TABLE I. Possible targets for neutrino reactions.

Target	Product	e^+ decay of product $\log ft$	$t_{\frac{1}{2}}$(sec)	$\sigma_{\max}$(cm^2)	$\nu_{\max}$ (Mev)
C^{12}	N^{12}	4.18	0.0125	4×10^{-41}	85
Al^{27}	Si^{27}	3.6	3.7	2.5×10^{-40}	66
P^{31}	S^{31}	3.6	2.9	2.5×10^{-40}	63
Cl^{35}	A^{35}	3.5	2.2	3×10^{-40}	61
K^{39}	Ca^{39}	3.6	1.0	2.5×10^{-40}	58

cumstance reduces considerably the prospects for a measurement of reaction (2).

The angular distribution, given by Eqs. (13) and (14), is plotted in arbitrary units in Fig. 2 for $\nu=85$ Mev, vs $\cos\theta=\hat{p}\cdot\mathbf{v}/\nu$.

III. DISCUSSION

Reaction (2), due to the identifying features of a well-defined energy of e^- (if monochromatic neutrinos are used), and a subsequent e^+ decay of the product nucleus, offered an attractive possibility for investigating the identity of ν_μ and ν_e. The smallness of the cross section is a less favorable aspect. One could ask whether other targets could be used instead of C^{12} in reaction (2), with similar features, and whose cross section could be larger due to a smaller ft value in the positron decay. Several elements are possible, and in Table I, we have chosen those which give rise to a product nucleus decaying back to the ground state of the target in no longer than several seconds and with smaller ft values. Very roughly, we have also estimated the maximum cross section for the neutrino-induced reaction (from the ratio of the ft values) and the neutrino energy corresponding to this maximum (from $\nu R\sim$const). One sees that somewhat larger cross sections might actually be obtained in this way; the subsequent decays, however, are quite slow in all cases.

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Production and Spin of the K^* Resonance*

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The experimental results of Alston *et al.* on the production of K^* in the reaction $K^-+p\to\bar{K}^0+\pi^-+p$ are discussed. If one assumes spin 1 for K^* a satisfactory explanation of the data is obtained using a model in which in addition to the exchange of a π meson the effect of the resonance Y_4^* ($m_4=1812$ Mev, $T=0$) is taken into account. This model requires Y_4^* to occur in the $d_{\frac{3}{2}}$ state of the K^-p system. We make the prediction $\langle\cos^2\theta\rangle=0.29$ in $K^-+p\to K^-+\pi^++n$. It is suggested that the measurement of a certain angular correlation at a higher energy might distinguish between $S=0$ and $S=1$ for K^*.

IN this paper we examine the production of the K^* resonance in the reactions:

$$K^-+p\to K^{*-}+p \quad \text{(A)}$$
$$\searrow \bar{K}^0+\pi^- \quad \text{(A')}$$
$$\searrow K^-+\pi^0, \quad \text{(A'')}$$
$$K^-+p\to \bar{K}^{*0}+n \quad \text{(B)}$$
$$\searrow K^-+\pi^+, \quad \text{(B')}$$

as related, in particular, to the question of the K^* spin. Our analysis is based on measurements by Alston *et al.*,[1] with incident K^- of momentum 1.15 Gev/c. We first give a summary of their results:

(1) The resonance energy is 885 Mev with a full width of 16 Mev.

(2) The branching ratio,

$$R=(K^{*-}\to K^-+\pi^0)/(K^{*-}\to\bar{K}^0+\pi^-)=0.75\pm0.35,$$

strongly favors isotopic spin $T=\frac{1}{2}$ for K^*.

(3) The branching ratio for reactions (A') and (B') is about one. If $T=\frac{1}{2}$, this branching ratio is the same as for the reactions (A) and (B).

(4) The total cross section for $\bar{K}^0\pi^-$ production is (2.0±0.3) mb. From a total number of 48 $\bar{K}^0\pi^-$ events, 21 have been classified as coming from an intermediate K^*. Hence, the cross section for reaction (A), assuming $T=\frac{1}{2}$, is (1.31±0.35) mb.

(5) The proton angular distribution is roughly isotropic.

