Asymmetry and angular distribution of deuteron photodisintegration in the 20–60 MeV range

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Theoretical results on the asymmetry function and angular distribution parameters for deuteron photodisintegration are obtained by adding the one- and two-body relativistic corrections to the charge density and meson exchange corrections to the current density to the normal $E1$, $M1$, and $E2$, multipoles and compared with the recent measurements of De Pascale *et al.* Phenomenologically, it is found that agreement with the angular distribution coefficients which depend on the $E2$ transitions can be improved if the' $E2$ radial matrix elements are reduced by about 15%. The physical process responsible for this reduction is not clear.

In recent years photodisintegration of the deuteron has been subjected to a number of investigations, both theoretical and experimental, because of its importance to the field of photonuclear physics. The refinements in theory have been made by adding the one-pion exchange and Δ-excitation processes to the current densities and one- and two-body relativistic corrections to the charge density in the traditional Hamiltonian for the photodisintegration process. Recently, new measurements on the cross section and polarization asymmetry have been reported by De Pascale *et al.*[1] in the 20–60 MeV γ-ray energy range. In this short note we plan to compare their data with our latest calculation[2] for this process. In our calculation, the one- and two-body charge and current densities with its local and nonlocal contribution had been added to the normal $E1$, $M1$, and $E2$ multipoles transitions. The results of our investigation were quite satisfactory up to 100 MeV γ-ray energies and fitted the experimental data at lower energies extremely well. In this paper, the angular distribution parameters and asymmetry function at 19.8, 29.0, 38.6, and 60.8 MeV γ-ray energies are calculated in order to make a comparison with the experimental data of De Pascale *et al.* and with the theoretical results of Arenhövel[3,4] and Cambi *et al.*[5,6] which include only meson exchange current and Δ-isobar configuration contribution to the work of Partovi.[7] All multipoles up to, and including $L=4$, were considered by Arenhövel and Cambi *et al.* Through our calculations, it is found that at γ-ray energies considered by us here there is no need to take multipoles higher than $E1$, $M1$, and $E2$ to explain the experimental data. We also attempt phenomenologically to fit the angular distribution parameters d and e which De Pascale[1] failed to obtain using the work of Refs. 3–6, by varying the radial integrals that occur in the $E2$ transitions.

The procedure laid out by Rustgi, Zernik, Breit, and Andrews[8] (RZBA) is followed. The interaction Hamiltonian given by Eq. (4) of RZBA on adding the above mentioned corrections can be rewritten as

$$H' = -eE_x A \ , \tag{1}$$

$$\begin{aligned} A = {} & \tfrac{1}{2}(\mathbf{l}_E\cdot\mathbf{r}) + \frac{i}{8}(\mathbf{k}\cdot\mathbf{r})(\mathbf{l}_E\cdot\mathbf{r}) + \frac{f^2}{4M}\{\tfrac{1}{3}(\phi_0\boldsymbol{\sigma}_1\cdot\boldsymbol{\sigma}_2+\phi_2 S_{12})\mathbf{r} + (2\mu_v\phi-\phi_1)[\boldsymbol{\sigma}_1(\boldsymbol{\sigma}_2\cdot\mathbf{r})+\boldsymbol{\sigma}_2(\boldsymbol{\sigma}_1\cdot\mathbf{r})]\}\cdot\mathbf{l}_E \\ & + \tfrac{3}{2}\frac{f^2}{M}\phi\alpha_s[\boldsymbol{\sigma}_1(\mathbf{r}\cdot\boldsymbol{\sigma}_2)-\boldsymbol{\sigma}_2(\mathbf{r}\cdot\boldsymbol{\sigma}_1)]\cdot\mathbf{l}_E + \frac{f^2}{2M}\frac{1}{\mu} \\ & \times\{\Phi_0[(\boldsymbol{\sigma}_2\cdot\overleftrightarrow{\nabla})(\boldsymbol{\sigma}_1\cdot\mathbf{r})+(\boldsymbol{\sigma}_1\cdot\overleftrightarrow{\nabla})(\boldsymbol{\sigma}_2\cdot\mathbf{r})]\mathbf{r} + \tfrac{1}{3}[(3\Phi_1+\Phi_2)(\boldsymbol{\sigma}_1\cdot\boldsymbol{\sigma}_2)+\Phi_2 S_{12}]\cdot\overleftrightarrow{\nabla}\}\cdot\mathbf{l}_E \\ & - \frac{1}{8M^2}[(2\mu_v-1)(\boldsymbol{\sigma}_1+\boldsymbol{\sigma}_2)+2(\mu_s-1)(\boldsymbol{\sigma}_1-\sigma_2)]\times\mathbf{P}_r\cdot\mathbf{l}_E \\ & + \frac{\hbar}{2Mc}[(\tfrac{1}{2}\mu_v+g_I+h_I)(\boldsymbol{\sigma}_1-\boldsymbol{\sigma}_2)+\tfrac{1}{2}(\mu_s-\tfrac{1}{2})(\boldsymbol{\sigma}_1+\boldsymbol{\sigma}_2)+(g_{II}+h_{II})T_{12}^{(-)}]\cdot\mathbf{l}_H \ . \end{aligned} \tag{2}$$

