INELASTIC PROCESSES NEAR THE $T=1$ K^+p PEAK AT 1250 MeV/c*

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K^+p inelastic final states in the region of the 1250-MeV/c Cool peak are examined for evidence of resonant behavior. The dominant KN^* final state is found to be about equally divided between $P_{1/2}$ and $P_{3/2}$ final states, with no rapid phase variation between 960 and 1370 MeV/c.

In a recent experiment, Cool et al.[1] found a peak in the total K^+p cross section at a momentum of about 1250 MeV/c. If interpreted as a resonance, it would have a mass of about 1910 MeV and a resonant cross section of about 4 mb, and would presumably belong to a $\underline{27}$ representation of SU(3). Furthermore, it would be a highly inelastic resonance, since the size of the peak implies a value $x \approx 0.3/(J+\frac{1}{2})$ for the ratio of elastic to total width.

In this paper we present an analysis of inelastic K^+p interactions between 860 and 1580 MeV/c with particular emphasis on the $KN^*(1236)$ final state, which is important in the entire region of the "Cool peak." We find some evidence for an enhancement in the N^* production cross section, at a slightly lower mass, which may correspond to the peak in the total cross section, whereas we observe no indication of a peak in the elastic-scattering cross section. From an analysis of the N^* production and decay angular distributions, we find that the enhancement occurs largely in the $P_{3/2}$ and $P_{1/2}$ states. There is no evidence for the rapid phase variation with primary momentum characteristic of a Breit-Wigner amplitude in a single state; hence, it does not appear that the major contribution to either the $P_{3/2}$ or the $P_{1/2}$ amplitude can be resonant, although a small resonant component cannot be ruled out.

The data were obtained from an exposure of the Lawrence Radiation Laboratory 25-inch hydrogen bubble chamber to a separated K^+ beam of variable momentum. Single-pion production is the only significant inelastic process in the momentum range under consideration,[2] and in this paper we confine ourselves primarily to the reaction

$$K^+ + p \to K^0 + p + \pi^+, \tag{1}$$

which accounts for the major part of the single-pion production and is richest in the two-body final states $KN^*(1236)$ and $NK^*(891)$.

Figure 1 shows the total partial K^+p cross sections in the region of the Cool peak, including data from both this experiment and others.[3-7] Figure 2(a) shows the production angular distribution of the N^* with respect to the incident proton direction at 1200 MeV/c, close to the Cool peak, and Figs. 2(b) and 2(c) give the corresponding distributions of $\cos\gamma$ and δ', where γ and δ' are the polar and azimuthal angles of the decay proton from the N^* with respect to the production plane normal.[8]

The production angular distribution can be expanded in terms of Legendre functions:

$$\frac{d\sigma(N^*)}{d(\cos\theta)} = \sum_l A_l P_l(\cos\theta); \tag{2a}$$

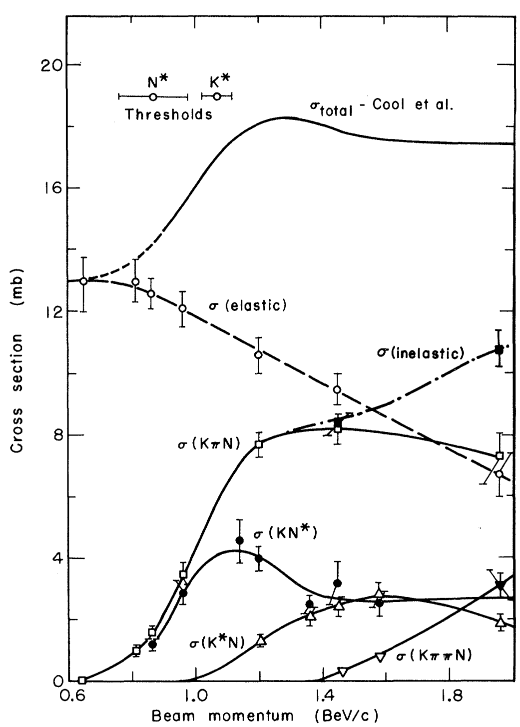

FIG. 1. Total and partial K^+p cross sections. Besides our own data, we have included those of Refs. 3-7. The partial cross-section curves are intended only to guide the eye, and have no further significance.

