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$^{12}C(^9Be,^9Be)^{12}C$(g.s., 4.43 MeV) reaction

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Angular distributions for the $^{12}C(^9Be,^9Be)^{12}C$(g.s.,4.43 MeV) reaction have been measured at ^{9}Be bombarding energies of 39.68 and 43.75 MeV over an angular range from 13° to 158° c.m. Back angle cross section enhancements were observed in both the elastic and 4.43 MeV channels. The enhancement of the back angle elastic cross section could not be described in terms of a simple optical model or coupled channels analysis. In an attempt to explain these back angle data, several reaction mechanisms were investigated. The importance of heavy ion resonance formation was determined from an excitation function measured in 200 keV intervals from 40 to 45 MeV at 158° c.m. A Hauser-Feshbach calculation was used to place an upper limit on the statistical compound nuclear contribution to the cross section. Finally, an exchange calculation in which a ^{3}He cluster was transferred between the two ^{9}Be cores has been made.

NUCLEAR REACTIONS $^{12}C(^9Be,^9Be)^{12}C$ (g.s., 4.43 MeV); measured $\sigma(\theta)$, $\theta = 13-158°$ c.m. at 39.68 and 43.75 MeV and $\sigma(E) = 40-45$ MeV, $\Delta E = 200$ keV; deduced reaction mechanism. Enriched targets. Hauser-Feshbach, coupled channels, and exchange analysis.

INTRODUCTION

In recent studies of elastic scattering of heavy ions with identical cores, angular distributions were found having large back angle cross sections which could not be described by simple optical model calculations. A number of authors have attributed these large back angle cross sections to elastic exchange. In particular, these effects have been experimentally observed in the back angle cross sections for the elastic scattering of ^{11}B, (Ref. 1), ^{10}B (Ref. 2), and ^{16}O (Ref. 3) from ^{12}C and have been attributed to proton, deuteron, and alpha particle exchange, respectively. If that interpretation is correct, then another system in this mass region which would be expected to show this back angle cross section enhancement is ^{12}C and ^{9}Be because of the large ^{3}He spectroscopic amplitude of ^{12}C calculated by Kurath and Millener.[4] Experimental data for the ^{12}C scattering by ^{9}Be have been taken by Barker et al.[5] at ^{12}C bombarding energies from 14 to 21 MeV. Back angle cross section enhancements were observed. However, because of the limited angular range of these data, reliable optical model parameters could not be obtained and no exchange transfer calculations were attempted. The more recent data of Lang et al.[6] cover a more complete angular range but were also measured at low energies. A recent study[7] of ^{12}C and ^{9}Be scattering in this energy range shows weak structure in the experimentally measured excitation function indicative of some compound nuclear process. To avoid both of these difficulties, complete angular distributions have been measured at energies of 39.68 and 43.75 MeV, and an excitation function was measured from 40 to 45 MeV at 158° c.m. to assess the importance, if any, of resonance contributions.

The cross sections have been calculated by taking a coherent superposition of the elastic scattering amplitude obtained from the optical model with a distorted-wave Born approximation (DWBA) amplitude for the transferred particle. The inclusion of elastic exchange leads to an increase in the back angle cross section and to interference around $\theta_{c.m.} = 90°$, where the elastic scattering and exchange processes are of approximately equal magnitude. This analysis quantitatively explains the elastic scattering of ^{9}Be on ^{12}C and supports the calculated ^{3}He spectroscopic amplitude of Kurath and Millener,[4] although an accurate experimental determination of the spectroscopic amplitude is impossible due to the limitations inherent in the first order optical model plus DWBA. Hauser-Feshbach calculations for the ^{12}C and ^{9}Be results place an upper limit on the statistical compound nuclear contribution to the back angle cross section of about twenty percent.

Finally, to determine the importance of coupled channel effects, calculations which included coupling to the ^{12}C 4.43 MeV level and the reorientation coupling of this state were performed within the framework of a simple collective excitation using a Woods-Saxon geometry.

