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STATIC MODEL FOR MESON PRODUCTION

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ABSTRACT

A phenomenological model is considered where a nucleon is supposed to be "predissociated" into a virtual $(\Lambda + K)$ or $(\Sigma + K)$ combination. These components are realized in a "stripping" type collision with an incident pion. Reasonable parameters for the model are obtained from fitting to $\pi^- + p$ measurements; the value of a corresponding $\pi^+ + p$ measurement in this connection is pointed out. The "radius" of the $(\Lambda + K)$ system turns out to be of order 5×10^{-14} cm. The same model can be applied to K production in 6 Bev proton-nucleon bombardment; it yields one component of K's with an extremely strong forward-backward peaking in the center-of-momentum system of the two nucleons.

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STATIC MODEL FOR MESON PRODUCTION

D. C. Peaslee

The present note discusses some numerical calculations with the following simplified model: a nucleon is regarded as being to some extent "predissociated" into a virtual $(\Lambda + K)$ or $(\Sigma + K)$ combination, with relative amplitudes α and β. The $\Lambda - \Sigma$ mass difference is neglected, and each combination is associated with the same internal momentum distribution $|g(k)|^2$. Production of real K, Λ, and Σ is effected by absorption of a π meson through three basic processes: $\pi + K \longrightarrow K$, $\pi + \Lambda \longrightarrow \Sigma$ (or $\pi + \Sigma \longrightarrow \Lambda$, which is the inverse) and $\pi + \Sigma \longrightarrow \Sigma'$, with respective amplitudes a_0, a_1 and a_2. The treatment is entirely phenomenological in character;[1] but the use of $g(k)$

[1] The corresponding field theoretical procedure has been described by Saul Barshay, UCRL-3482 (1956).

and the relative amplitudes allows a simple and fairly self-consistent interpretation of the following data: the relative charged to neutral and Σ^0 to Λ^0 production in π-nucleon collisions, as well as the angular distributions and forward-to-back rations;[2] also, the strongly peaked angular distribution found for θ^0 produced by 6 Bev protons.[3] In

[2] Budde, Chretien, Leitner, Samios, Schwartz and Steinberger, Nevis Report R135 (1956); Fowler, Shutt, Thorndike and Whittemore, Phys. Rev. 98, 121 (1954).

[3] Osher, Moyer and Parker, Bull. Am. Phys. Soc. 1, 185 (1956) and private communication.

terms of the model, the features of physical interest obtained from experimental comparison are the following: the predissociation into $(\Sigma + K)$

seems only about 1/3 as likely as that into $(\Lambda + K)$; the amplitude for the process $\pi + K \rightarrow K$ is comparable with and perhaps somewhat larger than that for either process of pion absorption by hyperons; a mean "radius" of the predissociated state is of order 5×10^{-14} cm. The parameters obtained from $\pi^- + p$ collisions can be used to estimate the hyperon production from the yet unobserved $\pi^+ + p$ at comparable energies; the measurement of this reaction would provide a check on the self-consistency of the model and allow a better determination of its parameters.

All higher-order processes like $\pi + p \rightarrow \Lambda + K + n\pi$ are neglected; they are expected to become increasingly prevalent with increasing energy, so that the present simple treatment is limited to energies not too far above threshold for $\Lambda + K$ or $\Sigma + K$ production. It is thus appropriate to analysis of present $\pi + p$ experiments but represents only a fraction of the total process initiated by 6 Bev protons. Its implications for the latter case are thus only of a qualitative nature.

I. Relative intensities of final states.

The relative intensities of the initial states are α^2 for $(\Lambda + K)$ and β^2 for $(\Sigma + K)$; for a proton the latter is 1/3 $K^+\Sigma^o$ and 2/3 $K^o\Sigma^+$, for a neutron 1/3 $K^o\Sigma^o$ and 2/3 $K\Sigma^-$. Only the relative quantities α/β and a_2/a_0, a_1/a_0 will be of importance; since those are all assumed to be real, no absolute magnitude signs will be used. Since few interference effects among final states will be considered, it is not necessary to consider the relative algebraic signs of the amplitude ratios or of the Clebsch-Gordan coefficients for isotopic spin, except in one special case: there the ambiguity of sign is explicitly introduced and determined by comparison with experiment.

The intensity for $\pi + K \rightarrow K$ is proportional to a_0^2, with coefficients for isotopic spin combination of 2/3 for $\pi^+ + K^0 \rightarrow K^+$ and $\pi^- + K^+ \rightarrow K^0$ and 1/3 for $\pi^0 + K^0 \rightarrow K^0$, $\pi^0 + K^+ \rightarrow K^+$. For $\pi + \Lambda \longrightarrow \Sigma$, $\pi + \Sigma \rightarrow \Lambda$, the intensity is a_1^2 for all cases, with no reduction factors; and for $\pi + \Sigma \longrightarrow \Sigma$, the intensity a_2^2 has a reduction factor of 1/2 in all cases, except for $\pi^0 + \Sigma^0 \longrightarrow \Sigma^0$, which is forbidden.

