π^- PHOTOPRODUCTION FROM DEUTERIUM AT LABORATORY ENERGIES 600 TO 1250 MeV*

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The differential cross section for the reaction $\gamma+n\rightarrow\pi^-+p$ was measured for laboratory photon energies between 600 and 1250 MeV, using a liquid deuterium target. The internal nucleon momentum distribution of the deuteron was used to calculate the major effect of using deuterium as a neutron target. The data show that the amplitude to excite the $F_{15}(1688)$ resonance is small, in agreement with a recent quark-model prediction.

In the experiment described in this Letter the cross section of the reaction $\gamma+n\rightarrow\pi^-+p$ was measured for lab photon energies of 600 to 1250 MeV and for c.m. π^- angles of 6° to 160°. The experiment was done in order to increase the experimental knowledge of π^- photoproduction from neutrons to a level comparable with the present knowledge of π^+ and π^0 photoproduction from protons. The new data, when combined with other photoproduction data, will yield much information on the electromagnetic character of the πN resonances. Such information is useful to theorists for a check of sum rules and quark model schemes.

The measurements in the energy region of the $F_{15}(1688)$ resonance were of special interest because that region had not been adequately covered before. The resonance shows up prominently in π^+ photoproduction, and it was very interesting to see in this experiment that the resonance is either absent or very small. This fact seems to confirm a recent quark-model prediction[1] that the resonant amplitude which is dominant in π^+ photoproduction is zero for π^- photoproduction.

The experiment was carried out with the California Institute of Technology 1.5-GeV synchrotron. A bremsstrahlung beam was produced by accelerated electrons impinging on a tantalum radiator. The beam passed through a collimator, scrapers, and a sweeping magnet before striking a liquid deuterium target. The π^- mesons were detected by a 1200-MeV/c spectrometer limited to <55° lab angle and a 600-MeV/c spectrometer limited to <148° lab angle. The experimental system mentioned above is described in detail by Thiessen[2] and by Ecklund and Walker[3] who used the equipment in π^+ photoproduction experiments. The major differences between the present experiment and those described in the references just mentioned were in the methods used to circumvent the problems of using deuterium as a neutron target.

Internal nucleon momentum, the Glauber effect,[4] and the Pauli principle[5] are the main complicating effects in using a deuteron target. Internal nucleon momentum broadens the energy resolution of the experiment. It also lowers the threshold photon energy for 2π photoproduction which contaminates the π^- rates. The Glauber effect lowers the cross section due to the shadowing of one nucleon by the other. The Pauli principle lowers the cross section by restricting the final states available to the two final protons in the reaction $\gamma+d\rightarrow\pi^-+2p$.

A common method[6] to avoid these problems is to assume that the relative effects are the same for both π^- and π^+ photoproduction from deuterium. Then the ratio of the π^- and π^+ counting rates from deuterium will be equal to the ratio of the counting rates from free nucleons:

$$R=(\pi^-\text{ rate}/\pi^+\text{ rate})_{\text{deut}} = (\pi^-\text{ rate}/\pi^+\text{ rate})_{\text{free}}. \qquad (1)$$

Multiplying the ratio by the π^+ photoproduction cross section from protons will yield the π^- photoproduction cross section from neutrons.

A second method is to assume that some of the deuterium effects are negligible and to use the spectator model of (γ, d) interactions. In this model the photon interacts with only one nucleon, and the other nucleon, the spectator, does not participate. The deuterium effect will then be just the smearing of the energy resolution due to the internal nucleon momentum. If one knows the ground-state deuteron wave function $\psi_d(r)$, the momentum representation of the ground state will be

$$\varphi_d(K)=\int\exp(-i\vec{K}\cdot\vec{r})\psi_d(r)d^3\vec{r}. \qquad (2)$$

$|\varphi_d(K)|^2$ is then the probability density of the initial nucleon momentum. Knowing this density, it is possible to calculate the resolution smearing. This method ignores the Glauber and Pauli-principle effects, and 2π contamination.

An improvement on the above method is obtained if one also detects the recoil proton as well as the π^- meson. A counter is placed at the position of the recoil proton corresponding to a target neutron at rest. In this manner, the energy resolution of the experiment can easily be improved by 40%. Furthermore, production of π^- mesons from high-velocity neutrons is suppressed, and 2π contamination is greatly reduced.

In this experiment, all three methods were used. The data reported in this Letter were obtained mostly by the second method. In places where 2π contamination appeared to be large, the measurements using the proton recoil counter were substituted. In order to check the validity of the spectator-model method, the π^+ photoproduction cross sections from deuterium were calculated from the π^+ rates and compared to the cross sections from hydrogen. The comparison, in general, was good.

Typical angular distribution curves for the reaction can be seen in Fig. 1. The fitted curves are Moravcsik fits[7] which have the form

$$(1-\beta\cos\theta)^2\sigma(\theta)=\sum_n A_n\cos^n\theta, \qquad (3)$$

where β is the c.m. velocity of the π^-, and θ is the c.m. production angle of the π^-. The A_n's are determined by a least-squares fit to the data. The term $(1-\beta\cos\theta)^2$ in (3) takes into account the one-pion-exchange (OPE) diagram which contributes many high partial waves not included in a sum over $\cos^n\theta$ terms. In this experiment, β ranged from 0.940 to 0.978. At the OPE pole, $\cos\theta=1/\beta$, the expression in (3) is directly calculable from the Born approximation. It is

$$(1-\beta\cos\theta)^2\sigma(\theta)\big|_{\cos\theta=1/\beta} = C(q/k)(1-\beta^2)/4W^2k^2, \qquad (4)$$

where q is the c.m. π momentum, k is the c.m. photon momentum, and W is the c.m. energy. If k, q, and W are all expressed in MeV, then $C=813.6\times10^9$ MeV^4 μb. Adding the value from (4) to the set of experimental data, the Moravcsik fits can be "interpolated" to obtain the 0° cross section.[3] The 0° cross sections obtained in this way are shown in Fig. 2. The total cross sections, also seen in Fig. 2, were obtained by integrating the fits to $\sigma(\theta)$.

