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DWBA Analysis of the $^{12}C(n, \alpha_0)^9Be$ Reaction at 14.1 MeV

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The DWBA calculation is performed to fit the experimental data of the angular distribution of the $^{12}C(n, \alpha_0)^9Be$ reaction which was obtained previously in this laboratory. The direct Interaction mechanisms, including the heavy-particle stripping, knock-on and pick-up processes, are investigated. The calculations are done assuming a form factor based on the harmonic oscillator wave functions for the bound state and on the interaction potential with the Gaussian form.

An incoherent combination of the knock-on and heavy-particle stripping processes yields the angular distribution which is in good agreement with the experimental one. The results obtained by the DWBA method are also discussed in comparison with those of PWBA method.

1. INTRODUCTION

THE $^{12}C(n, \alpha_0)^9Be$ reaction at 14.1 MeV was studied in this laboratory and the angular distribution was compared with the heavy-particle stripping (HPS) and the knock-on process using PWBA method(1).

Recent studies(2-5) of the (n, a) reactions on light nuclei have shown an importance for the existence of the direct-interaction mechanisms. The direct (n, a) reactions can proceed either by the pick-up of an ^3He by the incident neutron or the exchange interation like the knock-on and the HPS, depending largely on the probabilities that ^3He or α cluster exists in the target nucleus.

Since the target ^{12}C is known(6) to contain alpha-particle clusters, the exchange interactions could well make a significant contribution. It also has been suggested by Kitazawa *et al.*(4) that the a-cluster reduced width amplitudes are considerably large for the nuclei amenable to the a-particle model. On these bases one can expect that the knock-on and HPS mechanisms in the $^{12}C(n, \alpha_0)^9Be$ reaction are likely a priori. Since the pick-up and knock-on mechanisms do not differ so

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(2) M. L. Chatterjee and B. Sen, Nuclear Physics 51. 583 (1964).
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(4) R. A. Al-Kital and R. A. Peck, Jr. Phys. Rev. 130, 1500 (1963).
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much from each other(2-5) in the PWBA analysis, it is difficult to specify clearly which particular reaction is operative.

In this paper, the DWBA analysis is performed in attempts to obtain the best fit to the angular distribution and to clarify the ambiguities of the PWBA method. For the knock-on and pick-up processes, the finite range DWBA calculation are made. For the sake of simplicity the zero range interation with a cut-off in the lower range of the radial integral is considered for the calculation of the HPS process.

2. DWBA ANALYSIS AND RESULTS

The theoretical angular distribution curves are calculated with standard DWBA(7) method using the code INS-DWBA-3(8), slightly modified to permit an investigation of the HPS process. The optical potentials used have the form

$$U(r) = U_c(r) - Vf(r) - iWg(r),$$

where

$$f(r) = \left[1 + \exp\left(\frac{r - r_R A^{1/3}}{a_R}\right)\right]^{-1}$$

$$g_{\rm surf}(r) = \exp\left[-\left(\frac{r - r_I A^{1/3}}{a_I}\right)^2\right] \qquad \text{for neutron,}$$

$$g_{\rm vol}(r) = \left[1 + \exp\left(\frac{r - r_I A^{1/3}}{a_I}\right)\right]^{-1} \qquad \text{for a-particle,}$$

and $U_c(r)$ is the Coulomb potential from a uniformly charged sphere of radius $r_c . A^{1/3}$ fm. Since the main interest is the angular distribution predictions, but not in the polarization, no spin-orbit term(9) is used for the optical potential.

The optical pontential parameters, shown in Table 1, are obtained from the paper of Hodgson(10) for the entrance neutrons, and from the elastic scattering data of Devries et al.(11) for the exit alpha particles. These parameters are fixed throughout the whole investigation.

Table 1. Optical-model parameters

Channel	V (MeV)	r_R (fm)	a_R (fm)	W (MeV)	r_I (fm)	a_I (fm)	r_c (fm)
$n+{}^{12}$C	43.8	1.25	0.65	11.3	1.25	0.60	1.25
$\alpha+{}^{9}$Be	71.8	1.54	0.69	50.8	0.95	0.92	1.20

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(7) Bassel, R. H., Drisko, R. M., and Satchler, G. R. 1962. Oak Ridge Natl. Lab. Rept. ORNL-3240.

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(11) R.M. Devries, Jeau-Luc Terrenoud, I. Slaus and J W. Sunier, Nuclear Physics A178 424(1972).

2-1 Knock-on and Pick-up Mechanisms

In the case of knock-on and pick-up processes, the finite range DWBA without radial cut-off procedure is applied to fit the forward angle rise of the experimental result. The quantum numbers that are required in the form factor for the center-of-mass motion of the transferred or exchanged cluster are listed in Table 2. These numbers are usually computed from the " conservation of harmonic oscillator energy " rule on the basis- of a simplified cluster picture of the nuclei(12,13). The cluster is described by a " one body " wave function and is formally treated like that of a single nucleon.

