of the physical nucleon, it fails near the core where nuclear $\beta$-decay and Dirac moment are concentrated.

A more detailed account of this work will be published elsewhere.

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## EVIDENCE FOR RESONANCE STATES IN THE $K^-$-$N$ SYSTEM

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One of the striking features of $\sigma_{el}$ for $K^-$-$p$ scattering is its consistently high value compared with $\sigma_{el}$ for $K^+$-$p$ scattering,[1] $[\sigma_{el}(K^-p)/4\pi\lambda\!\!\!^{-2} \sim \frac{1}{8}$, $\sigma_{el}(K^+p)/4\pi\lambda\!\!\!^{-2} \sim \frac{1}{34}$ for $T_K(\text{lab}) \approx 25$ Mev], near threshold. This, combined with the suspicion that the $K^-p$ "potential" is attractive and the $K^+p$ "potential" repulsive at low energies, and a characteristic peaking[2] of $\sigma_{el}(K^-p)$ around $T_K(\text{lab}) = 25$ Mev, seems to suggest the possibility that interactions in the energy range 15-60 Mev proceed mainly through a $J=\frac{1}{2}$ resonance centered around $T_K = 25$ Mev. Such a resonance state (to be called $\Sigma^*$) would be expected to show itself both in elastic scattering as well as in the $K^-$-absorption processes. Assuming the existence of a resonance at $E_0$ (c.m. energy), we use the one-level resonance formulas

$$\sigma_{el} = \frac{(2J+1)}{2} f_e(I) \frac{\pi}{k_K^2} \frac{\Gamma_K^2}{(E-E_0)^2 + \frac{1}{4}(\Gamma_K+\Gamma_\pi)^2}, \quad (1)$$

$$\sigma_{abs}(\pi^\pm, \Sigma^\mp) = \frac{2J+1}{2} f_a(I) \frac{\pi}{k_K^2} \frac{\Gamma_K \Gamma_\pi}{(E-E_0)^2 + \frac{1}{4}(\Gamma_K+\Gamma_\pi)^2}. \quad (2)$$

Here $J$ is the angular-momentum of the resonance state and $f(I)$ are the isotopic spin factors:

$$f_e(I) = \tfrac{1}{4} \text{ for } I = 0,\ 1;$$

$$f_a(I) = \tfrac{1}{3} \text{ for } I = 0$$
$$= \tfrac{1}{2} \text{ for } I = 1;$$

and $\Gamma_K$ and $\Gamma_\pi$ are the partial widths. From (1) and (2),

$$\sigma_{el}/\sigma_{abs} = f_e(I)\Gamma_K / f_a(I)\Gamma_\pi. \quad (3)$$

The energy dependence of $\Gamma_K$ and $\Gamma_\pi$ is sensitive to the $(K\Sigma)$ and $(\Sigma^*\Sigma)$ parities. If we assume that both the $(\Sigma\pi)$ and $(Kp)$ systems are in $S$ states, with momentum $k$ in the center-of-mass system, we may take

$$\Gamma = 2ky^2, \quad (4)$$

where $y$ is an energy-independent parameter. This implies (with the convention that $N$ and $\Sigma$ have the same parity "plus") that both $\Sigma^*$ and $K$ have intrinsic parity "minus." Relation (3) then reduces to

$$\frac{k_K \sigma_{abs}}{k_\pi \sigma_{el}} = \text{const} = \frac{f_a(I) y_\pi^2}{f_e(I) y_K^2}. \quad (5)$$

This checks fairly well with the experimental results in the energy region $15 < T_K < 60$ Mev, provided we use the Berkeley bubble-chamber data (rather than the emulsion data) for $25 < T_K < 35$ Mev.

If we have $P$ waves, then

$$\Gamma = \frac{2ky^2}{1+(ka)^{-2}} \approx 2k^3a^2y^2, \ (ka \ll 1), \quad (6)$$

where $a$ is the interaction radius. The possibility that the reactions go purely through $P$ waves is excluded by the relation corresponding to (5), and a less satisfactory fit is obtained with the assumption that just the $\pi\Sigma$ system is in a $P$ state.

Noting that

$$\sigma_{el}(E=E_0) = \frac{k^2}{4\pi} f_e(I) \left[1 + \frac{k_\pi y_\pi^2}{k_K y_K^2}\right]^{-1}_{E=E_0}, \quad (7)$$

and combining (6) and (7) one should also be able to deduce the isotropic spin value of $\Sigma^*$. Unfortunately the data are not good enough to distinguish the case $I=0$ from $I=1$. We shall come back to this later.

However, with the spin and parity assignment $(\frac{1}{2}, -)$ to the $\Sigma^*$ state, we can now correlate the following facts:

(1) The angular distribution for

$$K^- + p \to \Sigma^* \to K^- + p$$

must be isotropic. This result depends on the fact that $J=\frac{1}{2}$.

