π-π resonance width is determined by the anomalous magnetic moment. In B, no attempt is made to fit the magnetic moment. Instead, the resonance width is fit to the π-N S-wave energy dependence (the S-wave thresholds are taken from experiment, and then the more long-range-dependent curvature above threshold is calculated). This procedure leads to a much narrower resonance than the Frazer-Fulco treatment would give at $t_R = 22.4\mu^2$, and if the anomalous moment were calculated at $t_R = 22.4\mu^2$ with this narrow resonance it would come out much too large. When the fit to the energy dependence of the nucleon form factors is made, the narrow resonance width is responsible for the above-mentioned factor of 4 reduction of the $N + \overline{N} \rightarrow 2\pi$ amplitude in B.

Thus the moderate π-π contributions in B are obtained at the expense of failing to explain the nucleon magnetic moment; if the π-π resonance were fit to the magnetic moment the work in B indicates that the π-N S state as well as $J = 1/2$, P state would disagree with experiment.

The early stages of this work were carried out in collaboration with Dr. J. D. Walecka. Discussions with Dr. G. F. Chew, Dr. S. Mandelstam, and Dr. W. R. Frazer were also helpful.

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[6] We give here the minimum ratio of $J = 1/2$ to $J = 3/2$ contributions, which holds at high π-π resonance energies t_R such as $t_R \sim 22\mu^2$; at lower t_R the preponderance of $P_{1/2,\,1/2}$ over $P_{3/2,\,3/2}$ increases. These ratios follow from Eq. (2) together with results from reference 5, and agree approximately with the static limit used in reference 4.

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SINGLE PION PRODUCTION IN 0.96-Bev π^--p INTERACTIONS*

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Photographs of interactions in a hydrogen bubble chamber (field 13.5 kilogauss) irradiated by 0.96-Bev negative pions from the Cosmotron were kindly supplied by Professor Steinberger. We have measured and analyzed 415 events of the neutron reaction

$$\pi^- + p \rightarrow n + \pi^+ + \pi^-,$$

and 267 events of the proton reaction

$$\pi^- + p \rightarrow p + \pi^0 + \pi^-.$$

Experimental values quoted in this Letter all refer to the barycentric system.

Alles-Borelli, Bergia, Ferreira, and Waloscek[1] have shown, from measurements of other photographs in the same irradiation, evidence for the presence of a resonant state $T = J = 3/2$; effects of this state have been calculated by Lindenbaum and Sternheimer.[2]

If this were the only resonant state involved, fast negative pions ("fast" designating a momentum $\geqslant 325$ Mev/c) would originate mostly as recoils from $(n\pi^+)_{3/2}$ or $(p\pi^0)_{3/2}$; they would, accordingly, have the same angular distribution in both reactions, and (from Clebsch-Gordan coefficients) would be twice as numerous in the proton as in the neutron reaction. Figure 1 shows that the angular distributions are quite different, and the observed ratio of proton to neutron events with fast π^- is 0.9 ± 0.2. It follows then, that at

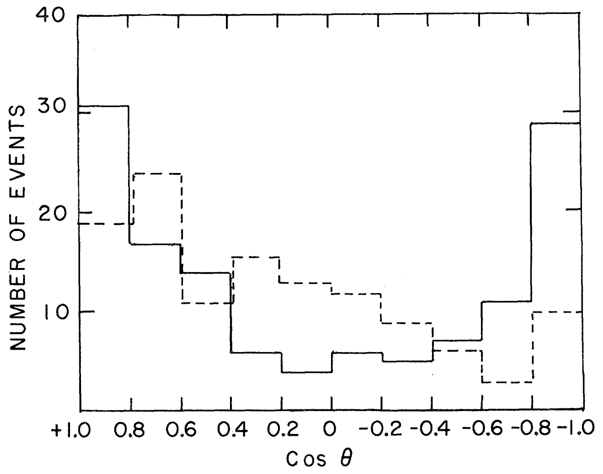

FIG. 1. Angular distributions of fast π^- particles. θ = barycentric angle between direction of produced and of incident pion. Solid line refers to neutron reaction, broken line to proton reaction.

least one state, in addition to the 3/2, is involved (and interferes destructively with the 3/2 state).

