PHYSICAL REVIEW C VOLUME 8, NUMBER 4 OCTOBER 1973

Communications

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Total Cross Section of Neutrons on Deuterium in the keV Region*

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(Received 3 July 1973)

Total neutron cross sections on deuterium in the energy range 1 to 1000 keV have been measured, and basically agree with our previously reported results.

[NUCLEAR REACTIONS ^{2}H(n,n), E = 1.0–1000 keV; measured σ_T. Enriched gaseous target. Iron-filtered neutron beam.]

Total neutron cross sections on deuterium provide a basic test for nuclear three-body theory. The most recent continuous-energy measurement in the MeV region was reported by Clement *et al.*[1] These measurements covered the neutron energy range 0.5 to 30 MeV. The only extensive measurements below 0.5 MeV were recently reported by the present authors.[2] They found a rapid rise in cross section for decreasing neutron energy below 300 keV. The experimental results were well explained by three-body theoretical calculations of the quartet n-^{2}H scattering.

The present communication reports a remeasurement of the total cross section below 1.0 MeV, under somewhat different experimental conditions, and a confirmation of the results of Ref. 2.

The experiment, as in the previous report,[2] was performed in two parts. The first part used a continuous-energy pulsed beam of neutrons produced by the Rensselaer electron linac. The neutrons were detected and energy sorted by ordinary time-of-flight techniques. The detector, a $^{10}B_4C$

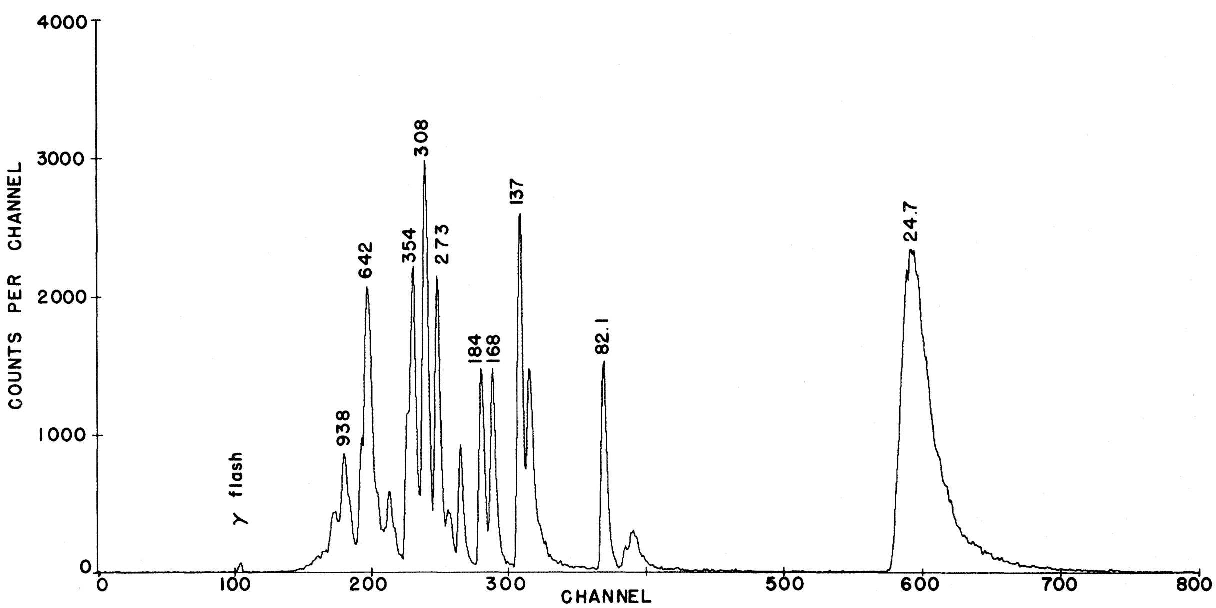

FIG. 1. The spectrum of neutrons after passing through 20.3 cm of iron. The numbers above the peaks correspond to the energy of the peaks in keV.

