Note on the photoproduction of the charged A_1

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Arguments made nearly 15 years ago by Fox and Hey are updated in the light of recent experimental findings. These indicate that the charge-exchange photoproduction of the A_1 should dominate that of the A_2. Consistency with the experimental data demands an A_1 mass of 1335 ± 20 MeV and width of 180 ± 55 MeV.

Over a decade ago when the very existence of the A_1 as a resonant state was in doubt, Fox and Hey[1] published a massive article wherein they pointed out that the photoproduction of the charged A_2 ($\gamma p \to A_2^+ n \to \pi^+\pi^+\pi^- n$) without the corresponding photoproduction of the A_1 would constitute powerful evidence that there was no A_1. Over the years there have been reports[2] of A_2 photoproduction but no reliable claim for that of the A_1. The purpose of this note is to point out that the arguments of Fox and Hey[1] are more compelling today than when they were first orchestrated and that the most likely escape from the dilemma created by the lack of A_1 photoproduction is for both the mass and width of the A_1 to approximate that of the A_2. This is clearly in serious conflict with the recent indications from τ-lepton-decay experiments[3] which suggest an A_1 mass of less than 1200 MeV and a width in excess of 300 MeV.

Fox and Hey[1] performed a quark-model calculation and found equal $\pi^\pm\gamma$ radiative widths for the $A_1^\pm$ and $A_2^\pm$. The cross section for the photoproduction of $A_1^\pm$ and $A_2^\pm$ via one-pion exchange then involves only integration over the pion propagator. The value these authors found for the ratio $\sigma(\gamma p \to A_1^+ n)/\sigma(\gamma p \to A_2^+ n)$ was $\frac{5}{9}$. The only parameters entering this calculation, other than the A_1 and A_2 radiative widths are their respective masses. Fox and Hey[1] used an A_1 mass of 1075 MeV which was the value prevailing at the time of their work. Subsequently, positive evidence for a resonant A_1 was extracted from partial-wave analyses[4] of the reaction $\pi p \to (3\pi)p$. Because of strong diffractive production of $\rho\pi$ via Deck processes,[5] which produces a low-mass enhancement in the $\rho\pi$ spectrum, the extraction of the A_1 signal requires a phenomenological model.[6] This deconvolution process yields the current entries for the A_1 in the Particle Data Group (PDG) tables:[7]

$$M(A_1) = 1275\pm28 \text{ MeV}, \quad \Gamma(A_1) = 316\pm45 \text{ MeV} .$$

The inclusion of an increased A_1 mass in the application of the one-pion-exchange model to A_1 photoproduction would lead to a larger relative A_1 cross section. Other advances have occurred in our knowledge of the radiative widths (to $\pi^\pm\gamma$) of the charged A_1 and A_2. Detailed quark-model calculations of Rosner and collaborators[8] have indicated that $\Gamma(A_1^\pm \to \pi^\pm\gamma) = 1.0-1.6$ MeV while $\Gamma(A_2^\pm \to \pi^\pm\gamma) = 375\pm75$ keV. Experimentally,[9] the Primakoff effect has been employed to measure these widths [$\Gamma(A_1 \to \pi\gamma) = 640\pm246$ keV, $\Gamma(A_2 \to \pi\gamma) = 295\pm60$ keV]. Considering the large uncertainties in both the theoretical and experimental radiative widths of the A_1, there is good agreement between these values. Both of these results indicate that $\Gamma(A_1 \to \pi\gamma)/\Gamma(A_2 \to \pi\gamma) \gtrsim 2$ rather than the value of unity employed by Fox and Hey.[1]

Thus, if we ignore any differences in the A_1 and A_2 mass, the unadorned one-pion-exchange model suggests that the ratio of A_1^+ to A_2^+ photoproduction, followed by their decays to three pions, is

$$\frac{\sigma(\gamma p \to A_1^+ n \to \pi^+\pi^+\pi^- n)}{\sigma(\gamma p \to A_2^+ n \to \pi^+\pi^+\pi^- n)} = \frac{10}{7}\,\frac{\Gamma(A_1^+ \to \pi^+\gamma)}{\Gamma(A_2^+ \to \pi^+\gamma)} = 3.1\pm1.5 ,$$

where the factor of $\frac{10}{7}$ accounts for A_2 decays[7] into other than 3π and the final numerical value is based on the experimental widths. An entirely similar ratio should obtain for the reactions $\gamma p \to A_{1,2}^- \Delta^{++}$.

