INVESTIGATION OF THE $C^{12}(t, \alpha)B^{11}$ REACTIONS

K. NIEDZWIEDZIUK, V. I. SALATSKIĬ, and I. V. SIZOV

Joint Institute for Nuclear Research

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Differential cross section for the $C^{12}(t, \alpha_0)B^{11}$ and $C^{12}(t, \alpha_1)B^{11*}$ reactions are measured at 90° in the laboratory system for tritium ion energies between 0.3 and 1.2 MeV. Angular distributions of α-particles corresponding to formation of a residual B^{11} nucleus in the ground state are measured for some energy values in the indicated range, and total cross sections for the reaction are obtained.

THE present work is a continuation of a detailed investigation of the interaction between tritium nuclei and carbon at low bombarding-particle energies, aimed at obtaining data for the study of the mechanism of these reactions.

In a previous paper[1] devoted to the $C^{12}(t, p)C^{14}$ reaction, a complicated relationship was established between the proton angular distributions and the bombarding-particle energy. It was noted that even at low energies the reaction could not be completely described by using the compound-nucleus concept, and that the direct processes made a definite contribution. It is natural to assume that the tritium-carbon reaction may have a complicated mechanism in other channels, too. Indeed, it is indicated in a recent paper by Gutsche et al[2] that the angular distributions of the α particles from the $C^{12}(t, \alpha)B^{11}$ reactions have a complicated character in the range of tritium ion energies from 800 to 2025 keV.

The present experiments were performed at lower tritium bombarding energies and the aim was to obtain data on the differential and total cross sections of these reactions at energies below the Coulomb barrier of C^{12} for tritium.

EXPERIMENTAL TECHNIQUE

The tritium ions accelerated in an electrostatic generator bombarded a thin carbon target without a substrate, mounted at 45° to the incident beam of tritium ions.

The target was made by evaporating graphite in vacuum on a glass plate[3]. The thickness of the carbon films in different series of measurements was 15 to 25 $\mu g/cm^2$. These films had sufficient mechanical strength and withstood a 1 μA tritium-ion current on an area of approximately 3 mm^2, with negligible bombarding-particle energy loss. A solid carbon-film target was used to measure the relative yield and the angular distributions of the α particles from the reaction. The absolute values of the differential cross sections were obtained for several tritium-ion energies with a CH_4 or CO_2 gas target. The gas pressure in the target was approximately 60 mm Hg and was measured with a mercury manometer. The exit window of the target was sealed with a mica film approximately 0.13 mg/cm^2 thick. The energy losses in this film were measured with a magnetic analyzer installed behind the target chamber.

The differential cross sections of the $C^{12}(t, \alpha_0)B^{11}$ and $C^{12}(t, \alpha_1)B^{11*}$ reactions were measured at 90° in the laboratory system with a previously employed chamber[4]. The α particles were recorded with silicon surface-barrier semiconductor detectors prepared at the Nuclear-reaction Laboratory of the Joint Institute for Nuclear Research. Pulses from the detector were fed after amplification to a 50-channel pulse-height analyzer. Two groups of α particles (α_0 and α_1) were observed in the reaction and corresponded to the formation of a residual B^{11} nucleus in the ground and 2.13-MeV first excited states.

Figure 1 shows typical α-particle spectra measured with the gas target. In some cases the initial part of the spectrum was measured with the analyzer in an enlarged scale to separate better the α-particle groups corresponding to the formation of B^{11} in the first excited state.

A chamber with two semiconductor detectors was used for the measurements of the angular distribution of the α particles. One, mounted at 90° to the tritium-ion beam, was used as a monitor. The other was rotated around the target in the angle range 0—155°. The pulses from this detector were fed to the pulse-height analyzer.

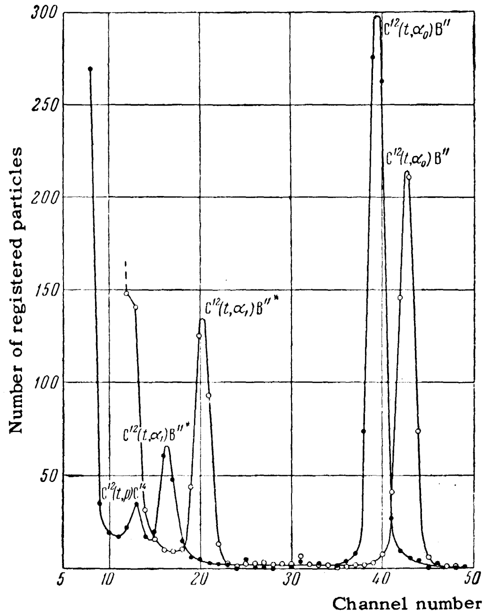

FIG. 1. Spectra from gas targets filled with methane. • – E_t = 669 keV (vertical scale 1:1), o – E_t = 1100 keV (vertical scale 1:5).