EXPERIMENTAL PROCEDURE

Using the Florida State University super FN tandem accelerator, two sets of $^{12}C + ^9Be$ elastic scattering angular distributions were measured at ^{9}Be laboratory bombarding energies of 39.68 and 43.75 MeV. A ^{9}Be beam was obtained from

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the FSU inverted sputter source using a Be metal cone to which small amounts of NH_3 gas were applied. Up to 500 charge nA of BeH^- were emitted by the source. Typical intensities of $^9Be^{4+}$ ranged from 50 to 150 charge nA on target. The center-of-mass angular range from 13° to 134° was covered with an array of three silicon surface barrier detectors separated by 10° in the lab. The detector depths were decreased with increasing angle so that only ^{9}Be or heavier particles were stopped in the detectors. Consequently, there was no background in the vicinity of the elastic ^{9}Be group due to light mass reaction products. The extreme back angle data, from 130° to 158°, were measured by recording the yield of recoil ^{12}C nuclei at forward angles with a solid state E-ΔE counter telescope. A monitor detector at a fixed angle was used to normalize between all runs.

The ^{12}C targets were self-supporting with thicknesses varying from 50–100 $\mu g/cm^2$. The product of solid angle and target thickness for each counter was determined by scattering 19.84 MeV ^{16}O from the ^{12}C foils at forward angles where the scattering is Rutherford. The absolute cross sections obtained are estimated to be accurate to within 15%.

ELASTIC SCATTERING OPTICAL MODEL ANALYSIS AND RESULTS

The optical model parametrization of the elastic data, see Fig. 1, was made with the computer code JIB[8] using a Woods-Saxon real and imaginary potential of the form

$$U(r) = -V_0\{1/[1+\exp(r-R_r/a_r)]\} - iW_0\{1/[1+\exp(r-R_i/a_i)]\} + V_c(r)\,,$$

where

$$V_c(r) = \frac{Z_1 Z_2 e^2}{2R_c}\left(3-\frac{r^2}{R_c{}^2}\right), \quad r \le R_c$$

$$= \frac{Z_1 Z_2 e^2}{r}, \quad r > R_c$$

and

$$R = r_0(A_T{}^{1/3} + A_p{}^{1/3})\,.$$

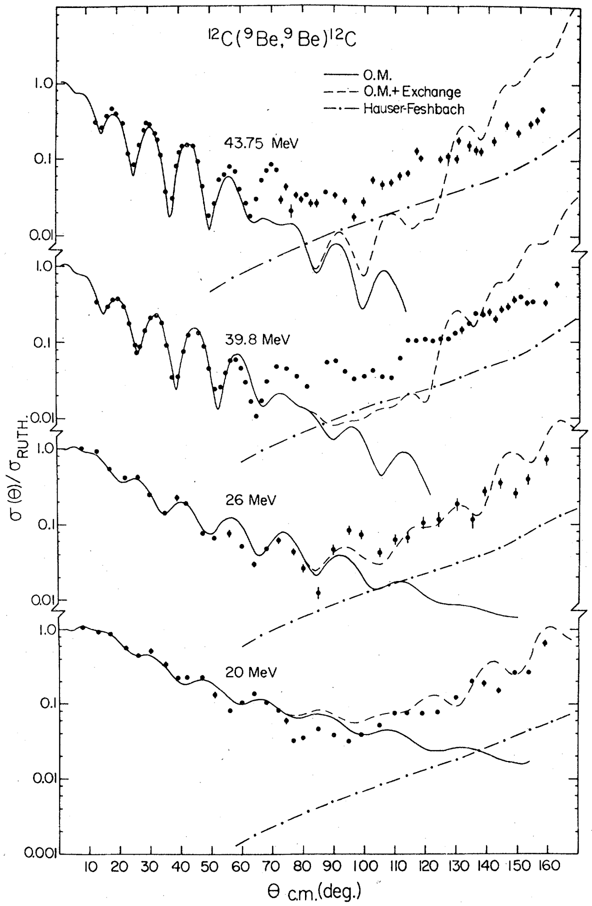

FIG. 1. Angular distributions of the elastic scattering of ^{9}Be from ^{12}C. The data at laboratory energies of 39.8 and 43.75 MeV were measured in the present work, those at 20 and 26 MeV are taken from the work of Lang *et al.* (Ref. 6). The curves are discussed in the text.

