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Alpha-Cluster Study by Measurements of Vector Analyzing Power in the (d,^{6}Li) Reaction

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The alpha-cluster states of the sd-shell nuclei are investigated measuring the vector analyzing powers from the (d,^{6}Li) reaction. The vector analyzing powers at small angles are sensitive to bound state wave functions in the target nuclei rather than the incident and outgoing distorted wave functions. Using the alpha-cluster bound state wave functions which reproduce the measured analyzing powers, alpha-spectroscopic factors for the first K=0^{+} band states of ^{16}O and ^{20}Ne were deduced from the differential cross sections and were compared with the theoretical spectroscopic factors for the $\alpha+\alpha+^{16}$O and the $\alpha+\alpha+^{12}$C of multi-cluster structures in the target nuclei.

§1. Introduction

One of the advantages in the reactions (^{6}Li, d) and (d,^{6}Li) for the study of direct α -transfer reactions is a diffractive j-dependent angular distributions from a single and allowed l transfer. This diffractive nature of the angular distribution is indicative of a direct α-cluster transfer, and it is ascribed to the transfer process occurring at an exterior region of nuclear surface. Therefore the distorted-wave Born approximation (DWBA) is more suitable for analysis of the experimental data obtained from these reactions. However, the ^{6}Li has a characteristic strong absorption property observed for heavy ions as exhibited by the elastic scattering data of ^{6}Li[1-3].

The other advantage in the (d,^{6}Li) reaction is measurements of analyzing powers for the study of direct α - transfer reactions. The distinctive dependence of the analyzing powers on the transferred angular momentum l has been observed at small angles[4]. 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 exterior region of nuclear surface and the distorted wave functions of the deuteron and the ^{6}Li channels little affect the analyzing power because of the Coulomb force. Therefore, the measurements of analyzing powers in the reaction (d,^{6}Li) are adequate to an examination of the α-cluster bound state wave function in the ground state of the target nucleus. In the present work, it is suggested for the p- and sd-shell nuclei that the analyzing powers in the DWBA calculation slightly depend on the optical potential parameters of the distorted wave functions and rather depend on the α-cluster bound state wave functions in the target nuclei. On the base of these results , the low-lying α-cluster states of ^{16}O and ^{20}Ne are examined by the measuring the analyzing powers in the reaction ^{20}Ne,^{24}Mg (d,^{6}Li)^{16}O,^{20}Ne at E_d=51.7MeV.

§2. Experiment and Analysis

The differential cross sections and the vector analyzing powers of (d,^{6}Li) reaction ^{20}Ne and ^{24}Mg have been measured using vector polarized deuterons of E_d=51.7MeV provided by the RCNP-AVF cyclotron. THe beam polarization was determined to P_y=0.46 ±0.05 by utilizing the vector analyzing power A_y=0.362 ±0.04 of the $^{12}C(d,d)$ scattering at θ_{LAB}=47°. Emitted ^{6}Li were detected by two

