Photodisintegration of the deuteron employing a supersoft core potential

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Employing the supersoft core potentials of deTourreil and Sprung, the differential cross section and polarization of the outgoing protons in the photodisintegration of the deuteron have been investigated for laboratory gamma-ray energies ranging from 10 to 150 MeV. The supersoft core potentials are found to give an appreciable decrease in the total cross section for the higher gamma-ray energies than when the Hamada-Johnston potential is used. These reductions in total cross section at higher energies are comparable with the increase obtained on including the effects of isobar configurations and meson exchange currents. The proton polarization is noticeably affected in $0° < \theta_{c.m.} < 60°$ at $E_\gamma^{lab} = 150$ MeV.

[NUCLEAR REACTION $^2H(\gamma, n)p$. Supersoft core potentials.]

In recent years the photodisintegration of the deuteron has been the subject of numerous investigations[1-8] since the current theories are found to be inadequate to account for the photodisintegration process. The interest in the problem has mainly arisen because of the serious discrepancy between the measurements of Hughes, Zieger, Wäffler, and Ziegler[9] for the differential cross section for the forward going proton at 0° and those predicted by calculations using the Hamada-Johnston potential. The measurements by Hughes *et al.* were made for lab photon energies ranging from 20 to 120 MeV. Over the entire energy range, a significant difference between the measured and calculated cross sections was found, the calculated values lying between 30% to 40% higher than the measured values. Subsequent calculations by Arenhövel and Fabian,[6] by Lomon,[7] and by Rustgi, Sandhu, and Rustgi[8] have shown that the discrepancy is greatly reduced when calculations with potentials yielding a lower percentage of the D state of the deuteron are carried out. The calculations of Arenhövel and Fabian included the effects of meson exchange currents and isobar configurations which were first considered by Brown and Riska[10] for the inverse reaction of thermal n-p capture.

The object of this note is to report the results of calculations for the cross section and polarization of the $^2H(\gamma, n)p$ reaction carried out with the supersoft core potential because of its success in explaining the data of Hughes *et al.*[9] The calculations have been performed with the three versions of the supersoft core potentials (A, B, and C) of de Tourreil and Sprung[11] and will be denoted as SSCA, SSCB, and SSCC in the following. These potentials provide good fits to the phase shifts and other two-body data and include the one pion exchange tail. The tensor force in the triplet even state in these potentials is much weaker than in other local potential models reported in the literature. The radial forms employed are essentially Yukawa's modified by gaussian or similar cutoff functions to keep the potential soft at short distances. The potentials have the general form

$$V(r) = V_c(r) + V_T(r)S_{12} + V_{LS}(r)\vec{L}\cdot\vec{S} + V_{L2}(r)\vec{L}^2 + V_Q(r)Q\ ,$$

where S_{12} is the usual tensor force operator

$$Q = \tfrac{3}{2}(\vec{\sigma}_1\cdot\vec{L})(\vec{\sigma}_2\cdot\vec{L}) + \tfrac{3}{2}(\vec{\sigma}_2\cdot\vec{L})(\vec{\sigma}_1\cdot\vec{L}) - (\vec{\sigma}_1\cdot\vec{\sigma}_2)\vec{L}^2$$

and $V_Q(r)$ occurs only in the triplet-even relative two-nucleon states. The other symbols have their usual meaning.

The wave functions used in the calculation are obtained from a solution of the Schrödinger equation using the above potentials. The interaction Hamiltonian discussed by Breit and Rustgi[12] is used and point nucleons are assumed. All transitions induced by electromagnetic multipoles up to and including the fourth order are considered and all the effects of retardation and of the nucleon magnetic moment on electric multipole transitions are taken into account. The amplitude method described earlier has been used.[13]

The same coordinate system as described in Ref. 13 is employed. The cross sections are calculated for unpolarized gamma rays and randomly

