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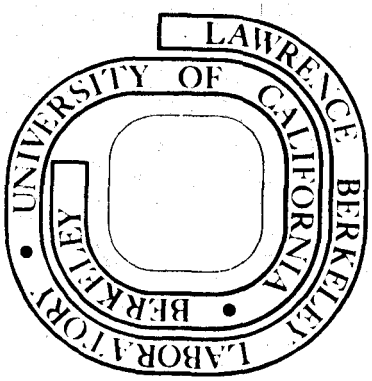

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ANALYZING POWERS IN $^{208}Pb(\vec{p},t)^{206}Pb$ TRANSITIONS[†]

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September 1973

A 40 MeV polarized proton beam was used to induce $(\vec{p},t)$ transitions to the lowest 0^+, 2^+, 4^+, and 6^+ states in ^{206}Pb. The analyzing power of the L = 0 transition was well fit by zero-range DWBA, but only qualitative agreement was obtained for the L = 2, 4, and 6 transitions.

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In the past three years several studies have been made of the analyzing powers associated with the two-nucleon transfer $(\vec{p},t)$ and $(\vec{p},{}^3He)$ reactions at medium energies on light targets [1,2,3] though, until now, few results [4] have been reported on any nucleus heavier than ^{28}Si. Attempts to apply the distorted wave Born approximation (DWBA) to the analysis of analyzing powers as well as to the differential cross sections of those reactions have met with mixed results. It is of interest then to examine the $(\vec{p},t)$ reaction in some heavier mass region where the DWBA has proven to be generally successful in describing differential cross sections, and to see whether similar agreement is obtained for the analyzing powers. We have, therefore, used a polarized beam to investigate the $^{208}Pb(\vec{p},t)^{206}Pb$ reaction, for which

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good DWBA fits to the differential cross sections have been obtained in studies using unpolarized beams [5,6,7,8].

Our experiments were carried out at the Lawrence Berkeley Laboratory 88-inch cyclotron using a 40 MeV proton beam from the polarized-ion axial injection source. Beam polarization of $|p_y| = 0.794 \pm 0.013$ [9] was obtained and beam intensities of ~ 10 to 50 nA on target were used. The beam polarization was monitored by a ^{4}He-polarimeter, whose analyzing power is well known [10], located downstream from the target chamber before the Faraday cup. The target was an evaporated 2 mg/cm^2 self supporting ^{208}Pb metal foil enriched to > 99%. Two pairs of ΔE-E counter telescopes were utilized, each pair being situated symmetrically on either side of the beam axis and feeding Goulding-Landis particle identifier systems [11]. Two angles could thus be observed simultaneously; angular distributions were obtained ranging from 15° to 60° in the center of mass, at intervals of 2.5°. Two additional detectors located in the scattering chamber were used to monitor the target condition and beam stability. Data were routed into a 4096 channel analyzer and then stored on magnetic tape for subsequent computer analysis.

Analyzing powers were calculated from the determined beam polarization and the measured left-right asymmetry, which was obtained from a geometrical average of the left/right ratios of peak intensities from two runs between which the sign of the beam polarization was reversed. This technique removes in first order all sources of error arising from any systematic instrumental asymmetry [12].

Our experiment did not permit an absolute determination of the total integrated beam current, since the beam was re-collimated after passing through the

target and before entering the polarimeter and Faraday cup. Absolute values of the differential cross section were obtained by a single normalization of the relative distributions to the literature [6,7,8]. Differential cross sections thus obtained agree well with previous measurements. Analyzing powers are, of course, unaffected by this normalization.