The $K - \pi$ absorption results in a "stripping" reaction with the K projected forward in the center-of-mass system; the other absorption processes strip off the hyperon and leave the K going backwards in the center-of-mass system. We thus neglect interference between K-forward and K-backward final states, even though the particles may be identical; this assumption is valid to the extent that the stripping momentum is large relative to the internal momentum of the predissociated state and seems to be in good accord with observation. With this approximation one obtains the relative intensities of final states shown in Table I. The corresponding final states for a pion incident on a neutron follow simply by the substitutions $\pi^+ \longleftrightarrow \pi^-$, $\Sigma^+ \longleftrightarrow \Sigma^-$, $p \longleftrightarrow n$, $K^0 \longleftrightarrow K^+$, and π^0, Λ^0, $\Sigma^0 \longleftrightarrow \pi^0$, Λ^0, Σ^0.

By assuming

$$(\beta/\alpha)^2 \approx (a_1/a_0)^2 \approx (a_2/a_0)^2 \approx 1/3 \qquad (1)$$

$$x = +1$$

one can estimate from Table I the following ratios for $\pi^- + p$:

$$K^+(\text{forward})/K^+(\text{back}) = 0 \qquad \Sigma^0/\Lambda^0 \approx .15 \qquad (2)$$

$$K^0(\text{back})/K^0(\text{forward}) \approx .15 \qquad \Sigma^-/(\Sigma^0 + \Lambda^0) \approx .24$$

TABLE I: Relative intensities of final states

Initial State	Final States	Intensities, forward K	Intensities, backward K
$\pi^- + p$	$(K^0 \Lambda^0)/(K^0 \Sigma^0)/(K^+ \Sigma^-)$	$\frac{2}{3}(\alpha a_0)^2/\frac{2}{9}(\beta a_0)^2/0$	$\frac{2}{3}(\beta a_1)^2/\frac{1}{3}(\beta a_2)^2/(\alpha a_1 - x \beta a_2/\sqrt{6})^2$
$\pi^0 + p$	$(K^+ \Lambda^0)/(K^+ \Sigma^0)/(K^0 \Sigma^+)$	$\frac{1}{3}(\alpha a_0)^2/\frac{1}{9}(\beta a_0)^2/\frac{2}{9}(\beta a_0)^2$	$\frac{1}{3}(\beta a_1)^2/(\alpha a_1)^2/\frac{1}{3}(\beta a_1)^2$
$\pi^+ + p$	$(K^+ \Sigma^+)$ (relative)	$\frac{4}{9}(\beta a_0)^2$	$(\alpha a_1 + x \beta a_2/\sqrt{6})^2$

Here $x = \pm 1$ depending on relative signs of amplitudes.

for $\pi^+ + p$,

$$K^+(\text{forward})/K^+(\text{back}) \approx .3 \tag{3}$$

and for the total yields under comparable conditions

$$K^+(\pi^- + p)/K^+(\pi^+ + p) \approx .3 . \tag{4}$$

The ratios Eq. (2) are in satisfactory agreement with observation[2] at $E_\pi = 1.4$ Bev, if one takes into account that the estimated efficiency of observing Λ^o and/or K^o is about 50%. The only real disagreement is the observation of about 15% K^+ (3 events) in the far forward direction; and this cannot be interpreted on the present simple model for any choice of parameters.

The ratios Eqs. (3) and (4) for $\pi^+ + p$ at the same energy have not been observed; their measurement would provide further information on the interference effect for backwards K production. Although the parameters Eq. (1) seem reasonable, it has not been established that they are unique in fitting observed ratios like Eq. (2). Trial calculations, however, have not revealed any parameter assignments substantially different from Eq. (1). Measurements Eqs. (3) and (4) would therefore be of great interest, to check the internal consistency of the model and to provide more definite values for its parameters. Of course Eqs. (3) and (4) can also be obtained from π^- on neutrons in heavy nuclei, but the $(K^o + \Sigma^-)$ product is harder to distinguish with certainty.

2. Angular distribution in $\pi + p$.

To estimate angular distributions from the simple knock-on model, we shall be content with very crude approximations; in particular, certain relativistic effects are not very precisely treated. After transformation to the center-of-momentum system of the $\pi + p$, the total momentum of the p must be apportioned between the K and Λ (Σ) of the predissociated state. Non-relativistically this division would be in proportion to the ratio of the rest masses of the K and Λ (Σ); relativistically, this division cannot be made without going into details of the Λ - K forces. For a phenomenological treatment we therefore take the angular distribution to be given by $|g(\Delta k)|^2$, where

$$\underset{\sim}{\Delta k} = \underset{\sim}{K} - f_{\Lambda} \underset{\sim}{\chi} \qquad \text{(forward K's)}$$
$$\underset{\sim}{\Delta k} = \underset{\sim}{K} - f_{K} \underset{\sim}{\chi} \qquad \text{(backward K's)} . \tag{5}$$

Here $\underset{\sim}{K}$ is the K momentum in the center-of-momentum system, $\underset{\sim}{\chi}$ is the incident pion momentum in the same system, and $f_K + f_{\Lambda} = 1$ are the fractions of the proton momentum $(-\underset{\sim}{\chi})$ apportioned to the K and Λ (Σ). Nonrelativistically, $f_K = .3$, $f_{\Lambda} = .7$; when $E_{\pi} = 1.4$ Bev, the center-of-momentum transformation has $\beta = 0.6$, $\gamma = 1.25$, so that we may allow some deviation from these values for f_K , f_{Λ} .

