theoretically predicted values, increasing the confidence in the experimental value of the Panofsky ratio, $\mathcal{P}=1.62\pm0.06$. It has been demonstrated that any investigation of the strong interaction in the $\pi^0\rightarrow 2\gamma$ process or any insight into the dynamics of virtual longitudinal gamma rays would require a sample of 5–50 times the present number of events.

In the $\pi^0\rightarrow 2\gamma$ case, the deviation of the form factor, $\Gamma(x/\mu)$, from unity was less than two standard deviations, the expansion parameter a being equal to -0.24 ± 0.16. Recently it has been shown[10,17] that negative values of a can be obtained by including interference effects between 2π and other intermediate states. In the case of virtual longitudinal γ rays in the $n+\gamma$ reaction, the data yielded a result which was consistent with a small contribution as predicted by the calculations of Joseph. It is hoped that the present project will be continued because of these two latter interesting questions, but these present results were considered to be of sufficient interest to warrant publication now.

[17] H. S. Wong, Phys. Rev. (to be published).

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$\Sigma^0\rightarrow\Lambda^0+e^++e^-$ and the $\Sigma^0-\Lambda^0$ Relative Parity*

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The $\Sigma^0-\Lambda^0$ relative parity may be measured by observing correlation of polarizations in the process $\Sigma^0\rightarrow\Lambda^0+\gamma$. Internal conversion of the photon into an electron pair (Dalitz pair) serves as an analyzer which selects polarized photons. Theoretical results are presented which show that the Dalitz-pair decay mode of polarized Σ^0's may be used to measure the $\Sigma^0-\Lambda^0$ relative parity.

KNOWLEDGE of the relative parity of the Σ^0 and Λ^0 hyperons would provide an important restriction on theoretical speculation about strong interactions. In this paper we wish to point out that there are correlations between the polarizations in the process

$$\Sigma^0\rightarrow\Lambda^0+\gamma, \qquad (1)$$

that depend on the $\Sigma^0-\Lambda^0$ relative parity. The direct production of an electron pair by internal conversion serves as an analyzer for the photon polarization.

The form of the correlations can be seen from the following argument. Consider first the process (1) where a real photon with momentum $\mathbf{k}$, electric vector $\mathbf{E}$, and magnetic vector $\mathbf{B}$, is emitted. Assuming that the Σ^0 as well as the Λ^0 has spin $\frac{1}{2}$, it follows from parity conservation, rotational and gauge invariance that, in the rest frame of the Σ^0, the S matrix in spin space has the form $\boldsymbol{\sigma}\cdot\mathbf{B}$ or $\boldsymbol{\sigma}\cdot\mathbf{E}$ according as to whether the $\Sigma^0-\Lambda^0$ parity is even or odd.[1] Since $\boldsymbol{\sigma}\cdot\hat{n}$ is the spin rotation operator which rotates the spin through 180° about the $\hat{n}$ direction, the spin of the Λ^0 will be that of the Σ^0 rotated through 180° about the direction of $\mathbf{B}$ ($\mathbf{E}$). Therefore, the Λ^0's will be polarized if the Σ^0's are polarized, and the expectation value $\mathbf{P}_\Lambda$ of the Λ^0 spin in its rest frame will be related to that of the Σ^0,

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[1] Throughout this paper the first, or upper, of two alternatives refers to the case of even $\Sigma^0-\Lambda^0$ relative parity, and the other to odd.

$\mathbf{P}_\Sigma$, by

$$\mathbf{P}_\Lambda = -\hat{k}\mathbf{P}_\Sigma\cdot\hat{k} \mp [\hat{E}\mathbf{P}_\Sigma\cdot\hat{E} - \mathbf{B}\mathbf{P}_\Sigma\cdot\mathbf{B}/B^2], \qquad (2)$$

where $\hat{k}$, etc., are unit vectors.

It is to be expected that Σ^0's produced at particular energies and angles in, for instance, pion-nucleon collisions will be polarized. Averaging (2) over all directions for $\hat{k}$ and $\hat{E}$, we find in agreement with Gatto[2]

$$\langle \mathbf{P}_\Lambda \rangle_{\text{av}} = -\tfrac{1}{3}\mathbf{P}_\Sigma. \qquad (3)$$

Since the directions of $\mathbf{P}_\Lambda$ and $\langle \mathbf{P}_\Lambda \rangle_{\text{av}}$ can be determined, apart from a common sign, by observing the favored directions for pion emission in the Λ^0 decays,[3] it follows from (2) that determination of the sign of, for instance, $\mathbf{P}_\Lambda\cdot\hat{E}\langle\mathbf{P}_\Lambda\rangle_{\text{av}}\hat{E}$ determines the $\Sigma^0-\Lambda^0$ relative parity.

