due to the pion cloud should change sign. Relativistic field theory shows on general grounds that $F(k^2)$ has the form

$$F(k^2)=\int_{2m_\pi}^{\infty}\frac{\rho(m)}{m^2+k^2}dm,$$

where the lower limit of integration corresponds to the threshold for pion pair creation by an external electromagnetic field. With our assumptions about ρ^0, it is thus possible that the two form factors F and F' cancel approximately for the neutron but reinforce for the proton, in agreement with observation. If we equate tentatively the mean square radius of the proton with the one due to ρ^0:

$$Gg/\mu^2 \sim e^2\langle a^2\rangle/b,$$

we get

$$(G^2/\hbar c)(g^2/\hbar c)\sim[(e^2/\hbar c)/b]^2\sim 10^{-6},$$

which checks with the previous estimate since $G^2/\hbar c$ would be of the order one. The decay lives become, very approximately,

$$\tau_a \sim 10^{-19}\text{—}10^{-20}\ \text{sec},$$

$$\tau_b \sim \tau_c \sim 10^{-17}\text{—}10^{-18}\ \text{sec}.$$

We can pursue further consequences of our assumption.

(1) ρ^0 could be produced by any strong nuclear reactions, but it would instantly decay mostly into a high-energy $\gamma(\gtrsim 140$ Mev) and a ρ^0. The ratio of charged to neutral components in high-energy reactions should accordingly be influenced.

(2) The second maximum of the pion-nucleon scattering around 1 Bev[2] could be attributed to the reaction

$$\pi^- + p \rightarrow n + \rho^0,$$

if a resonance should occur for such a system.

(3) ρ^0 would contribute a repulsive nuclear force of Wigner type and short range ($\lesssim 0.7\times 10^{-13}$ cm), more or less similar to the phenomenological hard core.

(4) The anomalous moment of the nucleon[3] should be affected by ρ^0. The main effect seems to be that ρ^0 and the usual pion give opposite contributions to the isotopic scalar part of the core moment, thus tending to bring better agreement between theory and experiment.

(5) If it is energetically possible, we ought to expect that K mesons and hyperons would sometimes decay by emitting a ρ^0.

It should perhaps be added that the neutral meson considered here is similar in nature to the one introduced by Teller for quite different purposes.[4]

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[1] R. Hofstadter, Revs. Modern Phys. **28**, 214 (1956). Other references are given in this paper. Also E. E. Chambers and R. Hofstadter, Phys. Rev. **103**, 1456 (1956); J. A. McIntyre, Phys. Rev. **103**, 1464 (1956); R. W. McAllister, Phys. Rev. **104**, 1494 (1956); Hughes, Harvey, Goldberg, and Stafne, Phys. Rev. **90**, 497 (1953); Melkonian, Rustad, and Havens, Bull. Am. Phys. Soc. Ser. II, **1**, 62 (1956). For theoretical interpretations, see Yennie, Lévy, and Ravenhall, Revs. Modern Phys. **29**, 144 (1957).

[2] Shapiro, Leavitt, and Chen, Phys. Rev. **92**, 1073 (1953); Cool, Madansky, and Piccioni, Phys. Rev. **93**, 637 (1954); O. Piccioni and other authors, *Proceedings of the Sixth Annual Rochester Conference on High-Energy Physics 1956* (Interscience Publishers, Inc., New York, 1956). See also F. Dyson, Phys. Rev. **99**, 1037 (1955); G. Takeda, Phys. Rev. **100**, 440 (1955).

[3] H. Miyazawa, Phys. Rev. **101**, 1564 (1956); see also G. Sandri, Phys. Rev. **101**, 1616 (1956).

[4] M. H. Johnson and E. Teller, Phys. Rev. **98**, 783 (1955); H. Duerr and E. Teller, Phys. Rev. **101**, 494 (1956); E. Teller, *Proceedings of the Sixth Annual Rochester Conference on High-Energy Physics 1956* (Interscience Publishers, Inc., New York, 1956); H. Duerr, Phys. Rev. **103**, 469 (1956).

Possible Detection of Parity Nonconservation in Hyperon Decay*

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RECENTLY, various experiments[1–3] established the nonconservation of parity in β decay, π decay, and μ decay. The purpose of this note is to emphasize that, in view of these developments, experiments on hyperon production and decay in $(\pi+p)$ collisions of the type done by various groups using bubble chambers,[4] seem now to be especially important for a clarification of the following related questions: (i) whether parity conservation is violated in hyperon decays[5] and (ii) whether parity doublets exist.[6]

A detailed analysis concerning the possible detection of parity doublets exists in the literature.[6] In the following we shall make a phenomenological study of the problem of possible detection of parity nonconservation in hyperon decay under the assumption that there exist no parity doublets for either K mesons or hyperons.[7]

To make the analysis unambiguous and to draw conclusions that are relatively definite, it is necessary that one knows something about the polarization of the hyperons produced. It seems that a good plan is to study hyperon production and decay near threshold.

