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Examination of the vector analyzing powers in the reaction ^{12}C,^{16}O($\vec{d}$,^{6}Li)^{8}Be,^{12}C

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Vector analyzing powers in the ($\vec{d}$,^{6}Li) reaction on ^{12}C and ^{16}O have been measured at $E_d = 51.7$ MeV. A distinctive dependence of the analyzing powers on the transferred angular momentum l_α was observed at small angles. The distorted-wave Born approximation analysis shows that the deuteron spin-orbit force has a significant effect on the analyzing powers and the weak effect of ^{6}Li spin-orbit force is caused by the deep real central potential rather than a strong absorption.

In the study of the direct reactions accompanying transfer of spins, the strong j dependence of the vector analyzing powers has been observed in the (d,p),[1] (p,d),[2] and (d,t) (Ref. 3) reactions. For the case of the transfer of spin-zero particles, such as the (d,^{6}Li) reaction, the l dependence of the analyzing power is expected at small angles, since the α-cluster transfer in this reaction occurs at the large distance and the analyzing powers of deuterons[4] and ^{6}Li (Ref. 5) in the elastic scattering are very small at the small angles because of the Coulomb force. Results of the distorted-wave Born approximation (DWBA) calculations for several targets support this expectation, as shown in Fig. 1. Other interest in the (d,^{6}Li) reaction are effects of the deuteron spin-orbit force and the ^{6}Li spin-orbit force with regard to the strong absorption properties of ^{6}Li ejectiles. The ^{6}Li spin-orbit force is estimated to be very small in comparison with that of deuterons by theoretical prediction based on the single folding cluster model.[6] The strong absorption property of ^{6}Li is a characteristic of heavy ions, as exhibited by the elastic scattering data of ^{6}Li (Refs. 7-9). Effects of these properties on the analyzing powers and the differential cross sections have been examined experimentally for the α-particle pickup reaction on the ^{12}C and ^{16}O targets in the present work.

The differential cross sections and the vector analyzing powers of the ($\vec{d}$,^{6}Li) reaction on ^{12}C and ^{16}O have been measured using vector polarized deuterons of $E_d = 51.7$ MeV provided by the RCNP-AVF cyclotron. The beam polarization was determined to $P_y = 0.46 \pm 0.05$ by utilizing the vector analyzing power $A_y = 0.362 \pm 0.040$ of the ^{12}C($\vec{d}$,d) scattering[10] at $\theta_{lab} = 47°$. Emitted ^{6}Li were detected by two telescope systems, each consisting of three solid state counters (50 μm ΔE, 500 μm ΔE, and 3 mm E).

The vector analyzing powers and the differential cross sections for the states of ^{8}Be and ^{12}C were obtained for $\theta_{lab} = 5.8° - 51°$ in 2.5° steps. The experimental results for the 0^+, 2^+, and 4^+ members of the ground-state band of ^{8}Be and ^{12}C are shown in Fig. 2 together with the results of the finite-range DWBA calculations.

The experimental differential cross sections and analyzing powers were analyzed using the finite-range DWBA-code TWOFNR.[11,12] The deuteron and ^{6}Li optical model parameters used in the present calculations are those obtained from the analyses of the elastic scattering data.[7,13] Parameters were varied to obtain better fit to the present data and the resultant values are listed in Table I. The α-spectroscopic factors extracted from the present data are in agreement with the theoretical predictions[14] within 20%

for the members of the ground-state bands except for the 11.4 MeV (4^+) state of ^{8}Be.

As seen in Fig. 2, the vector analyzing powers at small angles ($\theta_{\text{c.m.}} \leq 15°$) show a certain characteristic dependence on the angular momentum transfer for $l_\alpha = 0$, 2, and 4, i.e., a large negative value for $l_\alpha = 0$, a positive value for $l_\alpha = 2$, and nearly zero for $l_\alpha = 4$. The DWBA calculations reproduce well these experimental results. For the typical heavier targets ^{24}Mg, ^{58}Ni, and ^{94}Mo the analyzing powers are calculated by the DWBA theory as shown in Fig. 1. The optical model parameters used are those of the previous paper.[12] These results suggest that the vector analyzing powers at small angles may show the distinctive patterns depending on the transferred angular momentum l_α for these heavier targets also.