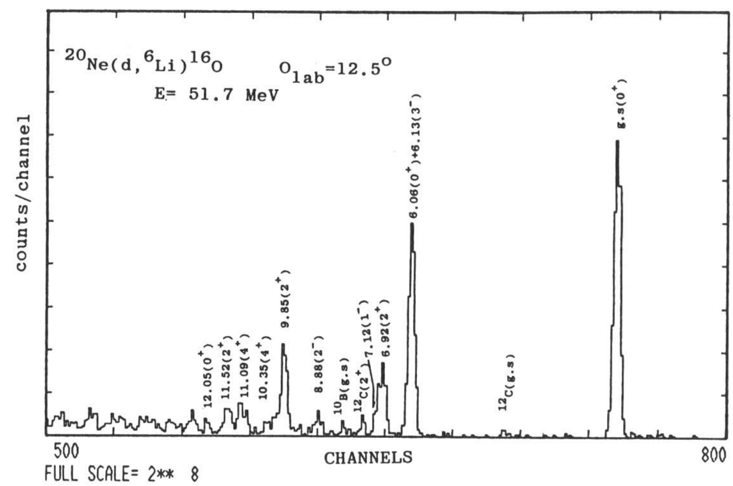

Fig.1. Spectra of ^{16}O

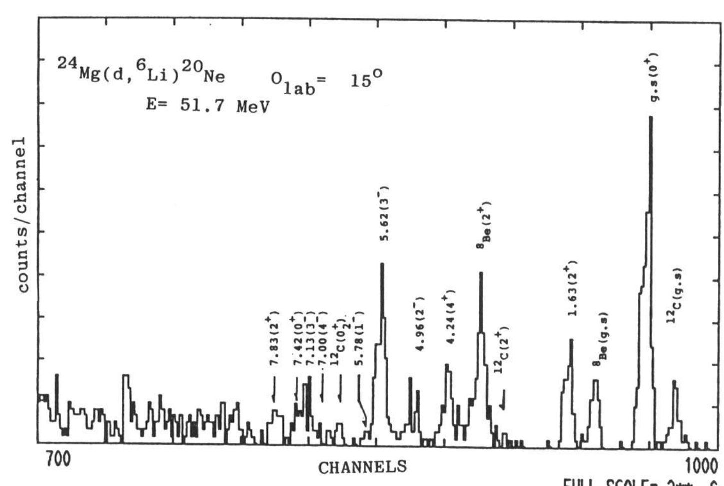

Fig.2. Spectra of ^{20}Ne

telescope systems, each consisting of three solid state counters (50μmΔE,500 μmΔE,and 5mm E). A gas cell filled at a pressure of 300 Torr at 20^{o}C with Ne gas isotopically enriched to 99% of ^{20}Ne was used as the target. In the reaction ^{24}Mg(d,^{6}Li)^{20}Ne,a 150 μ g/cm^2 self-supporting ^{24}Mg foil enriched to 99.92% was used.

The vector analyzing powers and the differential cross sections for the states of ^{16}O and ^{20}Ne were obtained for Θ_{LAB}=6.5^o-55^o and Θ_{LAB}=8^o-50^o in 2.5^o steps,respectively. Typical spectra are shown in Figs.1 and 2.

The analyses of the experimental differential cross sections and analyzing powers were performed using the finite-range DWBA-code TWOFNR[5]. The deuteron and ^{6}Li optical model parameters used in the present analyses are those obtained from the analysis of the elastic scattering data[2,6]. The geometric radius parameter r_o(d) of deuteron central real potential and the radius parameter r_I(Li) of the ^{6}Li central imaginary potential were varied within 10% to obtain better fits to the present data and the resultant values in the ^{24}Mg(d,Li)^{20}Ne reaction as an example are listed in Table I. in comparison with the parameters obtained from the elastic data[2,6]. In the analysis of the (d,^{6}Li) and (^{6}Li,d) reactions,the wave function of relative motion between the d- and α-cluster in the ground state of ^{6}Li is important for determining the effective interaction $V_{d\alpha}$ of these reactions. The effective interaction used in the present analysis was looked for by Kubo and Hirata[7] as an analytic representation of an potential shape which expressed the two body force reproducing phase shifts of the d+α scattering.

Table I. Optical Potential Parameters in the Reaction ^{24}Mg(d,^{6}Li)^{20}Ne

	V_R (MeV)	r_R (fm)	a_R (fm)	W_I (MeV)	W_V (MeV)	r_I (fm)	a_I (fm)	V_{so} (MeV)	r_{so} (fm)	a_{so} (fm)	Ref
d-elastic	86.1	1.05	0.787	12.6	-	1.28	0.75	5.0	1.05	0.787	6
Li-elastic	210.0	1.30	0.7	-	25.0	1.7	0.9	(on oxygen)			7
(d,^{6}Li) reaction											
d	86.1	1.15	0.787	12.6	-	1.28	0.75	5.0	1.15	0.787	
Li	250.0	1.30	0.7	-	25.0	2.2	0.9	2.0	1.0	0.935	

