K lab-momentum 150-400 Mev/c. In fact, the detection of either a large $\sin\theta$ or $\cos\theta\ \sin\theta$ dependence of the polarization intensity at 400 Mev/c would provide a strong clue to this parity, since it is likely that the amplitude $t_{1/2,0}$ is still larger than $t_{1/2,1}$ at this energy.

We conclude that the appropriate polarization measurements should be made in order that the parity of the 400-Mev/c anomaly in reaction (I) may be determined. If the K^- - p orbital angular momentum involved is even, it is unlikely that the intrinsic parities of the $\bar{K}N$ and $\pi\Sigma$ states are equal.

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ODD $\Lambda\Sigma$ PARITY AND THE NATURE OF THE $\pi\Lambda\Sigma$ COUPLING*

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In various symmetry models of strong interactions it has often been assumed that Λ and Σ belong to the same "supermultiplet" in some approximation.[1-3] Such a picture necessarily requires that the relative $\Lambda\Sigma$ parity be even. The purpose of the present Letter is twofold. We first summarize the recent experimental developments which are indicative of odd $\Lambda\Sigma$ parity. Secondly, we point out some unusual features of the scalar $\pi\Lambda\Sigma$ coupling; in particular we show that the scalar coupling constant is "calculable" from m_π, m_Λ, and m_Σ, and that the scalar coupling constant we calculate is in good agreement with that deduced from hypernuclear physics.

We wish to point out that, although even $\Lambda\Sigma$ parity has been tacitly assumed by many theoreticians, the available experimental data are suggestive of odd, rather than even, $\Lambda\Sigma$ parity. We can see this in the following eightfold way:

(1) According to recent Cornell data on associated photoproduction,[4] the angular distribution of

$$\gamma + p \rightarrow \Sigma^0 + K^+ \qquad (1)$$

at $E_\gamma = 1140$ Mev (threshold $E_\gamma = 1040$ Mev) seems anisotropic, and is reminiscent of a retarded $\sin^2\theta$ distribution, whereas at comparable K momenta the angular distribution for

$$\gamma + p \rightarrow \Lambda^0 + K^+ \qquad (2)$$

shows practically no structure. This feature agrees with the conventional view that the photoproduction of a charged meson near threshold takes place via the electric dipole absorption of the incident photon, only if K is pseudoscalar with respect to Λ (for which there is evidence from K^--He experiments[5]) but scalar with respect to Σ.[6]

(2) If a Taylor-Moravcsik type extrapolation analysis[7] is made for reaction (1), the available data strongly favor even $K\Sigma$ parity provided that only s waves and s-p interference are significant for the contributions other than the one-K exchange term (meson current term), or, what amounts to the same thing, provided that $(1 - \beta_K \cos\theta)^2(d\sigma/d\Omega)$ can be correctly extrapolated to $\cos\theta = \beta_K^{-1}$ by the use of a third-order polynomial with one constraint.[8] (The de Broglie wavelength of the K particle in the c.m. system is as large as 1.0×10^{-13} cm so that our cubic extrapolation may be justified.) Since there is some evidence for odd $K\Lambda$ parity elsewhere,[5,7] we see that odd $\Lambda\Sigma$ parity is favored.

(3) In the angular distribution for the reaction

$$\pi^- + p \rightarrow \Lambda^0 + K^0 \qquad (3)$$

at the ΣK threshold, an anomaly in the $\cos^3\theta$ term has been reported by Schwartz and collaborators.[9] If f waves are relatively unimportant for the final ΛK system at $p_K^{(\mathrm{c.m.})} \approx 230$ Mev/c ($\lambda\!\!\!^{-}_K \approx 0.85\times10^{-13}$ cm), then this anomaly should be attributed to p-d interference, which in turn implies that the $\Lambda\Sigma$ parity is odd.[10]

(4) In associated production of Σ particles in πp collisions no striking backward peaking of Σ's similar to the backward peaking of Λ's has been observed at low energies ($E_\pi^{(\mathrm{KE})} \lesssim 1.1$ Bev), although there is evidence for a backward peaking at higher energies. As already pointed out by Bég, Bernstein, and De Celles,[11] this feature can be nicely explained if the backward peaking of the hyperon is due to the pole arising from the exchange of a K^* (880-Mev $K\pi$ resonance) which is scalar with respect to Λ but pseudoscalar with respect to Σ.