The effect of the spin-orbit terms of the optical potential have been examined for the analyzing powers of the $(\vec{d},{}^6\text{Li})$ reaction. The ^{6}Li spin-orbit potential for ^{12}C target was derived from the deuteron spin-orbit potential given in Table I using a single folding method proposed by Thompson[15] and by Amakawa and Kubo.[6] The resultant parameters are $V_{\text{so}} = 0.47$ MeV, $r_{\text{so}} = 1.01$ fm, and $a_{\text{so}} = 0.935$ fm. In the present DWBA calculation, however, the ^{6}Li spin-orbit potential with $V_{\text{so}} = 2.5$ MeV was adopted to obtain the best fit curves for both the ^{8}Be and the ^{12}C residual nuclei. The results thus obtained were indicated by the solid curves in Fig. 2. The dashed curve and the dot-dashed curve for the ground states show the results of the calculations with $V_{\text{so}}(\text{Li}) = 0$ and $V_{\text{so}}(\text{d}) = 0$, respectively. The change of $V_{\text{so}}(\text{Li})$ has a slight effect on the analyzing powers, while the change of the $V_{\text{so}}(\text{d})$ significantly affects the analyzing powers and the differential cross sections. In previous papers,[12,16] the importance of the deuteron spin-orbit force has been pointed out in determining the α-cluster spectroscopic factors obtained by the comparison between the DWBA calculations and the experimental data. This fact was confirmed by the present results.

The effect of the ^{6}Li spin-orbit potential has been generally thought to be strongly affected by the strong absorption property of ^{6}Li. As a typical example, these effects have been examined for the transition to the ground state of ^{12}C. The solid curve in the top of Fig. 3 is the best-fit result of Fig. 2. The dotted curve and the dot-dashed

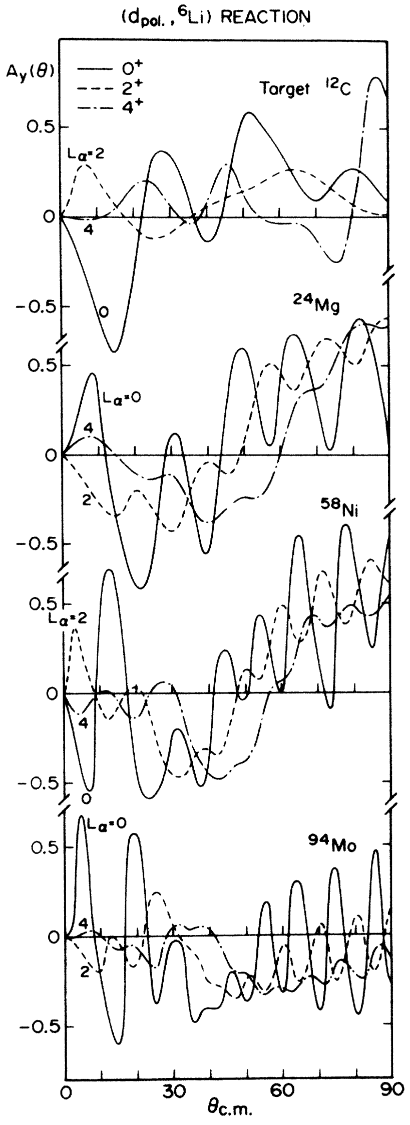

FIG. 1. The DWBA calculations of analyzing power for the targets ^{12}C, ^{24}Mg, ^{58}N, and ^{94}Mo in the $(\vec{d},{}^6\text{Li})$ reaction. The calculations have been done for the transitions to the 0^+ (solid), 2^+ (dashed), and 4^+ (dot-dashed) members of the ground-state band.

TABLE I. Deuteron and lithium optical model parameters used.

