A_2 Meson Production in K^-d Reactions.*

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ABSTRACT

A new interpretation of published data on the reaction $K^-n \rightarrow \Lambda^0 A_2^-$ is made which appears to make it compatible with a $J^{PC} = 2^{++}$ assignment for the A_2^- and hence with the simple quark model. New data on the reactions $K^-n \rightarrow \Lambda^0 A_2^-$ and $K^-n \rightarrow \Sigma^0 A_2^-$ are presented which are compatible with $J^{PC} = 2^{++}$ for the A_2^- . In addition, it appears that the A_2^- produced by kaons is narrow and has different branching ratios from the state thoroughly studied in pion induced reactions.

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In this paper we discuss the properties of the A_2^- meson produced in the reactions

$$K^- d \rightarrow A_2^- \Lambda^0 p_{sp} \quad (1)$$

$$K^- d \rightarrow A_2^- \Sigma^0 p_{sp} \quad (2)$$

where

$$A_2^- \rightarrow \pi^- \pi^- \pi^+ \quad (3)$$

Since the first indications of the existence of the A_2 meson¹ that object has inspired continual interest. Chung et al.² recognized quite early that the A_2 must have a $J^P = 2^+$ component by their observation of the production reaction

$$\pi^- p \rightarrow A_2^- p \quad (4)$$

with the subsequent decay

$$A_2^- \rightarrow K^- K_1^0 \quad (5)$$

Interest heightened and new parametrizations were required³ when the CERN missing mass spectrometer group⁴ observed a significant mass splitting of the A_2 produced in reaction (4).

Fitting the missing mass spectrum from reaction(4), Benz et al.⁵ were able to rule out the possibility that a superposition of two incoherent Breit-Wigner resonances could reproduce the observed splitting. These results suggested that two interfering A_2 states are produced in reaction (4) both having the quantum numbers $J^P = 2^+$. This conclusion has been confirmed by two definitive experiments by Baud et al.⁶ which not only split the $K^0 K^-$ decay of the A_2^- but determined the spin and parity of the $\rho\pi$ decay of each peak to be $J^P = 2^+$.

It is possible that the two peaks observed in references 4, 5, and 6 are due to the effect of a narrow width 2^+ object destructively interfering with a broad one.

This is analogous to the effect of $\rho^0 - \omega^0$ destructive interference observed by G. Goldhaber *et al.*⁷ If this is indeed the case, very little is known about the narrow state other than its spin and parity. In particular its branching ratios remain to be determined.

Recently, in the only previous study of reaction (1), Crennell *et al.*⁸ have observed the production of a narrow A_2^- . They have quoted a width of less than $40 \text{ MeV}/c^2$ at 90% confidence level. They also pointed out that the A_2 state produced there must have $I=1$ and $C=+1$. In an analysis of the spin and parity they favored an assignment of $J^P = 1^-$. However, since their limited statistics make a spin - parity determination difficult it is possible that they are indeed seeing the narrow 2^+ meson referred to above. A $J^P = 1^-$ assignment appears to be at variance with the results from pion production of the A_2 discussed above. It is also important to note that such an assignment would imply a breakdown of the quark-antiquark model for mesons, since a quark-antiquark pair cannot form a $J^{PC} = 1^{-+}$ state.

We now discuss an analysis of our data on the production and decay reactions (1), (2), (3). The data were obtained from a 5 event μb per nucleon exposure of the Argonne National Laboratory 30 inch deuterium bubble chamber to a beam of $4.48 \text{ GeV}/c$ K^- mesons.⁹ The separation of reactions (1) and (2) has been previously described¹⁰ and allows us to assign 497 events to the final state $\Lambda n^+ \pi^- \pi^-$, 234 events to the final state $\Sigma^0 n^+ \pi^- \pi^-$, leaving 87 events as ambiguous between these final states.

In Fig. 1(a) is shown the 3π mass spectrum for reaction (1) and (2) combined.¹¹ A strong signal is seen in the $1.3 \text{ GeV}/c^2$ mass region.