(5) Preliminary indications[12] seem to favor the spin $\frac{1}{2}$ assignment for Y^* (the $T=1$ $\pi\Lambda$ resonance discovered by Alston et al.[13]). If the relative $K\Lambda$ parity is odd,[5] and if $Y^* \to \pi + \Lambda$ via the $s_{1/2}$ channel, for which there is some preliminary evidence,[12] then Y^* has the same quantum numbers as the low-energy $\bar{K}N$ system, which means that Y^* is a resonance of the type discussed by Dalitz and Tuan.[14] In such a case the observed small $\pi\Sigma/\pi\Lambda$ ratio for Y^* decay seems to favor odd $\Lambda\Sigma$ parity, as recently emphasized by Ross and Shaw[15] and by Dalitz[16] (unless physically unlikely values of effective-range parameters are assumed).

(6) Regardless of the validity of the global symmetry model, a $T=1$, $J=\frac{3}{2}$ p-wave pion-hyperon resonance seems to be expected for a wide range of values of $G_{\pi\Lambda\Sigma}^2/4\pi$ and $G_{\pi\Sigma\Sigma}^2/4\pi$ as long as the relative $\Lambda\Sigma$ parity is even.[17] The nonexistence of a $T=1$, $J=\frac{3}{2}$ resonance might be taken as an argument against even $\Lambda\Sigma$ parity.

(7) In the even $\Lambda\Sigma$ parity case it is reasonable to expect, in addition, a $T=2$, $J=\frac{3}{2}$ p-wave $\pi\Sigma$ resonance, denoted by Z^*.[17] As pointed out by Lee and Yang,[18] if we take the global symmetry model seriously, this hypothetical $T=2$ state may be at 1539 Mev with a width about twice that of the πN three-three resonance. No evidence for Z^{*++} ($\to \Sigma^+ + \pi^+$) has been reported in the reaction

$$\bar{K}^0 + p \to \Sigma^+ + \pi^+ + \pi^-, \qquad (4)$$

studied at $p_K \sim (1.0 \pm 0.1)$ Bev/c by the Yale-Brookhaven bubble chamber group,[19] nor is there any indication for a $\pi\Sigma$ resonance in K^-p experiments.[12,13] [The threshold for Z^* ($\to \Sigma + \pi$) production in association with a π in $\bar{K}N$ collisions is at 750 Mev/c.]

(8) Barshay and Schwartz[20] have pointed out that the remarkable Gell-Mann–Rosenfeld triangle in Σ decay can be understood in terms of a single parameter if the Σ hyperon is a bound $\pi\Lambda$ system. Unless the spin-orbit force between π and Λ is unexpectedly strong, the bound $\pi\Lambda$ system is likely to be $s_{1/2}$.

We admit that none of these indications offers conclusive evidence against even $\Lambda\Sigma$ parity. But they do suggest that speculations on the odd $\Lambda\Sigma$ parity situation might be of more than academic interest.

We now turn our attention to the nature of the $\pi\Lambda\Sigma$ coupling, which, in the following discussion, is assumed to be of the scalar type. It has been known for some time that, if one of the particles in a trilinear coupling can be regarded as a bound system of the other two in the sense of dispersion theory,

$$m_1 < m_2 + m_3,$$
$$m_1^2 > m_2^2 + m_3^2, \qquad (5)$$

then so-called "structure effects" are expected to be important.[21] In particular, the coupling constant is determined by the asymptotic form of the bound-state wave function. Considerations along these lines have been made in connection with the "neutron-proton-deuteron coupling"[22] and also with a Fermi-Yang type model of the pion.[23]

Although one can discuss the $\pi\Lambda\Sigma$ coupling using the language of dispersion theory, we shall adopt here a more "low-brow" language. In a purely phenomenological discussion, the bound-state picture for Σ can be used as long as the Σ is coupled strongly to the $\pi\Lambda$ system, regardless of whether or not one subscribes to the bound-state picture in a literal sense. Let us consider the asymptotic wave function for the bound $\pi\Lambda$ system,

$$\psi \sim [\exp(-r/r_\Sigma)]/r,$$
$$r_\Sigma = (2\mu_\pi |E_B|)^{-1/2}, \qquad (6)$$

where

$$E_B = m_\Sigma - m_\pi - m_\Lambda = -60 \text{ Mev},$$
$$\mu_\pi = m_\pi m_\Lambda (m_\pi + m_\Lambda)^{-1} = 120 \text{ Mev}.$$

