SPIN DEPENDENCE OF (d,t) $l_n=1$ ANGULAR DISTRIBUTIONS IN Ni AND Fe

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It has recently been reported that, for 10-MeV incident deuterons, the (d,p) reaction on medium weight nuclei can be used to distinguish between $p_{1/2}$ and $p_{3/2}$ states of the "stripped" neutron.[1] The distinction between $p_{1/2}$ and $p_{3/2}$ transfers is made possible by a pronounced difference, for the two cases, in the angular distributions at large scattering angles ($\theta > 90°$). The same effect has subsequently been noticed for an incident deuteron energy of 12.0 MeV.[2]

The present paper investigates, in medium-weight nuclei, the extent of the above effect for the (d,t) reaction, in which a neutron is "picked up" by the incident deuteron rather than "stripped" from it. Several $l_n=1$ reactions proceeding to known spin states are studied, and the shapes of the corresponding angular distributions are determined.

Foil targets of ^{56}Fe, ^{60}Ni, and ^{64}Ni of thickness about one mg/cm^2 were bombarded with 14.7-MeV deuterons from the University of Pittsburgh cyclotron. The outgoing particles were detected by a system described in detail elsewhere.[3] Briefly, it consisted of two telescopically mounted solid state detectors of the silicon surface barrier type. The detectors formed an E, $dE \times E$ system which distinguished particles according to the value of their mass m multiplied by the square of their charge z. The energy and the particle analyzer pulses were fed into a two-dimensional, 4096-channel pulse height analyzer whose data display was a three-dimensional matrix with axes energy $\sim mz^2$, and intensity. Values of amplifier gains and biases were such that data from (d,d') and (d,t) reactions were recorded simultaneously. The energy resolution of the detected tritons varied from 80 keV to 200 keV depending on the scattering angle and the thickness of the target.

In an alternative detecting system,[4] used to collect one set of data, tritons from the (d,t) reaction were passed through a momentum-analyzing magnetic spectrograph and detected by nuclear emulsion plates located in the focal plane of the spectrograph.

Angular distributions of (d,t) cross sections in the angular range 70° to 150°, which were recorded for a total of three $p_{1/2}$ levels and three $p_{3/2}$ levels in ^{59}Ni and ^{63}Ni, are shown in Figs. 1 and 2. As the figures indicate, the angular distributions leading to $p_{1/2}$ and $p_{3/2}$ levels show pronounced differences at large scattering angles. Figure 3 illustrates these differences, for two levels observed in the reactions ^{64}Ni$(d,t)^{63}$Ni, in the form of a ratio of $p_{3/2}$-to-$p_{1/2}$ cross sections, where the ratio has been set equal to unity at a scattering angle of 70°. Below this angle, $p_{1/2}$ and $p_{3/2}$ angular distributions seem to have the

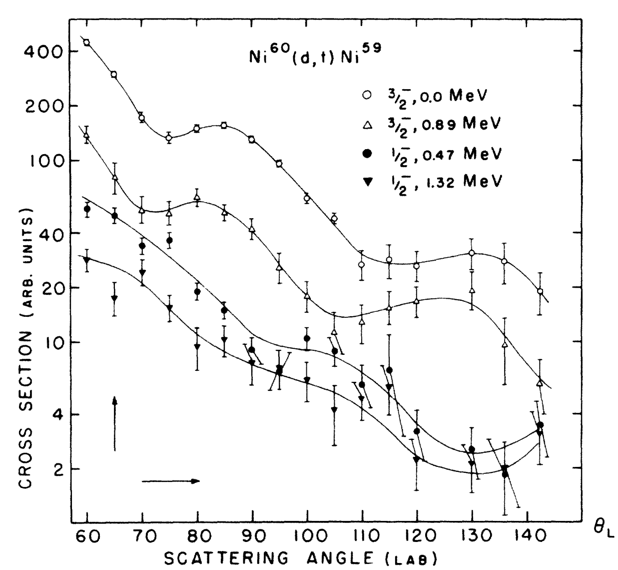

FIG. 1. Angular distributions for $p_{3/2}$ and $p_{1/2}$ levels in the reaction ^{60}Ni$(d,t)^{59}$Ni. Spins and excitation energies in the key refer to levels formed in ^{59}Ni.

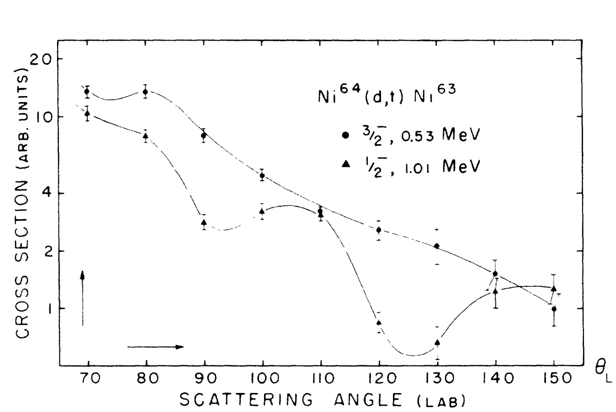

FIG. 2. Angular distributions for $p_{3/2}$ and $p_{1/2}$ levels in the reaction ^{64}Ni$(d,t)^{63}$Ni. Spins and excitation energies in the key refer to levels formed in ^{63}Ni.