In Fig. 1(b) the distribution of four-momentum transfer Δ^2 between the incident K^- and outgoing A_2 (mass region $1.28 - 1.33 \text{ GeV}/c^2$) is shown. The distribution is seen to be dominated by events at low Δ^2 , is meson exchange processes. The processes expected to dominate are indicated in the inset to the figure. The 3π spectrum has been fitted to a Breit-Wigner resonance form (energy independent width), resulting in a mass of $1330 \pm 15 \text{ MeV}/c^2$ and a width of 54 ± 30 . With our average mass resolution of $15 \text{ MeV}/c^2$ this implies a true width of $45 \pm 25 \text{ MeV}/c^2$.¹² Although this result is only approximately two standard deviations from the nominal A_2 width of 90 MeV it does tend to confirm the conclusion of Crennell et al. that a narrow substructure of the A_2 is being produced in K^-n interactions.

We next consider the relative amounts of $p\pi$ and 3π in the decay of an A_2 produced in reactions (1) or (2). The distribution in Fig. 1(c) shows the $\pi^+\pi^-$ spectrum for all events in the final states $\Lambda\pi^+\pi^-$ and $\Sigma^0\pi^+\pi^-$ (each event plotted twice), a clear ρ^0 signal is seen. In Fig. 1(d) is shown the $\pi^+\pi^-$ spectrum for all events in the A_2 region of 3π mass. The dashed curve represents phase space with a 10% ρ admixture which describes the neighboring 3π mass regions. The solid curve is that expected if all the A_2 events in the selected 3π mass region decayed to $\rho^0\pi^-$.¹³ The data is adequately described by the dashed curve. Similarly, we find that selecting only $\rho^0\pi^-$ events does not significantly enhance the A_2 signal to background beyond the effect due to the ρ band filling a substantial fraction of the Dalitz plot at the A_2 mass. Hence, we find no compelling evidence that the A_2 produced in reactions (1) and (2) decays predominantly to $\rho^0\pi^-$,

although fractional decays are certainly not excluded. Fig. 2 shows the Dalitz plot for the A_2 mass region. If a $J^P = 2^+$, A_2^- decays dominantly to $\rho^0\pi^-$, there will be strong constructive interference in the overlapping ρ^0 bands. No such effect is seen. Grennell et al. have argued that the absence of such constructive interference enabled them to rule out the $J^P = 2^+$ assignment. However, the weakness of the $\rho^0\pi^-$ signal in the current data makes uncertain the magnitude of the expected interference; and we prefer not to use it as a measure of the A_2 spin.

The production mechanism can be studied by examining the correlation between the A_2 decay plane normal and the incident K^- momentum. This correlation may be described in terms of the spin density matrix ρ_{ij} of the A_2 . The probability distribution $P(\theta)$ is given by

$$P(\theta) \propto \rho_{00} \cos^2 \theta + \rho_{11} \sin^2 \theta \quad (6)$$

for a 1^- meson and

$$P(\theta) \propto \frac{3}{4} \rho_{00} \sin^2 2\theta + \rho_{11} (\cos^2 \theta + \cos^2 2\theta) + \rho_{22} (1 + \cos^2 \theta) \sin^2 \theta \quad (7)$$

for a 2^+ meson. Where θ is the angle between the incident K^- momentum and the normal to the AA_2 decay plane in the A_2 center of mass.¹⁴

Grennell et al. fitted the distribution in $\cos \theta$ for their complete set of Λ^0 events and again found $J^P = 1^-$ to be favored. However, they found the density matrix element ρ_{00} to have the value 0.87 ± 0.1 a number suggesting dominance of K exchange. As pointed out by Grennell et al. these results are hard to reconcile because of the relation

$$G = (-1)^{J+I} \quad (8)$$

which holds for a $K\bar{K}$ state. If one produces a $G = -1$, $I = 1$ state by K exchange in reaction (1), equation (8) forbids $J = 1$.