(2) The angular distribution for

$$K^- + p \to \Sigma^* \to \pi + \Sigma$$

is isotropic. This is also because $J=\frac{1}{2}$ and does not depend on the parity assignment of $\Sigma^*$. Both (1) and (2) seem borne out experimentally.

(3) The $K^-p$ "potential" must be attractive. In a sense this is what first led to a consideration of the resonance hypothesis. Given the resonance hypothesis one can formally check back (using the usual computational approximations) that the effective "potential" is indeed attractive. So far as we know, this is the only "explanation" of this experimentally suspected result. Without the resonance hypothesis, the $K^-p$ "potential" turns out to be repulsive both for scalar and pseudoscalar $K$-mesons in a lowest order calculation.

(4) In the production processes

$$\begin{aligned} \pi^- + p &\to K^+ + \Sigma^-, && \text{(i)} \\ &\to K^0 + \Sigma^0, && \text{(ii)} \\ &\to K^0 + \Lambda^0, && \text{(iii)} \\ \pi^+ + p &\to K^+ + \Sigma^+, && \text{(iv)} \end{aligned}$$

it is easy to verify that the existence of $\Sigma^*$ effects only (i) and (iv), in the same approximation used in (3) (treating $\Sigma^*$ as a particle and working with lowest order graphs[3]). It is a long-standing problem that hyperons seem to be emitted in the backward direction in the c.m. system in processes (i) and (iv) and in the forward direction in (ii) and (iii). The existence of $\Sigma^*$ provides a natural mechanism for differentiating (i) and (iv) from (ii) and (iii).

Next we turn to the question of the isotopic spin of $\Sigma^*$. For pure $I=0$ or $I=1$ states the cross sections should be in the ratios indicated in Table I. Experimentally, for $20 < T_K < 60$ Mev, the production ratio on protons is

$$\Sigma^+/\Sigma^- \approx 1,$$

while nothing is known about neutral hyperon production. Also

$$\sigma(K^- + p \to n + K^0)/\sigma(K^- + p \to p + K^-) > \tfrac{1}{5}.$$

This is not sufficient to fix the $I$ value. A definite assignment would be possible, if one could determine whether $\Sigma^0$ or $\Lambda^0$ are produced predominantly in $K^-p$ absorption in this energy region, indicating $I=0$ or 1, respectively.

Table I. Predicted cross-section ratios for pure $I=0$ or $I=1$ states.

| | $I=0$ | $I=1$ |
|---|---|---|
| $K^- + p \to p + K^-$ | $a$ | $\alpha$ |
| $\to n + K^0$ | $a$ | $\alpha$ |
| $\to \Sigma^+ + \pi^-$ | $b$ | $\beta$ |
| $\to \Sigma^- + \pi^+$ | $b$ | $\beta$ |
| $\to \Sigma^0 + \pi^0$ | $b$ | 0 |
| $\to \Lambda^0 + \pi^0$ | 0 | $\gamma$ |
| $K^- + n \to n + K^-$ | 0 | $4\alpha$ |
| $\to \Sigma^- + \pi^0$ | 0 | $2\beta$ |
| $\to \Sigma^0 + \pi^-$ | 0 | $2\beta$ |
| $\to \Lambda^0 + \pi^-$ | 0 | $2\gamma$ |

So far we have only considered the $\Sigma^-/\Sigma^+$ ratio in the region $T_K > 20$ Mev. We now consider it near threshold. According to the one-level picture presented above, this ratio should be unity. Experimentally, for $T_K = 0$ this is nearer two; for increasing energy ($T_K \sim 10$ Mev) it rises to seven and then around 20 Mev it settles down to $\sim 1$. This behavior seems to call for a very special type of interference with amplitudes of opposite isotopic spin assignment in the energy range $0 < T_K < 20$ Mev. We have considered various simple models for this other amplitude which could give the experimental behavior in this region, while the resonance dominates for $T_K > 20$ Mev. Considerations on this will be published in a separate note with J. Tiomno.

[1]All data in this note are taken from the report given by M. F. Kaplon, at the 1958 Annual International Conference on High-Energy Physics at CERN, edited by B. Ferretti (Cern, Geneva, 1958), p. 171.

[2]See Fig. 8 and Fig. 13 of reference 1. Note that the simpler interpretation in terms of complex scattering lengths [see R. H. Dalitz, 1958 Annual International Conference on High-Energy Physics at CERN, edited by B. Ferretti (CERN, Geneva, 1958), p. 187] predicts a steady rising of the cross section as one approaches threshold. Both bubble-chamber and emulsion data suggest a fall, though the errors are large.

[3]The assumed interactions $\Sigma^* \to p + K^-$, $\Sigma^* \to \Sigma^\pm + \pi^\mp$ imply $\Sigma^* + K^+ \to p$, $\Sigma^* + \pi^\pm \to \Sigma^\pm$.