MEASUREMENT RESULTS

Figure 2 shows a plot of the differential cross section of the $C^{12}(t, \alpha_0)B^{11}$ reaction against the tritium-ion energy at 90° in the laboratory system. The curve is characterized by a sufficiently pronounced maximum at E_t = 0.66 ± 0.01 MeV, which may be connected with the 15.38 ± 0.01 MeV excited level of the compound nucleus N^{15}. This level is apparently identical with the 15.37-MeV level observed in the $B^{11}(\alpha, n)N^{14}$ reaction[5].

Particular attention was paid to measurements in the 1.1-MeV energy region. Unlike the $C^{12}(t,p)C^{14}$ and $C^{12}(t, \alpha_1)B^{11*}$ reactions, the differential cross section curve of the $C^{12}(t, \alpha_0)B^{11}$ reaction does not have a maximum in this region.

Figure 3 shows the differential cross section of the $C^{12}(t, \alpha_1)B^{11*}$ reaction. A rapid rise is observed on the differential cross section vs. energy curve in the region between 420 and 660 keV. In the 660—900 keV region the cross section remains practically constant, with weak maxima at approximately 670 and 850 keV. A sharp resonance is observed at 1.1 MeV and can be ascribed to the 15.74-MeV excited level of the compound nucleus N^{15}.

Figure 4 shows the distributions of the α particles from the $C^{12}(t, \alpha_0)B^{11}$ reaction for several tritium-ion energies. The relative angular distributions, measured on a solid target, were normalized to the absolute differential cross sections with the aid of the curve of Fig. 2. The measurements

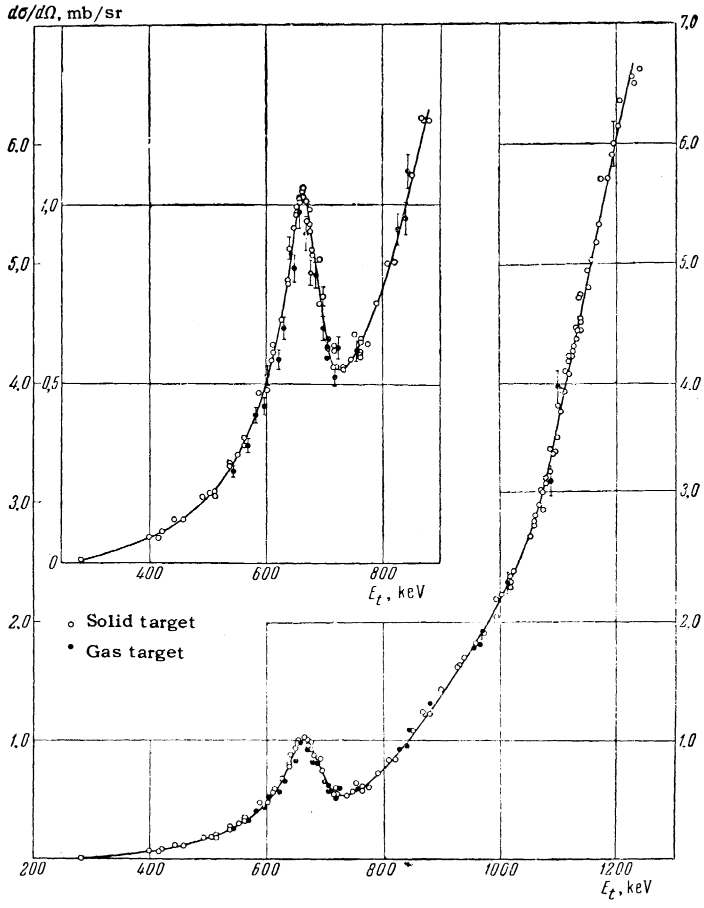

FIG. 2. Differential cross sections of the $C^{12}(t, \alpha_0)B^{11}$ reaction at 90° in the l.s.

