STUDY OF (p,d) REACTIONS ON ^{57}Fe, ^{61}Ni, ^{91}Zr WITH A PROTON-POLARIZED BEAM

J. L. Escudie, J. C. Faivre, J. Gosset, H. Kamitsubo, R. M. Lombard, and B. Mayer
Service de Physique Nucléaire à Moyenne Energie, Centre d'Etudes Nucléaires de Saclay, Gif-sur-Yvette, France
(Received 8 September 1969)

Differential cross sections and asymmetries were measured for the (p,d) reactions on ^{57}Fe at 17.3 MeV, ^{61}Ni at 16.6 MeV, and ^{91}Zr at 24.5 MeV, from 15° to 150°. With optical parameters fitting experimental cross sections and polarizations for both ingoing protons and outgoing deuterons, the distorted-wave Born approximation gives a good account of the measurements.

The (d,p) reactions have proved to be an important tool in nuclear spectroscopy. The angular distributions determine the orbital angular momentum transferred,[1] and absolute spectroscopic factors may be extracted using the distorted-wave Born approximation (DWBA). However the DWBA with spin-orbit terms in the proton and deuteron optical potential has not been systematically successful in reproducing the j dependence of cross sections in (d,p) and (p,d) reactions,[2] so that spin assignments from this j dependence must be only empirical. On the other hand, the polarization or the asymmetry of the outgoing particle is expected to be very strongly j dependent.[3] Few precise data exist for polarizations and asymmetries.[4,5] Nevertheless, an extensive study of j dependence[6] recently showed a qualitatively good agreement with the DWBA at forward angles for $A \leq 52$ nuclei.

For these kinds of calculations it is desirable to have realistic optical potentials for both ingoing and outgoing channels. A previous DWBA analysis using such realistic optical potentials for the reactions $^{52}\mathrm{Cr}(d,p)^{53}\mathrm{Cr}$ and $^{53}\mathrm{Cr}(p,d)^{52}\mathrm{Cr}$[7] has been successful. In a similar way, in order to study the (p,d) reactions on ^{57}Fe, ^{61}Ni, and ^{91}Zr, we have chosen the proton-beam energy so that the outgoing deuterons have an energy at which elastic-cross-section and polarization data exist. Unfortunately the maximum proton-beam energy obtainable was 24.5 MeV, while 26.4 MeV was required in the case of ^{91}Zr to make use of the existing $^{90}\mathrm{Zr}(d,d)^{90}\mathrm{Zr}$ data at 21.4 MeV.[8]

We have used the improved polarized-proton beam[9] at the Saclay variable-energy cyclotron to measure the angular distribution of both cross section and asymmetry. Because of time-reversal invariance the asymmetry is identical with the polarization of the protons in the inverse reaction.[10] The intensity of the beam was about 20 nA, with a polarization around 80%. The scattered particles were detected in 16 ΔE-E telescopes. The lithium-drifted E detectors were 4 mm thick and were cooled to -27°C.

The (p,p) and (p,d) cross sections and asymmetries were measured simultaneously. The energy resolution was about 110 keV for protons and 125-200 keV for deuterons. A carbon polarimeter which had been previously calibrated by comparison with a ^{4}He polarimeter was used to measure the beam polarization with an accuracy of 6%.

For the DWBA calculations[11] we used the optical parameters of Table I; the notation is the same as in Schwandt and Haeberli,[12] σ_R is the

Table I. Optical model parameters.

	E (MeV)	Target	V	r_o	a_o	W	r_w	a_w	V_{so}	r_{so}	a_{so}	χ^2_σ	χ^2_p	σ_R	Refs.
	17.3	^{57}Fe	46.65	1.24	0.643	14.45	1.356	0.482	6.43	1.16	0.39	10.4	3.8	1056	
protons	16.6	^{61}Ni	51.43	1.21	0.73	11.1	1.32	0.487	6.16	1.15	0.47	3.6	4.6	1094	
	24.5	^{91}Zr	50.66	1.184	0.726	8.75	1.257	0.692	5.65	1.057	0.66	2.9	2.8	1410	
	12.	^{56}Fe	102.7	1.05	0.85	16.07	1.38	0.695	5.07	0.9	0.6	4.7	1.8	1464	a, b
deuterons	10.9	^{60}Ni	110.8	1.05	0.86	19.21	1.32	0.69	5.5	0.75	0.4	1.05	10	1356	12[c]
	21.4	^{90}Zr	91.98	1.188	0.732	15.54	1.315	0.668	4.98	1.0	0.5	0.27	1.4	1718	8

