Bull. Inst. Chem. Res., Kyoto Univ., Vol. 52, No. 1

The ^{9}Be(^{3}He, α)^{8}Be Reaction from 1.3 to 3.2 MeV

Naoki SAKAMOTO, Kouya OGINO, Michio TOMITA, and Takafumi INAGAKI*

Received December 17, 1973

The ^{9}Be(^{3}He, α)^{8}Be reaction has been studied in the bombarding energy range $1.3 \leqq E(^3\mathrm{He}) \leqq 3.2$ MeV. States at 27.9 and 28.1 MeV were found in the excitation functions for α_0 and α_1, respectively. The 27.9 MeV state was considered to have a natural parity and a large $T=0$ component. The 28.1 MeV state was considered to be an unnatural parity state with $J \geqq 1$ and with a $T=0$ component.

I. INTRODUCTION

The purpose of this experiment is to investigate the alpha-like structure of ^{12}C nucleus in a high excitation energy region. Since the ^{9}Be+^{3}He system corresponds to 26.3 MeV excitation of ^{12}C, the region from 27.3 to 28.7 MeV state in ^{12}C can be studied with ^{3}He particles from 1.3 to 3.2 MeV bombarding energy.

This region is the high energy tail of giant resonance and some peaks have been observed in the excitation functions for the ^{11}B(p, γ)^{12}C[1,2] and the ^{12}C(γ, p)^{11}B[3] reactions. It is noted that one peak indicating a resonance at 28 MeV excitation energy is observed in common.

Moreover, the ^{12}C(p, p$'\alpha$)^{8}Be reaction[4,5] was studied to investigate the properties of several of the excited states of ^{12}C in the giant resonance region. Epstein *et al.* have observed resonances at 21.1, 22.2, and 26.0 MeV excitation energies. Alpha yield corresponding to higher excitation energy is also obtained in this reaction. Therefore, one may expect to observe the alpha-like structure state of ^{12}C at about 28 MeV excitation energy.

The reasons preferred the ^{9}Be(^{3}He, α)^{8}Be reaction are as follows. In the ^{9}Be(^{3}He, α) reaction the low binding energy of the last neutron in ^{9}Be is expected to favor a direct interaction between the loosely bound neutron and the ^{3}He projectile. It was shown by Brown and Knowles[6] that the three cluster configuration $\alpha+\alpha+n$ is apparently preferred over the two cluster configuration ^{8}Be+n in the ^{9}Be ground state.

Therefore, the ^{9}Be(^{3}He, α)^{8}Be reaction is seemed to be more suitable than any other reactions to investigate the three alpha configuration in the ^{12}C nucleus.

II. EXPERIMENTAL PROCEDURE

The singly charged ^{3}He beam from the Kyoto University 4.0 MeV Van de Graaff

* 坂本直樹，荻野晃也，富田道男，稲垣孝文: Department of Nuclear Engineering, Faculty of Engineering Kyoto University, Kyoto.

accelerator was used to bombard ^9Be target. Self-supporting ^9Be targets were prepared by electron bombardment method of metalic ^9Be. As the target contained contaminations such as ^{12}C and ^{16}O, its thickness was found by observing Rutherford scattering. A value of $20.4 \pm 1.75\ \mu g/cm^2$ was adopted for the target thickness used in the cross section calculations.

After passing through the target the beam was collected and monitored in a standard Faraday cup system. Two silicon surface barrier detectors approximately 300 μm thick were used. These were thick enough to stop the high energy alpha particles from the (^3He, α) reaction on ^9Be but too thin to stop the high energy protons from the (^3He, p) reaction. Thin aluminium foils were placed in front of the detectors to stop the elastically scattered ^3He particles. The amplified output pulses from the detectors were shed into two multichannel pulse height analysers. The energy resolution of whole system is about 70 KeV full width at half maximum to α_0 peak, whose energy is approximately 11 MeV.

The excitation function for the $^9Be(^3He, {}^3He)$ reaction was measured at 80° with respect to the beam axis. The excitation functions for the $Be^9(^3He, \alpha)^8Be$ reaction were obtained at 15° and 165° for α_0, and 165° for α_1. The excitation function for the $^9Be(^3He, \alpha_3+\alpha_4)^8Be$ reaction (unresolved) was measured at $\theta=80°$ and $\theta=-106°$ in coincidence work in order to avoid superposition of protons and other particles from the ^3He induced reactions on ^9Be, ^{12}C, and ^{16}O. To improve the statistics differential cross sections were obtained by summing two peaks arising from the detection of $\alpha_3+\alpha_4$ at 80° and $-106°$.

