Investigation of g-Meson Mass Region Utilizing High-Energy K^+p Collisions*

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We confirm at 12.7 GeV/c a result previously reported at 10 GeV/c, namely the production of a four-pion resonance at ~1630 MeV with a width of ~125 MeV in the reaction $K^+p \to K^0p\pi^+\pi^+\pi^-\pi^0$. No corresponding two-pion enhancement is observed in the reaction $K^+p \to K^0p\pi^+\pi^0$.

One of the continuing puzzles of meson spectroscopy concerns the mass region 1600–1900 MeV (frequently referred to as the R region). The latest version of the Particle Data Group tables[1] now lists a unique $I^G = 1^+$ state in this region [the $g(1680)$ with $J^P = 3^-$], although past versions of these tables have separately listed 2π and 4π states in this vicinity. The Particle Data Group authors explicitly caution, however, that their listing of a unique g meson is in the nature of a "working hypothesis," and is not meant to imply a formal judgment on their part concerning the interrelation between the 2π and the 4π enhancements which have been reported in the R region. There is at present no conclusive experimental evidence resolving this matter. The two principal high-statistics experiments in which this question has been directly investigated, $\pi^-p \to g^-p$ at 7 GeV/c (Ref. 2) and $\pi^+p \to g^+p$ at 8 GeV/c (Ref. 3), both have concluded that only a single resonant state is involved, and have obtained consistent branching ratios $[g^\pm \to (2\pi)^\pm]/[g^\pm \to (4\pi)^\pm] = 0.8 \pm 0.1$ (Ref. 4). The arguments presented in these analyses, however, basically stress the sufficiency of the single-resonance assumption rather than its necessity, and it would be very valuable to have additional reactions in which the R region could be studied with adequate statistics.

Some time ago, the existence of an $I^G = 1^+$ state at 1630 MeV decaying into four pions was reported at 10 GeV/c in the reaction[5]

$$K^+p \to K^0p\pi^+\pi^+\pi^-\pi^0.$$

No corresponding peak was observed in the final state,

$$K^+p \to K^0p\pi^+\pi^0.$$

The relationship between this alleged effect and the states detected in the aforementioned $\pi^\pm p$ collisions is, of course, uncertain. The authors of the above paper, in fact, concluded that a new resonant state was involved. Noting, however, the wide variations in the masses of the previously reported peaks in the R region,[6] it is perhaps

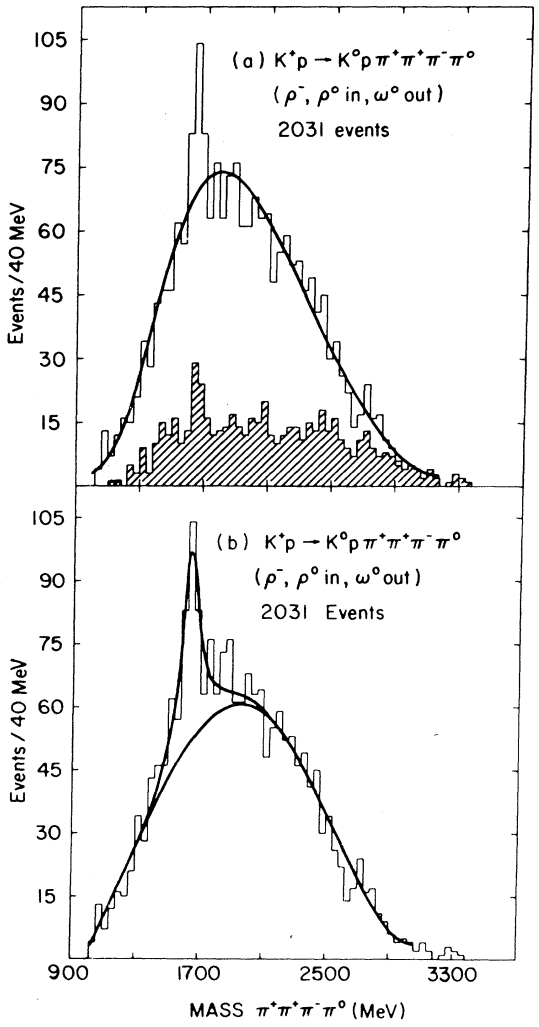

FIG. 1. (a) Combined $\pi^+\pi^+\pi^-\pi^0$ mass spectrum; cross-hatched events are from the 12.7-GeV/c experiment alone. Equivalent $\rho^{-,0}$ selections and ω^0 antiselection have been applied to both data samples (see footnote 8). The curve represents a polynomial fit to the combined data. (b) Combined $\pi^+\pi^+\pi^-\pi^0$ mass spectrum. The curves represent a fit of the data to a Breit-Wigner resonance shape and a polynomial representation of the background.

