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The express purpose of the study was to test the usual distorted wave procedures at a bombarding energy that is significantly greater than that normally used. Emphasis was placed on the excitation and study of the strong single-hole states. Values of the zero range normalization factor, D_0^2 , were obtained by comparison of exact finite range calculations with zero range calculations and a value of $1.23 \times 10^4 \text{ MeV}^2\text{fm}^3$ was extracted. As expected this is reduced from the value in the range of 1.5 to 1.6×10^4 used at lower energies. Deuteron D-state contributions become significant only at scattering angles greater than 30° or 40° .

Appropriate optical model parameters at these higher energies are less available and presently offer limitations to the accuracy of the distorted wave calculations that are carried out. Adiabatic deuteron potentials when used in a DWBA calculation appeared to describe the data better than those derived from deuteron elastic scattering.

Important deficiencies have been noted in the ability of the single step calculations to describe adequately the shapes and magnitudes of the angular distributions. While the calculated angular distributions have the correct general shape, many of the details of the experimental angular distributions are not reproduced. The general quality of the fits is considerably poorer than is usually the case at lower energies. There also appears to be an overall normalization problem for ^{58}Ni as well as an ℓ -dependent problem as evidenced in ^{208}Pb . In particular, the high ℓ -transitions appear to be underpredicted both in ^{90}Zr and ^{208}Pb . An example of this is indicated in Table 1 where the spectroscopic factors from various neutron pickup reactions on ^{208}Pb are summarized including the present data at 121 MeV. While the agreement with the sum rule and other data is tolerable for the lower spin states, the values of $C^2S_{\ell j}$ for the $13/2^+$ and $9/2^-$ states are only about one-half the expected value. It is

Table 1
Spectroscopic factors for neutron pickup reactions on ^{208}Pb

E(keV) ¹⁾	j^π	$C^2S_{\ell j}$							
		(p,d)					(d,t)	$(^3\text{He},\alpha)$	
		22 MeV ²⁾ †	22 MeV ³⁾ ††	35 MeV ⁴⁾	40 MeV ⁵⁾	55 MeV ⁶⁾	121 MeV ^{†††}	17 MeV ⁷⁾	28 MeV ⁸⁾
G.S.	$1/2^-$	2.2	2.0	1.8	2.15	1.68	2.5		3.2
570	$5/2^-$	4.0	6.0	5.2	6.3	6.0	5.3	6.8	6.0
898	$3/2^-$	4.0	3.7	3.2	3.8	3.33	4.8	4.0	6.5
1633	$13/2^+$	6.5	13.0	9.4	8.5	14.0	6.7	14.5	14.0
2340	$7/2^-$	3.4	6.0	4.4	5.1	6.55	6.4	7.1	9.7
2726	$(9/2)^+$				0.05		0.03	0.091	
3409	$9/2^-$	2,2	7.0	4.9	6.8	8.5	4.0	9.8	6.0

† Various calculations were completed by these authors; the spectroscopic factors shown were obtained with no radial cutoffs in the DWBA calculations.

†† Reanalysis of the data of Ref. 2 with adiabatic deuteron potentials.

††† Present study.

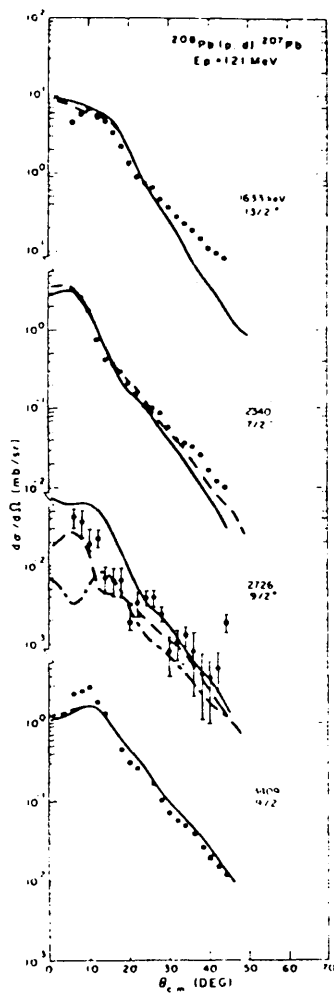


Fig. 1. The effects of two-step processes on the calculated angular distribution for several states in ^{207}Pb . For the states at 1633, 2340 and 3409 keV, the spectroscopic factors listed in Table 1 were assumed and the calculations that included the two-step processes are shown for the two choices of relative phase. For the state at 2726 keV a spectroscopic factor of 0.03 was assumed. For all four states the dashed curve was for constructive interference and the solid curve for destructive interference. The dash-dot curve for the 2726 keV state was for two-step processes alone.

interesting to note, however, that for the $13/2^+$ state several other studies have obtained low values for the spectroscopic factor. It would be interesting to analyze all of the existing data for the neutron pick-up reactions to this state in a consistent fashion as a test of the distorted wave method.