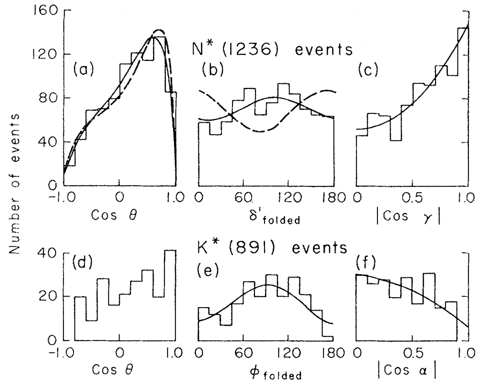

FIG. 2. Production and decay angular distributions for the $N^*(1236)$ and $K^*(891)$ at 1200 MeV/c. The N^* curves are results of the fits described in the text. [The dashed and solid curves are essentially identical in (c).] The K^* curves are fits to $W(\varphi)=A+B\sin^2\varphi$, $W(\alpha)=C+D\sin^2\alpha$.

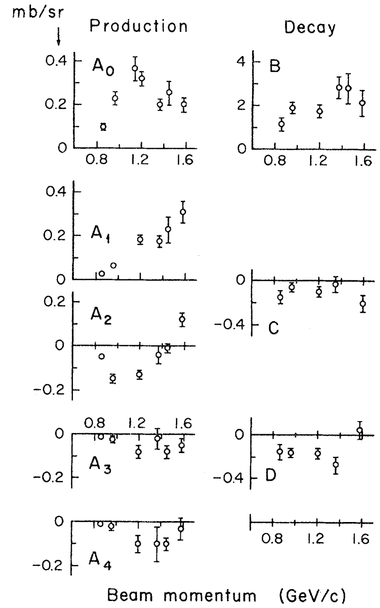

FIG. 3. Expansion coefficients for $N^*(1236)$ production and decay angular distributions as functions of beam momentum. The coefficients are defined in Eqs. (2) in the text.

and the $\cos\gamma$ and δ' distributions can be expanded as follows[9]:

$$W(\cos\gamma)\propto 1+B\cos^2\gamma, \tag{2b}$$

$$W(\delta')\propto 1+C\sin 2\delta'+D\cos 2\delta'. \tag{2c}$$

These coefficients, for all the momenta, are presented in Fig. 3. The following features are particularly relevant:

(a) The production angular distribution appears to be predominantly $\sin^2\theta$ and furthermore has a forward-backward asymmetry which is a smooth, monotonically increasing function of the incident momentum.

(b) The decay angular distributions are insensitive to incident momentum: The γ dependence has a strong positive $\cos^2\gamma$ component, and the δ' distribution deviates from uniformity only through a small negative $\cos 2\delta'$ term.

We have attempted to interpret these features in terms of a partial-wave expansion in the final KN^* state.[10] In Table I we give the angular distributions expected if the reaction proceeds through a single incoming and outgoing partial wave.

If we consider only the lowest partial waves required to account for the distributions given in Fig. 2, we conclude that (i) there must be strong $P_{3/2}$ present, since of all S and P final states it is the only one that gives a positive $\cos^2\gamma$ coefficient B, and can account for the large negative value of A_2 (see Fig. 3); (ii) the increasing forward-backward asymmetry in the production angular distribution is caused by interference between the dominant P state and higher waves of opposite parity, principally D waves; and (iii) the $P_{3/2}$ state

Table I. N^* angular distributions for production through a single partial wave. We have included only the lowest order term for the Stodolsky-Sakurai model production angular distribution; this term dominates near threshold.

