THE (p,d) REACTION AT 121 MeV ON ^{58}Ni, ^{90}Zr AND ^{208}Pb

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Cross sections have been extracted from the (p,d) data taken at the University of Indiana for the above three targets and extensive DWBA calculations have been carried out. The angular distributions for the low-lying states in ^{57}Ni and ^{207}Pb are shown in figs. 1 and 2. The data for ^{89}Zr and the higher lying states of ^{207}Pb and ^{57}Ni have been analyzed but the theoretical calculations are not yet complete.

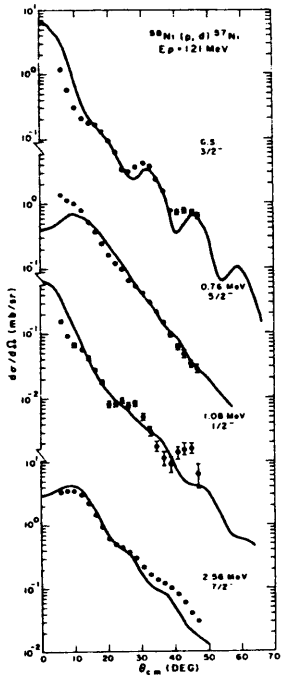

Figure 1. Angular distributions for four of the more strongly excited low-lying levels in ^{57}Ni by the ^{58}Ni (p,d) reaction. The solid lines represent DWBA calculations that are described in the text.

One of the principal uncertainties in the distorted wave calculations has been the optical model parameters appropriate for 121 MeV protons and approximately 111 MeV deuterons. A variety of proton potentials[1-4] were used in conjunction with several sets of deuteron potentials[5,6] with little success in adequately describing the ^{58}Ni(p,d)^{57}Ni data; particularly the $3/2^-$ ground state and the $1/2^-$ state at 1113 keV. At this point P. Schwandt of Indiana University kindly supplied optical potentials derived from recent 100 MeV proton elastic scattering data for ^{58}Ni, 100 and 135 MeV data for ^{90}Zr, and 121 MeV data for ^{208}Pb. The depth of the real potential was adjusted for the correct projectile energy by the use of $\Delta V = -0.2\,\Delta E$. These proton potentials together with adiabatic deuteron potentials produced remarkably better fits to the data. The adiabatic deuteron potential was made up of potentials for protons and neutrons at half the deuteron energy taken from the work of Becchetti and Greenlees.[7] The parameters were combined according to the prescription of Harvey and Johnson.[8] One exception was that the radius parameter for the imaginary term was increased from a nominal value of 1.29 to 1.39 in order to describe the data better. The parameters for the spin orbit term were taken from the work of Childs and Daehnick.[5] The parameters that were used for the calculations shown in Figs. 1 and 2 are indicated in Table I. It is apparent that while the calculations generally describe the slope of the cross sections satisfactorily, there are non-negligible differences, especially at the smaller angles. Numerous additional calculations were performed in which a

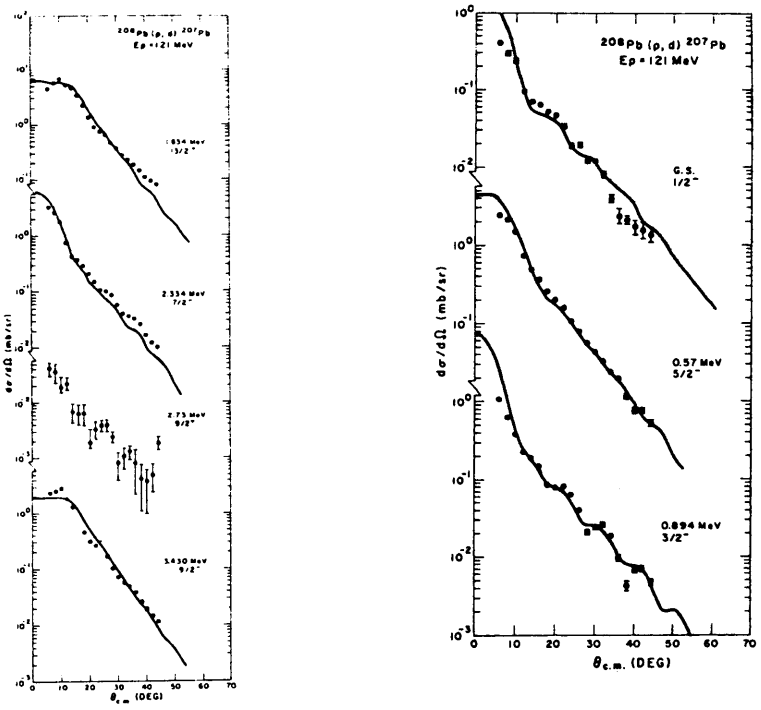

Figure 2. (a and b). Angular distributions for seven low-lying levels in ^{207}Pb by the $^{208}Pb(p,d)$ reaction. The solid lines represent DWBA calculations that are described in the text.

wide variety of parameter variation was tried. However, no improvement in the fits shown in Figs. 1 and 2 could be achieved.

