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ON THE INTERACTION OF Ξ^--HYPERONS WITH NUCLEONS AND LIGHT NUCLEI

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Spin correlations are determined for Λ particles produced in $\Xi^- + p \rightarrow \Lambda + \Lambda$ reactions (slow Ξ^-). An experimental study of such correlations would make it possible to establish the parity of Λ particles.

In the interaction of a slow Ξ^- hyperon with protons, the following reactions are possible:

$$\Xi^- + p \rightarrow \Xi^- + p, \quad \text{elastic scattering,} \tag{1}$$

$$\Xi^- + p \rightarrow \Xi^0 + n, \quad \text{charge exchange,} \tag{2}$$

$$\Xi^- + p \rightarrow \Lambda^0 + \Lambda^0, \quad \text{absorption.} \tag{3}$$

Other processes (of the type $\Xi^- + p \rightarrow \Sigma^0 + \Lambda^0$ and others) have a threshold and can be neglected at low energies. (We proceed on the assumption that the Ξ^- strangeness is equal to 2). If it turns out that the lifetime of the Ξ^- hyperon is sufficiently long (see the Report of the Seventh Rochester Conference), and that it is possible to experiment with slow Ξ^- hyperons, then it would be of particular interest to study the reaction (3), observing the subsequent decays of the Ξ^- hyperons. In particular, study of this reaction would make it possible to establish the parity of the Ξ^- hyperon relative to the nucleon.

The following analysis is based on the assumption that the decay of the Λ hyperon proceeds with nonconservation of parity. If parity is not conserved in the decay $\Lambda^0 \rightarrow p + \pi^-$, then the amplitude of this decay can be written in the form

$$a_\Lambda = a + b\sigma\mathbf{n}. \tag{4}$$

Here a and b are, in general, complex numbers and $\mathbf{n}$ is a unit vector in the direction of emission of the π meson.

The angular distribution of π mesons in the decay of polarized Λ hyperons has the form

$$1 + \varkappa\mathbf{s}\mathbf{n}, \tag{5}$$

where $\mathbf{s}$ is a unit vector in the direction of spin of the Λ hyperon and the asymmetry parameter κ is equal to

$$\varkappa = (a^*b + b^*a)/(|a|^2 + |b|^2). \tag{6}$$

Thus, the π meson should be emitted mainly parallel (or antiparallel) to the direction of polarization of the Λ hyperon.

On the other hand, the spins of two Λ hyperons produced in the reaction (3) are correlated because of the Pauli principle. In the table are given the

States of the system $\Xi^- + p$	States of the system $\Lambda + \Lambda$	
	Ξ parity + 1	Ξ parity − 1
$^1S_0$	$^1S_0$	$^3P_0$
$^3S_1$	Reaction (3) forbidden	$^3P_1$

spin and orbital states of two Λ hyperons for the case in which the Ξ^- hyperon is captured from an S-state by the proton. (We assume that the spin of the Ξ^- hyperon, as well as the spin of the Λ hyperon, is equal to $1/2$.)

Consequently, for a positive parity of the Ξ^- particle, only the amplitude for the one transition ($^1S_0 \rightarrow {}^1S_0$) has to be taken into account. Calculating the angular distribution of π mesons arising in the decay of two Λ hyperons with the aid of Eq. (4), we obtain

$$W(\mathbf{n}_1, \mathbf{n}_2) = 1 - \varkappa^2(\mathbf{n}_1\mathbf{n}_2). \tag{7}$$

Here $\mathbf{n}_i$ (i = 1, 2) is a unit vector in the direction of motion of the π meson in the rest system of that hyperon in the decay of which the π meson arises.

It is essential that Eq. (7) is valid for both polarized and unpolarized Ξ particles, and the resulting distribution does not depend on the direction of flight of the Λ particle.

For a negative parity of the Ξ hyperon, one must consider two amplitudes λ and μ for the two possible transitions $^3S_1 \rightarrow {}^3P_1$ and $^1S_0 \rightarrow {}^3P_0$, respectively, possible in the process (3). In this case, calculation gives for the angular distribution of π mesons produced in the decay of the Λ particle

$$W(\mathbf{n}_1, \mathbf{n}_2) = 1 + \frac{|\alpha|^2}{3+|\alpha|^2}\varkappa^2(\mathbf{n}_1\mathbf{n}_2) + \frac{3-2|\alpha|^2}{3+|\alpha|^2}\varkappa^2(\mathbf{k}\mathbf{n}_1)(\mathbf{k}\mathbf{n}_2)$$