The angular distributions of α_0 were roughly measured at bonbarding energies of 1.749, 2.124, 2.428, and 2.949 MeV. The differential cross sections given in this paper are in agreement with the values of Dorenbusch *et al.*[7] but slightly smaller than those of Weinman *et al.*[8] for α_0.

III. RESULTS

III.1 Energy Spectrum

A representative spectrum of alpha particles taken at 2.007 MeV bombarding energy and 165° is shown in Fig. 1. Because of detector thickness the high energy alpha particles are well separated from the high energy protons. The continuum would be due to alpha particles from the $^9Be(^3He, \alpha)^8Be \to \alpha+\alpha$ reaction. There is less difficulty in subtracting the continuum for α_0 peak; however, the subtraction is unreliable for α_1 peak owing to the uncertainty in the shape of this continuum.

Since the $^9Be(^3He, 3\alpha)$ reaction at low bombarding energies is known to proceed predominantly via a sequential process,[9] it is not proper to consider that the continuum is attributed to alpha particles from simultaneous break up process. Therefore, one can not make use of phase space factor for the shape of the continuum. It was found that the most consistent method of subtracting the continuum was by drawing it in by eye. The uncertainty was brought in the absolute values of the differential cross sections; however, these values were in good agreement with those of Dorenbusch *et al.*[7] and Weinman *et al.*[8]

In the energy region $1.5 \leqq E(^3He) \leqq 3.0$ MeV the energy spectrum of α_1 was fitted

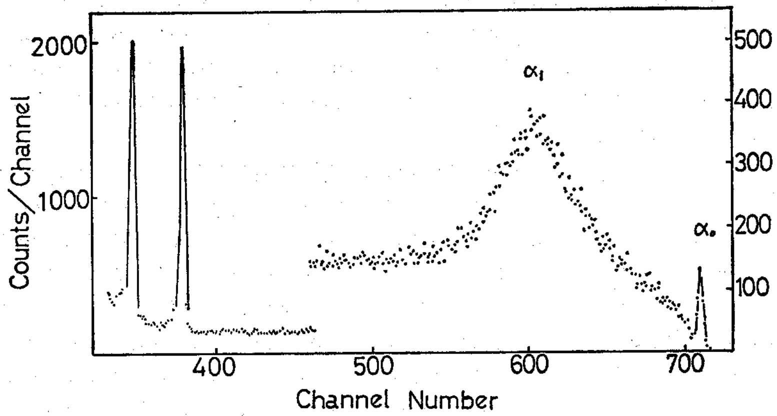

Fig. 1. Spectrum of alpha particles from the ^{9}Be(^{3}He, α)^{8}Be reaction at a bombarding energy of 2.007 MeV and a laboratory angle of 165°.

with a Gaussian distribution. Using the ground state Q-value of 18.913 MeV,[10] the excitation energy and the width of the first excited state of ^{8}Be were found to be 2.711 ± 0.031 MeV and 1.358 ± 0.51 MeV, respectively. No evidence was obtained as to the change of the width.

III.2 Excitation Function

Figure 2 shows the excitation function for the ^{9}Be(^{3}He, ^{3}He) reaction measured at 80°. The fact that it does not show any resonance behavior makes cross section calculations based on Rutherford scattering reliable. The excitation functions for the ^{9}Be(^{3}He, α)^{8}Be reaction were measured at 15° and 165° for α_0 and 165° for α_1 from 1.3 to 3.2 MeV bombarding energy. The results are shown in Fig. 3 and Fig. 4. The excitation function for the ^{9}Be(^{3}He, $\alpha_3+\alpha_4$)^{8}Be reaction was obtained at $\theta_1=80°$ and $\theta_2=-106°$ (Fig. 5).

The angular distributions were measured for α_0 at bombarding energies of 1.749, 2.124, 2.428, and 2.949 MeV to examine the property of the resonance-like peak in the excitation function. The total cross sections are shown in Fig. 6 and indicate the

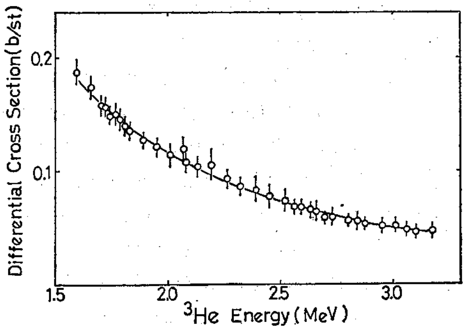

Fig. 2. The differential cross sections as a function of bombarding energy for the ^{9}Be(^{3}He, ^{3}He)^{9}Be reaction at a laboratory angle of 165°.