(6) Let $\boldsymbol{\theta}$ be the angle between the direction of the outgoing $\bar{K}^0$ in the K^* rest system and the direction of the incoming K^-. The mean value of $\cos^2\boldsymbol{\theta}$ is 0.275. If K^* has spin zero, one should obtain $\langle\cos^2\boldsymbol{\theta}\rangle=\frac{1}{3}$, with a standard deviation of ±0.066. For spin one, the value of $\langle\cos^2\boldsymbol{\theta}\rangle$ could range from 0.2 to 0.6. Under certain plausible assumptions higher spins can be excluded.

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[1] M. Alston, L. W. Alvarez, P. Eberhard, M. L. Good, W. Graziano, H. K. Ticho, and S. G. Wojcicki, Phys. Rev. Letters **6**, 300 (1961).

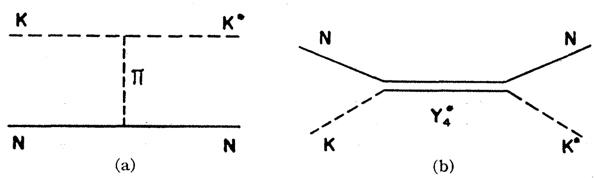

FIG. 1. Production of K^*: (a) through the exchange of a π meson; (b) through the resonance $Y_4{}^*$.

Reaction (A) has been investigated by several authors[2] assuming that it is produced mainly through the exchange of a single pion as shown in the diagram of Fig. 1(a). Such a model leads to certain results which have been considered as evidence in favor of spin 1 for K^*. Indeed, if $S=1$, the proton angular distribution is essentially flat, and the total cross section is in agreement with the experimental value. On the other hand if $S=0$, the model predicts the angular distribution strongly peaked backwards, and the total cross section smaller than the experimental value by a factor of 9. However, the predictions of the model for items (3) and (6) above, have been overlooked. Assuming $S=1$ for K^* the value of $\langle\cos^2\theta\rangle$, according to the model, would be very close to the threshold value[3] $\langle\cos^2\theta\rangle=0.6$, in complete disagreement with the experimental result. Moreover, the model gives $\frac{1}{4}$ for the branching ratio of reactions (A′) and (B′). This again is inconsistent with the experimental estimate. It is then clear that although the amplitude as given by the diagram of Fig. 1(a) has the right order of magnitude for $S=1$, the production mechanism cannot be explained in terms of that diagram alone. Consequently, the argument claimed in favor of $S=1$ is not entirely consistent.

We shall start our analysis by observing that the reported experiment has been done at an energy which falls within the width of the resonance $Y_4{}^*$ of the K^-p system[4] ($m_4=1812$ Mev; $\Gamma_4=120$ Mev). The isotopic spin of $Y_4{}^*$ is already known to be $T=0$. From unitarity one can put a lower limit on the spin of $Y_4{}^*$. The condition $\sigma_{\text{res}}(T=0)\leqslant 4\pi(J+\frac{1}{2})/q_{\text{res}}{}^2$ gives $J\geqslant\frac{3}{2}$. Let us suppose that $J=\frac{3}{2}$. Then if K^* is scalar, either the $p_{\frac{3}{2}}$ or $d_{\frac{3}{2}}$ wave of the $K^{*-}p$ system would be affected by the resonance $Y_4{}^*$ depending on its parity. On the other hand if K^* is vector, the s wave would be affected, provided that the resonance $Y_4{}^*$ occurs in the $d_{\frac{3}{2}}$ state of the K^-p system. Since the experiment was performed close to the threshold for K^* production and the proton distribution is nearly isotropic, one can assume that s waves are dominant. Therefore, a strong influence of the resonance $Y_4{}^*$ in the production of K^* is to be expected if $S=1$, but not much if $S=0$. Let us assume that $Y_4{}^*$ is a $d_{\frac{3}{2}}$ resonance of the K^-p system and K^* a p-wave resonance of the $K\pi$ system. Then, the amplitudes for transitions in which the state of the incoming particles is $d_{\frac{3}{2}}$, $T=0$, might be given by the diagram of Fig. 1(b) (isobar model). We shall examine the production processes (A) and (B) under the foregoing conditions.[5]

The general form of the angular correlation $d\sigma/d\cos\theta$ is

$$d\sigma/d\cos\theta=2\pi(|a|^2\cos^2\theta+\tfrac{1}{2}|b|^2\sin^2\theta). \qquad (1)$$

Here θ is the angle defined in item (6).