The determination of the optical potentials which best describe the data involved several steps. First, the best four-parameter optical model set was found for the 43.75 MeV data by searching on V_0 and W_0 at each point of a grid in r_0 and a, from $r_0 = 0.85$ to 1.6 fm and $a = 0.35$ to 1.15 fm in 0.5 fm steps. Only angles forward of 64° c.m. were used in this analysis, since the regular diffraction structure appears to end around 64°, indicating the presence of some additional mechanism contributing to the cross section at back angles. The best geometries were taken to be those which minimized the parameter χ^2 given by

$$\chi^2 = \sum_{i=1}^{n} \{\sigma_{\exp}(\theta_i) - \sigma_{\text{JIB}}(\theta_i)\}^2 / \Delta\sigma_{\exp}(\theta_i)^2\,,$$

where $\sigma_{\exp}(\theta_i)$, $\sigma_{\text{JIB}}(\theta_i)$, and $\Delta\sigma_{\exp}(\theta_i)$ are the experimental and calculated differential cross sections and the experimental error, respectively. Several local χ^2 minima were found in this grid. At these points the values of r_R and r_I plus a_r and a_I were uncoupled and a six-parameter search was performed. A marked improvement in χ^2 was obtained when six independent parameters were used; consequently, only six-parameter sets were considered when parametrizing the data at the other projectile energies.

TABLE I. Parametrization of the ^{9}Be scattering from ^{12}C. The parameters are described in text.

V_0 (MeV)	r_r (fm)	a_r (fm)	W_0 (MeV)	r_I (fm)	a_I (fm)	β
			Optical model			
33.686	0.964	0.921	6.524	1.509	0.478	
			Coupled channels			
35.093	0.992	0.882	6.262	1.529	0.446	−0.267

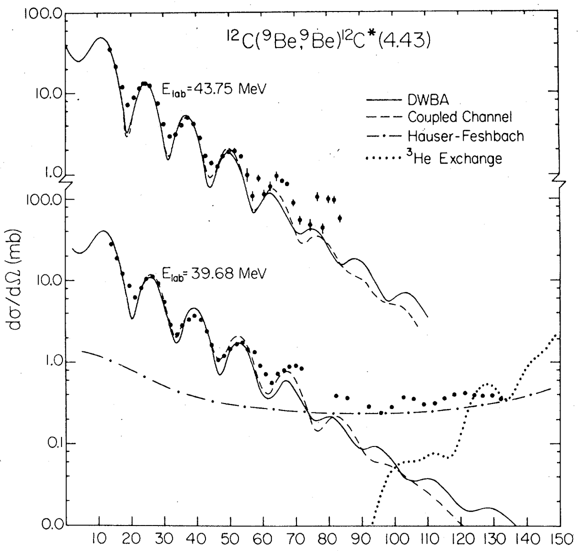

FIG. 2. Angular distributions of the inelastic scattering of ^{9}Be from ^{12}C leading to the 4.43 MeV first excited state of ^{12}C. The curves are discussed in the text.

It should be noted that for a fixed geometry (for a particular r and a), only one set of V_0 and W_0 were found to fit the experimental data, i.e., no discrete ambiguities were observed. A continuous Igo-type ambiguity was found, however.

The six-parameter sets from the 43.75 MeV data were then used as starting parameters for searches on the 39.68 MeV data set, again only including data to 64°. Only one parameter set was found to fit both sets of experimental data without large changes in V_0 or W_0. This geometry was used in all subsequent optical model calculations.

Finally, in order to determine if an energy dependence in V_0 and W_0 was necessary to describe the ^{12}C + ^{9}Be scattering over a large range of projectile energies, the 20 and 26 MeV data of Lang *et al.*[6] were fitted with this fixed geometry while allowing V_0 and W_0 to vary. No energy dependence of V_0 and W_0 was observed. The final values of V_0 and W_0 were found by averaging the values obtained at the four bombarding energies. The final parameter set is listed in Table I and the fits to the data at all energies are displayed in Fig. 1 as solid curves. The forward angle, high energy data are well reproduced, as are the overall falloff, phasing, and magnitude of the low energy data.

INELASTIC SCATTERING: DWBA AND COUPLED CHANNEL ANALYSIS

Angular distributions were measured for the strongly populated ^{12}C 4.43 MeV level at both ^{9}Be bombarding energies measured in this study. As is the case for the elastic channel, the ^{12}C 4.43 MeV level shows oscillations at forward angles, as can be seen in Fig. 2. No ^{9}Be excited states could be observed since these states are particle unstable. No data for the ^{12}C 4.43 MeV state have been reported in the literature at the lower bombarding energies.