A representative spectrum is shown in fig. 1 in which the analyzed transitions are labelled. The energy resolution is about 100 keV FWHM. Figures 2 and 3 present the differential cross sections ($d\sigma/d\Omega$) and analyzing powers (A_y), respectively. The following characteristics of the latter are noteworthy. First, the 0^+ ground state ($L = 0$) transition shows the most dramatic analyzing power behavior, extending to 0.85 at 25° c.m. Furthermore, this analyzing power has an approximate derivative relationship to the differential cross section, i.e., $|A_y(\theta)| \propto d/d\theta(d\sigma/d\Omega)$, which can simply follow from a spin-dependent distortion in the optical potential, as has been pointed out for elastic scattering and single nucleon stripping [13]. For transitions with $L > 0$ the analyzing power is substantially smaller than for $L = 0$ and the phases for the 0^+, 2^+, 4^+, and 6^+ transitions alternate as $(-1)^{L/2}$.

For processes such as these strong (p,t) transitions to low-lying positive parity states in ^{206}Pb, for which the dominant shell-model configurations belong to a single oscillator shell, Glendenning [5,14] has shown that the shape (but not the magnitude) of the differential cross section angular distribution can be calculated without a detailed knowledge of the nuclear wave function. Since the simple DWBA suggests [13] that the analyzing power will depend on the shape rather than on the magnitude of the cross section, one expects for these transitions that A_y is also affected by the nuclear structure in only a minimal way.

DWBA calculations have been undertaken using the program DWUCK [15] with structure factors from ref. 6. Using a fixed set of optical parameters the expected insensitivity of the analyzing power calculation to the wave function was confirmed for the transition to the ground state with structure amplitudes derived from several different wave functions [6,16]. Having established this, the optical parameters themselves were studied. The dashed curves for the ground state transition in figs. 2 and 3 show that parameters used in previous ^{208}Pb(p,t) DWBA studies [17] produce an acceptable fit to the differential cross section, though a poorer fit to the experimental analyzing power. However, if the proton optical potential derived from the global prescription of Becchetti and Greenlees [18] is used, as shown by the solid curve, it produces a good cross section fit and also better accounts for the analyzing power, particularly in predicting the large asymmetry at 25° and the lesser maxima at more backward angles. Although a comparison of the quality of the results from the two optical potentials is inconclusive on the basis of $d\sigma/d\Omega$ alone, it appears that the latter potential is superior when the comparison is extended to include the A_y predictions. Two triton potentials obtained from low energy ($\leqslant$ 20 MeV) elastic scattering [19,20] were tried, but the calculations gave fits to both $d\sigma/d\Omega$ and A_y which were inferior to those shown.

In figs. 2 and 3 calculations are also shown for the transitions to the 2^+, 4^+, and 6^+ states. One can see that the fits to these differential cross sections are good for both proton optical potentials. Agreement for the analyzing powers is poor in detail, although the predictions do oscillate in phase with the data. Calculations using the two triton potentials noted above failed, as in the ground state case, to bring any improvement to the excited state fits.

The limited success of these DWBA calculations may be due in part to finite range effects which were neglected, and which are expected to be important if processes involving the nuclear interior are significant [21], such as may be more the case for transitions to excited states. Suitable elastic scattering data with which to establish a proper triton optical potential would also remove some uncertainty in assessing the validity of the zero-range approximation. Nevertheless, this simple approach has been successful in accounting for the ground state transition as well as the phases and perhaps the overall magnitudes of the analyzing powers in the transitions to the excited states. Finally, combining the analyzing power and differential cross section data may help in evaluating the importance of second order terms in the transition amplitude describing the two-nucleon transfer reaction [22].

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Figure Captions

Fig. 1. Representative triton energy spectrum for $^{208}Pb(\vec{p},t)^{206}Pb$.

Fig. 2. Differential cross sections for transitions to states labelled in fig. 1. The curves are separately normalized DWBA calculations: the dashed line is the result using optical parameters from ref. 17; the solid curve was obtained by replacing the proton potential by one derived from ref. 18. See text.

Fig. 3. Analyzing powers for the corresponding distributions of fig. 2. The curves are DWBA fits as described in the caption to fig. 2.