The electron pairs produced by internal conversion of the photons in (1) provide one possible analyzer for the photon polarization[4] because the largest contribution to the production of such a pair comes from photons in the intermediate state whose electric vector is normal to the plane of the pair.[5] The energy denominator in this second-order process favors nearly real photons in the intermediate state whose longitudinal components make a small contribution [see Eq. (7)], so that the argument leading to (2) still applies. However, internal conversion does not provide a perfect analyzer for the photon polarization because transverse photons with both polarizations contribute to the production of the pair. We find that the Λ^0 polarization in internal conversion events averaged over all pairs produced with total momentum in the direction $\hat{k}$ in a plane whose normal is $\hat{n}$ is given by

$$\mathbf{P}_\Lambda = -\hat{k}\mathbf{P}_\Sigma\cdot\hat{k} \mp 0.43[\hat{n}\mathbf{P}_\Sigma\cdot\hat{n} - \hat{t}\mathbf{P}_\Sigma\cdot\hat{t}], \qquad (4)$$

where $\hat{t}=\hat{k}\times\hat{n}$. (Angular momentum conservation requires that the hyperon spin reverse when a transverse photon is emitted along the spin direction, so the correlation for $\mathbf{P}_\Sigma \| \hat{k}$ is complete.) The efficiency of internal conversion as an analyzer depends on the form factors for the interaction (1). We assume here that these form factors are constant.[6] In this case, the conversion coefficient is 1/180 (1/165).[7]

We take the interaction energy for (1) to have the form $ej_\mu A^\mu$.[8] Then the most general matrix element of the current j_μ satisfying parity conservation, Lorentz and gauge invariance has the form $\bar{u}_\Lambda J_\mu u_\Sigma$ where u_Λ and u_Σ are the free-particle Dirac spinors and

$$J_\mu = \begin{Bmatrix} 1 \\ \gamma_5 \end{Bmatrix} \left[F_1(k_\mu^2)\left(i\gamma_\mu - \frac{M_\Sigma \mp M_\Lambda}{p_\nu\cdot k^\nu} p_\mu \right) + F_2(k_\mu^2)\frac{\sigma_{\mu\nu}k^\nu}{2M} \right]. \qquad (5)$$

F_1 and F_2 are unknown form factors which can depend only on k_μ^2; p_μ is the Σ^0 4-momentum and k_μ the photon's 4-momentum; M is a mass chosen so that $F_2(0)=1$ if $F_2(0)\neq 0$. We here assume that $F_1=F_1(0)$ and $F_2=F_2(0)$. Then the lifetime τ for Σ^0 radiative decay (1) is given by

$$\tau^{-1} = \tfrac{1}{2}\alpha M_\Sigma^{-3}(M_\Sigma^2 - M_\Lambda^2)(M_\Sigma \mp M\Lambda)^2 \times |F_1 + F_2(M_\Sigma \pm M_\Lambda)/2M|^2. \qquad (6)$$

The transition probability for direct emission of a pair whose total 4-momentum has magnitude k_μ^2 ($k_\mu^2 = k_0^2 - \mathbf{k}^2$) is[5,7]

$$W(k_\mu^2) = \frac{\alpha}{3\pi}\frac{1}{k_\mu^2}\left(1-\frac{4m_e^2}{k_\mu^2}\right)^{\frac{1}{2}}\left(1-\frac{k_\mu^2}{\Delta^2}\right)^{\frac{1}{2}}\left(1+\frac{2m_e^2}{k_\mu^2}\right) \times\left(1+\frac{k_\mu^2}{2k_0^2}R_L^2\right)\begin{Bmatrix}(1-k_\mu^2/\Delta^2)\tau^{-1} \\ \tau^{-1}\end{Bmatrix}, \qquad (7)$$

where terms of order $\Delta/2M_\Lambda$ in the phase space factors have been neglected, $\alpha=1/137$, $\Delta=M_\Sigma-M_\Lambda$, and

$$R_L = |F_1 + F_2(k_0/2M)| / |F_1 + F_2(M_\Sigma \pm M_\Lambda)/2M|.$$

The quantity R_L is the ratio of the longitudinal to transverse parts of the hyperon current. If R_L is not much larger than one, pairs with $k_\mu^2 \ll \Delta^2$ dominate, and $\mathbf{P}_\Lambda$ has the form (4) with analyzer efficiency given by

$$\lambda^{-1}\int_{4m_e^2}^{\Delta^2} dk_\mu^2 W(k_\mu^2)(k_\mu^2 - 4m_e^2)(2k_\mu^2 + 4m_e^2)^{-1} = 0.43, \qquad (8)$$

where

$$\lambda = \int_{4m_e^2}^{\Delta^2} dk_\mu^2 W(k_\mu^2).$$

Note added in proof. The relation (2) between the polarizations in the process (1) has been given previously by R. Gatto, Phys. Rev. **109**, 610 (1957), and G. Feldman and T. Fulton, Nuclear Phys. **8**, 106 (1958).

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[2] R. Gatto, private communication to F. S. Crawford *et al.*, Phys. Rev. **108**, 1102 (1957).

[3] See, for instance, J. Ashkin, Suppl. Nuovo cimento **5**, 310 (1959).

[4] We have studied pair production from real photons and have found that effects which depend on the photon's polarization are small.

[5] N. M. Kroll and W. Wada, Phys. Rev. **98**, 1355 (1955).

[6] For a more detailed discussion see N. Byers, Institute of Theoretical Physics Technical Note TN-22, 1960 (unpublished). If the form factors do not remain constant, the effect would be to change the distribution in k_μ^2 of the pairs and the internal conversion rate. The polarization for a given value of k_μ^2 is

$$\mathbf{P}_\Lambda(k_\mu^2) = -\hat{k}\mathbf{P}_\Sigma\cdot\hat{k} \mp (1-4m_e^2k_\mu^{-2})(2+4m_e^2k_\mu^{-2})^{-1}(\hat{n}\mathbf{P}_\Sigma\cdot\hat{n} - \hat{t}\mathbf{P}_\Sigma\cdot\hat{t})$$

and is independent of the form factors for $k_\mu^2 \ll \Delta^2$.

[7] See G. Feinberg, Phys. Rev. **109**, 1019 (1958).

[8] We use units such that $\hbar = c = 1$.