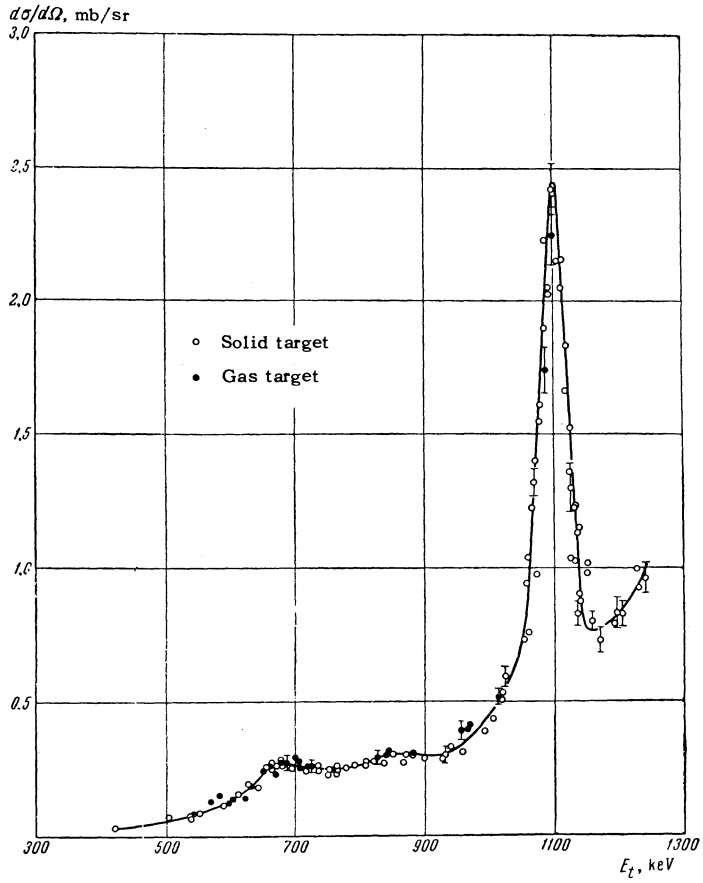

FIG. 3. Differential cross section of the $C^{12}(t,\alpha_1)B^{11*}$ reaction at 90° in the l.s.

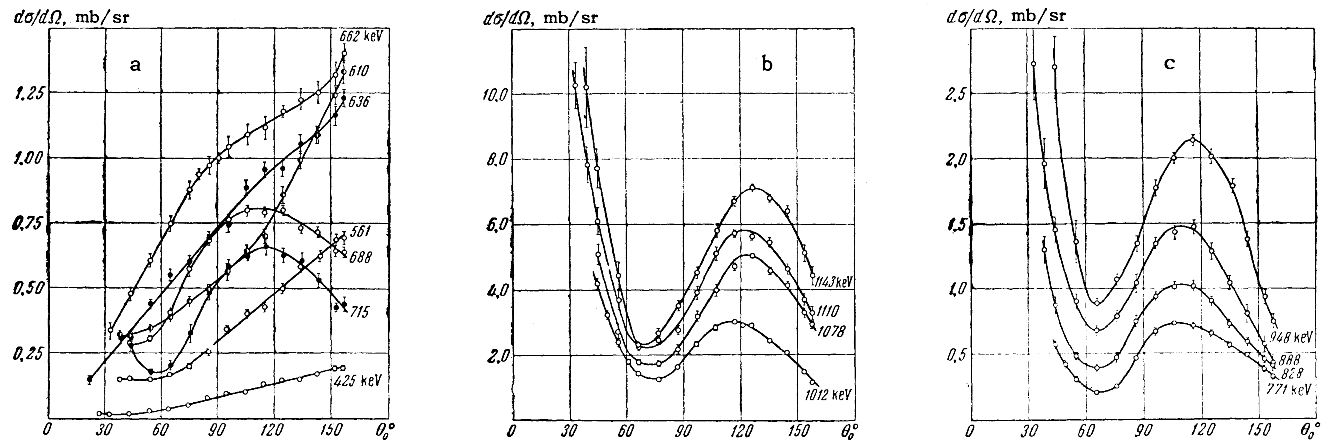

FIG. 4. Angular distributions of α particles from the $C^{12}(t,\alpha_0)B^{11}$ reaction for different tritium energies (angle in c.m.s.)

covered the angle interval approximately from 35 to 155°. The region of small angles was limited by the possibility of separating the α particles from the tritium nuclei scattered by the carbon. The upper angle limit was determined by the construction of the target chamber.

The angular distributions are asymmetrical with respect to the 90° angle in the c.m.s. and depend strongly on the energy of the bombarding particles.

To obtain the total reaction cross sections the angular distributions were expanded in Legendre polynomials and integrated. An electronic computer was used. The table lists the total reaction cross sections and the expansion coefficients ($a_0 - a_5$).

The data of the present paper partly overlap the results of Gutsche et al[2] (for the 0.8–1.2 MeV region). We cannot make a detailed comparison of our experimental results with the literature data, since the latter are in the form of small-scale plots. At the accuracy with which data can be obtained from these plots, the results of both investigations are in good agreement.