K^-p initial state	KN^* final state	Production angular distribution	Decay angular distributions $\cos\gamma$	Decay angular distributions δ'
$D_{3/2}$	$S_{3/2}$	Isotropic	$1-\frac{3}{5}\cos^2\gamma$	$1+\frac{1}{2}\cos 2\delta'$
$P_{1/2}$	$P_{1/2}$	Isotropic	$1-\frac{3}{5}\cos^2\gamma$	$1-\frac{1}{6}\cos 2\delta'$
$P_{3/2}$	$P_{3/2}$	$1-\frac{4}{5}P_2(\cos\theta)$	$1+(21/13)\cos^2\gamma$	$1+(11/30)\cos 2\delta'$
$S_{1/2}$	$D_{1/2}$	Isotropic	$1-\frac{3}{5}\cos^2\gamma$	$1-\frac{1}{6}\cos 2\delta'$
Stodolsky-Sakurai model		$1-P_2(\cos\theta)$ (to lowest order)	$1+3\cos^2\gamma$	Isotropic

is certainly not the only P state present, as the δ' distribution does not agree with pure $P_{3/2}$, and there is not enough D wave, particularly for momenta at or below 1200 MeV/c, to account for these discrepancies. These features are qualitatively those expected from the Stodolsky-Sakurai magnetic dipole ρ-exchange model[11] (hereinafter denoted by $M1$), whose predictions are shown at the bottom of Table I. In this model the contributing final-state partial waves are $P_{1/2}$, $P_{3/2}$, $D_{3/2}$, $D_{5/2}$, etc., where the D and higher waves contribute little to the cross section in the momentum range under consideration because of the short range associated with the exchange of a massive particle like the ρ. Consequently, absorptive corrections to the $M1$ amplitude are expected to occur mainly in the P waves. For this reason, and to allow for the possibility of resonant behavior in the dominant P waves, we have attempted a fit in which N^* production is assumed to proceed via $P_{1/2}$, $P_{3/2}$, $M1'$, and $S_{3/2}$ states whose contributions are left adjustable in both magnitude and phase, where $M1'$ is a magnetic dipole ρ-exchange amplitude from which the $P_{3/2}$ and $P_{1/2}$ contributions have been subtracted out. The $S_{3/2}$ wave has been introduced to account for the $\sin 2\delta'$ term required near the N^* production threshold.[12] (See Fig. 3.) In addition to the above N^* amplitudes we have introduced a three-particle final-state background amplitude in which all particle pairs are in relative S states. These amplitudes were fitted independently at each momentum, over the whole Dalitz plot at 860 and 960 MeV/c and over just the low $K\pi$-mass half of the Dalitz plot at the higher momenta, to avoid contributions from $K^*(891)$ production. The results of the fit are illustrated by the solid lines in Figs. 2(a)-2(c). We have also tried to fit the data with only a single P wave present. The χ^2's, for 60 degrees of freedom, are as follows: all waves present, 78; $P_{1/2}$ excluded, 162; $P_{3/2}$ excluded, 311. The dashed lines on Figs. 2(a)-2(c) show the results of the fit with the $P_{1/2}$ wave excluded. From these results we draw the following conclusions:

(1) The enhancement in the N^*-production cross section appears to be about equally shared between the $P_{3/2}$ and $P_{1/2}$ amplitudes. Indeed, the ratio of the $P_{3/2}$ to $P_{1/2}$ channel cross section seems to lie closer to unity, at all momenta under study, than to the $M1$-model prediction of 5/1. The $S_{3/2}$ amplitude leads to a cross section of less than 100 μb at all momenta, and is far too small to account for the Cool peak.

(2) The $P_{3/2}$ and $P_{1/2}$ amplitudes are approximately in phase at all momenta, as predicted by the $M1$ model. Furthermore the phase of either of these amplitudes relative to the partial waves of opposite parity (represented in our analysis by the $M1'$ terms) remains about the same as a function of incident momentum.