In the case of ^{58}Ni and ^{208}Pb , variations were made in the bound state calculations as well as other parameters in the calculations. Although many effects were noted no particular prescription for the bound state calculations resolved all of the problems encountered.

In the case of ^{208}Pb , two-step calculations were carried out with the general conclusion that such contributions are negligible for the strong single particle states. As with lower bombarding energies, however, such two-step contributions can play an important role

if the single step process is very weak. There appears no obvious enhancement of two-step contributions at a bombarding energy of 121 MeV.

An example of the two-step calculations is shown in Fig. 1. Calculations were performed based on the inelastic excitation of the 3^- state at 26.4 keV in ^{208}Pb followed by a $f_{7/2}$ neutron pickup from that state to the $13/2^+$ level in ^{208}Pb . A value of $\beta_3=0.11$ was taken for the inelastic excitation and a spectroscopic factor of 2.2 was assumed for the $f_{7/2}$ transition. The value of 2.2 was obtained by dividing the full spectroscopic strength of 8 among the seven levels of the $[3^- f_{7/2}]_j \pi$ multiplet according to a $2j+1$ weighing factor. This gives a much larger two-step component than most structure calculations suggest. Hence our two-step calculations may be viewed on that basis as an upper limit for such effects. The spectroscopic strength for the direct neutron pickup and the phase of the direct leg relative to the two-step leg were varied to obtain the best fit. The results are shown in Fig. 1 with $C^2S_{lj}=9$ for the direct component for both constructive and destructive interference between the two paths. As can be seen, inclusion of the two-step process in the excitation of the $13/2^+$ level results in only very minor changes in shape or magnitude compared to the one-step calculation discussed earlier.

The calculations including two-step processes do tend to be somewhat less diffractive in shape than the one-step process alone, although the differences are insignificant in terms of the data. Clearly the two-step process based on the $[3^- f_{7/2}]$ configuration alone cannot account for the reduced spectroscopic factor for the 1633 keV level observed within the present study at 121 MeV.

Similar results were obtained for the $7/2^-$ and $9/2^-$ states at 2340 and 3409 keV and these results are also

displayed in Fig. 1. The $7/2^-$ level is somewhat more strongly affected by the choice of the relative phase. In cases where the spectroscopic factor for the direct transition is a reasonably large fraction of the sum rule limit, inclusion of the two-step processes makes little difference in the shape and magnitude of extracted spectroscopic factors.

The $9/2^+$ state at 2726 keV can be excited either by a two-step process or directly due to particle-hole admixtures in the ^{208}Pb core. In Fig. 1 a pure two-step calculation is shown and it falls somewhat below the data, while inclusion of a small $2g_{9/2}$ admixture permits the calculation to approximately reproduce the data. Calculations are shown in Fig. 1 for both destructive and constructive interference with a spectroscopic factor of 0.03 for the direct transition. Either relative phase describes the data equally well.

In summary it appears that the (p,d) reaction at 121 MeV falls into the category of low energy reactions in that no new phenomena appear in the analysis of the strong single particle transitions. There are, however, discrepancies encountered that offer a challenge to the full understanding of the reaction at this energy.

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- 1) M.R. Schmorak and R.L. Auble, Nuclear Data Sheets 5 (1971) 207.
- 2) C.A. Whitten, Jr., N. Stein, G.E. Holland and D.A. Bromley, Phys. Rev. 188 (1969) 1941.
- 3) G.R. Satchler, Phys. Rev. C 4 (1971) 1485.
- 4) W.A. Lanford and G.M. Crawley, Phys. Rev. C 9 (1974) 646.
- 5) S.M. Smith, P.G. Roos, C. Moazed and A.M. Bernstein, Nucl. Phys. A173 (1971) 32.
- 6) K. Yagi, T. Ishimatsu, Y. Ishizaki and Y. Saji, Nucl. Phys. A121 (1968) 161.
- 7) R.A. Moyer, B.L. Cohen and R.C. Diehl, Phys. Rev. C 2 (1970) 1898.
- 8) W.P. Alford and D.C. Burke, Phys. Rev. 185 (1969) 1560.