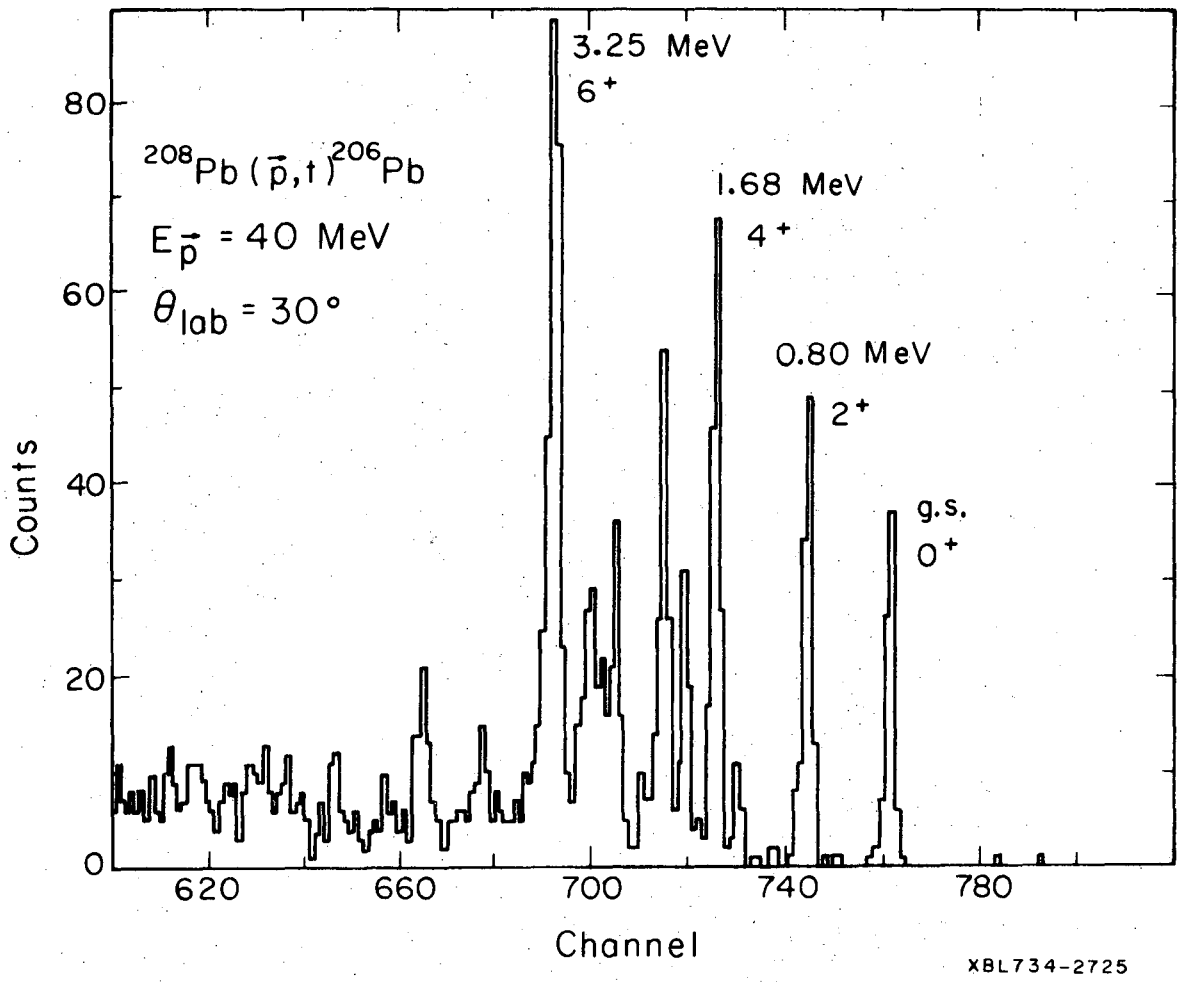
3.25 MeV
6+
1.68 MeV
4+
0.80 MeV
2+
g.s.
0+
208Pb (p⃗,t) 206Pb
Ep⃗ = 40 MeV
θlab = 30°
Counts
Channel
0
20
40
60
80
620
660
700
740
780
XBL734-2725