Figure 1 shows the fits at four different photon energies. The errors on the data are purely from statistics. Systematic errors may amount to 10%. The peak in the forward direction is the effect of the OPE diagram. The broader backward peak is probably due to the nucleon-exchange term. The behavior at 1000 and 1100 MeV showing peaks at 30° and 120° can be reproduced by a Born approximation with absorption of the lowest partial waves.[8]

The total cross section seen in Fig. 2(a) has a peak at 700 MeV, resulting from the $D_{13}(1518)$ resonance, commonly known as the "second resonance." The "third resonance," the $F_{15}(1688)$, which produces a prominent peak near 1000 MeV in π^+ photoproduction, displays no similar peak

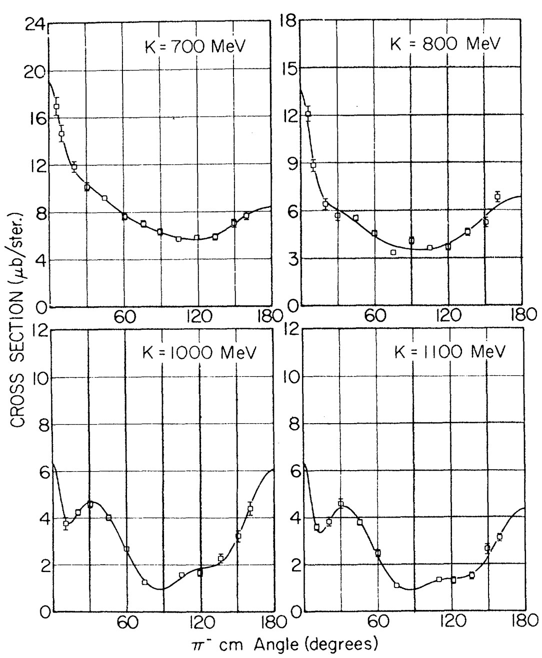

FIG. 1. Angular distributions for π^- photoproduction from deuterium. The solid lines are Moravcsik fits to the data.

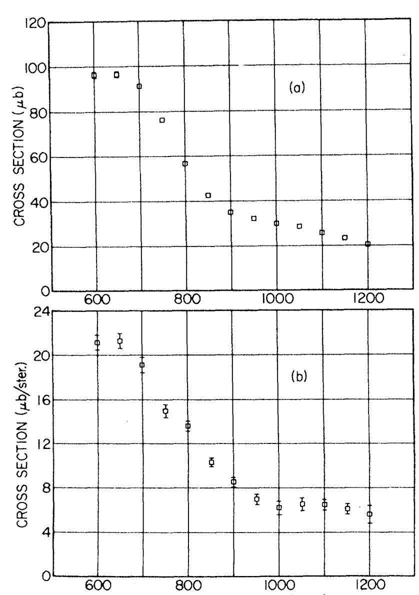

FIG. 2. π^- photoproduction cross sections as a function of energy. (a) Total cross section, (b) $\theta_\pi=0°$ c.m. cross section.

in the π^- case.

The 0° cross section seen in Fig. 2(b) falls rapidly near 800 MeV. This drop could be produced by several resonances which lie in this energy region. A likely candidate is the $S_{11}(1550)$ which can produce this effect from interference between the resonant A_{0+} amplitude and the nonresonant background.[8]

As indicated in Fig. 2(a), the F_{15} amplitude appears to be small. Its dominant amplitude in π^+ photoproduction is B_{3-}[8] which has a maximum near 45° c.m. π angle. In Fig. 3 is a comparison between the π^+ and π^- cross sections from deuterium at c.m. π angle of 45°. The dominant B_{3-} amplitude stands out clearly in the π^+ data as a bump near 1000 MeV. The lack of a corresponding bump in the π^- data indicates that B_{3-} in this case is either small or zero. B_{3-} can be written as a sum of an isovector and isoscalar amplitude,

$$B_{3-}(\pi^+) = B_{3-}^S - B_{3-}^V,$$
$$B_{3-}(\pi^-) = B_{3-}^S + B_{3-}^V. \quad (5)$$

This experiment indicates that $B_{3-}^S \approx -B_{3-}^V$.

Copley, Karl, and Obryk,[1] using a quark model, have predicted that the B_{3-} amplitude of the F_{15} resonance is proportional to the initial nucleon charge; since π^- is produced from a neutron, $B_{3-}(\pi^-) = 0$. A modified partial-wave analysis of the data from this experiment is now being done to determine (among other things) how close this amplitude is to zero.

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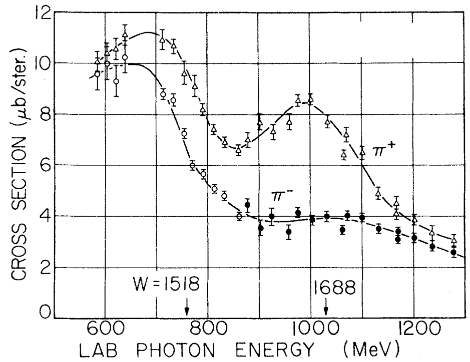

FIG. 3. Energy dependence of the differential cross section at 45° for π^- and π^+ photoproduction from deuterium.

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