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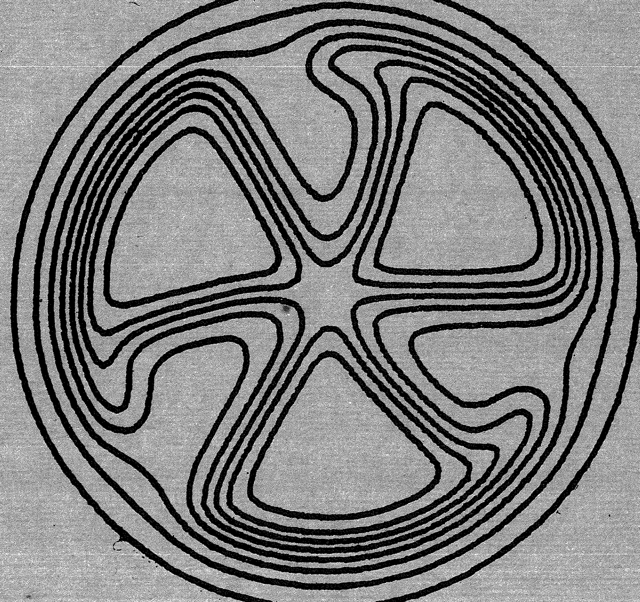

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J-Dependence Observed in $^{61,62}Ni(p,d)$ Reactions at 40 MeV*

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Several $\ell=3$ transitions observed in both $^{61,62}Ni(p,d)$ reactions demonstrate a very stable j-dependence of shape over a range of intensities and excitation energy.

The dependence of the angular distribution upon the total angular momentum, j, transferred in a (d,p) reaction was first reported by Lee and Schiffer.[1] More extensive studies[2-7] have shown the presence of this effect in both pick-up and stripping reactions which involve the proton and deuteron as well as the triton, ^3He and ^4He. Sherr et al.[3] have studied the (p,d) reaction at 28 MeV on several even-even nuclei in Ni region, and first noted the angular shift of the $\ell=3$, j=5/2 distritution relative to the $\ell=3$, j=7/2 distribution. Glashausser et al.[4] have studied the $^{56}Fe(p,d)$ and $^{58}Ni(p,d)$ reactions and observed the persistence of this j-dependence effect over the incident energy

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range of 18 to 27.5 MeV. In both cases, only one $f_{5/2}$ transfer has been compared to one or more $f_{7/2}$ transfers within a nucleus.

In the present experiment, four $f_{7/2}$ and three $f_{5/2}$ transfers have been observed in the $^{62}Ni(p,d)$ reaction at E_p=40 MeV. From the pronounced and consistent j-dependence of the shapes of these angular distributions, the 2.47-MeV level in ^{61}Ni can be inferred to be $7/2^-$ instead of $5/2^-$ as previously suggested.[7] Also three $\ell=3$ transfers in $^{61}Ni(p,d)$ reaction can be identified as relatively pure $5/2^-$ transfers.

A 40 MeV proton beam of the Michigan State University Cyclotron was used to bombard isotopically enriched targets (92.9% and 98.8%, respectively) of ^{61}Ni and ^{62}Ni. The outgoing deuterons were analyzed in a split-pole magnetic spectrograph and detected in a position-sensitive single wire proportional counter with an energy resolution of about 50 keV. A deuteron spectrum from $^{62}Ni(p,d)$ at 30° is shown in Fig. 1. Angular distributions were measured from 4° to 60°. A strong j-dependence was observed for $\ell=3$ transfer, while no evidence of such an effect was seen for $\ell=1$ over the angular range studied. Fig. 2a and 2b show three $f_{5/2}$ transfers leading, respectively, to states at 0.067, 0.909, 1.611 MeV in ^{61}Ni, and four $f_{7/2}$ transfers leading to states at 1.457, 2.47, 2.90 and 3.30 MeV in the same nucleus. The solid and the dashed lines drawn for each distribution are obtained from smooth curves drawn through the data of the $5/2^-$, 0.067-MeV state and the $7/2^-$ 3.30-MeV state, respectively.

The pronounced j-dependence and the consistency in shape among angular distributions of each j transfer are clearly exhibited from this comparison. The angular distributions for $f_{5/2}$ transfer are relatively flat at forward angles, then decrease from 20° to 30° with a second maximum around 40° and a deep minimum near 50°. For the $f_{7/2}$ transfer, the angular distributions are more structured at forward angles with a sharper maximum at 20° and drop off slower than in the $f_{5/2}$ case, with a less marked minimum near 40° and also a less pronounced second maximum at 45°.