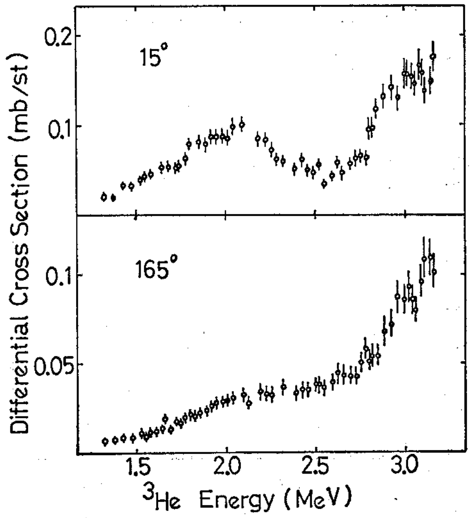

Fig. 3. The differential cross sections as a function of bombarding energy for the $^9Be(^3He,\alpha_0)^8Be$ reaction at laboratory angles of 15° and 165°.

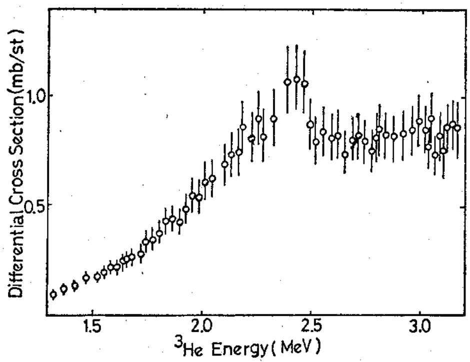

Fig. 4. The differential cross sections as a function of bombarding energy for the $^9Be(^3He, \alpha_1)^8Be$ rection at a laboratory angle of 165°.

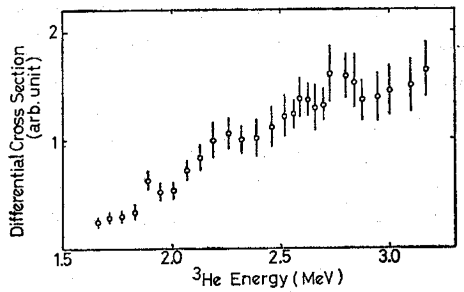

Fig. 5. The differential cross sections as a function of bombarding energy for the $^9Be(^3He, \alpha_3+\alpha_4)^8Be$ reaction at $\theta_1=80°$ and $\theta_2=-106°$.

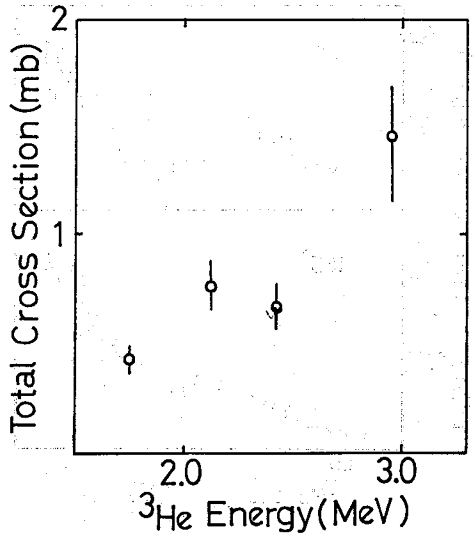

Fig. 6. The total cross sections as a function of bombarding energy for the ^{9}Be (^{3}He, α_0)^{8}Be reaction.

resonance. The main error arises from uncertainties in target thickness and continuum subtraction and from counting statistics. The absolute errors of the differential cross sections are shown in each figure and less than $\pm 15\%$ except the ^{9}Be(^{3}He, $\alpha_3+\alpha_4$) reaction.

IV. DISCUSSION

The excitation function for the ^{9}Be(^{3}He, α_0)^{8}Be reaction studied at 15° shows a significant resonance structure, while that measured at 165° shows little evidence of a resonance. This resonance corresponds to a level in the compound nucleus ^{12}C at 27.9 MeV excitation energy having a width of about 400 KeV. According to spin and isobaric spin conservation, this state may have a natural parity and a large $T=0$ component.

The excitation function for the ^{9}Be(^{3}He, α_1)^{8}Be reaction also shows a resonance possessing a narrower width than that for α_0. This resonance corresponds to a level at 28.1 MeV excitation energy in ^{12}C with a width of about 200 KeV. Moreover, the position of this resonance is at the dip part of the excitation function for α_0. An assignment of an unnatural parity state with $J \geqq 1$ could explain this observation.

At this excitation energy region a resonance has been observed in the reactions ^{9}Be(^{3}He, n)^{11}C[11,12], ^{9}Be(^{3}He, p)^{11}B,[13] ^{11}B(p, γ)^{12}C[1,2], and ^{12}C(γ, p)^{11}B[3]. These results indicate that the level is at 28.0 MeV excitation energy with a width of about 350 KeV.[10] Table I presents the summary of our results together with those reported by other experiments.