Channel	Targets	V_R (MeV)	r_R (fm)	a_R (fm)	W_I^S (MeV)	W_I^V (MeV)	r_I (fm)	a_I (fm)	V_{so} (MeV)	r_{so} (fm)	a_{so} (fm)
Deuteron	^{12}C	83.1	1.05	0.8	13	···	1.22	0.75	7	0.5	0.8
	^{16}O	85.0	1.2	1.0	9.3	···	1.28	0.7	6	1.1	1.3
^{6}Li	^{8}Be	190.0	1.085	0.55	9	···	2.2	2.0	2.5	1.01	0.935
	^{12}C	200.0	1.3	0.7	···	26.8	1.7	1.35	2.5	1.01	0.935

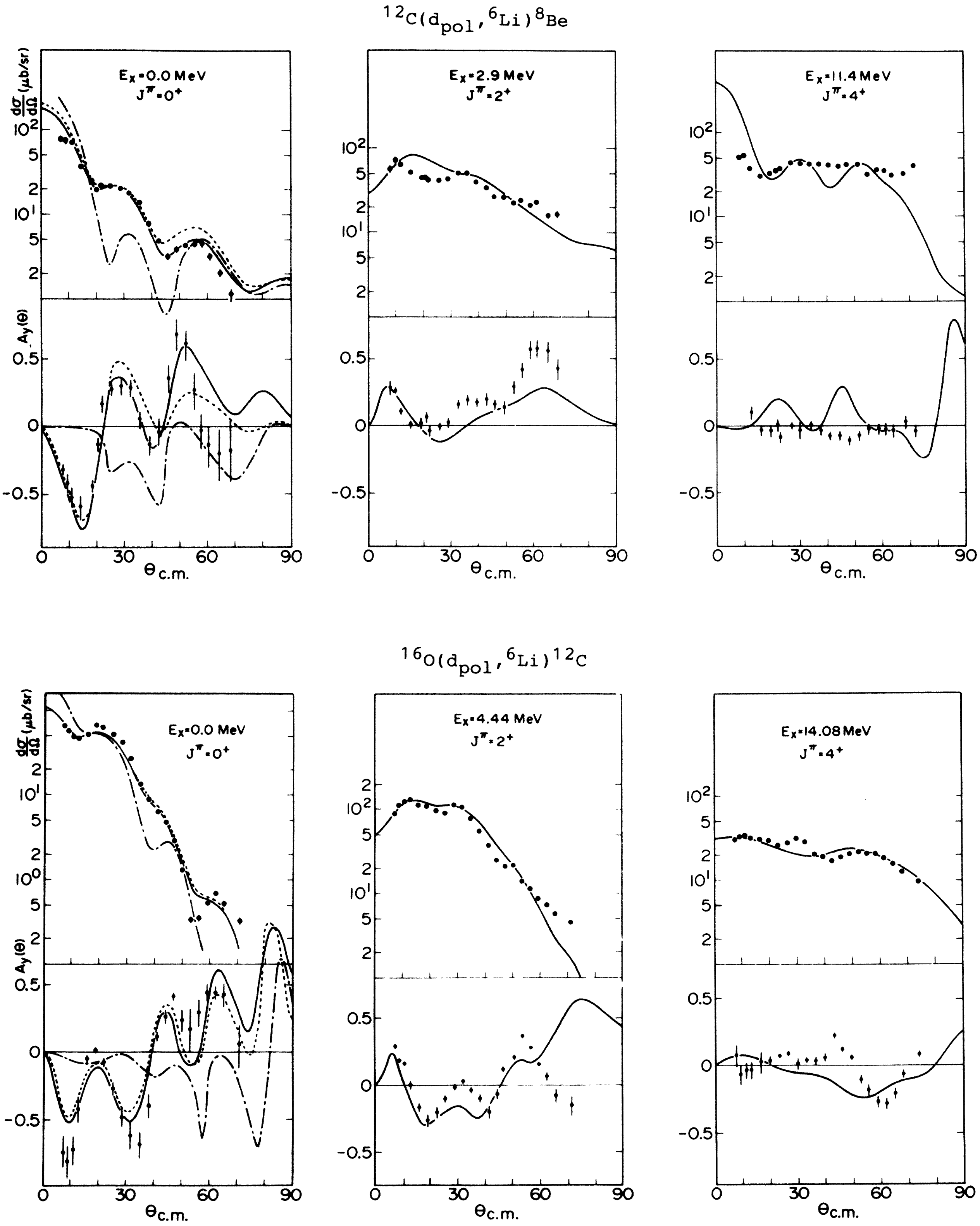

FIG. 2. Experimental cross sections and analyzing powers for the members of ground-state band of ^{8}Be and ^{12}C. The curves indicated the result of the finite-range DWBA calculations using the optical model parameters in Table I [solid curves: $V_{so}(d)=6$ or 7 MeV and $V_{so}(Li)=2.5$ MeV, dashed curves: $V_{so}(Li)=0$, dot-dashed curves: $V_{so}(d)=0$].