The notation and symbols used here are defined in RZBA and in Ref. 2. Owing to the above changes in the interaction Hamiltonian, the radial integrals of RZBA are modified as pointed out in Ref. 2.

For plane-polarized γ rays, the differential cross section of the outgoing proton may be expanded in powers of $\cos\theta$ and $\sin\theta$ and for $E1$, $M1$, and $E2$ multipoles transitions, following RZBA, can be written as

$$\sigma(\theta,\phi) = a_R + b_R\sin^2\theta + c_R\cos\theta + d_R\cos\theta\sin^2\theta + e_R\cos^2\theta\sin^2\theta + \cos2\phi(f_R\sin^2\theta + d_R\cos\theta\sin^2\theta + e_R\cos^2\theta\sin^2\theta) \ , \tag{3}$$

where the subscript R indicates the parameters as defined in RZBA. But to compare the parameters of RZBA with those defined by De Pascale *et al.*,[1]

$$\sigma(\theta,\phi)=a+b\sin^2\theta+c\cos\theta+d\cos\theta\sin^2\theta+e\sin^4\theta+\cos2\phi(f\sin^2\theta+g\cos\theta\sin^2\theta+h\sin^4\theta)\ , \quad (4)$$

we rewrite Eq. (3) as

$$\sigma(\theta,\phi)=a_R+(b_R+e_R)\sin^2\theta+c_R\cos\theta+d_R\cos\theta\sin^2\theta-e_R\sin^4\theta+\cos2\phi[(f_R+e_R)\sin^2\theta+d_R\cos\theta\sin^2\theta-e_R\sin^4\theta]\ . \quad (5)$$

Hence, the parameters a, b, c, d, e, f, g, and h of De Pascale *et al.* are related to those of RZBA by the relations $a=a_R$, $b=b_R+e_R$, $c=c_R$, $d=d_R$, $e=-e_R$, $f=f_R+e_R$, $g=d_R$, and $h=-e_R$. The total cross section is

$$\sigma_t=4\pi a+\frac{8\pi}{3}b+\frac{32\pi}{15}e\ . \quad (6)$$

Our results for the asymmetry function at 38.6 and 60.8 MeV γ-ray energies as a function of outgoing neutron c.m. angles and angular distribution parameters a, b, c, d, e, f, g, and h as a function of γ-ray energies are shown in Figs. 1, 2, and 3, respectively, for supersoft core B (SSC-B solid line)[9] and Paris[10] (dashed line) potentials using pseudoscalar πN coupling. The experimental data of De Pascale *et al.* are also shown in these figures. The asymmetry function at lower energies (19.8 and 29.0 MeV) is not shown, in the interest of brevity, but it agrees very well with our calculation. It is clear from Fig. 1 that our calculation with the Hamiltonian used in this paper and employing the SCC-B potential reproduces the experimental data for the asymmetry function at 38.6 and 60.8 MeV γ-ray energies perfectly well in pseudoscalar πN coupling. The results with the Paris po-