The reactions cited above patently involve charge exchange at the photon-meson vertex. Because of the peripheral nature of photoproduction processes, one-pion exchange is almost certainly the dominant process. ρ exchange is virtually eliminated as a candidate because of the absence of f^0 and A_2^0 photoproduction[10,11] even though their radiative widths[8] (to $\rho^0\gamma$) are expected to be large. Thus, if one-pion exchange is the operative production mechanism, the photoproduced 3π spectrum should be dominated by A_1 rather than A_2 production. If the parameters reported by the DELCO Collaboration[3] for the A_1 were to be employed, the lower mass would somewhat decrease the expected A_1 cross section relative to the A_2 but the larger A_1 width would at least partially compensate for this.

We have attempted to fit the experimental data[2] cited above to Breit-Wigner resonances for the A_2 (using the PDG parameters[7]) and to an A_1 of variable mass and width but with an intensity varying from 1 to 5 times that of the A_2. The average values found for the A_1 mass and width are

$$M(A_1) = 1335\pm20 \text{ MeV}, \quad \Gamma(A_1) = 180\pm55 \text{ MeV} .$$

The mass is somewhat larger and the width is somewhat smaller than the values given in the PDG tables. These latter values, it should be recalled, are based, almost exclusively on the phenomenological analyses of hadronically produced A_1 $[\pi p \rightarrow (3\pi)p]$, where there is always substantial background from nonresonant Deck processes.

We note in passing that the determination of the A_1 parameters from charge-exchange photoproduction processes are relatively immune from interference with Deck processes. This follows from the absence of A_1^0 and A_2^0 production in the reaction $\gamma p \rightarrow pA_{1,2}^0 \rightarrow p\pi^+\pi^-\pi^0$. Two recent, relatively large photoproduction experiments,[11] with π^0 detection capability, have reported data from the $(\pi^+\pi^-\pi^0 p)$ final state without any indications of either A_1^0 or A_2^0 production. The production of A_1^0 or A_2^0 in this reaction is forbidden for one-pion exchange by charge-conjugation invariance. Thus the peripheral photoproduction of A_1^0 or A_2^0 in the forward direction could occur only by an exchange mechanism other than one-pion exchange or by a simulation due to a Deck process. The failure to observe relatively narrow signals for either A_1^0 or A_2^0 in the $\pi^+\pi^-\pi^0$ spectrum suggests that both ρ exchange and diagrams such as those of Figs. 1(a) and 1(b) are ineffective in producing peaks in the A_1^0 (and A_2^0) mass regions. It follows that the equivalent diagram [Fig. 1(c)] for charged $(\rho\pi)$ production will not make a significant contribution to charged A_1 or A_2 production. The requirement of charge-conjugation invariance at the photon vertex thus renders charge-exchange photoproduction relatively immune from the difficulties arising from the principal of duality[12] in hadronic production processes.

Our values for the A_1 mass $[M(A_1)=1335\pm20$ MeV$]$ and width $(\Gamma=180\pm55$ MeV) also differ from the recent analyses of τ-lepton decay.[3] The A_1 masses, determined in these experiments were $1194\pm14\pm10$ MeV and

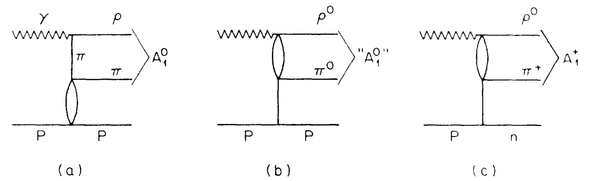

FIG. 1. Deck-type diagrams for the photoproduction of $\rho\pi$ states which could simulate neutral-A_1 production [(a) and (b)] or charged-A_1 production (c). Because the A_1 is an isovector, diagram (b) cannot correspond to real A_1 production.

$1056\pm20\pm15$ MeV. The large mass difference here arises mainly because of different parametrizations of the A_1 resonance. In fact, Schmidke *et al.*[3] also suggest that the differences between their A_1 parameters and those given in the Particle Data Group tables[7] may be attributable to ambiguities in the A_1 parametrization. In this same vein, mention should be made of another weak-interaction experiment,[13] where charged-current neutrino interactions yielded an axial-vector-meson mass of 1.35 ± 0.18 GeV.

In conclusion, whereas a decade ago, there was great speculation about the very existence of the A_1 meson, today, there is a plethora of experiments purporting to define its most basic attributes. Straightforward analyses of photoproduction data, which appear free from complications due to Deck processes, demand a relatively narrow $(\Gamma \lesssim 200$ MeV) A_1 of mass somewhat greater than that of the A_2. The problem now would appear to be the reconciliation of the A_1 parameters from their rather disparate determinations in hadronic, weak, and electromagnetic interactions.

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