$$+\frac{3}{3+|\alpha|^2}(\zeta\mathbf{k})(\mathbf{k}\cdot(\mathbf{n}_1+\mathbf{n}_2))$$
$$+\sqrt{\frac{3}{2}}\frac{\alpha^*+\alpha}{3+|\alpha|^2}([\mathbf{k}\times[\mathbf{k}\times\zeta]]\cdot(\mathbf{n}_1+\mathbf{n}_2))$$
$$+i\sqrt{\frac{3}{2}}\frac{\alpha-\alpha^*}{3+|\alpha|^2}\{([\mathbf{k}\times\zeta]\cdot\mathbf{n}_1)(\mathbf{k}\mathbf{n}_2)$$
$$+([\mathbf{k}\times\zeta]\cdot\mathbf{n}_2)(\mathbf{k}\mathbf{n}_1)\}. \quad (8)$$

Here $\alpha=\mu/\lambda$, $\mathbf{k}$ is a unit vector in the direction of flight of the Λ^0 hyperons, and $\boldsymbol{\zeta}$ is the polarization vector of the Ξ^- hyperons, i.e., the mean value of the spin of the Ξ particles.

Averaging Eq. (8) over direction $\mathbf{k}$ gives

$$W(\mathbf{n}_1,\mathbf{n}_2)=1+\frac{1}{3}\varkappa^2(\mathbf{n}_1\mathbf{n}_2)$$
$$+\frac{1-\sqrt{2/3}(\alpha+\alpha^*)}{3+|\alpha|^2}\varkappa\zeta(\mathbf{n}_1+\mathbf{n}_2). \quad (9)$$

Comparison of experimental data with (7) or (8) and (9) could facilitate the determination of the parity of the Ξ hyperon. We note in this connection that if the Ξ^- is not polarized ($\boldsymbol{\zeta}=0$), then, if the parity of the Ξ^- is negative, π mesons produced in the decay should be emitted mainly in the same direction. If the parity of the Ξ^- is positive, then the π mesons should be mainly emitted in opposite directions. Further, if Eq. (9) is averaged over $\mathbf{n}_2$, one obtains

$$W(\mathbf{n}_1)=1+\frac{1-\sqrt{2/3}(\alpha+\alpha^*)}{3+|\alpha|^2}\varkappa(\zeta\mathbf{n}_1). \quad (10)$$

Averaging Eq. (7) over $\mathbf{n}$ leads to an isotropic distribution for $\mathbf{n}_1$:

$$W(\mathbf{n}_1)=1. \quad (11)$$

Equations (7) to (11) for process (3) are valid for the capture of slow Ξ^- particles out of the continuous spectrum, as well as the capture from bound states of the $\Xi^-+\mathrm{p}$ system. It is not clear, however, what contribution will come from capture out of bound P-states. If this contribution is sufficiently large, then the angular distributions of the π mesons produced will differ essentially from those obtained here. Thus, the experimental data can be analyzed using Eqs. (8) to (10) or (7) and (11) and choosing the cases which correspond to capture out of the continuous spectrum, i.e., for capture out of a beam of slow Ξ particles. The criterion for this choice, in principle, can be that the sum of momenta of the four particles produced ($2\mathrm{p}+2\pi^-$), although small, is not equal to zero.

If the parity of the Ξ^- is equal to $+1$, and if the interaction between Ξ and p is such that there is a level* in the $^3S_1$ state, then, as can be seen from the table, the $\Xi^-+\mathrm{p}$ system will be metastable, since the decay into two Λ^0 hyperons is forbidden.

Such a system would have a greater probability of decay by emission of a hard γ-quantum

$$\Xi^-+p\rightarrow\Lambda^0+\Lambda^0+\gamma, \quad (12)$$

which could be detected either directly, or by the lack of energy-momentum balance.

If the Ξ + nucleon system has a bound state and if the splitting of the $(\Xi^-+\mathrm{p})$ and $(\Xi^0+\mathrm{n})$ levels, which comes basically from the difference in masses of the Ξ^- and Ξ^0 hyperons, is small compared with the splitting of the levels with $T=1$, $(\Xi^-\mathrm{p}+\Xi^0\mathrm{n})/\sqrt{2}$, and $T=0$, $(\Xi^-\mathrm{p}-\Xi^0\mathrm{n})/\sqrt{2}$, then the Ξ + nucleon system will be in a state of well-defined isotopic spin T. Here the $^3S_1$-state with $T=0$ will be analogous to the deuteron ($J=1$, $T=0$, $P=+1$).