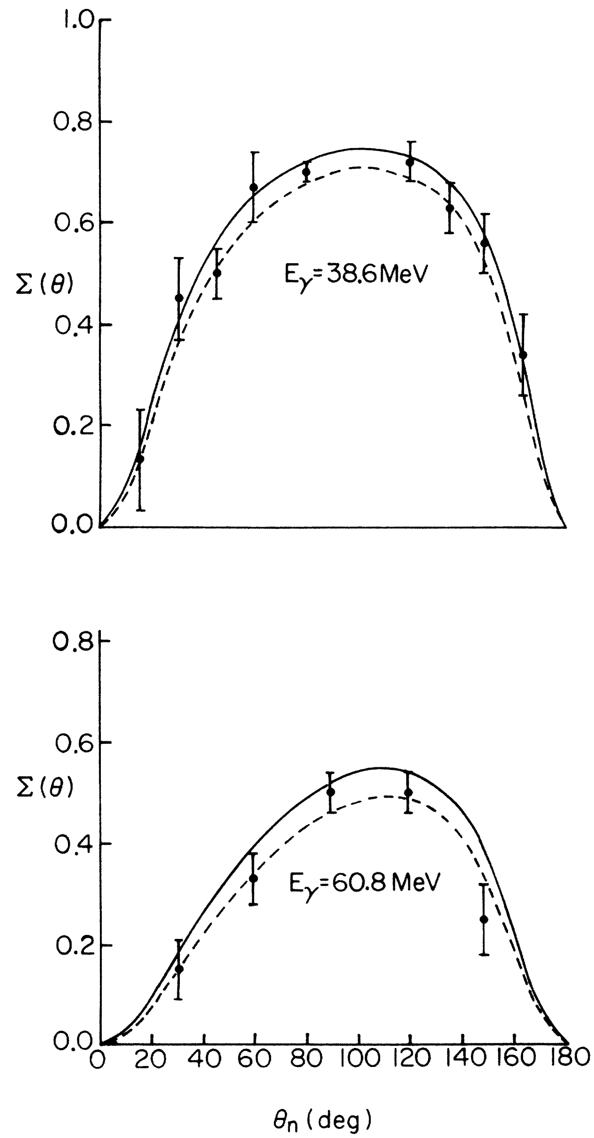

FIG. 1. Comparison of the asymmetry function with the present calculations for the supersoft core B (solid) and Paris (shown dashed) potentials.

