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INVESTIGATION OF THE $He^3 + H^3$ *REACTION*

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Using a thin gas target, the total cross section for the $He^3 + H^3$ reaction was determined over the range of triton energies from 150 to 970 kev. In this energy interval, the total cross section increases monotonically from 3.2 to 63.0 mb. The energy dependence of the ratios of cross sections for different branches of the reaction were measured. We determined the energy of the decay of He^5 into an α particle and a neutron.

THERE have been just two experimental papers on the reaction

$$He^3 + H^3 \rightarrow Li^6 \rightarrow He^4 + H^2 + 14.31\ \text{Mev}, \quad (1)$$

$$\rightarrow He^4 + H^1 + n + 12.08\ \text{Mev}, \quad (2)$$

$$\rightarrow He^5 + H^1 + Q \downarrow He^4 + n + Q'. \quad (3)$$

The work of Almqvist et al.[1] is qualitative. In the work of Moak,[2] which was carried out on a solid lithium target, values were obtained for the total cross section of the $He^3 + H^3$ reaction and for the ratio of the cross sections for various branches of the reaction, and the energy of decay of He^5 into an α particle and a neutron was determined. The precision in the determination of the total cross section is estimated to be $\pm 20\%$.

The present work, unlike these preceding efforts, was carried out on a thin gas target. The total cross section for the reaction was determined by the method of integral counting of neutrons from the branches (2) and (3) of the reaction, taking account of the ratio between the various reaction branches. This ratio was found from the spectra of charged particles measured at an angle of 90° in the laboratory system. On the basis of the measured spectra of reaction products, an estimate was made of the energy of decay of He^5 into an α particle and a neutron. As a control experiment, we measured under the same conditions using the integral method the cross section for the reaction $H^2 + H^3$.

EXPERIMENTAL METHOD

Tritium ions accelerated by an electrostatic generator, after passing through a series of limiting diaphragms, entered the entrance window of the gas target. The thin gas target was placed in a vacuum chamber located in the center of a tank containing a 2% aqueous solution of $KMnO_4$. At an angle of 90° to the direction of the triton beam we placed a FÉU-25 photomultiplier with a CsI crystal, which served as a monitor to check the constancy of the yield of reaction products. The entrance window of the gas target was covered by a nickel foil $0.9 - 1.4$ mg/cm^2 thick. The side window of the target which faced the scintillation counter was covered by a nickel foil 1 mg/cm^2 thick. The energy dependence of the energy loss of the tritons in the foils was determined by using an auxiliary magnetic analyzer.[3] A thermocouple was inserted in the gas target for determining its temperature. The target was filled with a 100% concentration of He^3 to a pressure of 60 mm of Hg.

The energy loss of the tritons in the gas target filled with He^3 was determined from the computed curve.[4] The flux of neutrons resulting from the