§3. Vector Analyzing Power and Alpha-Cluster Wave Function

The results of the α-pickup finite-range DWBA calculations are shown in Fig.3 for the transferred l dependence of the vector analyzing power in the (d,^{6}Li) reaction. The total quantum numbers N=4,8,12,and 20 are assumed for α-cluster in the target nuclei. These analyzing powers at small angles ($\Theta_{c.m.}$= 15^o) show a certain characteristic dependence on the angular momentum transfer for l =0,2,and 4. Namely, these show a large negative (positive) value for l =0, a positive (negative) value for l =2 and very small for l =4. These calculations reproduced well the experimental data on the targets ^{12}C,^{13}C,^{16}O,^{20}Ne and ^{24}Mg (see ref.4 for ^{12}C and ^{16}O target). The analyzing powers reproducing the experimental data in the reaction ^{20}Ne(d,^{6}Li)^{16}O(g.s.) are shown in Fig.4 for different central real potentials of the deuteron and ^{6}Li optical potentials. It is shown that the analyzing powers at small angles are dependent on the optical potential parameters of the incident and outgoing distorted waves not so strong as analyzing powers at large angles. The analyzing powers depending on the α -cluster bound state wave functions in the ground state of ^{24}Mg are shown in Fig.5(a) together with the corresponding bound state wave functions (Fig.5(b)). As seen in Fig.5, the vector analyzing powers at small angles show a certain characteristic

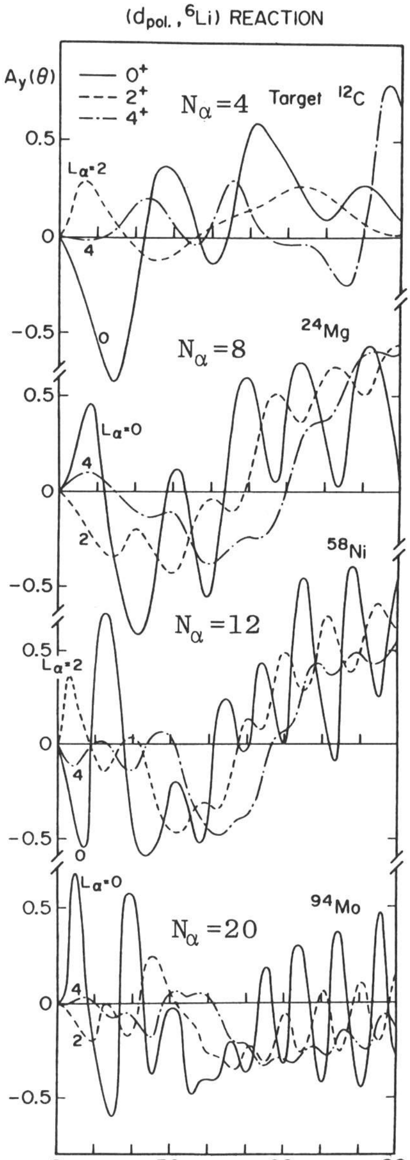

Fig.3. Transferred l-dependence of analyzing powers.

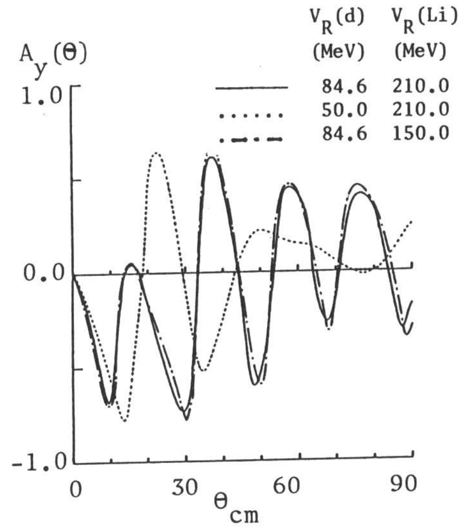

Fig.4. Analyzing power depended on $V_R(d)$ and $V_R(Li)$.