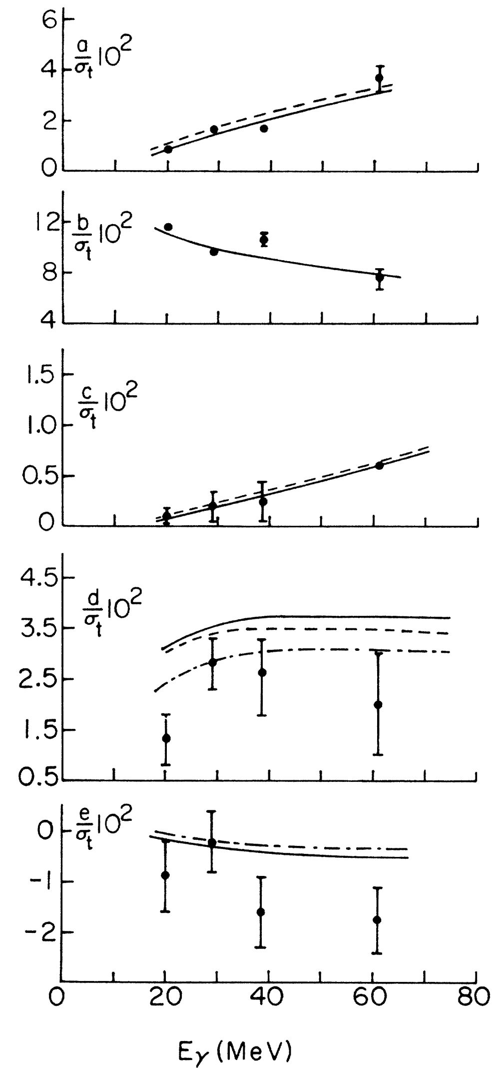

FIG. 2. Comparison of the calculated angular distribution parameters with the measured ones in Ref. 1 for the supersoft core B (shown solid) and Paris (shown dashed) potentials. Wherever the calculated results for the two potentials overlap, only the solid curve is drawn. The dot-dashed curve results when the $E2$ radial matrix elements for the supersoft core potential are reduced by 15%.

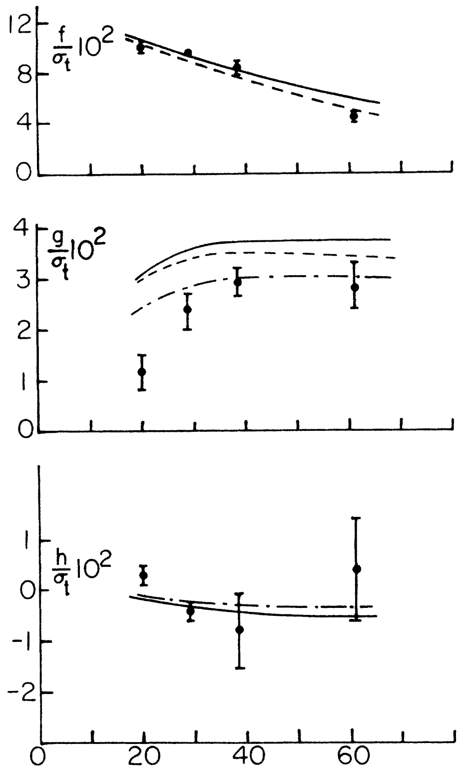

FIG. 3. Comparison of the calculated angular distribution parameters with the measured ones in Ref. 1 for the supersoft core B (shown solid) and Paris (shown dashed) potentials. Wherever the calculated results for the two potentials overlap, only the solid curve is drawn. The dot-dashed curve results when the $E2$ radial matrix elements for the supersoft core potential are reduced by 15%.

tential also fall within the experimental errors. The results on angular distribution parameters divided by the total cross section, as shown in Figs. 2 and 3, fit the experimental data quite well except for the coefficients d, e, g, and h where d and g, and e and h, are equivalent in our calculation. It also appears to be true in the drawings of Ref. 1. The quality of our agreement is the same as obtained by Cambi *et al.* and Arenhövel. As pointed out in RZBA, the coefficients d, e, g, and h appear in the angular distribution expression due to the existence of the $E2$ multipoles but d and g are more sensitive to the strength of this multipole than e and h as they arise from the interference of $E2$ with other multipoles. The reduction of $E2$ radial integrals in RZBA can be used to improve the agreement with the coefficient d and g of De Pascale *et al.* leaving the other parameters essentially unchanged. The results of 15% reduction for the angular distribution coefficients d, e, g, and h are shown in Figs. 2 and 3 by dot-dashed line for the SCC-B potential in pseudoscalar πN coupling. The polarization asymmetry results still fit the data within experimental errors. The physical process which may be needed to explain this reduction is not clear at this time.

In conclusion, our investigation shows that there is no need to include multipoles higher than $E1$, $M1$, and $E2$ to fit the experimental data of De Pascale *et al.* The quality of agreement obtained here is the same as that obtained by Cambi *et al.*[5,6] and Arenhövel.[3,4] Our work also suggests that some modification of the $E2$ radial matrix elements is needed if the fit to the coefficients d and g is to be improved. Further verification of this conjecture can be made through polarization measurements.

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