In order to get a comprehensive idea of the influence of the interaction range parameter ξ on the finite range corrections, ξ is varied over a wide reasonable range(14-16) during the calculation as shown in Fig. 1 and Fig. 2. The features of these results should be underlined in the effect of the force range parameter and should be compared with those of PWBA curves. Firstly, the shapes by knock-on process are considerably less sensitive to a variation of the parameter ξ and very similar to the PWBA prediction (Fig. 1). Secondly, in the case of

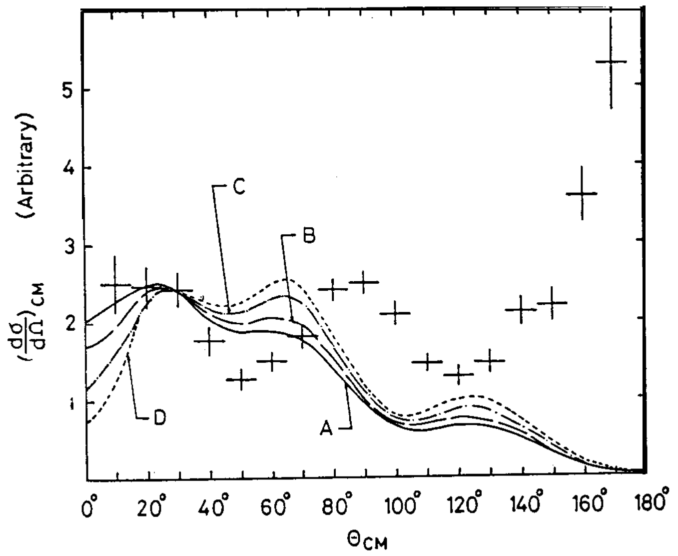

Fig. 1. Comparision of the differential cross sections by the PWBA and DWBA methods for the knock-on mechanism. (A) refers to the PWBA fit. (B), (C) and (D) refer to the DWBA fits when the interaction range parameter ξ is used at 1.0 fm, 1.4 fm and 1.8 fm, respectively.

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(12) K. Wildermuth and W. McClure, *Springer* Tracts *in Modern* **Physics,** Vol. 41 (Springer, **Berlin,** 1966).
(13) S. H. Suck and W. R. Coker, Nuclear Physics A176 89 (1971).
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pick-up process, the shapes are sensitive to the range of ξ (Fig. 2). However, the fit to the experimental data is still poor and different much from the result of the PWBA method(2-4) (Fig. 2).

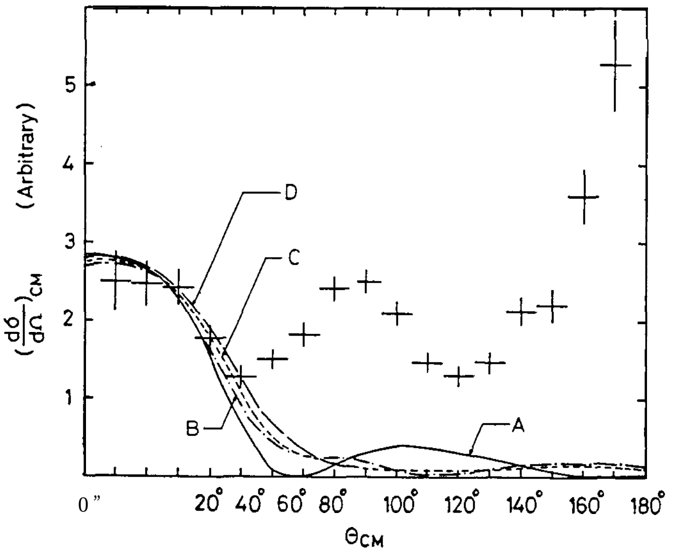

Fig. 2. The effect on the pick-up mechanism of the variation of the interaction range parameter ξ. (A), (B), (C) and (D) refer to range parameter ξ at 0.6 fm, 1.0 fm, 1.4 fm and 1.8 fm, respectively.

2-2 HPS Mechanism

Since the HPS mechanism involves very different mass ratios as well as ratios of interaction strength ’ “ ’ in the incoming and outgoing processes, many authors(18) have noticed that the ordinary finite range DWBA is inadequate to reproduce a steep backward rise in the angular distribution. This consideration has led us to use the zero range method(19).

The zero range DWBA method developed by Robson(19) is used for the present work by means of the computer code INS-DWBA-3 with a slight modification. This method was successfully used in the ^{16}O(n, a)^{13}C reaction by Lamot(20). The required quantum numbers are also listed in Table 2 and the calculated results are shown in Fig. 3. The cut-off in the lower range of the radial integration is done in order to introduce the finite range effect(21). Fig. 4 demonstrates that the main contribution to the HPS process comes from the radii between 4-5 fm

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(17) N. Austern, ***Direct Nuclear Reaction Theories*** (John Wiley & Sons, New York, 1970), P 339.