E_t, keV	a_0	a_1	a_2	a_3	a_4	a_5	σ, mb
425±8	—	—	—	—	—	—	1.09±0.08
561±9	—	—	—	—	—	—	4.4±0.3
610±10	0,617±0,008	—0.48±0.02	0,24±0.03	—0.08±0.03	0,07±0.03	0.01±0.03	7,8±0.3
636±10	0,709±0,007	—0,52±0.01	—0.04±0,02	—0.08±0,02	0.00±0.02	—0,03±0.02	8.9±0,4
662±10	0,925±0,009	—0,57±0.02	—0,17±0,02	—0,12±0.04	0,06±0,03	—0.05±0.05	11,6±0.5
688±10	0,607±0.006	—0.18±0.01	—0,10±0.01	0.33±0,02	0,13±0,02	0.12±0,03	7,6±0.3
715±12	0,47±0.01	—0.10±0.04	0.06±0.05	0,43±0.06	0.15±0,04	0,06±0,04	5,9±0.3
771±13	0.58±0.01	0,16±0,04	0.29±0,05	0.72±0,06	0,24±0.05	—0,01±0.04	7,3±0.3
828±14	0,87±0.02	0.38±0.07	0.48±0.09	1,11±0,09	0.45±0,08	0.04±0.06	11.0±0.6
888±15	1,31±0.04	0,67±0.09	0,66±0,12	1,6±0.1	0.44±0,12	0.06±0.10	16,4±0.8
948±16	2,1±0.1	1,48±0,27	1,3±0,3	3,0±0.3	1.0±0,2	0,4±0.1	26,3±1.6
1012±17	2,90±0.06	2,0±0,2	2,5±0.2	3.5±0,2	0,5±0,2	— 0,1±0.1	36±2
1078±18	3.91±0,09	0.9±0.2	2,9±0,3	4,0±0,3	0.1±0,3	0.0±0,2	49±2
1110±19	5,01±0,07	2.0±0,2	4,0±0.2	5,4±0,3	0,5±0.2	0,3±0.2	63±2
1143±20	6,26±0.18	2,8±0,4	6.4±0,6	7,9±0,6	2.0±0,5	1,2±0,4	78±4

The experimental results presented indicate that the interaction between the tritium nuclei and carbon has a complicated character. Pronounced resonances appear in the excitation functions of the $C^{12}(t, \alpha_0)B^{11}$ and $C^{12}(t, \alpha_1)B^{11*}$ reactions at N^{15} excitation energies 15.37 and 15.74 MeV, respectively. In spite of the isolated nature of these resonances and the low bombarding-particle energy, the form of the angular distributions and the character of their energy dependence cannot be described by the model of isolated compound-nucleus level. For the $C^{12}(t, \alpha_0)B^{11}$ reaction this follows from the analysis of the coefficient of the Legendre-polynomial expansion of the angular distributions. This analysis does not make it possible to determine uniquely the spin of the 15.37-MeV level of N^{15}, but the value $3/2$ does not contradict the experimental data. It must be noted that the same resonance appears in the $B^{11}(\alpha, n)N^{14}$ reaction[5]. We can therefore conclude that the excited state of N^{15} corresponds with high probability to the $\{B^{11} + \alpha\}$ configuration. On the other hand, this resonance is not observed in $C^{12}(t, \alpha_1)B^{11*}$ but at the 15.74-MeV excited level of N^{15} there is a resonance which does not exist for the $C^{12}(t, \alpha_0)B^{11}$ and $B^{11}(\alpha, n)N^{14}$ reactions[5].

The $\{B^{11*} + \alpha\}$ configuration may seem preferable for the 15.74-MeV level of N^{15}. We thus come up in these reactions against the problem of the structure of the excited states of N^{15} and the influence of this structure on the reaction mechanism. Indeed, if we disregard the resonances, the ratio of the total cross sections of the $C^{12}(t, \alpha_0)B^{11}$ and $C^{12}(t, \alpha_1)B^{11*}$ reactions in the investigated energy region amounts on the average to 3—5 and increases to approximately 10 with increasing energy[2]. The total cross sections of the $C^{12}(t, \alpha_0)B^{11}$ reaction exceed 2—5 times the cross sections for the $C^{12}(t, p)C^{14}$ reaction and are approximately double the total cross sections of the $C^{12}(t, n)N^{14}$ reaction. On the other hand, the kinematic hindrances connected with the penetrance of the compound-nucleus barrier are stronger for α particles and protons, and all the more for neutrons. The relations noted above between the total cross sections for the different reaction channels, and also the character of the angular distributions of the α particles and their dependence on the energy, indicate that a noticeable contribution is made by the direct processes. The theoretical analysis is complicated in this case by the large Coulomb and nuclear distortions due to the low energy of the bombarding particles, but some preliminary conclusions can be drawn. The relatively large values of the cross sections of the $C^{12}(t, \alpha_0)B^{11}$ reactions indicate that the most probable mechanism is the direct knock-on of an α particle, while for the $C^{12}(t, \alpha_1)B^{11*}$ the most probable mechanism is pickup connected with the disintegration of the α-particle group in the N^{15} nucleus.

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