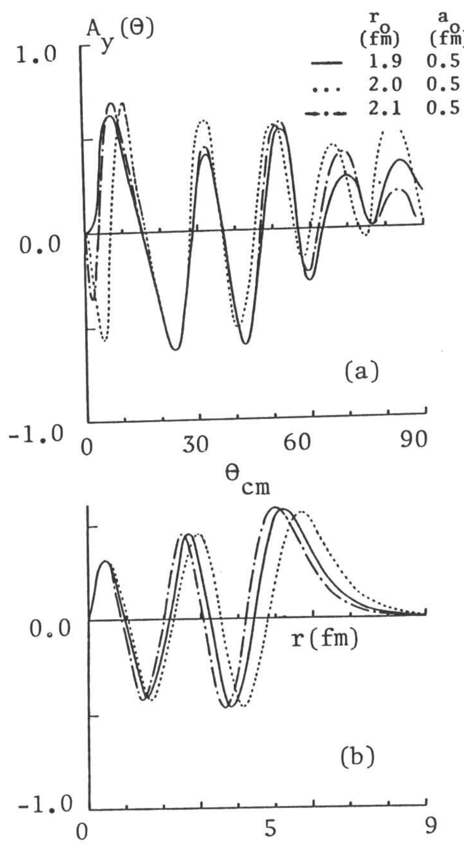

Fig.5. Analyzing powers (a) and bound state wave function (b)

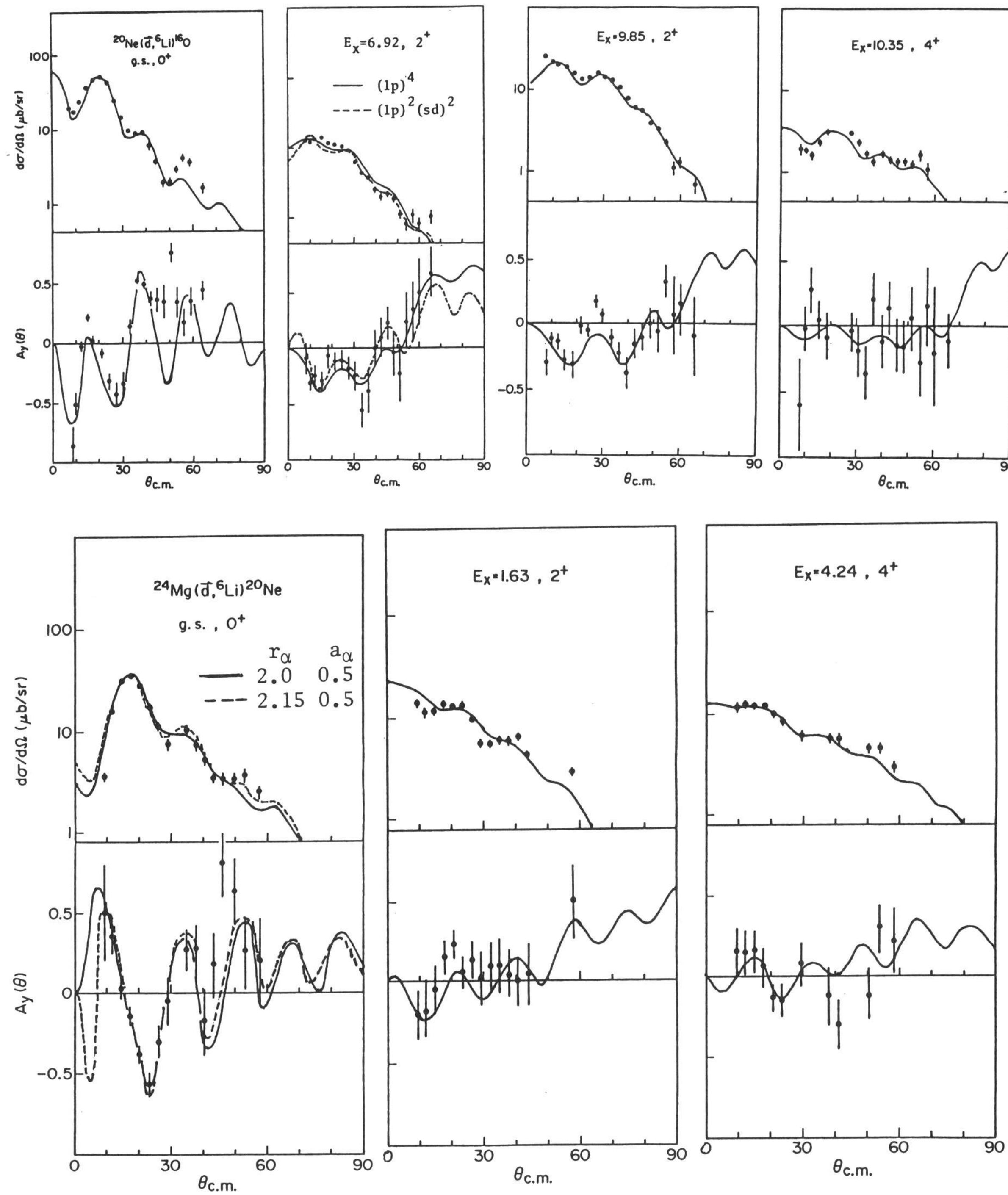

Fig.6. Angular distributions and analyzing powers. The curves show the results of the finite-range DWBA calculations.

