, 2] leads to a series of effects, the study of which allows one to establish whether, in reality, weak interactions are non-invariant relative to reflection of spatial coordinates, and also to clarify a number of other questions connected with this. In this note, the decay of hyperons by interactions which do not conserve spatial parity is considered. For simplicity we restrict ourselves to non-derivative couplings and to hyperon spins equal to ½.

The interaction Hamiltonian leading to the decay has the form

$$H = g\bar{\psi}_N (1 + \lambda\gamma_5)\, \psi_Y \varphi_\pi^* \qquad (1)$$

where ψ are spinor wave functions and φ_π is the wave function of the π-meson; λ is a quantity, which is complex in general, characterizing the degree of non-conservation of parity. The existence of K^0-particles with long lifetimes[3] can be made compatible with non-conservation of parity if we assume that either temporal or charge parity is conserved (see Ref. 4 with regard to this). In the first case λ is a real constant, in the second purely imaginary.

We now consider a hyperon at rest, the spin of which is directed along the unit vector $\boldsymbol{\eta}$. Calculation of the square of the matrix element M of the interaction (1), leading to emission of a nucleon with a given direction of momentum **n** and spin along the unit vector $\boldsymbol{\zeta}$, gives

$$|M|^2 = \frac{1}{4}\Big\{\Big(1 + \frac{m}{E_N}\Big)(1 + \eta\zeta) + |\lambda|^2 \Big(1 - \frac{m}{E_N}\Big)(1 - \eta\zeta) + 2|\lambda|^2 p^2 [(\mathrm{n}\eta)(\mathrm{n}\zeta)/E_N(E_N + m)] + (\lambda + \lambda^+)\frac{p}{E_N}(\mathrm{n}\eta + \mathrm{n}\zeta) + i(\lambda - \lambda^+)\frac{p}{E_N}(\mathrm{n}\,[\eta\zeta])\Big\}. \qquad (2)$$

Here m is the mass of the nucleon, $E_N = \sqrt{p^2 + m^2}$, $p = \sqrt{2\mu^* Q}$, where μ^* is the reduced mass of the π-meson and nucleon; Q is the energy of decay of the hyperon; $\hbar = c = 1$. The first three terms in the braces correspond to the usual treatment with conservation of charge for even (terms with $|\lambda|^2$) and odd (terms without $|\lambda|^2$ hyperons. Non-conservation of parity leads to the appearance of the pseudoscalar (relative to spatial reflection) quantities: $\mathbf{n}\boldsymbol{\eta}$, $\mathbf{n}\boldsymbol{\zeta}$, $\mathbf{n}[\boldsymbol{\eta}\times\boldsymbol{\zeta}]$.

If the Hamiltonian H is invariant relative to time-reflection, then the term $\mathbf{n}[\boldsymbol{\eta}\times\boldsymbol{\zeta}]$ drops out. In this case, contrary to the usual situations, even in the decay of unpolarized hyperons (absence of the term with $\boldsymbol{\eta}$) there will be a term of the order of the nucleon velocity (v/c) giving nucleons polarized along **n**. This term would be particularly noticeable for Σ-hyperons.

In case of invariance of H relative to charge conjugation the terms with $\mathbf{n}\boldsymbol{\eta}$ and $\mathbf{n}\boldsymbol{\zeta}$ drop out and the term proportional to $\mathbf{n}[\boldsymbol{\eta}\times\boldsymbol{\zeta}]$ remains, giving an additional correlation of the spins of the polarized hyperons and nucleons, different from that which would occur for variants with conservation of parity (this term leads to a mutually-perpendicular orientation of the spins). A similar situation arises in the case of gradient coupling.

Ioffe[5] arrived at analogous conclusions, starting from general considerations (within the framework of perturbation theory), about invariance of the decay probabilities relative to time-reflection and charge conservation, respectively.

In conclusion, we note that if there is invariance under reflection in time, then non-conservation of parity leads to correlation between the direction of emission of the Λ^0-particle in the decay of the Ξ^--hyperon and the direction of emission of the nuclei in the rest system of the Λ^0-particle in its subsequent decay, even for a Λ^0-spin equal to ½. A simple consideration leads to a correlation function of the form $a + b\cos\vartheta$, where ϑ is the angle between the directions indicated above.

In the case of invariance under charge conjugation, this effect does not arise.

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Nuclear Photoeffect in Be^9 at High Energies

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ÜBERALL[1] HAS INVESTIGATED the $Be^9(\gamma, n)Be^8$ reaction on the basis of the one particle model in the γ-energy interval 20–200 Mev. The interaction energy curve of the (Be^8, n) system is taken in the form of a potential well having spherical symmetry. He studies both the electric and magnetic transitions of the system taking account of retardation.

The Born approximation gives a photoneutron angular distribution proportional to $\sin^2\theta$ as well as the energy dependence of the total effective cross section. The cross section curve, generally falling with increasing energy, has zeros at several energy values (curve *1* of the figure), which do not correspond with the experimental data.

Überall shows that such an oscillation of the total cross section curve is possibly due to the special choice of the potential in the form of a square well. One can expect that with a different choice of the interaction potential the total cross section may not oscillate. To test this idea we investigated the same reaction taking as the interaction potential of the (Be^8, n) system the potential of an oscillator, terminated at some point $r = r_0$.

Our work[2] showed that with this choice of potential the wave function of the (Be^8, n) system can be represented with satisfactory approximation in the form

$$R(r) = \sqrt{2/3}\,(2\pi)^{-1/4}(r_0')^{-3/2}\exp\{-1/4\,(r/r_0')^2\}\,r/r_0', \tag{1}$$

where r_0' is a parameter proportional, on one hand, to the most probable distance between the nuclear core of B^8 and the neutron, and on the other hand, to the nuclear radius. The parameter r_0' may be regarded as the quantity which characterizes the behavior of the wave function inside the nucleus and hence in some measure takes into account the structure of the nucleus.

The differential cross section, found from Eq. (1), is likewise proportional to $\sin^2\theta$. The total effective cross section, as found by us, takes the form:

$$\sigma = 4.82\cdot 10^{-29}\delta^5\,[\hbar\omega]^{3/2}\exp[-0.094\delta^2\hbar\omega], \tag{2}$$

where $\delta = r_0' \times 10^{13}$ cm^{-1}, and $\hbar\omega$ is in Mev. Equation (2) shows the total effective cross section falling off exponentially with increasing γ-energy, while the damping coefficient depends upon r_0'.

It is easily seen that to get quantitative agreement between theory and experiment it is sufficient to set

$$\delta = 1.6\,(20/\hbar\omega)^{2/5}. \tag{3}$$

In this case we will have for the total effective cross section

$$\sigma = 2.36\cdot 10^{-25}\exp[-5.15\,(\hbar\omega/20)^{1/5}]\,(\hbar\omega)^{-1/2}. \tag{4}$$

The energy dependence of the effective cross section obtained from Eq. (4) is shown by Curve *2* of the figure. The experimental points, shown by crosses, fit the theoretical curve well.

The energy dependence of the parameter r_0', expressed by Eq. (3), can be determined approximately from the wave function (1). The point is that at high γ-energies the excitation of the nucleus is so large that it is not legitimate to assume that the liberated neutron leaves the nucleus in the definite stationary state given by the wave function (1). The energy dependence of r_0', apparently, in some measure takes account of the change in state of the (Be^8, n) system under the influence of radiation. As Eq. (3) shows, an increase in the γ-energy reduces r_0', which is natural, since with increasing excitation of the nucleus the role of the smaller dis-