Another source of concern is the magnitude of the spectroscopic factors obtained. In order to determine normalization factors for the DWBA calculations done in zero range (with a finite range correction parameter of 0.62), exact finite range calculations were carried out for representative states in ^{57}Ni, ^{89}Zr and ^{207}Pb. The shapes of the angular distributions were very much the same in the two calculations and values of D_o for ^{58}Ni, ^{90}Zr and ^{208}Pb were found to be 111, 114 and 98 MeV-fm$^{3/2}$, respectively. The use of these normalization constants provided spectroscopic factors that were in general agreement with those obtained in lower energy (p,d) studies. However, in ^{208}Pb, the values of $C^2S_{\ell j}$ for the $i_{13/2}$ and $h_{9/2}$ states are depressed by more than a factor of two relative to the values for the $3p_{1/2}$, $2f_{5/2}$, $3p_{3/2}$ and $2f_{7/2}$ orbitals. On the basis of the earlier (p,d) and (d,t) studies,[9] all of these states are expected to have a spectroscopic factor close to the sum rule limit. However, a more recent (p,d) experiment[10] has yielded spectroscopic strengths for the 1633 and 3409 keV levels which are in approximate agreement with those obtained in this work.

Various modifications were made in the bound state calculations and in the geometrical

Table I

Optical model parameters used in (p,d) calculations for 121 MeV data.

	V_R (MeV)	r_R (fm)	a_r (fm)	W_v (MeV)	r_I (fm)	a_I (fm)	V_{so} (MeV)	W_{so} (MeV)	r_{so} (fm)	a_{so} (fm)
^{58}Ni										
p	-22.0	1.23	0.76	-7.29	1.47	0.51	+4.46	-1.59	1.05	0.61
d	-78.31	1.17	0.79	-18.41	1.39	0.60	6.70		0.98	1.00
^{208}Pb										
p	-29.70	1.24	0.74	-7.83	1.44	0.67	4.00	-0.80	1.14	0.75
d	-79.04	1.17	0.79	-19.64	1.40	0.60	6.70		0.98	1.00

Table II

Spectroscopic factors extracted from the (p,d) data taken at 121 MeV.

		Spectroscopic Factors ($C^2S_{\ell j}$)		
Energy (keV)	Orbital	Others	This exper.	Sum Rule Limit
^{208}Pb				
0.0	$^3p_{1/2}$	1.7-2.2	3.1	2
570	$^2f_{5/2}$	4.0-6.3	7.8	6
898	$^3p_{3/2}$	3.3-3.9	8.3	4
1633	$^1i_{13/2}$	8.5-15.0	9.2	14
2304	$^2f_{7/2}$	5.1-6.5	8.1	8
3409	$^1h_{9/2}$	6.8-8.5	5.6	10
^{58}Ni				
0.0	$^2p_{3/2}$	0.8-1.0	1.6	4
769	$^1f_{5/2}$	0.5-0.6	0.34	6
1113	$^1p_{1/2}$	0.15-0.20	0.14	2
2578	$^1f_{7/2}$	2.9-3.0	2.4	8

parameters for the imaginary term in the deuteron optical parameters with considerable influence on the overall normalization but no appreciable effects on the relative j dependence of $C^2S_{\ell j}$. For example, use of the larger radii found by Rost[11] for the bound neutron well around ^{208}Pb (up to 0.5

fm greater than the proton well) did little to resolve the problem. The calculations shown were done with rather standard values for the diffuseness (0.65) and radius (1.25) parameters and a non-local correction factor of 0.85. The extracted spectroscopic factors are listed in Table II along with a range of values for C^2S found by others. As discussed above, this work supports ref. 10 in the claim that the first $13/2^+$ and $9/2^-$ levels contain only about 1/2 of the available strength. The origin of the observed j- dependence found with the 121 MeV (p,d) data is not understood at the present time.

The contribution of the two-step processes was investigated with the thought that they could become more important as the projectile energy is increased. The case of inelastic excitation of the 2^+ state in ^{58}Ni followed by neutron pickup to the 769 keV $5/2^-$ state was calculated along with the direct one-step contribution. The two-step contributions were found to be entirely negligible except for some minor effects at the very forward angles. Two-step effects could be more important for the levels in ^{207}Pb. For example, the spectroscopic factor for the 1633 keV $13/2^+$ state changes by up to 20% (depending on the phase of the two-step contribution relative to the single step) if excitation via an assumed $[^{208}Pb(3^-)\ \nu^{-1}f_{7/2}]_{13/2^+}$ component is permitted. States at higher excitation (e.g., $7/2^-$ or $9/2^-$ single-particle states which might nominally be found near 4 MeV excitation) could be affected more dramatically because of the near degeneracy in unperturbed single particle and core-excited energies. Two-step calculations for the 2304 and 3409 keV levels have not been carried out as yet.

The results of this study are being prepared for publication.

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