The theoretical cross sections were calculated with the computer code DWUCK[9] using the macroscopic, collective form factor option. The optical model parameters listed in Table I were used to generate the distorted waves and bound state wave functions. The DWBA cross sections were calculated both with and without Coulomb excitation. When it was included, the Coulomb scattering length $\beta_c R_c$ was assumed to be equal to the nuclear scattering length $\beta_n R_n$. The change in magnitude of the forward angle cross section due to the Coulomb interference was small, approximately 15%, and no change in shape was observed. The results of the DWBA calculations are given in Fig. 2. As can be seen, the overall phasing between the data and the theoretical predictions is good. The calculated forward angle minima are too deep, but because of the large deformation of both the ^{12}C and ^{9}Be nuclei, coupled channels effects are expected to be significant and an improvement in this angular region might be expected.

The deformation of the optical potential is described by a multipole expansion of the radius $R = R_0[1+\sum_{LM}\beta_L Y_L^M(\theta,\phi)]$. The nuclear deformation parameter β_L describes the effective deformation of the target-projectile system as opposed to the actual deformation of the target. As has been pointed out by Hendrie[10] and by Thompson and Eck,[11] the quantity which is invariant between the different interacting systems is the nuclear deformation length $\beta_n R_n$. The deformation length determined by Thompson and Eck[11] for a variety of projectiles on ^{12}C is −1.78 ± 0.11 fm. Since the above DWBA analysis is insensitive to the sign of the deformation the magnitude of the deformation length obtained in this study $\beta_n R_n = 1.4$ fm is in satisfactory agreement with the magnitude of the deformation length determined by Thompson and Eck.[11] (The radius R was taken to be the average of the real and imaginary radii, as was done in the calculation by Thompson and Eck.[11])

The coupled channels calculations for ^{12}C and ^9Be were also done within the framework of a simply collective excitation using a Woods-Saxon geometry. The computer code SOCC[12] was used. The couplings included in the calculation were between the ^{12}C ground state and the 4.43 MeV level and the reorientation coupling of the 4.43 MeV state. No couplings to the ^9Be states were included since these levels could not be observed experimentally. No Coulomb excitation was included in the coupled channels calculation since this was found to be a small effect in the DWBA analysis. The coupled channels parameters were determined by searching on the six-parameter optical model set and on the deformation parameter. As can be seen in Table I, no significant change in the parameters resulted, nor could an improvement in the fit to the ^{12}C 4.43 MeV data be obtained (see dashed curves in Fig. 2). The coupled channels deformation length −1.47 fm agreed well in both magnitude and sign with the global deformation length of Thompson and Eck.[11]

BACK ANGLE CROSS SECTION ANALYSIS

A number of examples of enhancements in the measured back angle cross sections, similar to those observed for the ^{12}C and ^9Be system studied in this work, exist for systems in this mass and energy range.[1-3] Several mechanisms might account for these back angle cross sections: statistical compound nuclear formation, heavy ion resonance formation, and the exchange of a nucleon or cluster between the projectile and target nuclei. An attempt has been made in the present work to assess the importance of each of these mechanisms for the ^{12}C and ^9Be system.

The statistical compound nuclear contribution to the cross sections to the ^{12}C ground state and 4.43 MeV level was estimated using the Hauser-Feshback (HF) code HELGA.[13] This code has been discussed previously by Gomez del Campo *et al.*[14] It has been demonstrated by Klapdor *et al.*[15] that the results of HF calculations are sensitive to various calculational parameters in different ways. For compound nuclear cross sections, the *ratio* of the calculated cross sections between discrete final states is dependent primarily on the value of the angular momentum cutoff J_{critical}. The *absolute* cross sections for all discrete final states in a particular exit channel are *all* decreased or increased by the same amount when the level density parameter a is varied. Finally, the *absolute* cross section depends strongly on the optical model parameters used to describe the various exit channels.

For the ^{12}C and ^9Be system a value of 15 $\hbar$ was used as the maximum allowed angular momentum for the 43.75 MeV data. This value for J_{crit} appears reasonable for the ^{12}C and ^9Be case if one considers both the $^{10}B+^{12}C$ and the $^{12}C+^{14}N$ systems for which the critical angular momenta have been measured.[15,16] Since the $^{12}C+^{10}B$ system has a critical angular momentum of 14± 1 $\hbar$ at 45 MeV, and that for the $^{12}C+^{14}N$ system has been measured to be 14–15 $\hbar$ at 53 MeV, the critical angular momentum for the ^{12}C and ^9Be system must be $\leq 15\ \hbar$ at 43.75 MeV. The value of the critical angular momentum at lower bombarding energies was found by scaling the 43.75 MeV critical angular momentum by the ratio of the calculated grazing angular momenta. The $^{12}C+^9Be$ optical model parameters used in the HF calculation were taken from the present study; the remainder of the optical model parameters, listed in Table II, were taken from the literature.[17-21] The level density parameters, pairing energies, and energy of the last discrete level for each exit channel are listed in Table III. The results of the calculation are shown in Figs. 1 and 2.