Thus, these data neither require nor suggest that any of the main amplitudes present in the KN^* production is dominantly of a Breit-Wigner form, although the possibility that some small fraction of one of these amplitudes is resonant cannot be ruled out. The qualitative agreement of the KN^* angular distributions with the $M1$ model suggests that something like the ρ-exchange mechanism, which appears to be the dominant process at higher momenta,[7,13] is of importance even near threshold.[14] In this connection it is interesting to note that near the KN^* threshold, current-algebra arguments supplemented by generalized partial conservation of axial-vector currents for K mesons lead to the same predictions as the $M1$ model for the angular distributions and rate of rise of the cross section, and furthermore correctly predict the magnitude of the cross section.[15] For the $K^0\pi^+p$ channel at 960 MeV/c the theory predicts an N^* production cross section of 1.8 mb, in good agreement with our experimental result of 2.3 ± 0.3 mb, and predicts a non-N^* background in rough agreement with the data.[16]

We now consider briefly the NK^* final state in Reaction (1). Its threshold occurs at about 1050 MeV/c, just below the Cool peak, and its cross section rises rapidly, being about 30% of the KN^* value at 1200 MeV/c and roughly equal to it at 1580 MeV/c. In Figs. 2(d)-2(f) we show the distributions of the production angle θ, the K-π scattering angle α, and the Treiman-Yang angle φ at 1200 MeV/c. There are extensive data on this reaction at higher momenta[7,13,17] and, just as in the case of N^* production, the production angular distribution shows a monotonically increasing asymmetry and the K^*-decay distributions are essentially independent of momentum. The K^*-decay angular distributions are qualitatively consistent with production largely by vector exchange,[18] again with no unusual behavior on passing through the region of the Cool peak.

Even if the sharp rise of the KN^* cross section near threshold is understood in terms of its p-wave momentum dependence, no detailed model predicts the subsequent fall-off. Note, in this connection, that at 1200 MeV/c the inelastic cross section is 7.7 mb, and the maximum contributions from the low K^+p incoming partial waves are, for $S_{1/2}$ or $P_{1/2}$, 3.4 mb; $P_{3/2}$ or $D_{3/2}$, 6.8 mb; etc. Thus the inelastic channels may perhaps be limited by unitarity if only low partial waves contribute near threshold. Then the sharp initial rise in the cross section for Reaction (1) and its subsequent fall-off as $\pi\lambda\!\!\!^{-2}$ could account for the peak in the total cross section. To substantiate such a speculation would require a detailed calculation of the manner in which the inelastic cross sections are affected by the onset of unitarity effects.

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[8]The zero of the azimuth δ' is taken along the incident-proton direction in the over-all c.m. system. This differs slightly from the azimuth δ, discussed in previous work, whose zero is along the incident-proton direction in the N^* c.m. system. (The decay-proton direction is in the N^* c.m. system in both cases.)

[9]The expansions (2b) and (2c) are completely general only for a pure KN^* final state, without interference from other final states.

[10]For the purpose of the decomposition, the N^* is treated as a particle. The lowest waves are $S_{3/2}$, $P_{1/2}$, $P_{3/2}$, $P_{5/2}$, etc. fed from incident $D_{3/2}$, $P_{1/2}$, $P_{3/2}$, $F_{5/2}$ states, respectively.

[11]L. Stodolsky and J. J. Sakurai, Phys. Rev. Letters 11, 90 (1963).

[12]A further motivation for introducing the $S_{3/2}$ wave is that if it were resonant the difference in centrifugal barriers between the KN^* $S_{3/2}$ and the K^+p $D_{3/2}$ final states might favor the KN^* decay mode, thus accounting for the large inelasticity. However, our analysis indicates that the $S_{3/2}$ cross section is less than $\approx$100 μb at all momenta, and thus is not responsible for the Cool peak.

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[14]It should be noted that whereas the KN^* angular distributions appear to be in qualitative agreement with the $M1$ model, with suitable modifications for absorptive effects at the higher momenta, the product of coupling constants relevant to this model is about an order of magnitude higher than that expected from estimates based on the ρ-photon analogy and SU(3), as discussed in J. D. Jackson and H. Pilkuhn, Nuovo Cimento 33, 906 (1964). From the KN^* cross sections at 860 and 960 MeV/c, without a form factor or absorption corrections, we find $(g_{p\rho-N^{*++}}g_{K^+\rho^-K^0}/4\pi)^2 \approx 250$.

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[16]A detailed study of the background amplitude and its interference with the KN^* amplitude is now in progress.

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