Lindenbaum and Sternheimer have recently extended their calculations of branching ratios and momentum spectra to include contributions from the $T=1/2$ state as well as from the $T=3/2$ state.[3]

Q values for the different nucleon-pion combinations have been computed from the observed momenta, Fig. 2. The distribution for $(n\pi^-)$ shows a strong peak at 150 Mev, attributable to the $T=J=3/2$ state; the distribution for $(n\pi^+)$ shows at least as marked a peak at about 400 Mev, which can be interpreted as the effect of the lower $T=1/2$ state ($Q=430$ Mev). The $(p\pi^-)$ and $(p\pi^0)$ Q-value distributions show the same peaks, but much less marked.

If only the 1/2 and 3/2 isobaric states are involved in the neutron reaction, fast π^- particles would be practically all recoils in the production of $(n\pi^+)_{3/2}$. The approximate cosine-squared distribution, solid line of Fig. 1, means, in that case, that the state of relative angular momentum of $(n\pi^+)_{3/2}$ and π^- is a P state (unless there is an accidental mixture of angular momentum states). The angular distribution of positive pions in the rest system of $(n\pi^+)$, restricted to events with fast π^-, shows approximately isotropic decay of $(n\pi^+)_{3/2}$ in its own rest system. An Adair spin analysis[4] of these events rules out $J=1/2$ and is quite consistent with $J=3/2$.

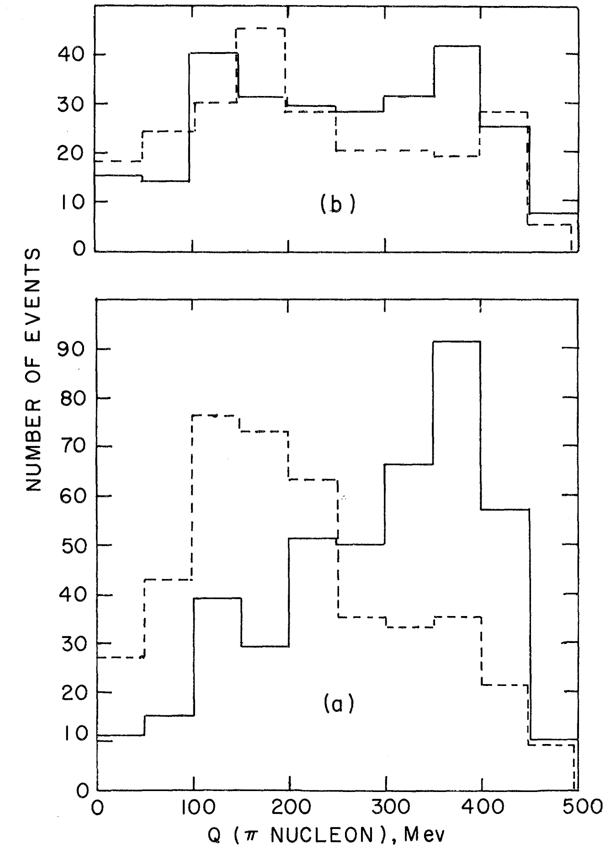

FIG. 2. Pion-nucleon Q values. (a) Solid line $(n\pi^+)$, broken line $(n\pi^-)$. (b) Solid line $(p\pi^-)$, broken line $(p\pi^0)$.

Neutrons show approximately fore and aft symmetry in the barycentric system, whereas twice as many protons move backward as forward; neutron and proton momentum spectra differ as well. The backward protons give rise to a peak at ~100 Mev in the laboratory kinetic energy spectrum. The low-energy laboratory peak has been interpreted by Bonsignori and Selleri[5] and by Derado[6] as evidence for strong pion-pion interaction.

