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METHOD FOR DETERMINING THE SPIN OF THE K-π RESONANCE

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In order to understand the recently observed[1] resonance in the K-π system, which is here labeled K*, it is essential to determine its spin. Recently there have appeared arguments[2] favoring a spin of 1 and a proposal[3] for determining the spin. The appearance of the latter has prompted the writing of this note describing a method of spin determination which may be simpler experimentally and can perhaps provide more information than that of reference 3. It has been tacitly assumed in that paper that the measurements[1] limit the K* spin to 0 or 1 and the isotopic spin to $^1/2$, and that because the decay $K^* \rightarrow K + \pi$ is seen to be rapid, parity is conserved and hence the K^* has either spin 0 and parity opposite to that of the K, or spin 1 and the same parity as the K. Under these same restrictions, if one observes the process

$$K + He^4 \rightarrow K^* + He^4 \qquad (1)$$

then the K* must have spin 1, since for the spin 0 case angular momentum and parity cannot be conserved in this reaction. If (1) is not seen, the K^* spin assignment can be checked by observing

$$K + He^4 \rightarrow K^* + He^4 + \pi \qquad (2)$$

and looking at the K^* decay distribution.

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There are two circumstances under which (1) will be forbidden and a third reason why it would be inhibited, however. Thus if (1) is observed, surely (a) the spin of the K^* is greater than zero (and presumably one) and (b) the isotopic spin of the K^* is the same as that of the K, which is $^1/2$. If the K^* had an isotopic spin of $^3/2$, which is allowed by its decay into $K + \pi$, then (1) would not occur, and hence this point can be checked for a non-zero spin K^*.

The inhibition of (1) will be discussed shortly, but first let us investigate what could in principle be learned from observing the decay angular distributions from the K^* produced by (1). These results will then be applied to (2), which is not inhibited, but which is more difficult to discuss.

It is well known[4)] that one can obtain information on the spin of an unstable particle if one observes such particles produced near the beam direction. A reaction like (1) is, however, particularly useful for this purpose because the decay angular distribution for the K^* is uniquely determined by its spin, and because most of the observed reactions could be utilized for this analysis. In justifying the first of these statements, let us begin by considering the initial state of (1): there can be no orbital angular momentum (ℓ) about the direction (z) of the incident K, and since there is no spin, the total angular momentum in that direction (j_z) is zero also. Therefore in the final state $j_z = 0$ too, and since for forward production $\ell_z = 0$, then the spin (S) can have no component in z-direction. Thus for a K^* of any possible spin, if the K^* is produced forward there will be a unique angular distribution[5)] for its decay, given by the spherical harmonic $|Y_{S,0}(\Theta)|^2$, where Θ is the angle between the direction of the incoming K and the decay momentum in the center of mass of the K^*. According to the uncertainty principle, the decay distribution should not change appreciably over K^* emission angles of the order of the reciprocal of the largest orbital angular momentum contributing to the production process, which is $\sim \hbar/pR$, where p is the incident K momentum and R is the "radius" of He^4. This, however, is just the typical emission angle for events in which the He^4 stays bound. To keep the He^4 together, the momentum transferred to the He^4, q, must be kept small. From the uncertainty principle, $q \sim \hbar/R \sim 0.2$ Bev/c. To satisfy this condition, p must be rather large ($\gtrsim 1.5$ Bev/c) and hence the emission angle, $\sim q/p \sim \hbar/pR$ is quite forward and is just that obtained above as a limiting one for the spin determination. Thus most events would be useful ones for this spin analysis which not only permits distinguishing between the likely values of 0 or 1, but also affords a means to measure possibly higher values in a less ambiguous way than is presently available.[1)]