Production and decay of Σ^-. For example, let us consider the production of Σ^- from (π^-+p) collisions:

$$\pi^- + p \rightarrow \Sigma^- + K^+. \tag{1}$$

It is perhaps worthwhile to try to do the experiments at laboratory kinetic energies of the pion of, say, 955 Mev and 1 Bev, corresponding to center-of-mass total kinetic energies of the Σ^-+K^+ system of 30 Mev and 60 Mev. At these energies one hopes that only s and p waves are produced in the Σ^-+K^+ system.

It is then easy to see that the differential production cross section per unit solid angle $d\Omega$ (in the center-of-mass system of production) of the Σ^- produced is given by

$$I(\theta)=|a+b\cos\theta|^2+|c|^2\sin^2\theta, \qquad (2)$$

where a can be chosen as real and b and c are complex numbers. We use the following notations:

$$\begin{aligned} \mathbf{p}_{\mathrm{in}}&=\text{momentum of the incoming } \pi^-,\\ \mathbf{p}_\Sigma&=\text{momentum of the } \Sigma^- \text{ produced}, \qquad (3)\\ \theta&=\text{angle between } \mathbf{p}_{\mathrm{in}} \text{ and } \mathbf{p}_\Sigma. \end{aligned}$$

In (3) both $\mathbf{p}_{\mathrm{in}}$ and $\mathbf{p}_\Sigma$ are measured in the center-of-mass system of production. The polarization of the Σ^- produced at the angle θ is always in the direction of $\mathbf{p}_{\mathrm{in}}\times\mathbf{p}_\Sigma$ and has the magnitude

$$P(\theta)=[I(\theta)]^{-1}2\sin\theta\times\mathrm{Im}[c^*(a+b\cos\theta)], \qquad (4)$$

where $P(\theta)$ is defined to be the average spin of the Σ^- in units of $\frac{1}{2}\hbar$. In Eq. (4) the *assumptions have been made that the spin of* Σ^- *is* $\frac{1}{2}$ *and that the spin of* K^+ *is* 0.

If parity is not conserved in the decay of Σ^-, the polarization $P(\theta)$ can be measured by using the decay process of Σ^-,

$$\Sigma^-\rightarrow n+\pi^-, \qquad (5)$$

as an analyzer. Let R be the projection of the momentum of the decay pion in the direction of $\mathbf{p}_{\mathrm{in}}\times\mathbf{p}_\Sigma$. The distribution function for R at an angle θ of production is given by

$$W(\theta,\xi)d\Omega d\xi=I(\theta)d\Omega\times\tfrac{1}{2}[1+\alpha p(\theta)\xi]\alpha\xi, \qquad (6)$$

where

$$\xi=R/(\text{maximum value of } R)\cong R/(100\ \text{Mev}/c).$$

In terms of the coefficients a, b, and c, defined in Eq. (2), $W(\theta,\xi)$ can be written as

$$\begin{aligned} W(\theta,\xi)d\Omega d\xi=&[|a+b\cos\theta|^2+|c|^2\sin^2\theta]d\Omega\times\tfrac{1}{2}d\xi\\ &+\alpha\sin\theta\,\mathrm{Im}[c^*(a+b\cos\theta)]d\Omega\times\xi d\xi. \qquad (7) \end{aligned}$$

The existence of a nonvanishing α would constitute an unambiguous proof of parity nonconservation in Σ^- decay. In such a case the final state of $(n+\pi^-)$ in process (5) would be a mixture of $s_{\frac{1}{2}}$ and $p_{\frac{1}{2}}$ states with amplitudes, say, A and B respectively. The asymmetry parameter α is related to these amplitudes by

$$\alpha=2\,\mathrm{Re}(A^*B)/(|A|^2+|B|^2). \qquad (8)$$

If time reversal leaves invariant the decay process of Σ^-, then[8]

$$\alpha=\pm\frac{2|A|\times|B|}{|A|^2+|B|^2}\cos(\delta_p-\delta_s), \qquad (9)$$

where δ_p and δ_s are, respectively, the phase shifts of $(n+\pi^-)$ scattering in the $p_{\frac{1}{2}}$ and $s_{\frac{1}{2}}$ states at about 117 Mev in their center-of-mass system. If the decay interaction is invariant under charge conjugation, then[8]

$$\alpha=\pm\frac{2|A|\times|B|}{|A|^2+|B|^2}\sin(\delta_p-\delta_s). \qquad (10)$$

The following remarks are useful concerning the measurements of α and $p(\theta)$.