On Fig. 2c, three angular distributions from the ^{61}Ni(p,d) reaction are shown. The solid and the dashed lines have the same meaning as in Fig. 2a and 2b. The characteristics of the final states in ^{60}Ni are respectively 2_2^+ (2.158 MeV), 4_1^+ (2.503 MeV) and 3_1^+ (2.626 MeV). For the 4^+ state, only f wave transfer is allowed by the J^π selection rules, while for the 2^+ and 3^+ states both p waves and f waves transfers can contribute. In the light of the ^{62}Ni(p,d) data, these distributions all exhibit quite pure $f_{5/2}$ characteristics. In fact, the dominance of the ℓ=3 wave contribution over the ℓ=1 wave contribution can be understood in the framework of the shell model. A calcualtion[8] using the wave functions of Glaudemans et al.[9] shows that the spectroscopic factors for $f_{5/2}$ are much larger than for $p_{3/2}$ or $p_{1/2}$ for these states (Table I).

Other ℓ=3 transfers observed at higher excitation energy in the ^{61}Ni(p,d) reaction do not show a definite j shape, probably because the mixing between $f_{5/2}$ and $f_{7/2}$ waves as well as the mixing between f and p waves is more extensive. In Fig. 3, the experimental data for levels at 0.067 MeV and 1.457 MeV of ^{61}Ni are compared with finite-range non-local D.W.B.A. predictions obtained with the DWUCK 72 code.[10] The solid and the dashed

lines represent respectively calculations using adiabatic model[11] and Hinterberger et al.[12] deuteron optical potential parameters. The dashed-dotted lines represent calculations obtained with an effective binding energy procedure together with adiabatic model parameters. In all cases the Becchetti-Greenlees proton parameters[13] were used. The conventional DWBA calculations fit the $f_{7/2}$ transfer quite well, while there is a systematic discrepancy of a 3 to 4° shift for the $f_{5/2}$ case. This angular shift is removed if the effective binding energy method is followed, such that one uses a smaller separation energy for the $f_{5/2}$ neutron (about 5 MeV less) than that of the normal energy separation prescription. However this procedure gives a calculated cross section which is a factor of 3 larger than is obtained with the conventional calculation. The failure of conventional DWBA calculations to explain the j-dependence has been discussed in more detail by Glashausser and Rickey.[4] Other explanations of the j-dependence through the influence of the deuteron D-state,[14,15] or in terms of configuration mixing[16] have been proposed but no conclusion can yet be drawn.

In conclusion, the j-dependence effect observed in $^{61-62}$Ni(p,d) reactions at 40 MeV for ℓ=3 transfer is quite independent of the excitation energy of the level studied as well as of the spin and parity of the initial and final nuclei. This effect is then an interesting tool with which to identify both the spins and parities of states in an odd-mass residual nucleus and also to identify the particular orbit involved in transfer from an odd-mass target. The DWBA calucaltions which use optical parameters of the adiabatic-model type for the deuteron channel reproduce the general features of the experimental angular distributions, but the j-dependent differences between $f_{5/2}$ and $f_{7/2}$ pickup are not accounted for by any calcuations which use the conventionally correct formulation for the bound-state wave function.

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FIGURE CAPTIONS

Fig. 1--Deuteron spectrum of $^{62}Ni(p,d)$ reaction at 30° Lab.

Fig. 2--Experimental ℓ=3 angular distributions observed in $^{61-62}Ni(p,d)$ reactions. The solid and dashed lines represent respectively smooth curves through the experimental data points of the known $f_{5/2}$ and $f_{7/2}$ transfers to the levels at 0.67 and 3.30 MeV of ^{61}Ni.

Fig. 3--Comparison of $^{62}Ni(p,d)$ experimental data with finite range non-local DWBA calculations. The solid and the dashed lines represent respectively calculations with adiabatic-model[11] (AD) and Hinterberger[12](HN) deuteron optical-potential parameters. The dashed-dotted lines represent calculations with an effective binding energy for the pickup neutron and adiabatic-model deuteron parameters(EB). The Becchetti and Greenlees[13] proton optical-potential parameters are used in all cases. The normalization is the same for (AD) and (HN) curves and is smaller by a factor 1/3 for (EB) curve.

TABLE I.--Experimental spectroscopic factors compared with the shell model predictions.

E_x	J	Experiment (ℓ=3)	$f_{5/2}$	$p_{3/2}$	$p_{1/2}$
2.158	2_2^+	0.18	0.14	0.0018	0.025
2.503	4_1^+	0.44	[illegible].62	0.	0.
2.626	3_1^+	0.70	0.40	0.0019	0.