There is a second method of using (1) (and (2), as will be discussed later) to determine the K^* spin, and this method can be utilized also to check parity conservation in the production and decay of the K^*. One uses not-too-forward events so as to define better the direction, x, of the normal to the plane formed by the relative momentum of the incident particles and that of the outgoing particles (before K^* decay). Performing an inversion about that plane followed by a 180° rotation about x would change the initial wave function by $(-1)^{P_K}$, where P_K is the parity of the K, and the final wave function by $(-1)^{P_{K^*}}(-1)^{S_x}$.[6)] Therefore, if $P_{K^*} = P_K$, the projection of the K^* spin in the x-direction, S_x, is even, whereas if $P_{K^*} = -P_K$, S_x is odd. Thus for example if the K^* spin is 1, the decay distribution should be given by $|Y_{1,0}(\Theta')|^2 \propto \cos^2 \Theta'$ (where Θ' is the angle between x and the decay momentum in the rest system of the K^*), because $P_{K^*} = P_K$ for S = 1 if parity is conserved in $K^* \to K + \pi$. However, if parity is not conserved, then P_{K^*} can be $-P_K$ and one would see a $\sin^2 \Theta'$ distribution.

Thus one can in principle determine from observations of (1) the spin of the K^*, no matter how large it is, and also get information on its isotopic spin and on whether parity is conserved in its decay or production. However, the previously mentioned inhibition of this reaction limits its usefulness in practice. That (1) will not occur with large probability even if it is allowed by spin and isotopic spin considerations can be seen by considering the case in which the K^* is produced forward, followed by K^* decay also along the beam direction. In this case one has $K + He^4 \rightarrow K + \pi + He^4$, with all the momenta essentially along a line, the z-axis. If parity is conserved in the production and decay process, a reflection of the system about any plane containing the z-axis should not alter the parity. However, this is not true for the postulated system because the π is pseudoscalar, and there can be no compensating parity change provided by angular momentum, since there is no orbital angular momentum about the z-axis. Since we have seen above that forward K^* production and forward K^* decays would otherwise be highly probable, this conflict can be resolved only if the amplitude for K^* production goes to zero in the forward direction. Thus reaction (1) is inhibited, and it would be difficult to obtain the information for the analysis of the decay distributions.

This analysis can, however, be applied to reaction (2), which is not forbidden by spin or isotopic spin considerations, and is not inhibited as (1) is, because for (2) there are two pions in the final state, and hence there is no difficulty in conserving the parity. For (2), one must look at those cases in which both the K^* and the π travel near the z-direction; then, as with (1), the K^* decay distribution about z is the same unique function of the K^* spin. Even the analysis of the decay distributions with respect to x to determine spin and to check parity conservation can be applied to (2) provided x is as defined above; i.e., the K^*, π, and He^4 lie essentially in a plane, although the noncoplanarity angle can again be of the order of $\hbar/pR$. Then because of the additional π, $P_{K^*} = P_K$ makes S_x odd, whereas $P_{K^*} = -P_K$ makes S_x even.

An important experimental problem in any of the above observations is being sure that one has He^4 in the final state.

Fortunately He^4 has no excited states, and its disintegration into hydrogen isotopes is clearly distinguishable, but the emission of $He^3 + n$ instead of He^4 provides some difficulty. Of presently available techniques, the helium bubble chamber appears the most suitable for this investigation, and in such a device with a magnetic field the $He^3 + n$ events should usually be rejected on the basis of a kinematic fit. In some cases, the fraction of the total depending strongly upon the incident K energy and the chamber size, the He^4's and He^3's can be separated on the basis of momentum and range. In fact, observation of the He^4 range and angle alone clearly separates reaction (1) from other processes, such as elastic scattering. Reaction (2) is harder to measure than (1), but all of the final particles can be charged, and hence clear cases can be obtained. Thus although the mere observance of (1) can determine whether the K^* spin is 0 or 1 under the highly probable assumptions of reference 3, it seems possible to settle this important question with fewer restrictions by observing the decay distributions from (2) and perhaps from the much rarer (1).

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5. Interactions resulting from the decay of the K^* within the He nucleus could distort these distributions, but this effect is probably not very important because He^4 is tightly bound and the K^* would be moving much faster than K^*'s and Y^*'s observed so far.

6. This argument has been used by T.D. Lee and C.N. Yang, Phys.Rev. 104, 254 (1956), and has been explicitly applied to the type of problem considered here by A. Bohr, Nuclear Phys.10, 486 (1959).