For simplicity in calculation we take

$$|g(k)|^2 \sim e^{-\epsilon k^2} . \tag{6}$$

This can scarcely be correct for all k but may be a sufficient approximation over the range of interest. The angular dependence in the center-of-momentum system is then as[4]

$$e^{\pm 2\epsilon fK\chi \cos\theta} \tag{7}$$

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[4] This distribution can be strongly peaked, since all orbital angular momentum values are taken into account. In the model of Landovitz and Leitner, Nuovo cimento 3, 1093 (1956), a severe restriction is imposed that $J = \frac{1}{2}^+$ for the total system, precluding the possibility of any very peaked angular distributions.

where θ is the angle of $\underset{\sim}{K}$ relative to $\underset{\sim}{\kappa}$, the $\pm$ sign and appropriate f are chosen for forward and backward K emission. The variation of f between forward and backward emission implies that the forward angular distribution should be more narrowly peaked than the backward distribution. This is not peculiar to the form Eq. (6) but would occur with any $|g(k)|^2$ that decreased monotonically with increasing k provided $f_\Lambda > f_K$.

Actually, the measurements on $\pi^- + p$ at $E_\pi = 1.4$ Bev do not show any appreciable distinction between the forward and backward (average of K^0 and K) distributions. This makes the determination of ϵ somewhat uncertain; but by weighting most heavily the forward K^0, where the statistics are best, one concludes that

$$\epsilon K \kappa \sim 3 \quad . \tag{8}$$

In this case $K\kappa = .32\ (\text{Bev/c})^2$. The mean square momentum given by Eq. (6) is of order $\langle k^2 \rangle = \frac{3}{2\epsilon}$; and a corresponding "radius" of the predissociated Λ - K system is

$$r \sim \hbar \langle k^2 \rangle^{-\frac{1}{2}} \sim 5 \times 10^{-14} \text{ cm} \tag{9}$$

which seems not unreasonable.

3. Angular distribution in p + p, p + n.

The same model can be applied to describe one component of K, Λ production in nucleon-nucleon collisions at high energy. The nucleon at rest (its motion in a target nucleus may be ignored) is again predissociated into a K and Λ (Σ); the dissociation is realized by absorption of a pion from the cloud surrounding the incident nucleon. A 6.2 Bev nucleon has $\gamma = (1 - \beta^2)^{-\frac{1}{2}} \approx 7.7$; the energy of a pion moving with this velocity is $E_\pi = 1.1$ Bev, which is not far from the conditions considered above. We therefore assume the same parameters throughout. In the laboratory system, the incident pion transfers a momentum $k_\pi \approx 1.1$ Bev/c to either the K or Λ (Σ), stripping it off with this momentum and leaving the other component about at rest.

According to Eqs. (6) and (8), the mean transverse momentum of the Λ - K system is $\sim .33$ Bev/c, while that parallel to k_π is $\sim .23$ Bev/c. This latter is neglected in comparison with k_π, and the momentum distribution of the π in the incident nucleon is entirely neglected as small relative to that of the Λ - K system. If we now transform to the center-of-momentum system of the two incident nucleons, the transverse momentum of the stripped particles is unchanged; their longitudinal momenta are $k_K = .1, -.9$ Bev/c, $k_{\Lambda\Sigma} = -.6, -2.0$ Bev/c, according as the particle was stripped forward or left behind in the laboratory system. The most strongly peaked components are thus backwards in the center-of-momentum system.

Of course there is a symmetrical forward peak, obtained by reversing the picture. Transform to a system where the incident nucleon is at rest, and the target nucleon impinges at 6.2 Bev from the opposite direction. Again let the nucleon at rest be predissociated and subject to stripping. Then a repetition of the argument above shows a strong peaking in the center-of-momentum system of the two nucleons, this time in the direction of the originally incident nucleon. This is just a lengthy statement of the fact that a p-p collision must be symmetric in all respects in its center-of-momentum system.

To estimate the degree of peaking of the K meson component in the center-of-momentum system, note that the mean value of cos θ for the strongly peaked component is of order $[1 + (.33/19)^2]^{-\frac{1}{2}} = 0.94$. If one takes a distribution as $(\cos\theta)^m$, the value corresponding to $\langle\cos^2\theta\rangle^{\frac{1}{2}} = 0.94$ is $m \sim 30$. It is perhaps of interest to note that the corresponding Λ, Σ peak should be even sharper than the K peak; this is because the Λ, Σ carry a larger fraction of the original logitudinal momentum, while having the same transverse momentum distribution as the K's. There are, of course, many additional components in the total K productions that are less strongly peaked, such as the higher-order processes $p + p \rightarrow K + \Lambda + N + n\pi$, etc.; and even the first-order process considered here has a second component that is much broader.

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