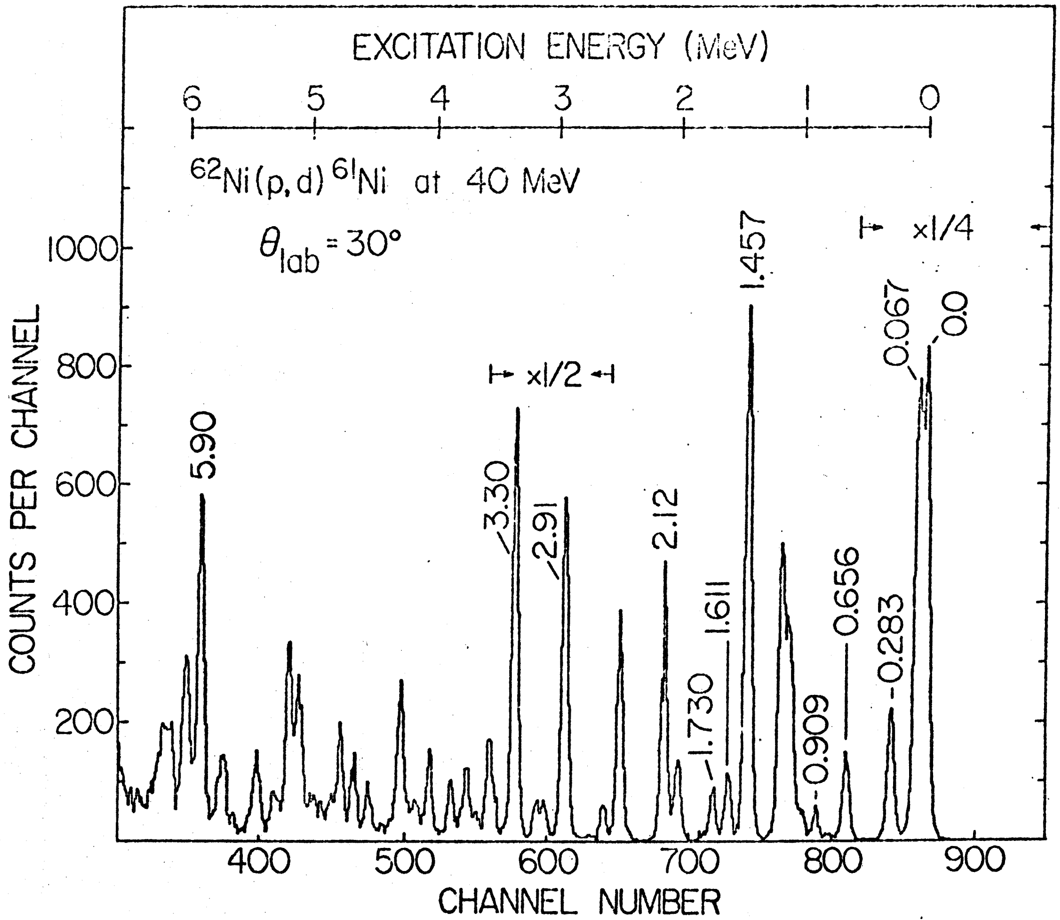

Figure 1

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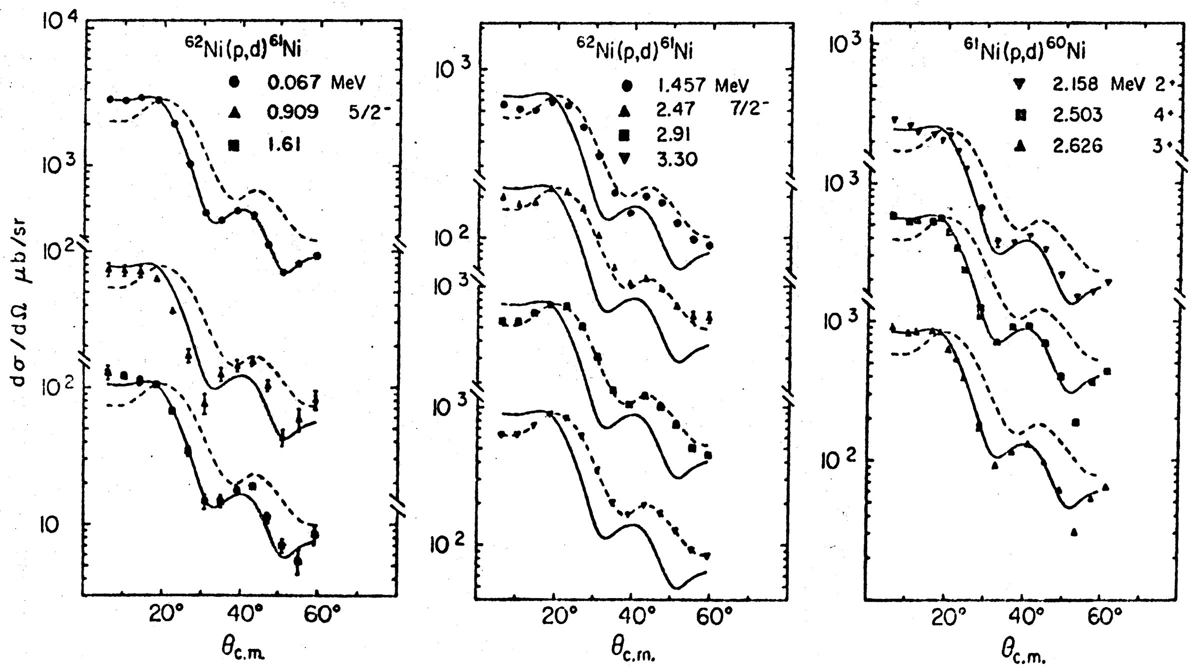
