Measurement of Differential Cross Section for $\gamma d \rightarrow pn$ by Monochromatic Photons in the Energy Range of Dibaryon Resonances

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The differential cross section for $\gamma d \rightarrow pn$ has been measured in the energy range between 180 and 600 MeV at c.m. angles 15°, 30°, 42°, and 72°, by using tagged photons. The results, in particular at smaller angles, are in disagreement with theoretical calculations which take into account the effect of dibaryon resonances.

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Among various reactions which take place when photons of several hundred megaelectronvolts are incident upon deuterons, the photodisintegration,

$$\gamma + d \rightarrow p + n, \tag{1}$$

has recently attracted much interest in connection with the possible existence of dibaryon resonances (DB).[1] A phenomenological analysis by Ikeda *et al.*[2] claims two DB's with masses of 2.26 and 2.38 GeV in order to consistently explain polarization and cross-section data in the energy range between 400 and 650 MeV.

However, there is a great kinematical complexity due to the spin, the number of invariant amplitudes for (1) being 12, while the data used in the above analysis are rather poor, and one needs much more experimental data to confirm or to disprove the existence of DB's. Even for the differential cross section (DCS), there have been no data at c.m. angles less than 30°, where the difference among the predictions becomes considerable. We present here new data of DCS for the process (1) and compare them in detail with some calculations.

The experiment was performed by using a tagged photon facility[3] at the 1.3-GeV electron synchrotron at the Institute for Nuclear Study (INS), University of Tokyo. The merit of employing tagged photons is summarized as follows: (a) A finer energy resolution is more easily attainable compared with usual (untagged) bremsstrahlung photons, (b) kinematical overconstraints resulting from (a) make the event selection very clean and stringent (this is particularly effective at smaller angles), and (c) for a fixed value of the primary electron energy E_e, a simultaneous measurement is possible over a wide range of photon energy E_γ (240 MeV in the present case), which enables us to reduce the majority of systematic errors.

An electron beam extracted from the synchrotron was led to an external aluminum radiator. The electrons which emitted bremsstrahlung photons at the radiator were measured by a tagging spectrometer. This spectrometer consisted of an analyzer magnet and two sets of scintillation counters: One was a hodoscope consisting of 24 pieces of counter placed downstream of the magnet and the other was a set of six backing counters behind the hodoscope. Each piece of the hodoscope corresponded to a width of 10 MeV for E_γ. A careful calibration of E_γ was made by measuring electron pairs converted from tagged photons by means of pair spectrometery. The energy resolution, which included uncertainties resulting from the finite width of the counters and beam size and divergence of the primary electrons, was found to be ± 7 MeV. The range of E_γ for a given value of E_e was between $E_e - 365$ and $E_e - 125$ MeV. The beam intensity was typically 1×10^4/s·(10 MeV). The target was liquid deuterium contained in a cylinder 20 cm long and 5 cm in diameter.

Charged particles in the final state were detected by a magnetic spectrometer consisting of a large-aperture magnet, four layers of multiwire proportional chambers, and three sets of trigger counters. The momentum resolution $\Delta p/p$ was typically ± 3% and the systematic error in momentum determination was estimated to be within ± 5 MeV/c from an elaborate calibration by using extracted electrons. The stability of the magnetic field was monitored by NMR throughout the experiment. The angular acceptance was ± 5° in lab angle. We also measured the time of flight for about 2 m between the first and the second trigger counters with a time resolution of ± 0.6 ns.

The measurement was carried out at four different settings corresponding to c.m. angles 15°, 30°, 42°, and 72°. The protons were easily identified on a two-dimensional plot of the momentum versus time of flight. The event selection was unambiguously made by imposing kinematical constraints to identify the two-body reaction (1).

The results are shown in Fig. 1, where measured values of DCS are plotted as a function of E_γ, together with similar data from other experiments.[4] The errors quoted are statistical only and the total systematic error is estimated to be less than 15% at 15°, while it is less than 10% at other angles. In this figure, also shown are three curves given by Ikeda *et al.*[2] The dashed and dot-dashed curves are those containing two DB's; the former corresponds to the solution with DB's of J^P (mass) $=3^-(2.26)+3^+(2.38)$, while the latter is with $3^-(2.26)+1^+(2.38)$. The solid curve represents the nonresonant contribution.

From Fig. 1, we see that above 300 MeV, the measured DCS decreases rapidly as E_γ increases without showing any marked structure within the sensitivity of the experiment. The most striking feature is that none of the curves can reproduce the data at smaller angles; the discrepancy between the data and the curves goes larger as c.m. angle becomes smaller.

This situation can be seen more clearly in Fig. 2, where the data available at present are shown in the form of angular distributions. At any value of E_γ, the magnitude of the DCS increases slowly with increasing angle in the forward region, reaches a maximum somewhere between 60° and 90°, and gradually decreases above 90°. In this figure, two curves, the dot-dashed and solid ones, are the same as those in Fig. 1, while the dashed one represents the contribution only from the one-pion-reabsorption (OPR) diagram in which a single pion appears in the intermediate state.

