Determination of cross sections for disintegration of the deuteron by photons polarized parallel and perpendicular to the reaction plane

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The first data are reported on the cross sections for the disintegration of the deuteron by photons polarized parallel and perpendicular to the reaction plane in the energy range 30–100 MeV. There is an indication of a possible manifestation of a narrow dibaryon resonance with a mass of 1919.5 MeV.

In research on photonuclear reactions in the intermediate energy range, questions of special interest concern the excitation of nonnucleon degrees of freedom and differences between the properties of free nucleons and those bound in nuclei. Corresponding calculations carried out for the reaction $\gamma d \to pn$ over the energy range up to the pion production threshold, with allowance for virtual electromagnetic currents of the nucleons, show that they play an important role in the case in which magnetic transitions are dominant, e.g., in photodisintegration at angles $\theta_p = 0$ and 180° (Ref. 1; θ_p is the proton emission angle in the c.m. frame of reference). However, effects associated with magnetic transitions can be studied not only under such "extreme" kinematic conditions but also in the cross sections for the disintegration of the deuteron by photons polarized perpendicular to the reaction plane at angles $\theta_p \sim 90°$. No studies of this sort have previously been carried out.

In this letter we are reporting measurements of the cross sections for the reaction $\gamma d \to pn$ caused by photons polarized parallel to ($d\sigma_{\parallel}/d\Omega \equiv d\sigma_{\parallel}$) and perpendicular to ($d\sigma_{\perp}/d\Omega \equiv d\sigma_{\perp}$) the reaction plane for and angle $\theta_p = 90°$ and for photon energies over the range $E_\gamma = 30$–100 MeV. The experiments were carried out at the LU-2 GeV Kharkov Linear Electron Accelerator in beams of ordinary bremsstrahlung and linearly polarized radiation, produced through the coherent bremsstrahlung of electrons in a diamond single crystal. The experimental apparatus and measurement procedure are described in Ref. 2. The cross sections $d\sigma_{\parallel}$ and $d\sigma_{\perp}$ were found from the cross sections for an unpolarized photon beam ($d\sigma_0/d\Omega \equiv d\sigma_0$) and the cross-section asymmetry $\Sigma = (d\sigma_{\parallel} - d\sigma_{\perp})/(d\sigma_{\parallel} + d\sigma_{\perp})$ measured simultaneously in the same experiment.[2] The low-temperature target had two plane appendices 5 and 10 mm thick with walls of 30-μm-thick copper foil, filled with liquid deuterium, and an identical empty appendix, for measuring the background. The protons were detected by a four-channel telescope of scintillation counters in vacuum behind the magnetic spectrometer. The energy resolution of the apparatus in terms of the photon energy was 2.8–3 and 4–5 MeV for target thicknesses of 5 and 10 mm, respectively. The protons were selected by magnetic analysis, on the basis of dE/dx, and on the basis of their range. We used a computer-controlled goniometric system, which could rapidly change the direction of the polarization vector of the photon beam. To reduce the measurement errors due to the instability of the electron beam, data were sampled in short exposures (from 1 to 5 min) at each experimental point, with a total of 15–20 measurements. In addition, in the measurement of the asymmetry, the direction of the polarization vector was changed automatically after each brief exposure. The data were acquired and monitored by an SM-4 computer. The procedure for calculating the cross sections $d\sigma_{0,\parallel,\perp}$ and Σ is described in Refs. 2 and 3.

Figure 1 shows the experimental results. We see that the cross section $d\sigma_{\perp}$ is essentially independent of the energy in this energy range, in contrast with $d\sigma_{\parallel}$. At $E_\gamma \simeq 44$–45 MeV, which corresponds to $W = 1919.5$ MeV, however, we see a maximum, whose position agrees with that of the maximum which has been observed in several studies (e.g., Ref. 4) in the distribution in the invariant mass of the (p,p) system at $W = 1920$–1923 MeV and which has been interpreted as a dibaryon resonance. A theoretical analysis of the results was carried out in a relativistic gauge-invariant approach, with allowance for the internal structure of the deuteron.[1] The reaction cross section was found through a gauge-invariant selection of s, t, and u pole amplitudes, by means of the "longitudinal" part of the contact amplitude, which was calculated on the basis of the Ward–Takahashi identities, and by means of the "transverse" (gauge-invariant) part of the contact amplitude. This part was found by means of loop diagrams constructed through a "minimal" incorporation of the electromagnetic field in the corresponding blocks after the separation of two-particle-reducible