Physically speaking, r_Σ is the "radius" of the Σ hyperon analogous to the deuteron radius. Numerically,

$$r_\Sigma = 1.6 \times 10^{-13} \text{ cm}.$$

(A fully relativistic treatment leads to essentially the same value.) The surprisingly large value of this number is the starting point of our investigation.

If the range of the $\pi\Lambda$ force is much shorter than the "radius" of the bound $\pi\Lambda$ system, the logarithmic derivative of the wave function evaluated at some radius just outside the range of the $\pi\Lambda$ force does not vary appreciably as the energy is lowered from the zero kinetic energy to the observed binding energy of -60 Mev. It then becomes possible to equate the scattering length a to the "radius" r_Σ:

$$-a = r_\Sigma = (2\mu_\pi |E_B|)^{-1/2}. \qquad (7)$$

This relation is simply the well-known relation between the binding energy and the scattering length in the zero-range approximation.

Generally speaking, the range of the $\pi\Lambda$ force is expected to be roughly equal to or less than $(2m_\pi)^{-1}$. Since the pion and the Λ hyperon cannot exchange a pair of pions having the same quantum numbers as the Frazer-Fulco resonance ($T=1$, $J=1$, even G parity), it is probably legitimate to ignore pion-pion interactions. The $\pi\Lambda$ force may then be as short-ranged as the force associated with the so-called "baryon exchange" diagram whose range $\approx (m_\pi m_\Sigma)^{-1/2} = 0.4\times10^{-13}$ cm is much smaller than the "radius" of the Σ hyperon. Physically speaking, this means that the Σ hyperon has a relatively "open" structure; the pion and the Λ hyperon spend most of their time outside the range of the interaction.[24]

We now calculate the scalar coupling constant $G_{\pi\Lambda\Sigma}^2/4\pi$. This can be carried out either by noting that the normalization constant for the asymptotic bound-state wave function is related to the "sticking probability" for $\pi + \Lambda \rightarrow \Sigma$ or by comparing (7) with the expression for the scattering length computed under the assumption that the Σ pole dominates in low-energy $\pi\Lambda$ scattering. We obtain

$$\frac{G_{\pi\Delta\Sigma}^2}{4\pi} = \frac{m_\pi}{\mu_\pi}\left(\frac{|E_B|}{2\mu_\pi}\right)^{1/2}$$

$$= \left(\frac{m_\pi + m_\Lambda}{m_\Lambda}\right)\left(\frac{(m_\pi + m_\Lambda - m_\Sigma)(m_\pi + m_\Lambda)}{m_\pi m_\Lambda}\right)^{1/2}$$

$$\approx 0.6. \qquad (8)$$

Of course, this formula is exact only in the zero-range approximation. If the effective range for $\pi\Lambda$ scattering is 0.3×10^{-13} cm, then the value of the coupling constant gets increased by about 15%.

That we can calculate the coupling constant from the mass spectrum alone is the most interesting feature of the scalar-type $\pi\Lambda\Sigma$ coupling. The physical origin of this remarkable fact is clear; although we do not know the detailed dynamics of the short-range interaction between π and Λ, as far as its large-scale manifestations such as the scattering length and the binding energy are concerned, only one parameter, depth times (range)^2 in potential theory, is relevant, which means that E_B and $G_{\pi\Lambda\Sigma}^2/4\pi$ are not independent of each other.[25]

Up to now the only other information on the $\pi\Lambda\Sigma$ coupling comes from the ΛN potential fitted to the binding energies of various hypernuclei. Ferrari and Fonda[26] have shown that if the $\Lambda\Sigma$ parity and the $K\Lambda$ parity are both odd, the binding energy of $_\Lambda He^5$ together with the requirement that the two-body ΛN system be unbound leads to the coupling constant combination

$$G_{\pi\Lambda\Sigma}^2/4\pi = 0.5, \quad \text{(scalar coupling)}$$

$$G_{K\Sigma N}^2/4\pi \gtrsim 0.8, \quad \text{(scalar coupling)}$$

$$3 > G_{K\Lambda N}^2/4\pi > 0, \quad \text{(pseudoscalar coupling).}$$

So our result on the $\pi\Lambda\Sigma$ coupling constant is in good agreement with the calculations of Ferrari and Fonda.