As far as DCS data are concerned, Fig. 2 indicates that the OPR contribution gives an unexpectedly good fit. Since the nonresonant contribution, the solid curve, consists of the OPR term and the nucleon-pole term in which no intermediate pion appears, this fit implies that the nucleon-pole term should not be included in the calculation. Similar circumstances have been reported also in the pionic processes $\pi^+d\to pp$.[5]

On the other hand, polarization and asymmetry parameters such as P, T, and Σ, for which experimental data have recently been accumulated,[6] cannot be reproduced by the OPR amplitudes alone. As these observables are sensitive to small admixture of resonant amplitudes, one of the natural ways to get a fit to the data is to supplement the OPR amplitudes with DB ones. We have tried to obtain a good fit to all the existing

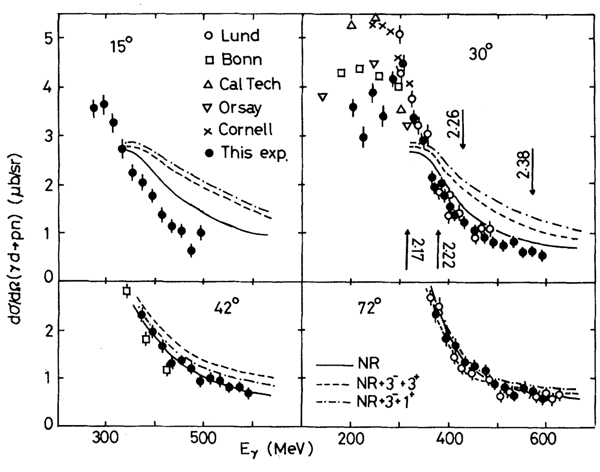

FIG. 1. The differential cross section for the process $\gamma d\to pn$ as a function of E_γ at fixed angles. The errors are statistical only. The curves are from Ref. 2; the dashed and dot-dashed ones are NR + DB's of $J^P=3^-+3^+$, and NR + 3^-+1^+, respectively, while the solid one is NR only. The arrows indicate the position of possible DB's.

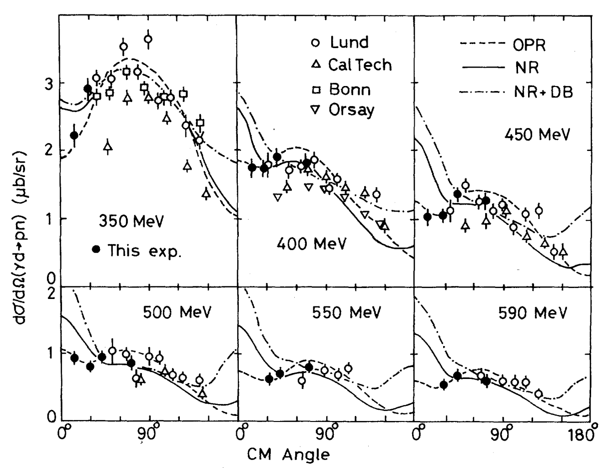

FIG. 2. The differential cross section for $\gamma d\to pn$ as a function of c.m. angle of proton. The dot-dashed and solid curves are the same as in Fig. 1, and the dashed one is the OPR contribution.

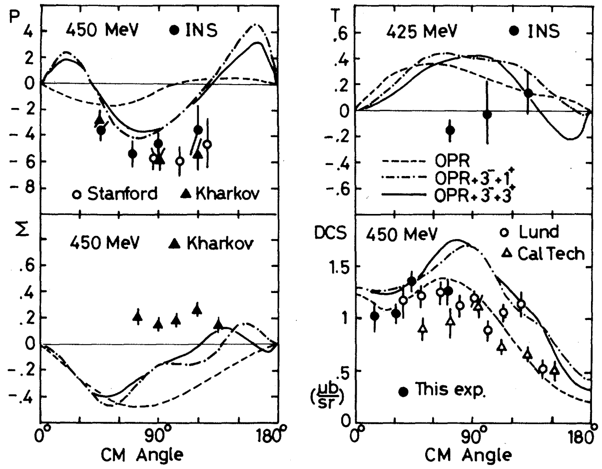

FIG. 3. Comparison of the results obtained by χ^2 fit with the data around E_γ = 450 MeV. Fitting is made by varying all the resonance parameters and the relative angle between the OPR and DB amplitudes starting from the original values in Ref. 2. The dashed curve represents the OPR contribution as a nonresonant background, and the other two, the dot-dashed and solid ones, are OPR + 3^- + 1^+, and OPR + 3^- + 3^+, respectively.

data of DCS,[4] P,[2,7] Σ,[8] and T,[9] by varying the resonance parameters and introducing the phase of the DB amplitudes relative to the OPR ones. Starting values are taken to be those originally given in Ref. 2.

Figure 3 shows typical examples of the results of such an attempt. The data for various observables at around 450 MeV are compared with calculated results with minimum χ^2; the solid and dot-dashed curves are OPR $+3^-$ (mass: 2.21 GeV, width: 133 MeV, relative phase: $-85°$) $+3^+$ (2.23 GeV, 117 MeV, 109°), and OPR $+3^-$ (2.24 GeV, 96 MeV, $-77°$) $+1^+$ (2.37 GeV, 651 MeV, $-11°$), respectively, whereas the dashed one is OPR only.

As is seen in Fig. 3, all of the calculated results give no satisfactory fit to the data as a whole. The situation is more or less common to all energy points considered. In particular, it seems impossible to reproduce the forward non-peaking DCS and the observed behavior of polarization and asymmetry parameters at the same time with the present combinations of the phenomenological amplitudes.

Thus, the present data indicate that the existence of two DB's conjectured in the process (1) is doubtful and, if they exist, the resonance parameters should be greatly modified from those originally proposed.

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