(18) P. E. Hodgson, ***Nuclear Reactions and Nuclear Structure*** (Oxford, London, 1971), P. ***434.***
A183, 417 (1972).

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which is able to announce clearly the peak in the angular region of 90°, in contrast with the ambiguous result of the PWBA calculation.

Table 2. Bound state quantum numbers

knock-on	^{12}C	^{8}Be$+\alpha$	3 s
	^{9}Be	^{8}Be$+n$	1 p
pick-up	^{12}C	^{9}Be$+^{3}$He	2 p
	^{3}He	^{3}He$+n$	1 s
HPS	^{12}C	$\alpha+^{8}$Be	3 s
	^{9}Be	$n+^{8}$Be	1 p

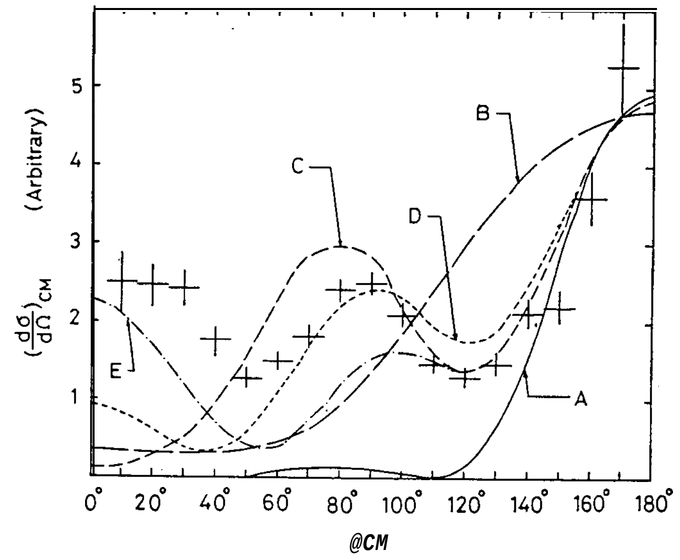

Fig. 3. The effect on the HPS mechanism of the various cut-off in the lower range of the integration by the zero range DWBA method. (A) refers to the PWBA fit. (B), (C), (D) and (E) refer to the DWBA fits when cut-off is used at $R_c=0.0$ fm, 3.6 fm 4.5 fm and 5.4 fm, respectively.

3. CONCLUDING REMARKS

From the above DWBA analyses, it can be clearly seen that the knock-on and HPS mechanisms are predominant in the ^{12}C$(n,\alpha_0)^9$Be reaction and that the incoherent sum of these mechanisms as indicated in Fig. 4 is generally in good agreement with experimental data. This reasonable result can clarify the ambiguities of the PWBA method, and agrees with the qualitative effects observed by Graig(22) and Kitazawa(5).

It is felt that the success of the present simple reaction model in DWBA calculations has been suprisingly good so that it may be even more useful for

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(22) R. M. Craig, B. Hird, C. J. Kost and T.Y. Li, Phys. Letters 21, 177 (1966).

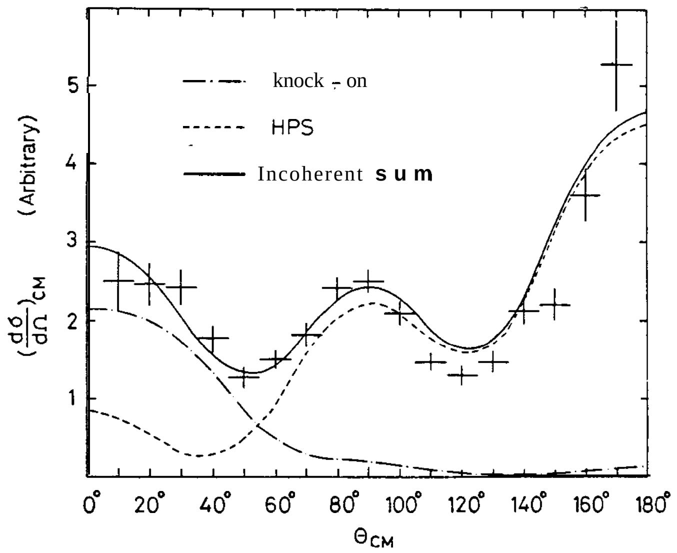

Fig. 4. Comparision of the experimental data and the incoherent summation of the knock-on and the HPS mechanisms by the DWBA method.

heavier targets. However, there are still several points improvable in the near future. Firstly, a better form factor may be obtained by binding a cluster with proper quantum numbers at the experimental separation energy in the Woods-Saxon potential(23). Secondly, it has been shown(13),(25) that the angular distribution in the (p,α) and (α,p) reactions, which are the similar reactions with the (n,α) reaction, depends on the total angular momentum transfer J. Therefore, the (n,α) reactions on light nuclei are suggested to have a strong J-dependence too.

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