Figure 3 shows distributions of Q values for pion-pion combinations in each reaction, with backward-nucleon events and forward-nucleon events plotted separately. No evidence of peaking is seen for $(\pi^-\pi^+)$, either for forward or backward neutrons, nor for $(\pi^-\pi^0)$ for forward protons. However, the Q distribution for $(\pi^-\pi^0)$ in events with backward protons shows a distinct peak (at least as well marked as the proton-pion peaks), at about 325 Mev, suggestive of a 600-

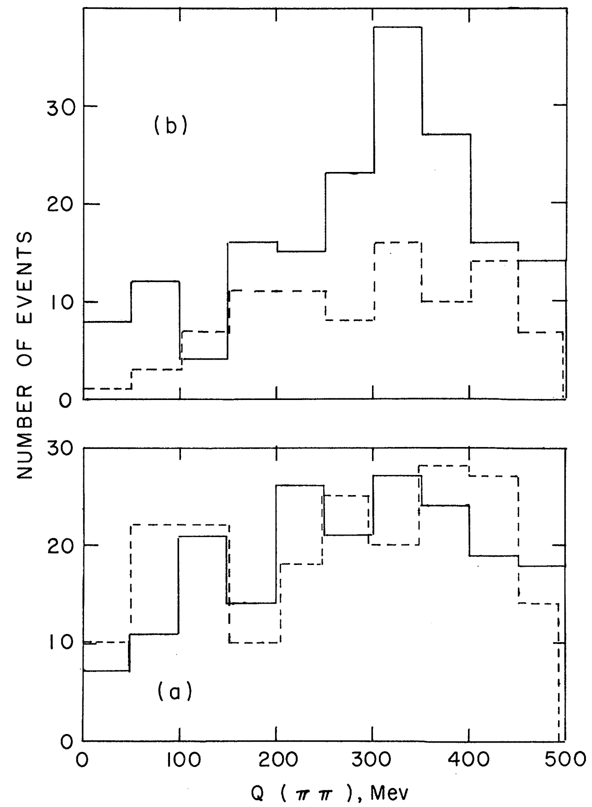

FIG. 3. Pion-pion Q values. (a) $(\pi^-\pi^+)$. (b) $(\pi^-\pi^0)$. Solid lines are for backward-nucleon events, broken lines for forward-nucleon events.

Mev resonant "di-pion" state, $T=1$ or 2. It will be interesting to see what happens to this peak in production by incident pions of different energies, now being analyzed.

Assuming that the Q peak really means a $T=1$ or 2 state, it may be noted that the observed ratio, 1.19 ± 0.14, of fast to slow π^- in the proton reaction does not lie within the limits of the ratio, 0.44-0 for $T=1$ and 16-4 for $T=2$, computed by Landovitz and Marshall,[7] so that one of these states alone would be inadequate to describe the proton reaction.

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GENERALIZED ISOBAR MODEL, AND THE PIONIC FORM FACTOR OF THE NUCLEON*

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Chadwick et al.[1] have studied the inelastic proton spectrum from p-p collisions at 1 to 2 Bev, and have found that although some features of the results are in rough agreement with predictions of the isobar model theory of Lindenbaum and Sternheimer,[2] there are several discrepancies of particular interest.

This note is to point out that in a simple model in which the isobar is excited by means of a virtual pion, the deviations can be understood in a simple way in terms of the decreasing probability of isobar excitation for increasing four-momentum transfer between the colliding nucleons. This decrease is due to two effects—(a) the characteristic energy-denominator associated with the virtual pion, in the transition-amplitude matrix element, and (b) the effect of the "pionic form factor" of the nucleon. This latter term is defined in analogy with the electromagnetic form factor.

The isobar model predicts moderately well-defined peaks in the inelastic spectrum, corresponding to the various nucleon isobars. These isobars are in turn considered to correspond to the peaks in the pion-nucleon cross section; the first three correspond to isobar masses $M_1' = 1.23$ Bev, $M_2' = 1.52$ Bev, $M_3' = 1.67$ Bev. The following features of the experimental results