It should be noted that if isotopic spin is a good quantum number for the Ξ + nucleon system, then all bound states of this system with $T=1$ will be metastable, since the reaction (3) is forbidden for them.

The reaction (12) can be observed if there is no nuclear bound state of the Ξ + nucleon system, but

$$m_{\Xi^-}+m_p-V_{\mathrm{Coul}}<m_n+m_{\Xi^0}.$$

In this case the Coulomb level $^3S_1$ will be metastable because the charge exchange reaction (2) will be energetically forbidden.

It is of interest to represent also the interaction of a slow Ξ^- hyperon with the deuteron

$$\Xi^-+d\rightarrow\Lambda^0+\Lambda^0+n. \quad (13)$$

Study of the angular distribution of hyperons in this case can give information about the mutual interaction of two Λ hyperons. For example, presence of a level near zero in the system of two Λ hyperons would lead to the fact that small angles between them are preferred. For this, the still unknown amplitude for interaction between the Λ and neutron, knowledge of which is necessary for the interpretation of reaction (13), can be obtained directly from the reaction of the type

$$K^-+d\rightarrow\Lambda+p+\pi^-,$$

considered in Ref. (2).

*These requirements do not contradict the models of strange particles proposed recently be Gell-Mann,[11] according to which the parity of all hyperons is equal to + 1, and their interaction with π mesons is just as strong as the interaction of π mesons with nucleons.

Capture of the Ξ^- in He^4 can lead to a series of inelastic processes; included in the possible reactions is the production of hypernuclei containing two Λ hyperons

$$\Xi^- + He^4 \rightarrow \begin{matrix} p + (\Lambda\Lambda nn), \\ n + (\Lambda\Lambda np), \dots \end{matrix}$$

The existence of such hypernuclei should lead to a characteristic cascade decay.

We note that the ratio of cross sections for inelastic and elastic interactions on He^4 will depend on the relative parity of the Ξ and nucleon (in the case of negative parity of the Ξ, inelastic scattering will be suppressed since one of the particles produced in the inelastic scattering must be emitted in a P-state, and the energy given up in this case is small (30 Mev minus the binding energy of He^4 plus the binding energy of the fragments produced)).

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249

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ON THE POLARIZATION OF THE ELECTRONS EMITTED IN THE DECAY OF MU MESONS

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Expressions have been obtained for the energy spectrum, the angular distribution, and the polarization of the electrons emitted in the decay of polarized μ mesons. The calculations have been carried out for a decay interaction Hamiltonian of the most general form, characterized by ten complex constants, It is shown that the experiments carried out up to the present time are insufficient to test the validity of the predictions made in Refs. 4 and 5; in addition to these experiments, it is necessary to measure the sign of the polarization of the decaying μ mesons.

THE experimental data from studies of the spectrum, angular asymmetry, and polarization of the electrons from the decay of polarized μ mesons are in evident agreement with the predictions of the theory of the two-component neutrino, proposed by Salam,[1] Landau,[2] and Lee and Yang.[3] Within the framework of this theory, if we take into account the experimentally observed spectrum of the electrons, out of the ten complex constants C and C′ which describe the decay of the μ meson in the general case [cf. Eq. (I) of the Appendix] only four are different from zero:

$$C_V = C'_A \neq 0, \quad C_A = C'_V \neq 0; \tag{1}$$

$$C_S = C'_S = C_P = C'_P = C_T = C'_T = 0. \tag{2}$$

It can be hoped that more precise experimental data will be found to be in agreement with the more restrictive hypothesis of Feynman and Gell-Mann[4] and Marshak and Sudarshan[5] about the two-component nature of the electronic interaction, according to which

$$C_V = \pm C'_V, \quad C_A = \pm C'_A. \tag{3}$$

In this latter case the distribution of the electrons from the decay of stationary μ mesons must be proportional to

$$(1 \mp \boldsymbol{\zeta}\mathbf{n})(3 - 2\varepsilon \pm \boldsymbol{\eta}\mathbf{n}(1 - 2\varepsilon))\,\varepsilon^2 d\varepsilon. \tag{4}$$

Here ϵ is the energy of the electron divided by its maximum possible energy, $\mathbf{n}$ is the unit vector in the direction of motion of the electron, $\boldsymbol{\zeta}$ is the unit vector in the direction of the spin of the electron in the rest system of the electron, and $\boldsymbol{\eta}$ is the unit vector in the direction of the spin of the