The Hauser-Feshbach calculation predicts the statistical compound nuclear cross section to both the ground state and the 4.43 MeV levels in ^{12}C and should be compared to data for both states.

TABLE II. Optical model parameters for the Hauser-Feshbach calculations.

Channel	V (MeV)	r (fm)	a (fm)	W (MeV)	r_I (fm)	a_I	Type	Ref.
$n+^{20}Ne$	$47.01-0.267E_{\text{c.m.}}-0.0015E_{\text{c.m.}}^2$	1.308	0.660	$9.52-0.53E_{\text{c.m.}}$	1.259	0.480	Surf.	17
$p+^{20}F$	36.330	1.197	0.746	11.310	1.196	0.786	Vol	17
$d+^{19}F$	94.300	1.027	0.806	7.490	2.175	0.560	Vol	18
$^3He+^{18}O$	179.000	1.140	0.660	16.760	1.610	0.910	Vol	19
$\alpha+^{17}O$	160.800	1.500	0.535	27.550	1.500	0.390	Vol	20
$^8Be+^{13}C$	$7.5+0.4E_{\text{c.m.}}$	1.350[a]	0.450	$0.4+0.125E_{\text{c.m.}}$	1.350	0.450	Vol	21
$^9Be+^{12}C$	33.686	0.964[a]	0.921	6.524	1.509	0.478	Vol	

[a] Real and imaginary radii taken as $R=r(A_T^{1/3}+A_p^{1/3})$.

TABLE III. Level density parameters. For definitions and parameter values see Refs. 14 and 15.

Residual nucleus	a/A (MeV^{-1})	Δ (MeV)	E_{cut} [a] (MeV)	Number of discrete [b] levels
^{20}Ne	0.16	5.10	7.20	9
^{20}F	0.16	0.0	2.20	9
^{19}F	0.16	2.55	5.50	20
^{18}O	0.16	5.10	5.40	9
^{17}O	0.16	2.55	5.75	9
^{13}C	0.16	2.55	9.50	9
^{12}C	0.16	5.10	10.80	5

[a] Energy of last discrete level.
[b] Reference 22.

Since the direct contribution to the ^{12}C 4.43 MeV data is smallest at back angles, we consider the 39.68 MeV data initially since angular distributions have been measured to 130° c.m. for the 4.43 MeV level at this energy. The ratio between the experimental elastic and inelastic cross sections near 130° c.m. is 0.73; the Hauser-Feshbach estimate of this ratio, assuming $J_{\mathrm{crit}} = 12\,\hbar$ at 39.68 MeV, is 0.23. The calculated ratio $\sigma_{\mathrm{g.s.}}/\sigma_{4.43}$ could not be altered by a variation of either the level density parameter a or the ^{12}C and ^{9}Be optical model parameters, a result consistent with the results of Klapdor *et al.*[15] The calculated cross section ratio could only be made to approach the experimental cross section ratio by increasing the critical angular momentum cutoff to a value of approximately 30 $\hbar$. This value for the critical angular momentum is clearly too large for the ^{12}C and ^{9}Be system at 39.68 MeV when compared with the critical angular momenta of 14 to 15 $\hbar$ measured at similar energies for the ^{12}C + ^{14}N and ^{10}B + ^{12}C systems.[15,16]

Since the cross sections calculated with this set of level density and optical model parameters just reproduce the magnitude of the data for the ^{12}C 4.43 MeV level at back angles (see Fig. 2), it is clear that the elastic cross section (see Fig. 1) is at best underpredicted by a factor of 4 to 5. It will be seen later that this is most likely the extreme case, since there is some evidence that the back angle cross section to the ^{12}C 4.43 MeV state is at least partially due to the transfer of a ^{3}He cluster to this level and is not entirely due to a statistical compound nuclear process. A reduction in the magnitude of the calculated statistical compound nuclear cross section to the 4.43 MeV level by a variation in either the level density or optical model parameters would result in a similar reduction in the predicted statistical compound nuclear cross section to the elastic channel.