not unreasonable, at least at this point, to associate the reported effect in the K^+p reaction (questions of statistics aside) with at least part of the 4π state previously observed in the $\pi^\pm p$ experiments. In any event, it is the purpose of the present note to confirm at 12.7 GeV/c the experimental observation[7] of a relatively narrow enhancement at ~1630 MeV in the reaction

$$K^+p \to K^0p\pi^+\pi^+\pi^-\pi^0.$$

Figure 1(a) displays the $\pi^+\pi^+\pi^-\pi^0$ mass spectrum for the 12.7-GeV/c data and for the combined experimental data from the two K^+p experiments. Equivalent $\rho^{-,0}$ selections and ω^0 antiselection have been made on both data samples.[8] The solid curve is a polynomial fit to the combined data, assuming no resonant peak, and the observed enhancement would represent an ~4.5σ fluctuation above this curve. Considering that two separate experiments are involved, and that the effect is seen independently in each, we regard these data as providing convincing evidence that a real effect is being observed. In Fig. 1(b) the total data have been fitted to a Breit-Wigner resonance shape of mass 1630 ± 15 MeV and width 130 ± 30 MeV along with a polynomial representation of the background.[9] This is in good agreement with the values obtained in the 10-GeV/c experiment. A Breit-Wigner resonance shape of this mass and width has been similarly fitted to the 12.7-GeV/c data alone (weighted for K^0 detection efficiency), and a cross section of 25 ± 5 μb thus obtained. This may be compared to a reported cross section of ~60 μb for the 4π effect observed in the π^+p experiment at 8 GeV/c.

In Fig. 2 we present the $\pi^+\pi^0$ mass spectrum from the reaction

$$K^+p \to K^0p\pi^+\pi^0$$

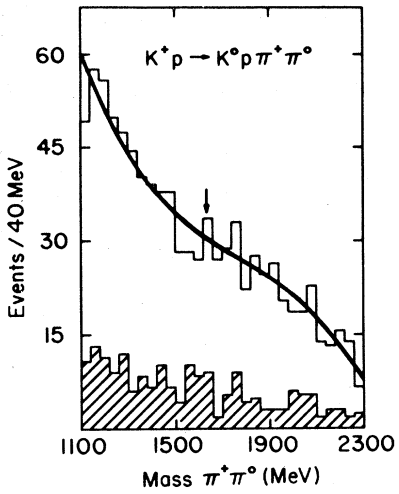

FIG. 2. Combined $\pi^+\pi^0$ mass spectrum; cross-hatched events are from the 12.7-GeV/c experiment alone. The curve represents a polynomial fit to the combined data.

at 12.7 GeV/c and for the combined data from the two experiments. The curve is a polynomial fit to the total data. No narrow structure is observed in the R region in this distribution, and on this basis we report as our upper limit for the branching ratio of the 4π state produced in the K^+p experiments $[R^+ \to (2\pi)^+]/[R^+ \to (4\pi^+)] < 0.2$ (1σ upper limit). Consequently, the K^+p data are very suggestive that there may indeed be in the R region an $I^G = 1^+$ meson distinct from the g. The present availability of a large amount of bubble-chamber data involving K^+p interactions in the 9–13-GeV/c region should permit more conclusive resolution of this important question, and it is our hope that this note may help stimulate the necessary collaborative effort.

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[1]Particle Data Group, Phys. Letters 39B, 1 (1972).

[2]T. F. Johnston *et al.*, Phys. Rev. Letters 20, 1414 (1968).

[3]J. Bartsch *et al.*, Nucl. Phys. B22, 109 (1970).

[4]Lower branching ratios have been obtained by J. Ballam *et al.*, Phys. Rev. D 3, 2606 (1971), who obtained $[g^- \to (2\pi)^-]/[g^- \to (4\pi)^-] \leq 0.12$ using π^-p collisions at 16 GeV/c, and by J. A. J. Matthews *et al.*, Nucl. Phys. B33, 1 (1971), who obtained $[g^0 \to (2\pi)^0]/(g^0 \to \text{all}) = 0.22 \pm 0.04$ using π^-p and π^+d collisions at 7 GeV/c. The former determination is based on rather low statistics (i.e., these authors have ~$\frac{1}{7}$ as many 2π events and ~$\frac{1}{4}$ as many 4π events as reported on in Ref. 2), and the latter is an "indirect" determination of the indicated branching ratio in that it is based on a one-pion-exchange calculation. Nevertheless, these results serve to emphasize that there is no general agreement among experimentalists concerning the branching ratios of the g meson.

