Differential Cross Section for the $C^{13}(He^3,\alpha)C^{12}$ Reaction at 2.00 Mev

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(Received December 31, 1956)

The differential cross sections for the $C^{13}(He^3,\alpha)C^{12}$ reaction have been measured for ground state and first excited state α-particle groups at a bombarding energy of 2.00 Mev for sixteen center-of-mass angles extending from 5 to 152 degrees. These data have been fitted with Legendre polynomial expansions including polynomials up to the sixth degree by the method of least-squares. The coefficients in these expansions and the total cross sections are tabulated.

RECENT work[1,2] on the $Be^9(He^3,p)B^{11}$ reaction has suggested the possibility that this reaction may take place partly by a direct process. If this is the case, then it is possible that (He^3,α) reactions may also proceed by a direct process, particularly those reactions in which the target nucleus has a loosely bound neutron, such as Be^9, C^{13}, or O^{17}. It will be shown in the following paper,[3] however, that it is difficult to account for this type of reaction on the basis of the ordinary concept of pickup reactions.

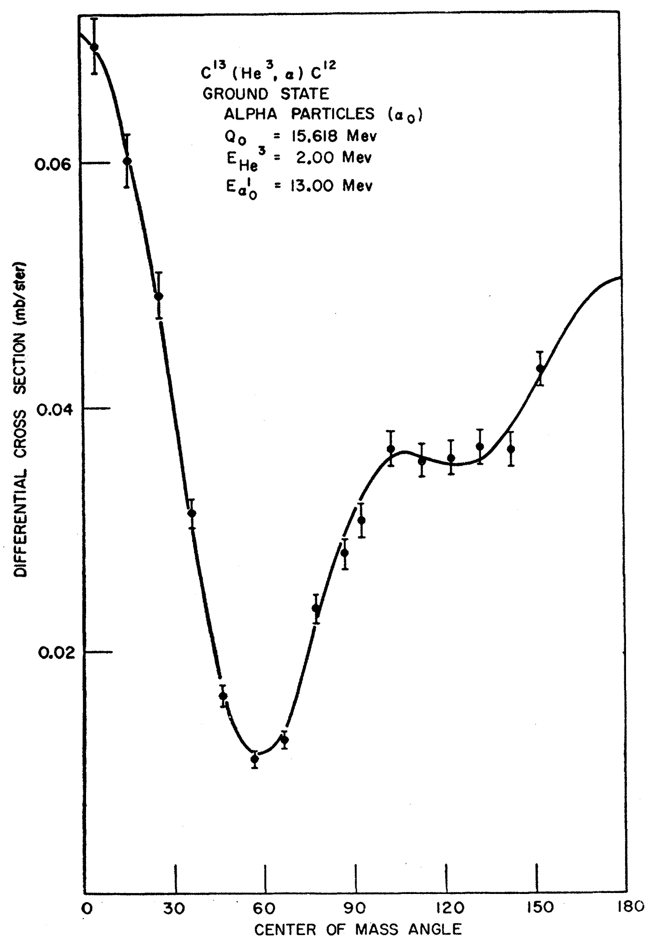

FIG. 1. The differential cross sections for the α particles from the $C^{13}(He^3,\alpha)C^{12}$ reaction which leave C^{12} in the ground state. Q_0 is the ground-state Q value for this reaction, E_{He^3} is the bombarding energy, and E'_{α_0} is the energy of the ground-state α particles in the center-of-mass system.

Early attempts to investigate the angular distributions of the α particles from the $Be^9(He^3,\alpha)Be^8$ reaction at this laboratory were unsuccessful. The ground state α-particles group was found to have a very low yield and was difficult to identify due to the large yield of short range protons. The α particles corresponding to the first excited state of Be^9 were difficult to identify due to the rather large yield of the three-body-breakup α particles. The angular distributions of the α-particle groups from the $C^{13}(He^3,\alpha)C^{12}$ reaction were considerably easier to investigate, since the α particles resulting from three- or four-body breakup have very low energies.

The experimental procedure for studying the angular distributions was almost identical to that described in the $Be^9(He^3,p)B^{11}$ paper[1] except that Ilford E1 nuclear emulsions were used to record the α particles. The thin C^{13} targets used for this phase of the investigation were prepared by cracking methyl iodide enriched to 66% C^{13} onto 5-micro-inch nickel foils. One of the Naval Research Laboratory's 2-Mv Van de Graaf accelerators was used.

In order to determine the absolute cross sections for the $C^{13}(He^3,\alpha)C^{12}$ reactions the α-particle yields were measured from a second C^{13} target whose thickness was easier to determine. The C^{13} enriched methyl iodide was cracked onto a 50-microinch foil, and the carbon deposit on the back of the foil was peeled off in order to obtain a single thin layer of carbon. The yields of the α particles from this target were then measured in a small reaction chamber with CsI crystal counters placed at 30, 60, and 120 degrees. Leaving the target in place, the average thickness of carbon deposit on this target was then found to be 35 $\mu g/cm^2$ by measuring the height and area of the 1.745-Mev resonance of the $C^{13}(p,\gamma)N^{14}$ reaction. In addition, the yield of the protons from the $C^{13}(d,p)C^{14}$ reaction was measured for the target in the same position. The differential cross sections for the $C^{13}(d,p)C^{14}$ reaction, determined on the basis of these measurements at five angles, were