dependence on the α -cluster bound wave function rather than on the incident and outgoing distorted wave functions.

§4. Alpha-spectroscopic Factors of ^{16}O and ^{20}Ne

The measured differential cross sections and vector analyzing powers to the members of first $K=0^+$ bands of ^{16}O and ^{20}Ne from the reaction ^{20}Ne,^{24}Mg(d,^6Li)^{16}O,^{20}Ne are shown in Fig.6 in comparison with the results of finite-range DWBA calculations. The DWBA calculations to the states of first $K=0^-$ band did not reproduce well the differential cross sections as direct -pickup reaction. In the present paper, only the states of the first $K=0^+$ band are discussed.

Recently, the spectroscopic amplitudes of the multi-cluster states in the cluster transfer reactions have been calculated with SU(3) model.[8] Furthermore, and ^8Be-spectroscopic factors of ^{20}Ne and ^{24}Mg have been calculated in the $^{12}C+\alpha+\alpha$ cluster configurations[9]. The spectroscopic factor including higher-order configurations for the internal wave functions in the target nuclei ^{20}Ne and ^{24}Mg have been also calculated for the α -pickup reaction by K.Kato[10] (indicated by S_H in Table II). The $(sd)^4$, $(sd)^2(fp)^2$ and $(fp)^4$ configurations for the ^{20}Ne ground state and the total oscillation quanta $N_{max}=38$ for the ^{24}Mg ground state are assumed. In Table II, the results deduced from the present data are compared with those obtained by the different theoretical calculations. In deducing the spectroscopic factors from the present data, the reproduction of the measured analyzing power by the DWBA calculations at the small angles is particularly considered for determining the α-cluster bound state wave functions. For the 6.92MeV, 2_1^+ state, results of the α-pickup DWBA calculations from both $(1p)^4$ and $(1p)^2(sd)^2$ configurations well reproduced the data (see Fig.6). Also, for the ground state of ^{20}Ne, two types of α -cluster bound state wave functions well reproduced the data. If we could measure analyzing powers at smaller angles, $\Theta_{LAB}=5^o$, we could decide which bound state wave functions are correct (see Fig.6). For the states of $K=0^+$ band of ^{16}O, the experimental spectroscopic factors are in agreement with S_H except for first and second 2^+ states. These 2^+ states are also in disagreement with the other theoretical values. For the

Table II. Spectroscopic factors from the present data and the Theoretical calculations

Excitation energy	J^π	The present results	S_{pure} (Ref. 10)	S_{mix}	S_H
^{16}O					
0.0	0^+	0.26	0.208	0.229	0.273
6.92	2^+	$0.203(1p)^4$	0.018	0.059	0.039
		$0.072(1p)^2(sd)^2$			
9.85	2^+	0.285	0.039	0.181	0.130
10.35	4^+	0.034	0.017	0.006	0.037
^{20}Ne			($\alpha+\alpha+^{16}O$ model)		
0.0	0^+	$0.21(r_\alpha=2.15, a_\alpha=0.5)$	0.081		0.143
		$0.38(r_\alpha=2.0, a_\alpha=0.5)$			
1.63	2^+	0.083	0.010		0.055
4.24	4^+	0.043	0.065		0.013

states of K=0+ band for 20Ne, the experimental results are in better agreement with theoretical values S_H than the other results, except for the 4_1^+ state.

According to the present analyses for the measurements of analyzing powers in the (d,^{6}Li) reaction, the measurement at very small angles ($\Theta_{LAB}<5^o$) are expected for determining more exact α -cluster wave functions in the ground state of the target nucleus.

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