We shall take into account only those transitions leading to s states of the K^*p system. This approximation is justified by the arguments given before. Then one finds

$$\begin{aligned} a&=2f_{\frac{3}{2}}-f_{\frac{1}{2}},\\ b&=\sqrt{2}(f_{\frac{3}{2}}+f_{\frac{1}{2}}), \end{aligned} \qquad (2)$$

where $f_{\frac{1}{2}}$ and $f_{\frac{3}{2}}$ are the amplitudes for transitions $s_{\frac{1}{2}}\rightarrow s_{\frac{1}{2}}$ and $d_{\frac{3}{2}}\rightarrow s_{\frac{1}{2}}$, respectively. The total cross section for reactions (A) or (B), and the mean value of $\cos^2\theta$ are given by

$$\sigma=\tfrac{4}{3}\pi(|a|^2+|b|^2)=4\pi(2|f_{\frac{3}{2}}|^2+|f_{\frac{1}{2}}|^2), \qquad (3)$$

and

$$\langle\cos^2\theta\rangle=(1/15)(14|f_{\frac{3}{2}}|^2+5|f_{\frac{1}{2}}|^2 -8\,\mathrm{Re}f_{\frac{3}{2}}f_{\frac{1}{2}}{}^*)/(2|f_{\frac{3}{2}}|^2+|f_{\frac{1}{2}}|^2). \qquad (4)$$

Since the diagram of Fig. 1(a) gives $\langle\cos^2\theta\rangle\approx 0.6$, the partial amplitudes obtained therefrom would approximately satisfy the relation $f_{\frac{1}{2}}+f_{\frac{3}{2}}=0$.

The amplitudes for reactions (A) and (B) may be expressed in terms of transition amplitudes f^T in states of definite isotopic spin $T=0$ and $T=1$. One obtains

$$\begin{aligned} f^A&=\tfrac{1}{2}(f^1+f^0),\\ f^B&=\tfrac{1}{2}(f^1-f^0). \end{aligned} \qquad (5)$$

The isotopic spin dependence of graph 1(a) is contained in the factor $\tau_1\cdot\tau_2=P_1-3P_0$, where P_1 and P_0 are the projection operators for the respective isotopic states. Thus, for that graph, $f^0=-3f^1$. Now, according to our basic hypothesis, $f_{\frac{3}{2}}{}^0$ will be obtained from graph 1(b) and has the form $f_{\frac{3}{2}}{}^0=\rho_0(\exp i\varphi)$, where $\tan\varphi=\Gamma_4 m_4/(m_4{}^2-E^2)=-1.15$. The other amplitudes will be taken from graph 1(a) and can all be expressed in terms of $f_{\frac{3}{2}}{}^1=-\rho_1$. The total cross section for reaction (A) calculated from the diagram 1(a) is $\sigma_A=4.70$ Gev^{-2} $=12\pi\rho_1{}^2$, from which one finds $|\rho_1|=0.353$ Gev^{-1}. Collecting all these pieces together we obtain the following set of partial amplitudes:

$$\text{Reaction (A):}\quad \begin{aligned} f_{\frac{3}{2}}{}^A&=\tfrac{1}{2}[-\rho_1+\rho_0(\exp i\varphi)],\\ f_{\frac{1}{2}}{}^A&=-\rho_1. \end{aligned} \qquad (6)$$

$$\text{Reaction (B):}\quad \begin{aligned} f_{\frac{3}{2}}{}^B&=\tfrac{1}{2}[-\rho_1-\rho_0(\exp i\varphi)],\\ f_{\frac{1}{2}}{}^B&=2\rho_1. \end{aligned} \qquad (7)$$

[2] M. A. Baqi Bég and P. C. De Celles, Phys. Rev. Letters **6**, 145 (1961); Chia-Hwa Chan, Phys. Rev. Letters **6**, 383 (1961); D. Itô, A. H. Zimerman, and S. Ragusa (to be published).

[3] The amplitude for graph 1(a) is proportional to $\cos\theta'=\cos\theta\times\cos\delta+\sin\theta\sin\delta\cos\phi$, where δ is the angle between the directions of the incident K^- meson in the center-of-mass system and in the rest system of K^*. Hence $d\sigma/d\cos\theta\sim\langle\cos^2\delta\rangle\cos^2\theta+\frac{1}{2}\langle\sin^2\delta\rangle\times\sin^2\theta$, near the threshold $\delta\approx 0$.

