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NEUTRONS FROM THE $C^{12}(t, n)$ *REACTION*

P. I. VATSET, L. Ya. KOLESNIKOV, and S. G. TONAPETYAN

Physico-Technical Institute, Academy of Sciences, Ukrainian S.S.R.

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The neutron yield at an angle of 0° from the $C^{12}(t, n)$ reaction has been studied over a range of triton energies from 0.37 to 2.4 Mev. Seven resonances were observed corresponding to excited states of N^{15} with excitation energies of 15.887, 15.955, 16.066, 16.206 16.326, 16.430, 16.582, 16.67, and 16.77 Mev. For five values of the energy of the bombarding tritons we measured the angular distributions of the neutrons. It was established that the angular distributions for triton energies greater than 1 Mev are anisotropic, and that for energies above 1.5 Mev they are characterized by a marked predominance of neutrons in the backward direction. From the angular distributions we have determined the value of the total cross section of the reaction, which is equal to 4.8 ± 0.2 mb for $E_t = 0.652$ Mev and increases to 298.6 ± 19.7 mb for $E_t = 2.017$ Mev.

THE use of tritium in nuclear reactions as a bombarding particle is unquestionably of interest for nuclear spectrometry. In the interaction of tritons with nuclei one studies mainly reactions with yield of charged particles, whereas a study of the yield of neutrons has been comparatively slighted in the various papers.[1-6]

In the present paper we discuss the results of experiments on the yield of neutrons from the reaction

$$C^{12} + H^3 \rightarrow N^{15} \rightarrow N^{14} + n, \qquad Q = 4.007 \text{ Mev}. \qquad (1)$$

The minimum energy of excitation of the intermediate nucleus in reaction (1) is 14.848 Mev.[7] Measurement of the excitation function made it possible to obtain information concerning excited levels of the intermediate nucleus N^{15} with energies of excitation above this minimal energy. The study of the angular distributions of the outgoing neutrons for various triton energies made it possible to determine the total cross section for the $C^{12}(t, n)$ reaction for the corresponding triton energies.

The fact that in experimental practice one frequently observes a deposit of carbon on the target bombarded by accelerated ions makes the study of the reaction of tritons with carbon of technical interest.

Despite the high effective potential barrier for tritons on carbon, equal to 3.14 Mev, the yield of neutrons from the $C^{12}(t, n)$ reaction is sizable in the range of lower energies of impinging particles.

ARRANGEMENT OF THE EXPERIMENT AND RESULTS OF THE MEASUREMENTS

The arrangement of the experiment, the measurement technique, and the analysis of the background neutrons has been discussed in detail previously.[4,5]

In the studies we used targets of carbon which were deposited on a platinum disk 16 mm in diameter and 0.2 mm thick by using a smoky flame from a burner while burning purified benzene. To eliminate possible dirtying of the target, it was heated at a temperature somewhat lower than the ignition temperature of carbon. The target thickness was determined by weighing on a microbalance. The additional weight of the target was checked by the relative yield of neutrons per unit weight of target for a single triton energy.

In the experiments we used targets of thickness 0.14, 0.195, 0.22, and 0.24 mg/cm^2, in which the energy losses for tritions with an energy of 1.6 Mev were respectively 49, 66, 75, and 82 kev.

In Fig. 1 is shown the dependence on triton energy of the differential cross section for the yield of neutrons at an angle of 0°.

The differential cross section increases slowly from 0.22 ± 0.13 to 2.31 ± 0.24 mb/sr as the triton energy increases from 0.450 to 1.055 Mev, and then increases sharply, reaching a value of 56.4 ± 2.7 mb/sr for a triton energy of 2.371 Mev. The absolute errors of the cross section determination vary from 18 to 10% within the interval of triton

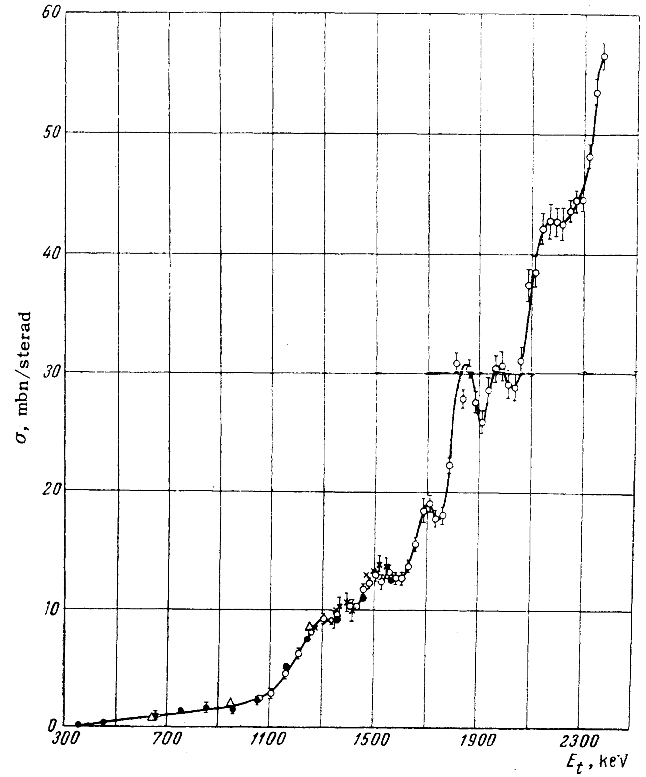

FIG. 1. Differential cross section for neutron yield at an angle of 0° from the reaction C^{12} (t,n) for target thicknesses: × – 0.14, ● – 0.195, ○ – 0.22, Δ – 0.24 mg/cm².