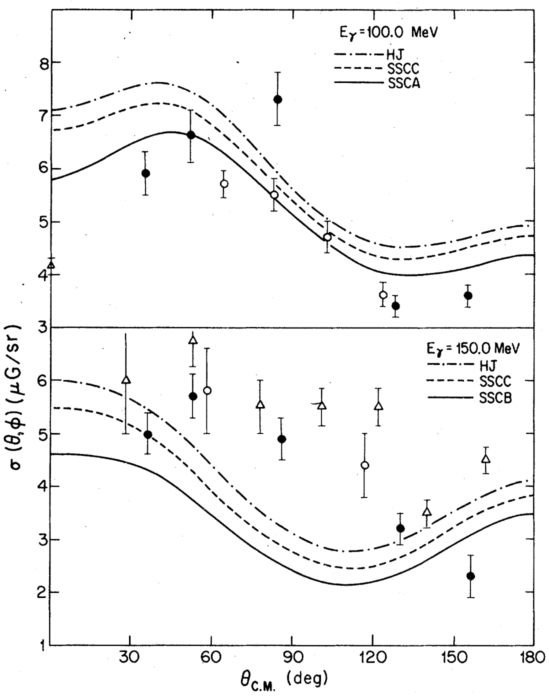

FIG. 1. Differential cross section for the $^2H(\gamma,n)p$ reaction with unpolarized gamma rays of energy 100 and 150 MeV in the laboratory system. The experimental points of the various investigators are represented as follows: for the upper part of the figure solid circles for those of Whalin *et al.* at 105 MeV; open circles for those of Keck and Tollestrup at 105 MeV; triangle for Hughes *et al.* For the lower part solid circles for those of Whalin *et al.* at 149 MeV, open circles for those of Dixon and Bandtel at 150 MeV; triangles for Aleksandrov *et al.* at 148 MeV.

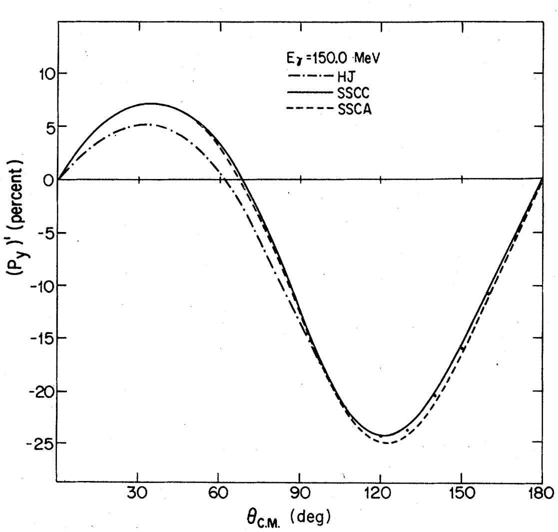

FIG. 2. Percentage polarization of protons from the $^2H(\gamma,n)p$ reaction with unpolarized gamma rays of energy 150 MeV in the laboratory system.

oriented deuterons and the polarization of the proton is computed along the y axis of the primed coordinate system.

The results of the calculations for cross sections are shown for $E_\gamma^{lab} = 100$ and 150 MeV in Fig. 1 and for proton polarization in Fig. 2 for $E_\gamma^{lab} = 150$ MeV. The results for the Hamada-Johnston potential,[1] labeled as HJ, include the Yale modification of this potential. Since potentials SSCA and SSCB yield almost identical results, results for only one of them are shown. It is clear from Fig. 1 that for all angles $\theta_{c.m.}$, the differential cross section for photoprotons for potentials A and B having ~ 4% D state is lower than the values obtained with the HJ potential as modified by the Yale group. The shape of the curve hardly changes beyond $\theta_{c.m.} \simeq 60°$. According to Arenhövel, Fabian, and Miller,[5] inclusion of the interaction effects increases the photoproton cross section for $30° < \theta_{c.m.} < 150°$ and lowers it at other angles for gamma-ray energies of 80 MeV. Addition of these effects to the results obtained with the SSCA or SSCB potentials will not improve the agreement in any significant way except in the forward and backward direction. It may be relevant to point out that for some of the experimental data,[14-21] the results of the various investigators do not always agree within the limits of the claimed experimental error. Figure 2 shows that the proton polarization increases with decreasing percentage of the D state.