[5]K. W. J. Barnham *et al.*, Phys. Rev. Letters 24, 1083 (1970).

[6]See Ref. 1; the very wide range of reported mass values may arise from real dynamical effects rather than experimental uncertainties which might be expected to produce only much smaller shifts.

[7]The 12.7-GeV/c data presented in the text are from an experiment carried out using the BNL 80-inch hydro-

gen bubble chamber. For the details of the experimental analysis employed, see R. Holmes, Ph.D. thesis, University of Rochester (unpublished).

[8]p bands of 160-MeV width were employed and significantly improved the signal-to-noise ratio in the resonance region. The ω removal was made to obtain a sample of events equivalent to that published at 10 GeV/c. Most previous studies of the 4π state have found $(g \to \omega\pi)/(g \to 4\pi) \approx 0.25$. [See, for example, C. Baltay *et al.*, Phys. Rev. Letters 20, 887 (1968); an exception is the 8-GeV/c $\pi^+ p$ experiment of Bartsch *et al.*, in which no $\omega\pi$ decay mode was reported.] The combined $\omega\pi$ spectrum from the 10-GeV/c and 12.7-GeV/c data shows no narrow structure in the R region, but is not inconsistent with a branching ratio of the above magnitude.

[9]The data were fitted by the maximum-likelihood method to an expression of the form $B(m)[1 + R(m)]$, where $B(m)$ is a polynomial representing the background and $R(m)$ is a simple Breit-Wigner term representing the resonance.

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Ar^+-C_2Cl_4 Reactions and Their Role in the Collection of $^{37}Ar^+$ Produced by Solar Neutrinos*

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A high-pressure gas phase study of the Ar^+-C_2Cl_4 ion-molecule system has been made to determine relative rates of charge transfer and ion-molecule reaction. This study was initiated to investigate assumptions made concerning the collection of $^{37}Ar^+$ produced by the reaction $^{37}Cl(\nu, e^-)\,^{37}Ar$ in the Brookhaven solar neutrino experiment. Charge transfer was found to proceed at high pressures in the gas with a rate more than two orders of magnitude greater than other possible Ar^+-C_2Cl_4 ion-molecule reactions. These results support the argument that Ar^+ is not converted into stable charged species which might be missed with techniques used in the solar neutrino experiment.

Experiments which use the $^{37}Cl(\nu, e^-)\,^{37}Ar$ reaction as a monitor of the solar neutrino flux have shown that the neutrino-produced ^{37}Ar is detected in much smaller yields than theoretically predicted.[1,2] While there has been considerable speculation on possible errors in existing solar models or fundamental nuclear theory,[3] a prime concern of Davis and his colleagues in the Brookhaven Chemistry Department has been the possibility of experimental error. A specific area of concern is the problem of efficient recovery of ^{37}Ar in trace concentrations from the 10^5-gallon tank of perchloroethylene. The purpose of this communication is to report results of a study designed to investigate the possibility that ^{37}Ar ions, produced in the nuclear reaction, might undergo ion-molecule reaction with C_2Cl_4 and produce an exotic $ArC_nCl_m^+$ species which would not necessarily be carried out of the tank in the helium purge designed to recover neutral Ar atoms. Molecular compounds of Ar^+ with a variety of other species have been long known to atomic and molecular physicists. Ar^+ should be considered more closely related in its chemical combining properties to chlorine atoms than to the very inert neutral Ar. For example, Field *et al.*[4] found that when mixtures of methane and argon were irradiated with low-energy electrons the ionic compounds ArH^+, ArC^+, $ArCH_2^+$, and $ArCH_3^+$ were detected. In these experiments carried out between 0.04 and 0.12 Torr in a mass-spectrometer ion source the predominant reaction was charge transfer between Ar^+ and CH_4. The charge-transfer rate was roughly 100 times greater than any ion-molecule reaction rate. No data of this type are available for the Ar^+-C_2Cl_4 system. The relative rates of charge transfer and ion-molecule reaction, under conditions where stabilizing collisions can take place in short times after the initial ion-molecule interaction, are needed to provide some evidence for the validity of assumptions made on the fate of neutrino-produced ^{37}Ar in liquid C_2Cl_4. A rapid charge transfer between Ar^+ and C_2Cl_4 cannot be anticipated from the results of the Ar^+-CH_4 system because of the 6.4-V difference[5] in ionization energies of Ar and C_2Cl_4, respectively. The difference between the ionization potential of Ar and CH_4 is only 3 V.[5] Neither system affords the possibility of resonant charge transfer to ground-state product ions. The Ar^+-CH_4 system can re-