Table I. Ratio of cross sections between laboratory scattering angles of 70° and 90°.

Reaction	Final state Excitation (MeV)	Spin$^{\text{parity}}$	$\sigma(70°)/\sigma(90°)$	Spin reference
^{56}Fe$(d,t)^{55}$Fe	0.0	$\frac{3}{2}^-$	1.75 ± 0.19	b
	0.42	$\frac{1}{2}^-$	4.13 ± 0.91	c
^{60}Ni$(d,t)^{59}$Ni	0.0	$\frac{3}{2}^-$	1.32 ± 0.06	d
	0.47	$\frac{1}{2}^-$	3.76 ± 0.56	d
	0.89	$\frac{3}{2}^-$	1.30 ± 0.20	d
	1.31	$\frac{1}{2}^-$	3.12 ± 0.60	d
^{64}Ni$(d,t)^{63}$Ni	0.0	$\frac{1}{2}^-$	2.26 ± 0.18[a]	e, f
	0.16	$\frac{3}{2}^-$	1.25 ± 0.05[a]	e, f
	0.53	$\frac{3}{2}^-$	1.72 ± 0.22	e, f
	1.01	$\frac{1}{2}^-$	3.67 ± 0.48	e, f

[a]Ratio of cross sections between 74° and 88°.
[b]K. Way et al., Nuclear Data Sheets (National Research Council, Oak Ridge, Tennessee).
[c]D. S. Gemmel, L. L. Lee, Jr., A. Marinov, and J. P. Schiffer, Bull. Am. Phys. Soc. 8, 523 (1963).
[d]G. A. Bartholemew and M. R. Gunye, Bull. Am. Phys. Soc. 8 367 (1963).
[e]R. H. Fulmer and A. L. McCarthy, Phys. Rev. 131, 2133 (1963).
[f]R. E. Cote, H. E. Jackson, L. L. Lee, Jr., and J. P. Schiffer, Bull. Am. Phys. Soc. 7, 551 (1962); and (to be published).

same shape,[3] although from Fig. 3 we recognize a strong j dependence at large angles (which is possibly due to the spin-orbit part of the nuclear force).

From Figs. 1, 2, and 3, one test of the spin of a transferred p neutron is afforded by comparing the relative differential cross section at 70° with that at 90°. The ratio of cross sections should be

$$\sigma(70°)/\sigma(90°) \approx 1.5 \text{ (spin } \tfrac{3}{2}) \qquad \approx 3.5 \text{ (spin } \tfrac{1}{2}) \tag{1}$$

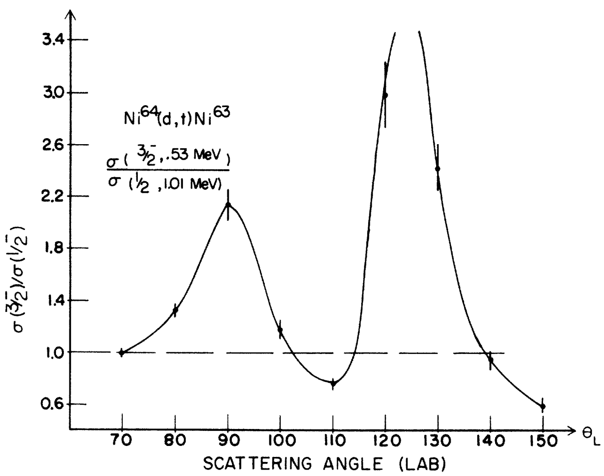

FIG. 3. Ratio of cross sections for the 0.53-MeV and 1.01-MeV levels in ^{63}Ni. The ratio has been adjusted to be unity at a scattering angle of 70°.

Numerical values of this ratio are listed in Table I for the six cases shown in Figs. 1 and 2 and for four additional cases where the spin transfer is known. In all ten cases the value of the cross section ratio agrees, via Eq. (1), with the known spin transfer.

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[1]L. L. Lee, Jr., and J. P. Schiffer, Phys. Rev. Letters 12, 108 (1964).
[2]R. H. Fulmer and R. E. Sass (to be published).
[3]R. H. Fulmer and W. W. Daehnick (to be published).
[4]B. L. Cohen, R. H. Fulmer, and A. L. McCarthy, Phys. Rev. 120, 698 (1962).