The variation of the total cross section as a function of the gamma-ray energy for the various potentials is shown in Table I. It is found that for low photon energies the total cross sections are close for SSCA, SSCB, SSCC, and HJ, having a $3\frac{1}{2}$% spread at 10 MeV, 3% at 20 MeV, 2.5% at 50 MeV, in essence due to the accuracy of the effective range theory. On the other hand at 20 MeV, the data of Baglin *et al.*[15] is approximately 5 of his standard errors below theory. It appears that the data of Baglin *et al.* are wrong. This interpretation is supported by the data of Ahren *et al.*[16] and Skopic and collaborators.[17] At higher energies, the supersoft core potentials yield total cross sections which are lower than those given by the Hamada-Johnston potential. This reduction is as much as ~ 20% for $E_\gamma^{lab} = 150$ MeV. The increase in total cross section at lower energies arises because the supersoft core potentials yield a larger cross section for $30° < \theta_{c.m.} < 150°$ but at other angles the cross sections are smaller. The variation of the polarization of outgoing protons for $\theta_{c.m.} = 60°$ vs the gamma-ray energy is shown in Fig. 3. It is found that the polarization with potential SSCB is always slightly larger than that obtained with the Hamada-John-

TABLE I. The variation of the total cross section with gamma-ray energy for the various potentials. The total cross sections are given in units of microbarns.

E_γ^{lab} (MeV)	SSCA	SSCB	SSSC	HJ	Expt.
10			1466.0	1433.3	1200±200 [a]
20	632.4	634.1	629.3	615.9	500± 25 [b]
					585± 14 [c]
					604± 29 [d]
30	362.6	362.8	362.4	357.0	
40	239.9	239.5	241.4	239.1	238± 6 [e]
50	173.5	172.8	176.0	176.3	
60	133.6	132.8	136.9	138.6	150 [f]
70	107.6	106.8	111.4	113.8	
80	89.4	88.6	93.5	96.4	90 [f,g]
90	76.0	75.2	80.3	83.6	
100	65.7	65.0	70.2	73.8	70 [h]
110	57.7	57.0	62.2	66.2	
120	51.2	50.6	55.8	60.1	65 [h]
130	46.0	45.5	50.5	55.1	
140	41.6	41.1	46.1	50.9	
150	37.9	37.5	42.4	47.2	

[a] Reference 14.
[b] Reference 15.
[c] Reference 16.
[d] Reference 17.
[e] Reference 18.
[f] Reference 19.
[g] Reference 20.
[h] Reference 4.

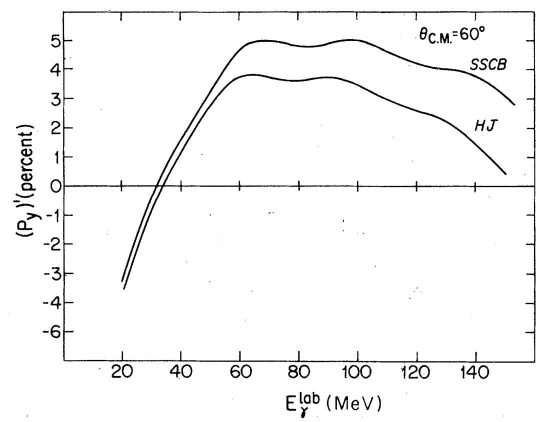

FIG. 3. Percentage polarization of protons from the $^2H(\gamma,n)p$ reaction with unpolarized gamma rays at $\theta_{c.m.} = 60°$.

ston potential.

The present work indicates that while employment of the supersoft core potentials improves the agreement with the data for the differential cross section at 0° for the outgoing protons in comparison with the Hamada-Johnston potential, the total cross section at higher energies is substantially reduced. The decrease in the cross section is more pronounced for potential SSCB corresponding to $P_D = 4.25\%$ than SSCC with $P_D = 5.45\%$. The shape of the angular distribution is not changed much. The magnitude of the decrease in the total cross section is comparable with the increase obtained on including the meson exchange currents and isobar configurations, and will spoil the agreement claimed by Arenhövel *et al.*[5] It will be desirable to extend these calculations by including two-body contributions to the electric dipole operator which have been recently reported by Gari and Sommer.[24]

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