[1] Holmgren, Bullock, and Kunz, Phys. Rev. **104**, 1446 (1956).
[2] Wolicki, Geer, Holmgren, and Johnson, Bull. Am. Phys. Soc. Ser. II, **1**, 196 (1956).
[3] Holmgren, Geer, Johnston, and Wolicki, Phys. Rev. **106**, 102 (1957).

found to be about 25% lower than those determined by Marion and Weber.[4]

The differential cross sections for the $C^{13}(He^3,\alpha)C^{12}$ reactions which leave the C^{12} nuclei in the ground state and first excited state are given in Fig. 1 and Fig. 2. The solid lines in these figures represent Legendre polynomial expansions fitted to the experimental data by the method of least-squares. It was necessary to include polynomials of the sixth degree in order to obtain a reasonable fit to these data. The coefficients for these expansions and the total cross sections are given in Table I for each group of α particles.

The uncertainties indicated in the above figures are the relative uncertainties. They include the statistical uncertainty in the number of tracks counted, the uncertainty in the determination of the solid angles of the cameras, and an estimated counting uncertainty of 1%. The square roots of the sums of the squares of these uncertainties range from 2.5 to 6%. The differential cross section for the first excited state α-particles groups at 152 degrees is somewhat more uncertain than indicated due to the fact that at this angle these α particles had very short ranges in the emulsion and were difficult to distinguish from the protons of the same range. This uncertainty may be as large as 10%. The uncertainty in the determination of the absolute cross sections is due mainly to the uncertainty in the measurement of the number of target nuclei per square centimeter. This uncertainty is estimated to be of the order of 25%.

TABLE I. Total cross section and coefficients of Legendre polynomial expansion of differential cross section for each group of α-particles in the reaction $C^{13}(He^3,\alpha)C^{12}$. $E_{He^3}=2.00$ Mev. $\sigma(\theta)=(\sigma_0/4\pi)[P_0+a_1P_1(\cos\theta)+a_2P_2(\cos\theta)+\cdots]$.

Group	σ_0(mb)	a_1	a_2	a_3	a_4	a_5	a_6
α_0	0.40	−0.26	+0.45	+0.59	+0.57	−0.02	−0.06
α_1	1.32	−0.04	+0.09	+0.64	−0.08	+0.27	−0.02

It is obvious from the foregoing figures that the angular distributions of the α particles from these reactions are not symmetrical about 90 degrees. Both angular distributions are peaked in the forward direction and exhibit a minimum in the region of 60 degrees. Rather incomplete data for the second excited state α-particle group indicates similar behavior of the angular distribution for this group at small angles. It is also of interest to note that the total cross section of the first excited state group is more than three times as large as that for the ground state group. A discussion of these results is found in the following paper.[3]

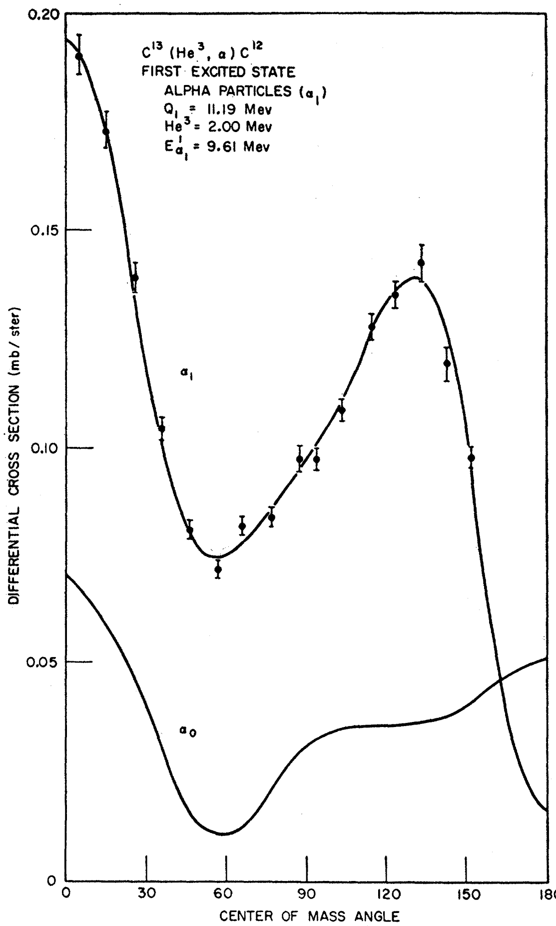

FIG. 2. The differential cross sections for the first excited state α particles from the $C^{13}(He^3,\alpha)C^{12}$ reaction. Q_1 is the Q value for this reaction when C^{12} is left in the first excited state, E_{He^3} is the bombarding energy, and E'_{α_1} is the energy of the first excited state α particles in the center-of-mass system.

The author wishes to thank Dr. J. W. Butler, Dr. E. Geer, Dr. E. Wolicki, Dr. R. Gossett, and Mr. R. Johnston for their help during the course of the experiment.

[4] J. B. Marion and G. Weber, Phys. Rev. **103**, 167 (1956). This discrepancy is about the same as our estimated uncertainties in the measurement of the target thickness and may indicate that the values of the cross sections for $C^{13}(He^3,\alpha)C^{12}$ reactions reported in this paper should be increased by about 25%.