While the results of the Hauser-Feshbach calculations would seem to allow a significant cross section due to some mechanism other than statistical compound nuclear formation, the possibility remained that some nonstatistical compound nuclear process, i.e., heavy ion resonance formation, was taking place. This possibility could only be eliminated experimentally. Excitation functions have been measured in 200 keV intervals from 40 to 45 MeV in which the recoil ^{12}C particles were detected at 11° in the lab with a ΔE-E silicon telescope. This is equivalent to detecting ^{9}Be at 158° c.m. The measured yield (see Fig. 3) is flat within our counting statistics (~7%). This result suggests that the rise in the back angle cross section at this energy is not due to resonance formation.

An alternate explanation which could account for the back angle cross section enhancement is a ^{3}He cluster exchange between the ^{12}C nuclei and the incoming ^{9}Be projectile. From kinematical considerations and from optical model calculations, the ^{12}C(^{9}Be, ^{9}Be)^{12}C cross section is expected to decrease as a function of increasing angle. At large angles the predicted elastic scattering cross section is small ($<10^{-3}\ \sigma/\sigma_R$), whereas the competing transfer cross section peaks at back angles. The unique properties of elastic transfer reactions, identical bound state and elastic scattering states in the initial and final channels, should lead to a good overlap of the internal wave functions, and consequently, large cross sections. The large calculated[4] spectroscopic amplitude for ^{3}He in ^{12}C also suggests a cross section enhancement. In a fully antisymmetric calculation of the elastic scattering cross section, the transfer contribution would be automatically included. As a first approximation for the transition to the ground state in identical core systems, it has been shown that a coherent superposition of the elastic scattering amplitude obtained from the optical model with a DWBA amplitude to account for the transfer describes such systems well.[1] The exchange transfer amplitudes do not include the additional terms usually present in exchange calculations, namely

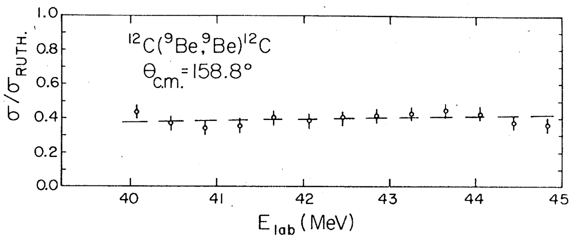

FIG. 3. The measured energy dependence of the elastic scattering of ^{9}Be from ^{12}C at $\theta_{\mathrm{c.m.}}=158.8$ (Ref. 6). The straight line is a guide to the eye.

the heavy particle knockout term. Thus we are employing the usual DWBA assumption[23]

$$\langle \chi_f^{(-)} / V(^9\mathrm{Be} - {}^9\mathrm{Be}) - V(^9\mathrm{Be} - {}^{12}\mathrm{C}) / \chi_i^{(-)} \rangle \simeq 0\,.$$

For the ^{12}C + ^{9}Be case, the elastic scattering amplitudes were generated with the computer code SOCC[12] using the optical model parameters in Table I. The ^{3}He cluster transfer amplitudes were generated with the finite range DWBA version of the computer code OUKID.[24] Distorted waves for the incoming and outgoing channels were calculated from the optical model parameters measured in the present work. The bound state was calculated with a Woods-Saxon potential using the known ^{3}He binding energy of 26.282 MeV and with the number of nodes estimated from the harmonic oscillator approximation for clusters:

$$2N + L = \sum_{i=1} (2n_i + l_i)\,,$$

where n_i and l_i are the individual nucleon shell model orbitals. The allowed ground state angular momentum transfer is $\frac{3}{2}$ with both N and L equal to one. The Woods-Saxon radius and diffuseness were taken to be $R = 1.2(A_T^{1/3} + A_p^{1/3})$ fm and $a = 0.65$ fm. The calculated cross section was found to be stable against changes in the bound state radius and diffuseness parameters. Variations in the parameters as large as 15% were tried and found to produce only slight changes in the slope of the calculated cross sections and small (20%) changes in the predicted magnitude. The spectroscopic amplitude was taken from the calculations of Kurath and Millener[4] for a ^{3}He cluster in ^{12}C. The spectroscopic amplitude was not treated as a free parameter in this calculation. The calculation represents an extreme "pre-formed" ^{3}He cluster model. The results are shown in Fig. 1. At low energies the magnitude of the back angle cross section is correctly predicted, and so is the general structure and phasing. At the energies measured in this experiment, 39.68 and 43.75 MeV, the agreement in overall magnitude is still good; however, the agreement between the theoretical and experimental shapes is poor. As can be seen by the dashed curve in Fig. 3, the transfer calculation reproduces the shape of the energy dependence at 158° c.m. quite well. The fact that the shape of experimental cross section does not change rapidly from 39.68 to 43.75 MeV and the transfer calculation reproduces the general energy dependence of the experimental cross section does suggest that a significant part of the back angle cross section is due to an exchange process.

