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Decay Modes of K^* †

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Using strong selection rules alone, the principal decay channels for the $K\pi$ resonance (K^*) are enumerated. It is pointed out that the reactions $K^* \to K+\gamma(e^++e^-)$ and $K^* \to K+2\pi$ determine the spin on qualitative grounds alone. A plausible estimate is made of the radiative width ($\Gamma_{K+\gamma} \sim 10^{-2}\Gamma_{K+\pi}$). Experiments are suggested which may shed some light on the electromagnetic coupling of the K^*K system.

THE experimental data[1] on the K^* (a resonance in $\pi+K$ scattering at an energy of 885 ± 3 Mev and width $\Gamma_{\text{total}}=16$ Mev) indicates that the spin (J) of the resonance is <2. Recent theoretical studies[2] of this resonance give evidence for excluding $J=0$ and thereby result in the tentative identification $J=1$; i.e., $K^*=K_V$ in the notation of reference 2. Since $K^* \to K+\pi$, the K^* is scalar or vector (rather than pseudoscalar or pseudovector) relative to the S-wave $K\pi$ system.

In this note we wish to discuss various possible alternative decay modes of K^*, contrasting those of K_V with K'. Using strong selection rules only, we show that it may prove feasible to determine experimentally the spin of the K^* on qualitative grounds alone.

In Table I we list the principal decay modes of K_V and K' which are not forbidden by strong selection rules (i.e., parity, angular momentum, or strangeness conservation).

Clearly the $K+\gamma$ and $K+2\pi$ decay modes are the most significant; a single event of the type $K^* \to K+\gamma$, $K+e^++e^-$ or $K+2\pi$ (unambiguously identified) would establish the identification $K^*=K_V$ on qualitative grounds alone.[3]

The total width of K_V may be expressed as

$$\Gamma=\Gamma_{K+\pi}+\sum_i \Gamma_i=\Gamma_{K+\pi}(1+\delta),$$

where the summation extends over all open channels other than the $K\pi$ channel. A plausible estimate of δ based on available experimental data is given in the Appendix, where it is found that

$$\delta \sim 0.155^{+0.365}_{-0.155}.$$

That is to say, it seems consistent with present experimental data that the rare decay modes constitute a substantial part of the total K_V width.

Consider the radiative decay modes. Of these the processes $K_V \to K+\pi+\gamma$ and $K_V \to K+2\pi+\gamma$ give continuous energy spectra for the photon with an inner bremsstrahlung peak at zero frequency. In contrast to this the photon energy spectrum in $K_V \to K+\gamma$ has a sharp peak at an energy $E_\gamma=306$ Mev in the c.m. system (with a full width at half maximum of 16 Mev).

In the c.m. system of the $K+\pi+\gamma$ final state, the high-energy end of the photon spectrum is at 215 Mev whereas the minimum photon energy in the $K+\gamma$ final state may be considered to lie around 290 Mev. Experimental detection of the photons with a moderate energy resolution could distinguish between the two alternatives.

We next estimate the partial width for $K_V \to K+\gamma$.

The matrix elements of the electromagnetic current contributing to this transition may be written quite generally as

$$\langle K|j^\mu|K_V\rangle=\frac{a(q^2)}{(8q_0k_0'k_0)^{\frac{1}{2}}}\epsilon^{\mu\nu\alpha\beta}\eta_\nu k_\alpha k_\beta', \tag{1}$$

where q, k', and k are the 4-momenta of the photon, K_V, and K, respectively ($q\equiv k'-k$); and $\epsilon^{\mu\nu\alpha\beta}$ is the 4-dimensional Levi-Civita symbol. Equation (1) immediately leads to

$$\Gamma_{K+\gamma}=|a(0)|^2E_\gamma^3/12\pi, \tag{2}$$

where $E_\gamma=306$ Mev and $|a(0)|$ is a coupling constant having the dimensions of length. It is difficult to make a reliable calculation of the constant $|a(0)|$. However, for a not unreasonable value of $|a(0)|^2=\alpha\times10^{-26}$ cm^2, $\Gamma_{K+\gamma}=14.2\times10^{-2}$ Mev.

The constant $|a(0)|$ may be determined, for example, from an experiment of the type first suggested by Primakoff.[4] The differential cross section for production of $K_V^0(\bar{K}_V^0)$ in the Coulomb field of a heavy nucleus

Table I. Allowed decay modes of K^*.

Particle	$K+\pi$	$K+\gamma$	$K+\pi+\gamma$	$K+2\pi$	$K+2\pi+\gamma$
K'	allowed	forbidden	allowed	forbidden	allowed
K_V	allowed	allowed	allowed	allowed	allowed

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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).