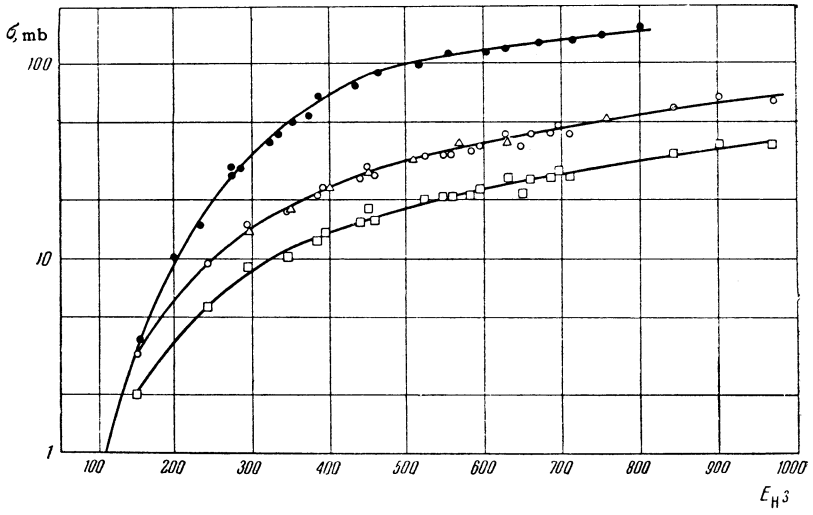

FIG. 1. Cross sections for the $He^3 + H^3$ reaction as a function of triton energy E_{H^3}; ● – total cross sections after Moak[2]; □ – cross sections for neutron branches; o – total cross sections obtained from the cross sections for the neutron branches and the ratio between the various reaction branches; △ – total cross sections obtained by counting charged particles.

interaction of H^3 and He^3 nuclei was determined in relative units by measuring the β activity induced in the manganese in the $KMnO_4$ solution. The absolute value of the neutron flux from the target was obtained by comparing it with the flux from a standard Ra + Be source in the same solution. To determine the ratio between the various reaction branches and also to measure the differential cross section we used a spectrometer consisting of a FÉU-S photomultiplier and a CsI crystal. The crystal was 20 mm in diameter and 1.8 mm thick. The spectrometer was placed at an angle of 90° with respect to the beam of accelerated tritons. In measuring the energy spectra, pulses from the photomultiplier passed through a cathode follower and amplifier, and entered a 50-channel pulse analyzer. The whole system was calibrated in energy and had excellent linearity.

RESULTS OF THE MEASUREMENTS

Figure 1 shows the results of measurements of cross sections for the neutron branches of the reaction, obtained by integral counting of neutrons.[5,6] The root mean square error of the measurements is ±5% in the energy range 240 – 970 kev, and ±31% at 149 kev.

The ratios of the various branches for the $He^3 + H^3$ reaction (as a function of the energy of the incident tritons) was determined from measurements of the energy spectrum of charged particles at an angle of 90° in the laboratory system. One such spectrum is shown in Fig. 2. The spectrum of particles has two peaks, due to the α particles and deuterons of branch (1). Between these peaks there is a continuous spectrum of protons from branch (2). The proton peak, corresponding to the ground state of He^5, is close in energy to the

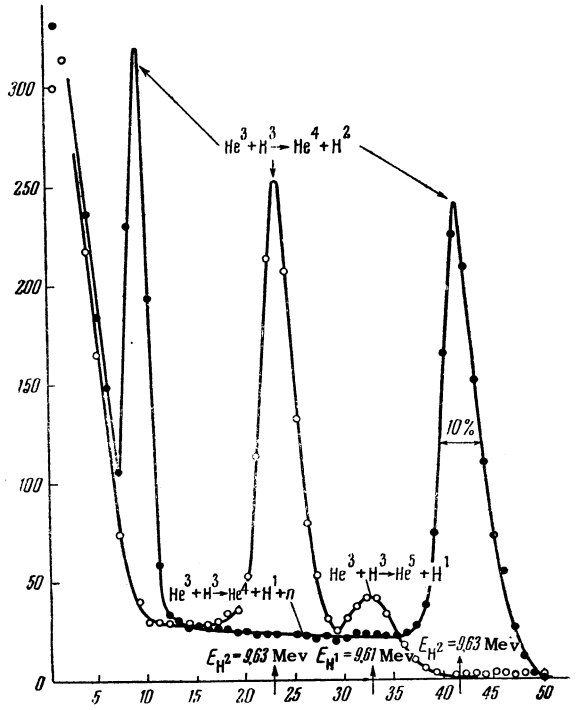

FIG. 2. Energy spectrum of particles from the $He^3 + H^3$ reaction for E_{H^3} = 506 kev: ● – total spectrum; o – the same spectrum after passing through an aluminum foil 59.08 mg/cm² thick. The abscissa gives the number of the channel in the analyzer, and the ordinate the relative number of counts per unit energy range (arb. units).