TABLE IV. Allowed total angular momentum transfers, harmonic oscillator quantum numbers, and spectroscopic amplitudes from Kurath and Millener (Ref. 4) for the ^{3}He cluster transfer calculation discussed in the text.

J_{transfer}	N	L	δ
$\frac{7}{2}$	0	3	−0.520
$\frac{5}{2}$	0	3	−0.062
$\frac{3}{2}$	1	1	0.164
$\frac{1}{2}$	1	1	0.787

Although less extensive back angle data were obtained for the inelastic scattering to the 4.43 MeV level in ^{12}C, a ^{3}He cluster transfer calculation was made to determine whether or not the theoretical calculation could correctly predict the magnitude of these back angle cross sections. The spectroscopic amplitudes calculated for this state by Kurath and Millener[4] were used. The four allowed total angular momentum transfers along with the harmonic oscillator quantum numbers and the Kurath and Millener[4] spectroscopic amplitudes are listed in Table IV. The final cross section was found by taking an incoherent superposition of four partial cross sections for the allowed angular momentum transfers. No attempt was made to take a coherent superposition of these summed scattering amplitudes with the scattering amplitudes from the forward angle collective calculation described earlier. Consequently, a correct prediction of the total cross section at the region where the two cross sections are of equivalent strength should not be expected since the interference term has been neglected. However, for the farthest back angle data where the interference term should be small, the ^{3}He transfer calculation does predict the magnitude of the experimentally measured cross section (see Fig. 2).

SUMMARY

An excitation function for ^{9}Be scattering from ^{12}C from 40 to 45 MeV at 158° c.m. together with angular distributions covering an angular range from 13° to 150° c.m. at energies of 39.68 and 43.75 MeV have been measured in an attempt to understand the mechanism responsible for the observed back angle cross section enhancement. The usual optical model parametrization of the data could not reproduce the back angle cross sections, although it could account very well for the strong forward angle diffraction pattern observed over a large range of ^{9}Be bombarding energies. In addition, it was found that coupled channel effects, at least those involving the ^{12}C 4.43 MeV level, were small and that the inelastic scattering to the 4.43 MeV level was well described out to angles of 60° c.m. by a simple DWBA collective model calculation. Again, coupled channel effects did not account for the back angle cross section enhancement present in either the elastic or inelastic (4.43 MeV) data. Three other mechanisms were investigated to account for the enhancement of the back angle cross section: heavy ion resonance formation, statistical compound nuclear formation, and the exchange between ^{9}Be cores of a ^{3}He cluster. From the measured excitation function, no significant contribution to the cross section from heavy ion resonance formation is evident at these energies. This effect could not be ruled out until the experimental excitation function was measured, since some weak structure in the elastic excitation function had been observed at lower ^{9}Be bombarding energies.[7] The contribution from statistical compound nuclear processes was estimated by a Hauser-Feshbach calculation. This calculation placed an upper limit on the contribution to the back angle cross section from statistical compound nuclear formation at approximately 20% of the elastic cross section. The most successful description of the data was obtained from a ^{3}He exchange between the two ^{9}Be cores. Using a ^{3}He spectroscopic amplitude calculated by Kurath and Millener,[4] the calculation was able to describe not only the magnitude but also the shape of the back angle data for the low energy angular distributions which had been measured previously by Lang *et al.*[6] The description of the back angle data was less satisfactory at the higher ^{9}Be bombarding energies measured in this study. The magnitude of the measured back angle cross section was reproduced, but the agreement between the slope of the calculated cross section and the slope of the experimental results was poor. However, higher order processes which were neglected in this cluster transfer approach might be expected to become more important as the bombarding energy is increased.

Cross section data for the reactions discussed in this paper are deposited in the Physics Auxiliary Publication Service.[25]

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