The 27.9 MeV state is seen in the ^{9}Be(^{3}He, n)^{11}C and the ^{9}Be(^{3}He, p)^{11}B reactions but not in the reactions ^{9}Be(^{3}He, γ)^{12}C[14] and ^{10}B(d, α)^{8}Be.[15] The excitation functions for the ^{9}Be(^{3}He, n) reaction were measured for E(^{3}He) from 1.2 to 2.7 MeV at

Table I. Comparison of ^{12}C Excitation Energies (in MeV).

$(^{3}He, \alpha_0)$[a]	$(^{3}He, \alpha_1)$[a]	$(^{3}He, n)$[b]	$(^{3}He, p)$[c]	$(^{3}He, \gamma)$[d]	(p, γ)[e]&(γ, p)[f]
27.9		27.9	27.9		
	28.1				28.0
				28.2	

a): Present Exp. b): References 11. 12 c): Reference 13
d): Reference 17 e): References 1. 2 f): Reference 3

$\theta_n = 0°$ and 81.5° by Duggan *et al.* Those measured at 0° showed a resonance structure, while those measured at 81.5° did not. These seem to imply the similarity of reaction mechanism between $(^{3}He, \alpha_0)$ and $(^{3}He, n)$ reactions on ^{9}Be. It is interesting that this state was not observed in the $^{10}B(d, \alpha)^{8}Be$ reaction. The $^{9}Be(^{3}He, \alpha)^{8}Be$ reaction would be more favorable than that reaction to form three alpha configuration.

Since the third and the fourth excited states of ^{8}Be are members of an isobaric spin doublet ($T=0$ and $T=1$),[16] $T=0$ and $T=1$ states can be observed by the $^{9}Be(^{3}He, \alpha_3+\alpha_4)^{9}Be$ reaction. Sufficient information as to such states were not obtained in the excitation function for that reaction. If the 28.1 MeV state has a $T=1$ component, it is expected that the state is excited more strongly in the $^{9}Be(^{3}He, \alpha_3+\alpha_4)^{8}Be$ reaction than in the $^{9}Be(^{3}He, \alpha_1)^{8}Be$ reaction. Therefore, the 28.1 MeV state is considered to have a $T=0$ component. Blatt *et al.* have recently studied the $^{9}Be(^{3}He, \gamma)^{12}C$ reaction[17] and suggested a 1^-, $T=1$ state of ^{12}C at 28.2 MeV with a width of about 1.6 MeV. Though any conclusion can not be drawn with confidence about the relation between this state and 28.1 MeV state, $T=1$ state would be excited relatively in the $^{9}Be(^{3}He, \alpha_5)^{8}Be$ reaction as well as the $^{9}Be(^{3}He, \alpha_3+\alpha_4)^{8}Be$ reaction. The study of these reactions will be performed in the near future.

The authors wish to express their thanks to members of Research Laboratory of Heavy Ions for technical support during the course of the experiment.

REFERENCES

(1) R. G. Allas *et al.*, *Nucl. Phys.*, **58**, 122 (1964).
(2) L. Feldman *et al.*, *Phys. Rev.*, **157**, 931 (1967).
(3) W. R. Dodge and W. C. Barber, *Phys. Rev.*, **127**, 1746 (1962).
(4) N. Epstein *et al.*, *Phys. Rev.*, **178**, 1698 (1969).
(5) S. Yamashita *et al.*, *Few-Particle Problems in the Nuclear Interaction* (North-Holland and American Elsevir, 1972) p. 1006
(6) L. B. Brown and H. B. K nowles, *Phys. Rev.*, **125**, 1339 (1962).
(7) W. E. Dorenbusch and C. P. Browne, *Phys. Rev.*, **131**, 1212 (1963).
(8) J. A. Weinman and R. K. Smither, *Nucl. Phys.*, **45**, 260 (1963).
(9) C. Moazed *et al.*, *Rev. Mod. Phys.*, **37**, 354 (1965).
(10) F. Ajzenberg-Selove and T. Lauritsen, *Nucl. Phys.*, **A114**, 43 (1968).
(11) J. L. Duggan *et al*, *Nucl. Phys.*, **46**, 336 (1963).
(12) G. U. Din and J. L. Weil, *Nucl. Phys.*, **71**, 641 (1965).
(13) N. A. Wolicki *et al.*, *Phys. Rev.*, **116**, 1585 (1959).
(14) J. L. Black *et al.*, *Nucl. Phys.*, **54**, 689 (1964).
(15) K. Takimoto *et al.*, private communication.
(16) W. D. Callender and C. P. Browne, *Phys. Rev.*, **C2**, 1 (1970).
(17) S. L. Blatt *et al.*, *Phys. Rev.*, **C6**, 1536 (1972).