It is hoped that the present note will prompt experimentalists to concentrate their efforts on experiments that have bearings on an unambiguous determination of the relative parity. Search for possible correlation effects in

$$\Sigma^0 \rightarrow \Lambda^0 + e^+ + e^- \qquad (9)$$

seems particularly promising.[27]

To conclude, if there is one observable on which the future of strange particle physics depends, it is the relative $\Lambda\Sigma$ parity.[28]

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[6]In the even $\Lambda\Sigma$ parity case, it may be difficult to explain why the magnetic dipole absorption is anomalously strong for Σ^0 production but not for Λ^0 production.

[7]M. J. Moravcsik, Phys. Rev. Letters 2, 352 (1959).

[8]A detailed account on this point will be given elsewhere. Preliminary investigations made by one of us (J.J.S.) have led to the scalar constant $G_{K\Sigma N}^2/4\pi \sim 0.6$. Since there are only three experimental points available, extrapolations with higher order polynomials are not feasible at the present moment.

[9]M. Schwartz, in Proceedings of the Conference on Strong Interactions, Berkeley, California, 1960 [Revs. Modern Phys. (to be published)].

[10]The argument goes as follows: It has been established experimentally by the Berkeley hydrogen bubble chamber group that the energy and angular dependence of $\pi^- + p \rightarrow \Sigma^- + K^+$ very near threshold is typical of the s-state excitation. So the cusp state of the ΛK system must be either $s_{1/2}$ (even $\Lambda\Sigma$) or $p_{1/2}$ (odd $\Lambda\Sigma$). In the $s_{1/2}$ case, the observed $\cos^3\theta$ anomaly would be possible only via s-f interference.

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[23]Y. Nambu, in Proceedings of the Midwest Conference on Theoretical Physics (Purdue University, Lafayette, Indiana, 1960).

[24]It is of interest to compare this situation with Y^* assuming that Y^* is a bound $\bar{K}N$ system in the s state as suggested by various people.[15,16] In the Y^* case the radius turns out to be 1.1×10^{-13} cm, and the range of the $\bar{K}N$ force might be as large as $(2.2\,m_\pi)^{-1} \sim 0.65 \times10^{-13}$ cm, particularly if the anomalous state seen in p-d collisions by A. Abashian, N. E. Booth, and K. M. Crowe [Phys. Rev. Letters 5, 258 (1960)] turns out to be a neutral vector particle coupled to the hypercharged current [J. J. Sakurai, Ann. Phys. 11, 1 (1960); see also Gell-Mann[3]]. Incidentally, if the Σ is regarded as a bound state of a $\bar{K}$ and an N as in Goldhaber's model [M. Goldhaber, Phys. Rev. 101, 433 (1956)], the Σ "radius" under this assumption turns out to be 0.6×10^{-13} cm so that no reliable information on the $K\Sigma N$ coupling can be obtained from analogous considerations.

[25]It has been suggested that in the odd $\Lambda\Sigma$ parity case one may still equate, in the bare Lagrangian, the pseudoscalar $\pi\Sigma\Sigma$ coupling constant to the scalar $\pi\Lambda\Sigma$ coupling constant [S. Barshay, Phys. Rev. Letters 1, 97 (1958); F. Gürsey, Phys. Rev. Letters 1, 98 (1958); R. E. Behrends, Nuovo cimento 11, 424 (1959)]. However, (8) tells us that even if the unrenormalized pseudoscalar constant and the unrenormalized scalar constant did satisfy a certain relation, there would be no reason whatsoever to expect a similar relation for the corresponding renormalized constants.

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[28]It appears that the original vector theory of strong interactions proposed by one of us (J.J.S.[24]), but not Gell-Mann's "eightfold way,"[3] is the only "verifiable" symmetry model which can accommodate (but does not require) odd $\Lambda\Sigma$ parity.