Fig. 1

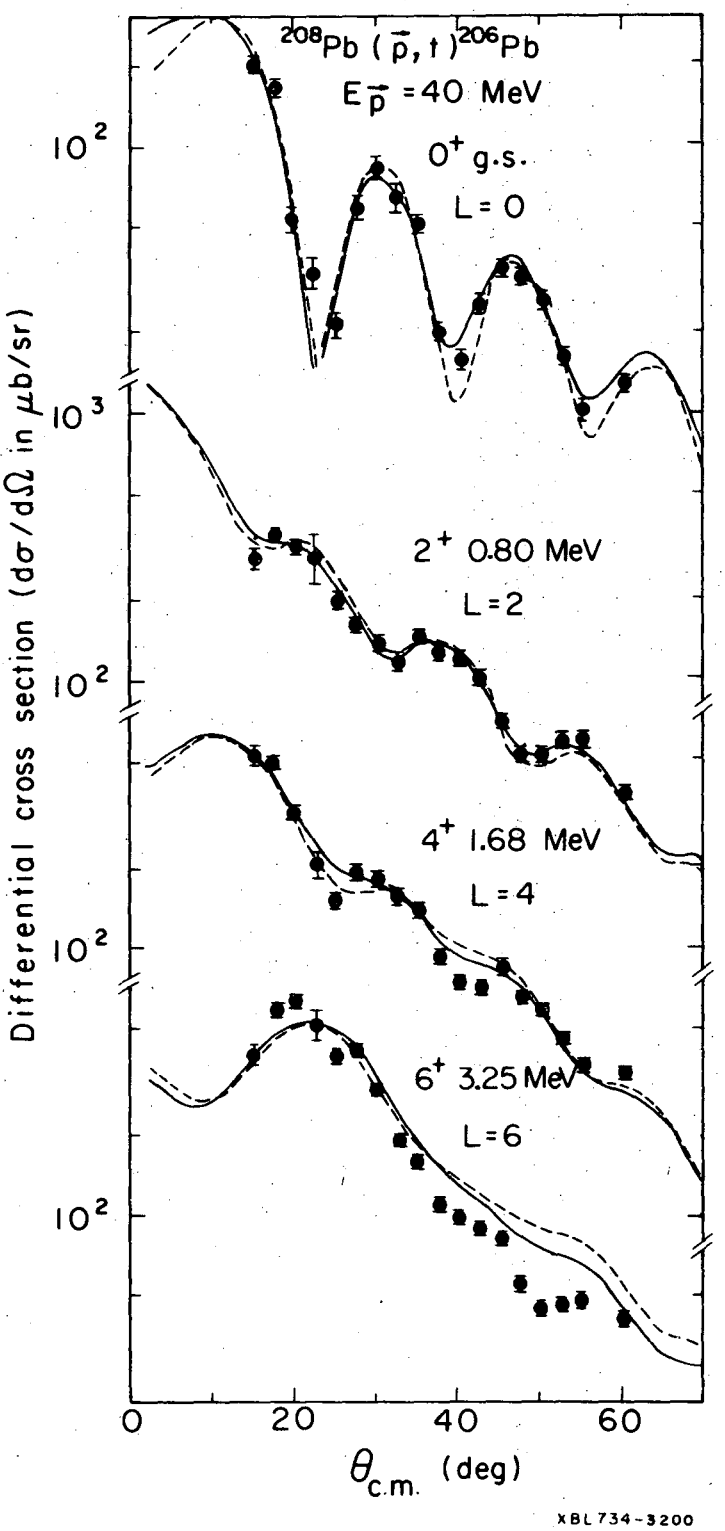
^{208}Pb ($\vec{p}$, t)^{206}Pb
$E_{\vec{p}}$ = 40 MeV
0$^+$ g.s.
L = 0
2$^+$ 0.80 MeV
L = 2
4$^+$ 1.68 MeV
L = 4
6$^+$ 3.25 MeV
L = 6
Differential cross section (dσ/dΩ in μb/sr)
10^2
10^3
0
20
40
60
$\theta_{c.m.}$ (deg)
XBL 734-3200