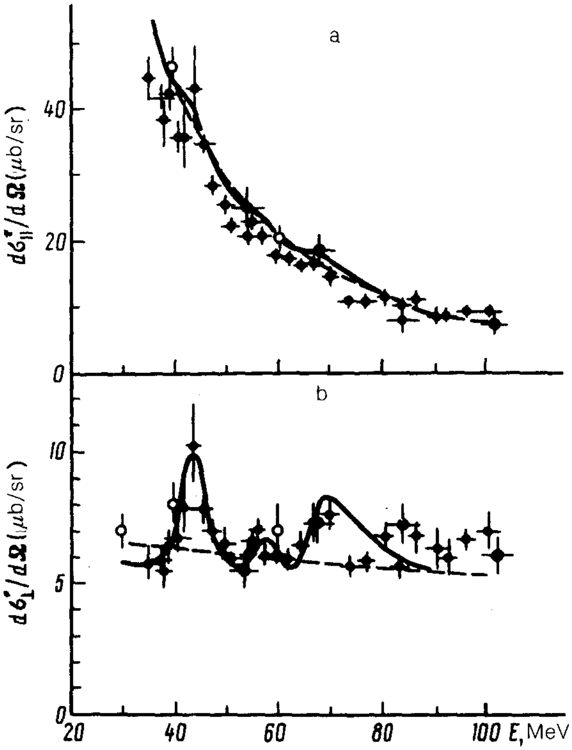

FIG. 1. Differential cross sections for the photodisintegration of the deuteron by polarized photons. a—$d\sigma_{\parallel}$; b-$d\sigma_{\perp}$. $\theta_p = 90°$ in the c.m. frame. ♦) results of the present study; ♦) data of Re. 2; ♢) data from Ref. 6. The results of the theoretical calculations (see the text proper) have been averaged over the energy resolution of the apparatus.

contributions with half-off-shell amplitudes $f_{NN}^{\rm off}$ for the elastic rescattering $NN \rightarrow NN$. The amplitudes $f_{NN}^{\rm off}$ were calculated through the use of a separable representation of the Paris potential.[5] Since the cross section $d\sigma_{\perp}$ is determined primarily by magnetic transitions over the E_{γ} range studied, and since the selection rules based on the total angular momentum and the parity for the dominant $M1$ dipole transition at low energies point to even values of the orbital angular momentum l of the final (p,n) system, corresponding to isovector $(T=1)$ $M1(^1S_0)$,$M1(^1D_2)$ transitions and isoscalar $(T=0)M1(^3S_1)$,$M1(^3D_1)$,$M1(^3D_2)$ transitions, it is natural to suggest that possible isotriplets of narrow resonances with a small mass arise in the $^1S_0$ and $^1D_2$ phase shifts in this case. The manifestation in the cross section $d\sigma_{\perp}$ of isosinglet resonances with $M<2$ GeV may be associated with $^3S_1$,$^3D_1$, and $^3D_2$ phase shifts, whose contributions are substantially suppressed, according to the calculations. The resonances in the NN scattering amplitude were taken into account in the following way:

$$f_e = [\exp(2i\delta_t^e) - 1]/2i; \quad \delta_t^e = \delta_{\rm ph}^e + \delta_R^{ej}; \quad \delta_R^{ej} = \tan^{-1}\{\Gamma_j^e/2(M_j^e - W)\},$$

where M_j and Γ_j are the mass and width of resonance j. The phase shifts $\delta_{\rm ph}^e$ were calculated on the basis of Ref. 5. Each resonance is thus described by only two parameters, and the "strength of the resonance" in the multipole amplitude is calculated in terms of loop diagrams.

The solid line in Fig. 1 shows the results calculated for cross sections under the assumption of the following set of masses and widths (Ref. 4,for example): A resonance with $M = 1919.5$ MeV and $\Gamma = 4.5$ MeV is manifested in the $^1S_0$ phase shift, while resonances with $M = 1933$ MeV, $\Gamma = 2.7$ MeV and $M = 1942$ MeV, $\Gamma = 6.6$ MeV are manifested in the $^1D_2$ phase shift. The dashed line shows the result of a calculation without resonances. We see that these experimental data indicate a possible manifestation of a 0^+ dibaryon resonance with $T = 1$ ($M = 1919.5$ MeV, $\Gamma = 4.5$ MeV) in $d\sigma_\perp$ and do not contradict the idea of an excitation of 2^+ resonances ($M = 1933$ MeV, $\Gamma = 2.7$ MeV and $M = 1942$ MeV, $\Gamma = 6.6$ MeV). Since the contributions of the magnetic transitions to $d\sigma_\parallel$ are relatively small at $E_\gamma = 50$ MeV (as expected), resonances with these quantum numbers are essentially not manifested in $d\sigma_\parallel$ or thus in $d\sigma_0$. In order to study possible manifestations of narrow $T = 1$ resonances in P phase shifts, it will be necessary to carry out a joint analysis of the cross sections $d\sigma_\parallel$ and $d\sigma_\perp$ measured at a substantially higher accuracy.

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