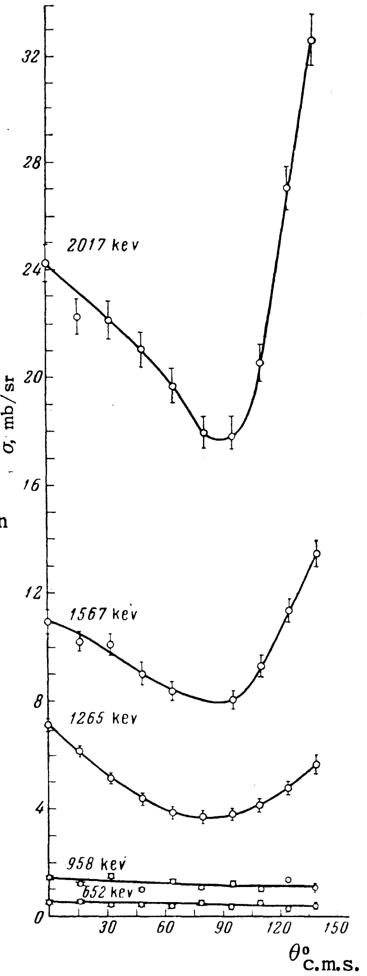

FIG. 2. Angular distributions in the C^{12} (t,n) reaction in the c. m. s.

energies from 0.650 to 1.1 Mev, and from 10 to 5% in the energy interval from 1.1 to 2.371 Mev.

In the determination of the absolute uncertainties, the error in determining the number of carbon nuclei was assumed to be ± 3%, the error in determining the number of tritons incident on the target ± 1%, the error in determining the strength of the standard Ra + Be source by which we calibrated the neutron detector was ± 3%, the error in determining the triton energies was ± 0.5%. No corrections were made for the yield of neutrons from the C^{13}(t, n) reaction.

On the excitation curve of the C^{12}(t, n) reaction we observe resonances for triton energies of 1.300, 1.385, 1.525, 1.700, 1.850, 1.980, and 2.170 Mev. In addition, the behavior of the experimental points indicates the presence of a resonance for a triton energy of 2.28 Mev, and finally the rise in the excitation function above 2.3 Mev gives a basis for assuming the existence of a resonance in the region of 2.4 Mev. To these resonances there correspond highly excited levels in N^{15}, whose energies are given in the table. In the same table, in the second column, we give the energy levels of N^{15} found by other authors (from the B^{11}(α, n) N^{14} reaction — the data of Haddad et al. given in reference 7, the N^{14}(n, α) B^{11} reaction — data from reference 8, C^{13}(d, p)C^{14},[9] and C^{13}(d, n) N^{14},[7,10] including the data from the latest paper of Ajzenberg and Lauritsen.[11]

There is no information in the literature concerning the energy level at 15.887 Mev. The level at 16.206 Mev has not previously been mentioned, but its presence is confirmed by the weak reso-

Energies of levels in N^{15} (Mev)

Data of the present work	Data from the literature	Data of the present work	Data from the literature
—	15.61 [7,11]	12.206±0.020	(16.24)[8]
15.887±0.018	—	16.326±0.021	16.38 [8,11]
—	15.92 [7,11]	16.430±0.022	16.47 [9] } 16.50[11]
15.955±0.019	15.93 [7,11]	16.582±0.023	16.59 [8]
—	15.99 [7,11]	16.67±0.03	16.67[8] } 16.69[11]
16.066±0.020	16.04[7], 16.06[8], 16,05[11]	16.77±0.05	16.72[10]

nance in the excitation function of the $N^{14}(n, \alpha)B^{11}$ reaction[8] for an α particle energy of ~ 5.8 Mev, which was not pointed out by the authors. The remaining levels, as one sees from the table, coincide within the limits of experimental error with those given in the literature. (For example, in the work of Gabbard et al.,[8] the error in the determination of the energy of the levels exceeds ± 70 kev.)

In Fig. 2 are shown angular distributions of the neutrons in the center of mass system from the $C^{12}(t, n)$ reaction, obtained for triton energies of 0.652, 0.958, 1.265, 1.567, and 2.017 Mev over an angular range from 0 to 135° with respect to the incident triton beam. For triton energies of 0.652 and 0.958 Mev the angular distributions are isotropic within the limits of error of the measurements. With increasing energy of the tritons the relative yield of neutrons at angles 0 and 135° increases.

A characteristic feature of the angular distribution is the increase in neutron yield in the backward direction with increasing triton energy. Thus for a triton energy of 1.265 Mev the angular distribution curve is almost symmetric around 90°. For an energy of 1.567 Mev the ratio of the differential cross section for neutrons at 135° to the cross section for neutrons at 0° becomes equal to 1.18, while for an energy of 2.017 Mev this ratio increases to a value of 1.28.

On the basis of the neutron angular distributions we obtain computed values for the total cross section for the yield of neutrons from the $C^{12}(t, n)$ reaction. For triton energies of 0.652, 0.958, 1.265, 1.567, and 2.017 Mev these cross sections are equal respectively to 4.9 ± 0.2, 14.6 ± 0.7, 59.6 ± 2.7, 129.5 ± 6.2, and 298.6 ± 19.7 mb.

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