deuteron peak from branch (1), so that it is not resolved by the spectrometer. The resolution needed for separating these peaks can be obtained by making use of the difference in range of protons and deuterons in any material. For this purpose we placed along the path of the particles from the gas target to the scintillation counter an aluminum foil 59.08 mg/cm² in thickness. After passing through this foil, the particles had quite different energies (for example, the protons had 7.37 Mev and the

deuterons 5.48 Mev for $E_{H^3} = 636$ kev) and could easily be resolved. In Fig. 2 we show one of the spectra obtained using the foil. Similar spectra were taken for eleven values of the triton bombarding energy in the interval 150 — 950 kev. As the measurements showed, in the range of energies investigated the ratios of the various branches of the reaction $He^3 + H^3$ remain constant and are equal, on the average, to

$$He^3 + H^3 \rightarrow He^4 + H^2 + Q_1 \ldots\ldots (41 \pm 2)\ \%, \quad (1)$$

$$\rightarrow He^4 + H^1 + n + Q_2 \ldots (55 \pm 2)\ \%, \quad (2)$$

$$\rightarrow He^5 + H^1 + Q_3 \ldots\ldots (4 \pm 1)\ \% \quad (3)$$

Using the cross sections obtained for the neutron branches (2) and (3), and the ratios of the contributions from the different branches, under the assumption of spherical symmetry of the angular distributions of the reaction products, we calculated the total cross sections. The computational results are shown in Fig. 1. On this same figure we show the total reaction cross section determined by counting of charged particles. These were obtained from the measured differential cross section at 90° by multiplying by 4π. Since the beam of tritium ions also contains some deuterium ions (the impurity amounts to 0.5 — 0.6%), in measuring the yield of charged particles we eliminated the contribution from the $He^3 + H^2 \rightarrow He^4 + H^1$ reaction. The root mean square error of the measurement of differential cross sections was ±6% on the average.

As a check on the operation of the whole apparatus, we made a measurement of the cross section for the $H^2 + H^3$ reaction by the integral method. The cross section for this reaction is known to good accuracy (3 — 5%) over a wide energy range, and, naturally, the agreement of the results obtained by our method with the data in the literature is a convincing proof of its suitability for determining the cross sections of the neutron branches of the $He^3 + H^3$ reaction. As our measurements showed,[7] the results obtained by us agree within the limits of error (±8%) with all the main papers concerning this reaction.

DETERMINATION OF ENERGY OF DECAY OF He^5 AND DISCUSSION OF RESULTS OF THE EXPERIMENT

From the experimentally determined energy of the protons from branch (3) we calculated the energy ϵ of decay of He^5 into a neutron and an α particle. The calculation was made using the formula

$$\varepsilon(He^5) = 0.4E_{H^3} - 1.2E_{H^1} + 12.08\ \text{Mev},$$

where E_{H^3} is the energy of the incident tritons; $E_{H^1} = (9.6 \pm 0.1)$ Mev is the energy of the protons from branch (3) (also in the lab system). The value found for the decay energy of He^5 is (0.8 ± 0.1) Mev.

The total cross sections given in Fig. 1 for the $He^3 + H^3$ reaction, as measured by two independent methods, agree with one another within the limits of error. On the same figure, we also show the results of Moak.[2] The cross sections found by Moak are three times higher than those of the present work. Such a large discrepancy is rather difficult to explain. We feel that the agreement of the values for total cross sections obtained in the present work by two independent methods, as well as the positive result of the control experiment for determining the cross section of the $H^2 + H^3$ reaction, speak convincingly in favor of the reliability of the values obtained by us for the total cross sections.

The data of the present work with regard to the ratio of the various branches of the $He^3 + H^3$ reaction are in good agreement with the data of Moak.

As for the decay energy of He^5, the value (0.8 ± 0.1) Mev obtained here is close to the value of $\epsilon(He^5)$ given in the summary of Ajzenberg and Lauritsen[8] which is (1 ± 0.1) Mev, and the value of (0.95 ± 0.07) Mev given by Moak.[2]

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