[4] L. T. Kerth, Revs. Modern Phys. **33**, 389 (1961).

[5] J. S. Ball and W. R. Frazer, Phys. Rev. Letters **7**, 204 (1961). In this article the resonance $Y_4{}^*$ is explained in terms of K^* production.

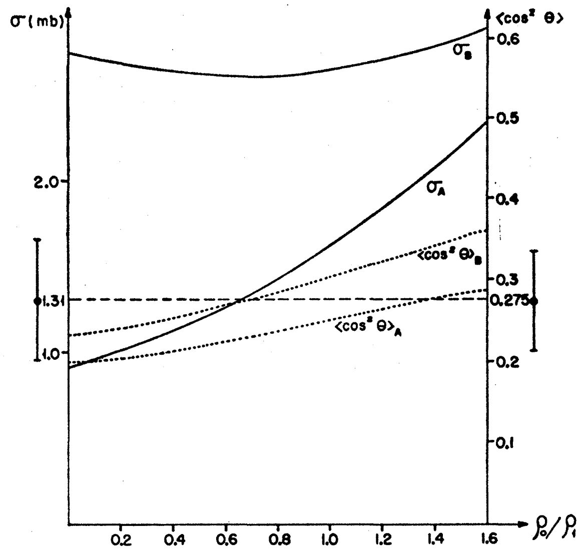

FIG. 2. Theoretical curves for the total cross section and mean value of $\cos^2\theta$, for processes A and B at 1.15 Gev/c momentum of the K^- meson, as function of the parameter ρ_0/ρ_1. The experimental value (dashed line) is shown for σ_A and $\langle\cos^2\theta\rangle_A$ with the statistical error on the margin. Actually the standard deviation of $\langle\cos^2\theta\rangle_A$ is not constant but increases slowly with $\langle\cos^2\theta\rangle$.

The results for the total cross section and $\langle\cos^2\theta\rangle$ for both reactions (A) and (B) using these amplitudes are shown in Fig. 2, as function of the parameter ρ_0. The best fit to the experimental data in reaction (A) is obtained with ρ_0/ρ_1 in the range 0.8 to 1.0. The total cross section for reaction (B) is still too large by a factor of about two; this, however, should not be considered as a serious drawback, in view of the rough nature of the experimental estimate. On the other hand, the model itself must be considered as a first approach. The main objection to it is that s-wave interactions depend on short-range forces and are usually not well reproduced by Born terms, as shown in diagram 1(a). We remark that, fixing ρ_0/ρ_1 within the range (0.8–1.0) and changing the amplitude $f_{\frac{1}{2}}{}^0$ by as much as 20 to 30% one can reduce the cross section for reaction (B) and, at the same time, slightly improve the results for reaction (A). We give in Table I a summary of theoretical results for $\rho_0/\rho_1=0.9$ and different values of $f_{\frac{1}{2}}{}^0$. We would like to point out that this model predicts for $\langle\cos^2\theta\rangle$ in the reaction (B) a value around 0.29. It would be interesting to check this prediction. If this model is correct, it is rather unfortunate that one cannot use this test to identify the spin of K^*. At higher energies, however, and for events with relatively small momentum transfer, it is reasonable to expect a preponderance of peripheral collisions. Under such conditions the angular correlation (1), will distinguish between spins $S=0$ and $S=1$. For $S=0$ one should still obtain $\langle\cos^2\theta\rangle=\frac{1}{3}$ and for $S=1$, $\langle\cos^2\theta\rangle=0.6-O(\beta^2)$, where β is the ratio of the velocities of K^* and the incoming K meson, in the center-of-mass system. Actually, it is better to measure, instead of θ, the angle θ' between the incoming and outgoing K mesons in the rest system of K^*. The angular correlation for $S=1$, would simply become $\cos^2\theta'$ ($\langle\cos^2\theta'\rangle=0.6$) if the scattering amplitude is given by diagram 1(a).

TABLE I. The parameter λ is defined by $f_{\frac{1}{2}}{}^0=-3\lambda\rho_1$.

λ	σ_A (mb)	σ_B (mb)	σ_B/σ_A	$\langle\cos^2\theta\rangle_A$	$\langle\cos^2\theta\rangle_B$
0.70	1.21	1.96	1.61	0.284	0.289
0.75	1.26	2.06	1.64	0.276	0.290
0.80	1.31	2.17	1.66	0.268	0.291