Fig. 2

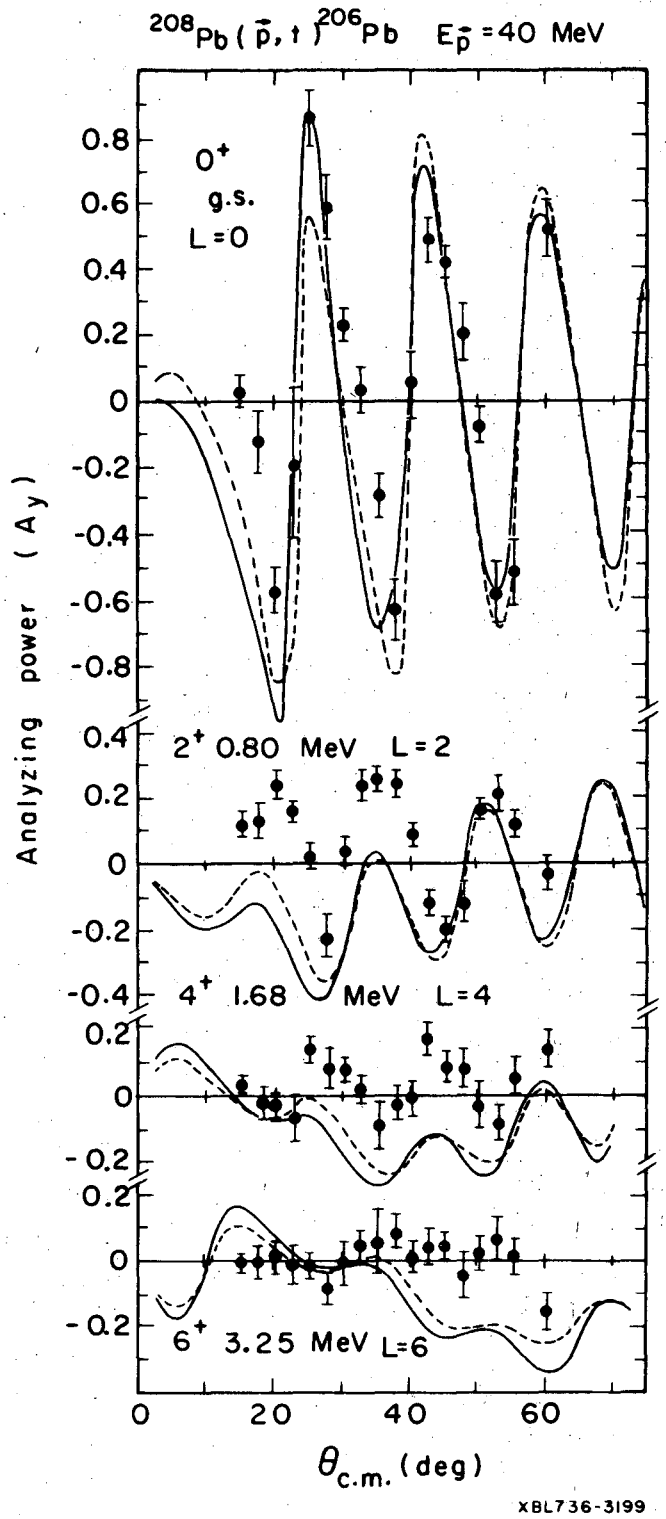
$^{208}Pb(\vec{p},t)^{206}Pb$ $E_{\vec{p}}$ = 40 MeV
0+ g.s. L=0
2+ 0.80 MeV L=2
4+ 1.68 MeV L=4
6+ 3.25 MeV L=6
Analyzing power (Ay)
θc.m. (deg)
XBL736-3199

Fig. 3

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