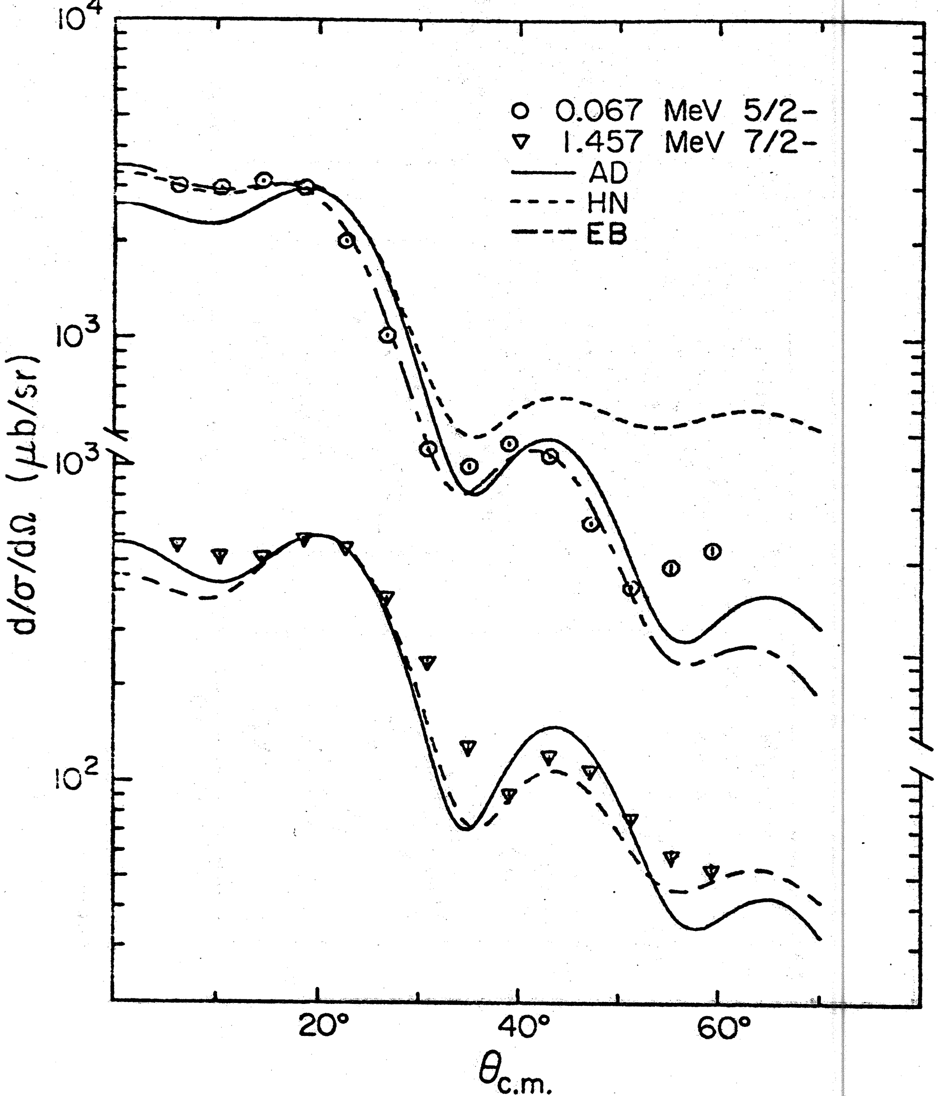


2a 2b 2c

Figure 2



0.067 MeV 5/2-
1.457 MeV 7/2-
AD
HN
EB
10^4
10^3
10^3
10^2
d/σ/dΩ (μb/sr)
20°
40°
60°
$\theta_{c.m.}$

Figure 3