1. The polarization $P(\theta)$ may sometimes be very small. E.g., if (1) gives

$$I(\theta)=(1+\cos\theta)^2,\quad\text{or}\quad I(\theta)=(1-\cos\theta)^2, \qquad (11)$$

then $P(\theta)=0$ identically.

2. At production energies *near the threshold*, the variations of the quantities a, b, and c, introduced in Eq. (2), with respect to p_Σ are given by

$$\begin{aligned} a&=a_0(p_\Sigma)^{\frac{1}{2}},\\ b&=b_0(p_\Sigma)^{\frac{3}{2}}\exp(i\chi_b), \qquad (12)\\ c&=c_0(p_\Sigma)^{\frac{3}{2}}\exp(i\chi_c), \end{aligned}$$

where a_0, b_0, c_0, χ_b, and χ_c are all *real* constants independent of p_Σ. Thus by selecting two or three energy values near threshold, it is possible to determine a_0, b_0, c_0, and χ_b from the angular and energy dependence of $I(\theta)$ alone.

If the energy dependence of the cross section should be not representable by (12), one would have an indication that resonance effects might be important in the π^-+p system near the threshold for Σ^- production.

3. If $\chi_b\neq0$, then by comparing the coefficients of the $\sin\theta$ and $\sin\theta\cos\theta$ terms in $W(\theta,\xi)$, the phase χ_c cal also be determined.

4. From the values of these five real constants, a_0, b_0, c_0, χ_b, and χ_c, the asymmetry parameter α can then be deduced from $W(\theta,\xi)$ [Eq. (7)].

5. If

$$|\alpha|>|\sin(\delta_p-\delta_s)|,$$

then from Eq. (10) both invariance under charge conjugation and conservation of parity do not hold in the decay of Σ^-.

Since the phase shifts in the $J=\frac{1}{2}$ states are all small, the conclusion is essentially that any appreciable asymmetry with respect to the sign of ξ in $W(\theta,\xi)$ is an indication that conservation of parity and invariance under charge conjugation do not hold in the decay of Σ^-.

Production and decays of other hyperons. The foregoing analysis can also be applied to the productions and decays of other hyperons. We consider, for definiteness, the following processes concerning Λ^0:

$$\pi+p\rightarrow\Lambda^0+K^0, \qquad (13)$$

and

$$\Lambda^0 \rightarrow p+\pi^-. \tag{14}$$

All the previous formulas for $I(\theta)$, $p(\theta)$, $W(\theta,\xi)$, and α [i.e., Eqs. (2), (4), (6), (7), and (8)] remain unchanged. The only difference is that in Eq. (8) the amplitudes A and B of s- and p-wave final states in the decay process of Λ^0 are now each a mixture of two isotopic spin states. These amplitudes can be written as

$$\begin{aligned} A &= (\tfrac{2}{3})^{\frac{1}{2}}A_{\frac{1}{2}}+(\tfrac{1}{3})^{\frac{1}{2}}A_{\frac{3}{2}}, \\ B &= (\tfrac{2}{3})^{\frac{1}{2}}B_{\frac{1}{2}}+(\tfrac{1}{3})^{\frac{1}{2}}B_{\frac{3}{2}}, \end{aligned} \tag{15}$$

where $A_{\frac{1}{2}}$, $B_{\frac{1}{2}}$ are, respectively, the s- and p-wave amplitudes for final states with the total isotopic spin value $I=\frac{1}{2}$, and $A_{\frac{3}{2}}$, $B_{\frac{3}{2}}$ the corresponding amplitudes for states with $I=\frac{3}{2}$. In place of Eqs. (9) and (10) we have now the following conditions for invariance under time reversal and charge conjugation:

If the decay process is invariant under time reversal, then we can choose[8]

$$\begin{aligned} A_{\frac{1}{2}} &= |A_{\frac{1}{2}}|e^{i\delta_1}, \\ A_{\frac{3}{2}} &= \pm|A_{\frac{3}{2}}|e^{i\delta_3}, \\ B_{\frac{1}{2}} &= \pm|B_{\frac{1}{2}}|e^{i\delta_{11}}, \\ B_{\frac{3}{2}} &= \pm|B_{\frac{3}{2}}|e^{i\delta_{31}}. \end{aligned} \tag{16}$$