[2] M. A. B. Bég and P. C. DeCelles, Phys. Rev. Letters **6**, 145, 428(E) (1961). See also C. H. Chan, Phys. Rev. Letters **6**, 383 (1961); M. Jacob, G. Mahoux, and R. Omnes (unpublished); S. Minami, Progr. Theoret. Phys. (Kyoto) (to be published).

[3] Strictly speaking, $K' \to K+e^++e^-$ is not forbidden; however, since $\langle K'|j_\mu|K\rangle=0$ even if the photon is virtual, the transition probability for this process is probably negligible, being proportional to α^4.

[4] H. Primakoff, Phys. Rev. **81**, 899 (1951).

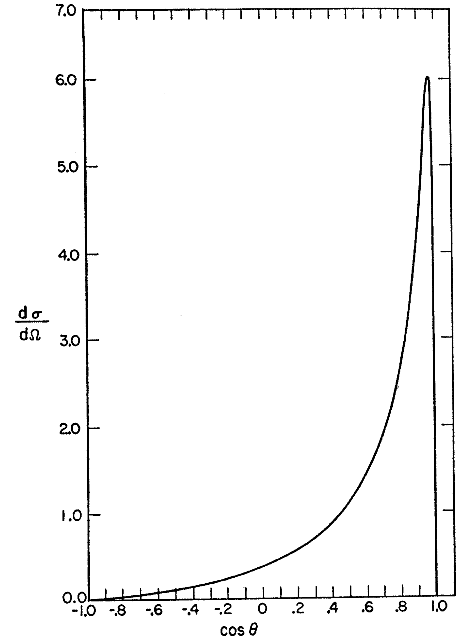

FIG. 1. Plot of $d\sigma/d\Omega(K+Ze\rightarrow K_V+Ze)$ in units of $\alpha Z^2\lambda^3|a(0)/4\pi|$ vs $\cos\theta=\hat{k}\cdot\hat{k}'$, for incident K of 1.15-Bev/c momentum.

(charge Ze) may be written as

$$\frac{d\sigma}{d\Omega}=\alpha Z^2\left[\frac{a(0)}{4\pi}\right]^2\frac{\lambda^3\sin^2\theta}{(1+\lambda^2-2\lambda\cos\theta)^2}, \tag{3}$$

where $\lambda^2=1-(m_V^2-m_K^2)/|k|^2$, k is the momentum of the incident $K^0(\bar{K}^0)$, and m_V is the mass of K_V. The Coulombic contribution to K_V production may be identified from the sharp small-angle peak (see Fig. 1).

The non-Coulombic contribution can be suppressed by choosing a target nucleus of zero isotopic spin. Furthermore, as was pointed out in reference 2, in connection with the reaction $K+p\rightarrow K^*+p$, the exchange of a single pion in the production of the K_V gives rise to a nearly isotropic angular distribution of the K_V in the c.m. system. If this behavior persists for the pion exchange contribution to the reaction $K+A\rightarrow K_V+A$, the Coulombic production may be separable from the background for a nucleus of any isotopic spin.

Another possible method for determining $|a(0)|$ would be to determine the residue, at the $K(K_V)$-meson pole, of the cross section for the reaction $\gamma+N\rightarrow K_V^0(K^0)+N$. However, due to the large mass of the $K(K_V)$, one has to venture rather far into the unphysical region. This would, of course, make the analysis unreliable.

APPENDIX

An estimate of δ is obtainable in the following manner.

Let σ^* be the cross section for $K^-+p\rightarrow K^*+p$ and σ for $K^-+p\rightarrow K^*+p\rightarrow \bar{K}^0+\pi^-+p$. Then

$$\sigma=\sigma^*\frac{\frac{2}{3}\Gamma_{K+\pi}}{\Gamma_{K+\pi}+\Sigma_i\Gamma_i}=\frac{2}{3}\frac{\sigma^*}{1+\delta}. \tag{A1}$$

Also, within the framework of the approximation in reference 2 (i.e., that the production process is dominated by the single pion exchange process), we have, for 1.15-Bev/c incident K^-,

$$\sigma^*\approx(\tfrac{1}{8}\text{ mb Mev}^{-1})\Gamma_{K+\pi}\approx(\tfrac{1}{8}\text{ mb Mev}^{-1})\Gamma/(1+\delta). \tag{A2}$$

Thus

$$(1+\delta)^2\sim(\tfrac{1}{12}\text{ mb Mev}^{-1})\Gamma/\sigma. \tag{A3}$$

Using $\Gamma=16$ Mev and $\sigma\cong\frac{1}{2}\sigma(K^-+p\rightarrow\bar{K}^0+\pi^-+p)=1\pm0.42$ mb in Eq. (A3), we get

$$\delta\sim0.155_{-0.155}^{+0.365}, \tag{A4}$$

where the lower limit $\delta=0$ corresponds to $\sigma=1.33$ mb.

Actually, if δ were as large as the extreme value $\delta\sim0.52$, the method of analysis used in reference 2, and here as well, would fail.