curve indicate the results of calculations with $V_{so}(\mathrm{Li})=0$ and 7.0 MeV, respectively. Comparison of these two curves gives evidence that the spin-orbit term of the ^{6}Li optical potential plays no crucial role, irrespective of the magnitude of the spin-orbit potential. In order to examine the effect of the strong absorption with regard to the spin-orbit term of ^{6}Li the DWBA calculations without the ^{6}Li imaginary central potential have been performed for the cases of $V_{so}(\mathrm{Li})=0$, 2.5, and 7.0 MeV (for the dotted, the solid, and the dot-dashed curves, respectively). The results are given in the middle of Fig. 3. Drastic change is not found among the three curves. This result demonstrates that the effect of the ^{6} Li spin-orbit force is also weak even when the ^{6}Li strong absorption is switched off, although the ^{6}Li strong absorption itself affects the analyzing powers as can be seen by comparison between solid curves in the top [$W(\mathrm{Li})=26.6$ MeV] and the middle [$W(\mathrm{Li})=0$ MeV] of Fig. 3. Finally, the analyzing powers have been calculated with artificially increased spin-orbit radius and diffuseness, i.e., $r_{so}(\mathrm{Li})=2.5$ fm and $a_{so}(\mathrm{Li})=2.0$ fm, that are chosen to set the spin-orbit term outside the real central potential. The resultant curves are illustrated in the bottom of Fig. 3. In this case the spin-orbit term of ^{6}Li affects the analyzing powers significantly. On the basis of these resuts, it can be concluded that the weak effect of the ^{6}Li spin-orbit term in the $(\vec{d},{}^6\mathrm{Li})$ reaction is ascribed to the fact that the ^{6}Li spin-orbit potential derived from the single folding model forms itself into a volume type and locates inside the deep real central potential.

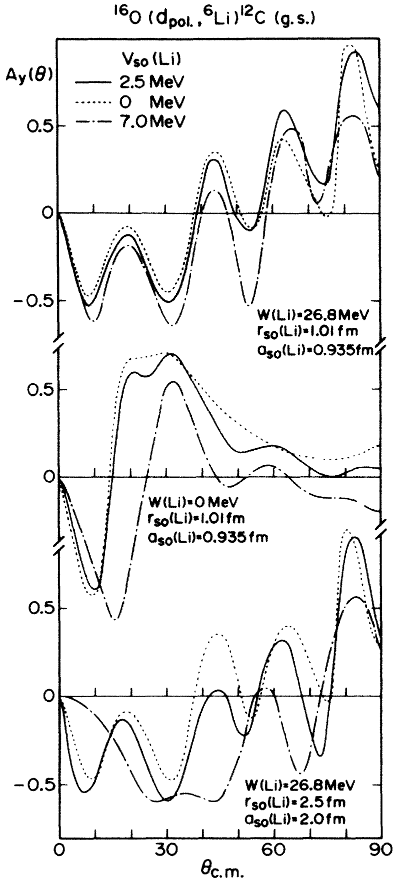

FIG. 3. Calculated analyzing powers in the $^{16}\mathrm{O}(\vec{d},{}^6\mathrm{Li})^{12}\mathrm{C}$ (g.s.) reaction with ^{6}Li spin-orbit parameters $V_{so}(\mathrm{Li})=0$ (dotted curves), 2.5 MeV (solid curves), and 7.0 MeV (dot-dashed curves). Other optical model parameters are shown in Table I except for the $W(\mathrm{Li})=0$ (middle) and the $r_{so}(\mathrm{Li})=2.5$ fm, $a_{so}(\mathrm{Li})=2.0$ fm (bottom).

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