On the other hand, if the decay process is invariant under charge conjugation operation, then these amplitudes are[8]

$$\begin{aligned} A_{\frac{1}{2}} &= |A_{\frac{1}{2}}|e^{i\delta_1}, \\ A_{\frac{3}{2}} &= \pm|A_{\frac{3}{2}}|e^{i\delta_3}, \\ B_{\frac{1}{2}} &= \pm i|B_{\frac{1}{2}}|e^{i\delta_{1,1}}, \\ B_{\frac{3}{2}} &= \pm i|B_{\frac{3}{2}}|e^{i\delta_{3,1}}. \end{aligned} \tag{17}$$

The phase shifts δ are the usual pion-nucleon scattering phase shifts at 37-Mev total kinetic energy:

δ_1 = phase shift for s waves, $I=\frac{1}{2}$, $J=\frac{1}{2}$,

δ_3 = phase shift for s waves, $I=\frac{3}{2}$, $J=\frac{1}{2}$,

$\delta_{\lambda\mu}$ = phase shift for p waves, $I=\lambda/2$, $J=\mu/2$.

All these phase shifts are small at 37-Mev total kinetic energy. Therefore any appreciable asymmetry in $W(\theta,\xi)$ with respect to the sign of ξ is an indication that conservation of parity and invariance under charge conjugation do not hold in the decay of Λ^0.

A measurement of the branching ratio in the decay processes

$$\Lambda^0 \rightarrow p+\pi^-, \tag{18}$$

$$\Lambda^0 \rightarrow n+\pi^0, \tag{19}$$

and a measurement of the distribution function $W(\theta,\xi)$ for process (19) would lead to additional information concerning the amplitudes $A_{\frac{1}{2}}$, $B_{\frac{1}{2}}$, $A_{\frac{3}{2}}$, and $B_{\frac{3}{2}}$.

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[1] Wu, Ambler, Hayward, Hoppes, and Hudson, Phys. Rev. **105**, 1413 (1957).
[2] Garwin, Lederman, and Weinrich, Phys. Rev. **105**, 1415 (1957).
[3] J. Friedman and V. Telegdi, Phys. Rev. **105**, 1681 (1957).
[4] Budde, Chretien, Leitner, Samios, Schwartz, and Steinberger, Phys. Rev. **103**, 1827 (1956); D. A. Glaser (private communication); R. Adair (private communication).
[5] T. D. Lee and C. N. Yang, Phys. Rev. **104**, 254 (1956).
[6] T. D. Lee and C. N. Yang, Phys. Rev. **104**, 822 (1956).
[7] In view of the recent experimental developments (references 1, 2, and 3) there appears to be at present no *theoretical* necessity to introduce the complication of parity doublets. (See footnote 8 in reference 5.)
[8] Lee, Oehme, and Yang, Phys. Rev. **106**, 340 (1957). See the proof of Theorem 2.

Excited States in the Proton $f_{7/2}$ Shell*

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GOLDSTEIN and Talmi[1] have pointed out that it is sometimes possible to determine the excitation energies of the states of a j^n configuration by making use of the experimentally measured splittings of the j^2 configuration together with the tabulated coefficients of fractional parentage.[2] We have used this technique to make spin assignments for the excited states of nuclei with $(f_{7/2})^n$ protons and 28 (closed shell) neutrons. The purpose of this note is to stimulate interest in obtaining experimental verification of these predictions.

As our starting point we take the excitation energies for the configuration $(f_{7/2})^{-2}$ as given by (p,p') measurements[3] on Fe^{54}. Making use of these, one finds it a simple matter to compute the energy splittings for $(f_{7/2})^{-3}$—which, of course, should be the same as $(f_{7/2})^3$. We also predict that the lowest states of $(f_{7/2})^4$ should be the same as those of $(f_{7/2})^{\pm 2}$. This conclusion follows from the supposition that the lowest states should be those of lowest seniority. Consequently, the $(f_{7/2})^4$ states of seniority two, $J=2$, 4, 6, correspond to the recoupling of only two of the protons, the identical physical situation occurring in $(f_{7/2})^2$. A summary of our predictions together with the known experimental information is contained in the table.

It should be noted that the predictions for $(f_{7/2})^{\pm 3}$ are extremely sensitive to the values assumed for the two-particle energies. If, for example, one averages the $(f_{7/2})^{-2}$ excitation energies from Buechner and the $(f_{7/2})^4$ values obtained by Huiskamp *et al.*,[4] one obtains for $(f_{7/2})^{\pm 3}$ the energies 0.32 (5/2) Mev (above ground), 0.89 (3/2), 1.73 (9/2), 1.75 (11/2), and 3.12 (15/2).