However, one might expect to find evidence for both K and K^* exchanges.¹⁵ Both K and K^* exchange can occur for reaction (1) but only K^* exchange can be significant for reaction (2).¹⁶ In order to partially separate the K and K^* exchange processes in reaction (1) we look separately at A_2 events in different regions¹⁷ of Δ^2 . In an attempt to display a sample with the K exchange process enhanced, we plot in Fig. 3(a) the distribution in $\cos\theta$ for events from reaction (1) with four-momentum transfer $\Delta^2 \leq 0.6$. The curves show the expected distributions for mesons of J^P equal to 1^- and 2^+ produced by scalar (S) exchange (presumably K exchange for the 2^+ state). Similarly in an attempt to display a sample with the K^* (890) exchange process enhanced, we plot in Fig. 3(b) the distribution in $\cos\theta$ for all Σ^0 events with $\Delta^2 \leq 1.4$ and those Λ^0 events in the range $0.6 \leq \Delta^2 \leq 1.4$. The curves show the expected distributions for a J^P equal to 2^+ meson produced by vector (V) exchange (presumably the K^* (890)) and for a J^P equal to 1^- meson produced by pure vector (V) or pure scalar (S) exchange.¹⁸ While the data of Fig. 3 are obviously limited, we feel that they are certainly compatible with the hypothesis that the A_2 here observed is a 2^+ meson; and is produced by K and K^* exchanges in Δ^2 regions correlated with the mass of the exchanged particle.

In conclusion we suggest that the A_2 meson produced in K^+n interactions does indeed have $J^{PC} = 2^{++}$ and presents no difficulty for the simple quark model. It seems quite possible that this state has width and branching ratios quite different from those of the state relatively thoroughly studied in π nucleon interactions. It is clear that additional data on the A_2 produced by K nucleon interactions would be of great interest.

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9. We measured all events in the 3 prong + V topology, and those in the 4 prong + V topology which contained a proton of momentum less than 300 MeV/c. The programs TVGE and SQUAN were used to reconstruct and file the events.

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11. Ambiguous events are not plotted to avoid distortion due to incorrect assignments. Including these events would not alter any of our conclusions.
12. These values are for reaction (1) only and are to be compared to those of Crennell et al. who found a mass of $1289 \pm 10 \text{ MeV}/c^2$ and a width of less than $40 \text{ MeV}/c^2$ at 90% confidence level.
13. The expected $\pi^+\pi^-$ spectrum for A_2 decays was calculated from the known distribution on the Dalitz plot of $J^P = 1^-$ and 2^+ $\rho^0\pi^-$ states. The curves are similar and it is the 2^+ curve which is plotted on Fig. 1(d). The $\rho\pi$ matrix elements were calculated using the relations given by W. R. Frazer, J. R. Fulco, and F. R. Halpern, Physical Review 136, B1207 (1964).
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15. Each of two components of the A_2 produced in π induced reactions is known to couple to both $\rho\pi$ and $K\bar{K}$. Hence SU(3) implies a coupling to $\bar{K}K^*$ as well.
16. The suppression of K exchange in reaction (2) is due to the smallness of the ratio of the coupling constants $g_{\Sigma\bar{K}N}/g_{\Lambda\bar{K}N}$ (See J. K. Kim, Phys. Rev. Letters 19, 1074 (1967)).
17. We expect K exchange processes to have a lower average Δ^2 than K^* exchange processes. The A_2 region was chosen as $1.28 < M(A_2) < 1.38 \text{ GeV}/c^2$, and all histograms of $\cos\theta$ are folded to improve the statistics.
18. The background events (non A_2) appears to compromise less than or of the order of 40% of the events. They seem to be distributed uniformly in $\cos\theta$. Because of the uncertainty in the amount and

and shape of the background distribution, the curves have been normalized so the total number of events; and no fit is attempted.

FIGURE CAPTIONS

- Fig. 1. (a) Effective mass histogram of $\pi^+\pi^-\pi^-$ from final states $\Lambda\pi^+\pi^-\pi^-$ and $\Sigma^0\pi^+\pi^-\pi^-$.
 (b) four-momentum transfer Δ^2 for A_2 production
 (c) effective mass histogram of both $\pi^+\pi^-$ combinations from the final states $\Lambda\pi^+\pi^-\pi^-$ and $\Sigma^0\pi^+\pi^-\pi^-$
 (d) same as (c) but with the 3π effective mass in the A_2 region.
- Fig. 2. Dalitz plot for the A_2 region of $M(\pi^+\pi^-\pi^-)$
- Fig. 3. (a) $\cos(\theta)$ distribution for low Δ^2 events from reaction (1)
 (b) $\cos(\theta)$ distribution for intermediate Δ^2 events from reaction (1) and both low and intermediate Δ^2 events from reaction (2).
 The curves are described in the text.

b