[a]See G. Igo, W. Lorenz, and U. Schmidt-Rohr, Phys. Rev. 124, 832 (1961).
[b]See A. M. Baxter, J. A. R. Griffith, S. W. Oh, and S. Roman, Nucl. Phys. A112, 209 (1968).
[c]We used the parameters given in this reference; however a slightly different cross-section normalization has improved χ_δ^2.

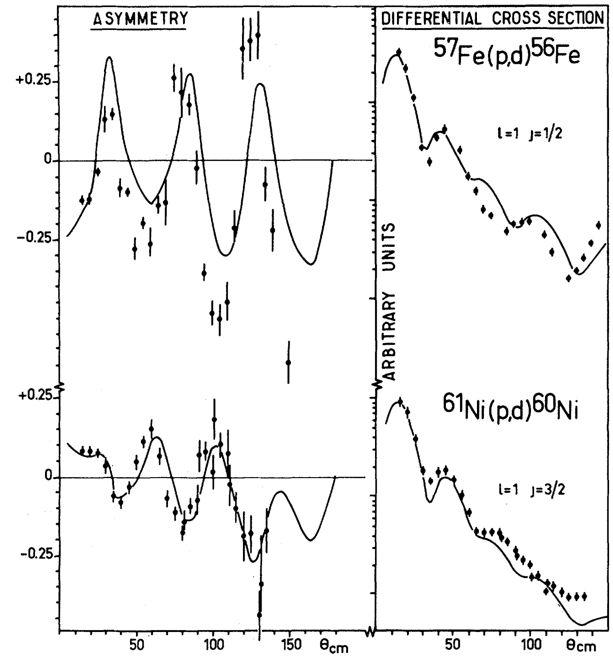

FIG. 1. Experimental differential cross sections and asymmetries for the ground-state reactions ^{57}Fe(p, d)^{56}Fe and ^{61}Ni(p, d)^{60}Ni compared with DWBA calculations.

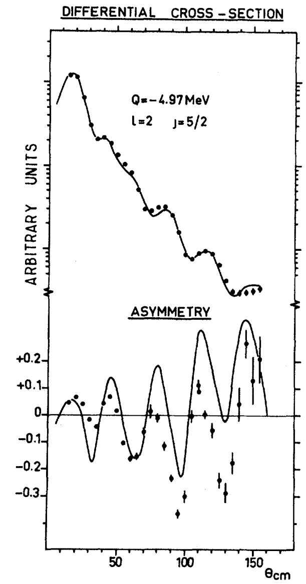

FIG. 2. Experimental differential cross sections and asymmetries for the ground-state reaction ^{91}Zr(p, d)^{90}Zr compared with DWBA calculations.

reaction cross section, and χ_p^2 is the χ^2 for vector polarization. The potentials were computed using the automatic search code MAGALI of J. Raynal, with our data for the protons and the data referred to in Table I for the deuterons. The neutron was assumed to be captured in a potential well defined in analogy with the potential for elastic proton scattering; the depth of the well was adjusted to reproduce the binding energy of the neutron.

The experimental asymmetries for the ground-state reactions ^{57}Fe$(p,d)^{56}$Fe$(l_n=1, j_n=\frac{1}{2})$ and ^{61}Ni$(p,d)^{60}$Ni$(l_n=1, j_n=\frac{3}{2})$ exhibit a strong j dependence throughout the entire angular range. The theoretical predictions using the DWBA give a good account of the observed j dependence (Fig. 1).

The ground-state reaction ^{91}Zr$(p,d)^{90}$Zr gives rise to an $l_n=2$, $j_n=\frac{5}{2}$ transition; the fit is very good for the cross section but there is poorer agreement for the asymmetry at backward angles (Fig. 2). This may be due to the contribution of the D state of the deuteron that has been suggested to be important for high l_n,[13] or perhaps to the fact that the deuteron optical potential was not computed for the actual energy of the outgoing deuterons.

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