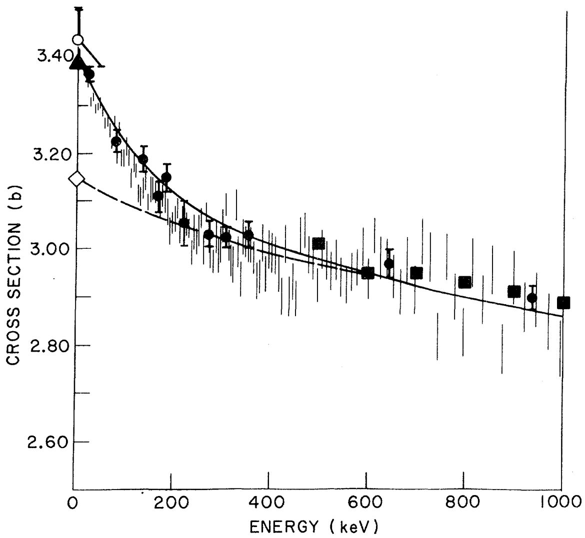

FIG. 2. Total neutron cross sections of deuterium below 1000 keV. Filled circles, results of the iron filtered-beam experiment as discussed in the text. These are the results of the present experiment, combined with the results of the experiment reported in Ref. 2. Filled squares, obtained from the higher-energy measurements of Clement *et al.* (Ref. 1). Vertical lines, results of the continuous-energy experiment as discussed in the text. The open circle and solid triangle near zero energy represent the thermal cross section of Fermi and Marshall (Ref. 5) and Dilg, Koester, and Nistler (Ref. 4), respectively. The open diamond is the thermal cross section deduced from the works of Gissler (Ref. 7) and Bartolini, Donaldson, and Graves (Ref. 8). The dashed curve, below 300 keV, is excerpted from the evaluation by Seagrave (Ref. 6). The solid curve is due to a three-body theoretical calculation (Ref. 2). The errors shown reflect statistical uncertainties only.

slab viewed by four photomultiplier tubes, was 33 m from the neutron source. The dead time of the system was 32 ns so that more than one neutron could be detected per neutron burst. (In Ref. 2 only one neutron was detected per neutron burst.) The deuterium sample consisted of a 1.0-m-long tube containing D_2 gas at 61.0 atm. The sample was continually cycled into and out of the beam in 5-min cycles. For greater detail of the experiment the reader is referred to Ref. 2. The resulting continuous-energy data contain a continuous time-dependent background component which is accounted for in the second part of the experiment.

The second part was identical to the first part, except that an 20.3-cm-thick iron block was placed in the beam. Nearly all the neutrons were filtered out of the beam, except at those energies corresponding to deep minima in the iron total neutron cross section. This provided a beam of neutrons having discrete energies, and small, easily determined background between these energies. The resulting neutron spectrum is shown in Fig. 1.

The total neutron cross section was evaluated at these discrete energies. Comparison of these "filtered-beam" results with those reported in Ref. 2 showed agreement within the statistical uncertainties of the data. The present "filtered-beam" results were then combined with those of Ref. 2 to somewhat improve the over-all statistical precision of the cross sections. The results are indicated in Fig. 2 by solid black dots with error bars. From analysis of previous works[1,3] at higher energies, but using similar experimental procedures and apparatus, it is felt that the overall accuracy of these measurements are in the vicinity of 1% or better, which is about the magnitude of the statistical error on most of the points shown.

It is noteworthy that the present cross sections join smoothly to the thermal measurements of Dilg, Koester, and Nistler[4] and Fermi and Marshall.[5] They also substantially agree with the measurements of Clement *et al.*[1] above 0.5 MeV.

A time-dependent background function was determined which normalizes the continuous-energy cross section of the first part of the experiment with the "filtered-beam" cross sections of the second part of the experiment. The resulting cross sections are shown in Fig. 2 as vertical bars which represent 2 standard deviations of statistical precision. These results compared with Ref. 2 indicate no substantial intrinsic structure between the filtered-beam points. It is felt that the slight indication of possible small structure in the present continuous-energy cross section, as well as in Ref. 2, are probably due to the incomplete subtraction of time-dependent background.

The solid curve in Fig. 2 is the result of the three-body calculation of Ref. 2. The good agreement between the present experiment and theory tends to substantiate the results and conclusions of Ref. 2. The hatched curve is the evaluation by Seagrave,[6] and the open triangle at thermal energies is the combined result of measurements of Gissler[7] and Bartolini, Donaldson, and Groves.[8] Both are in disagreement with present results.

Finally, Seagrave and van Oers and Seagrave[9] have analyzed n-^{2}H phase shifts and found them to be consistent with the quartet and doublet scattering lengths[7,8] which, in turn, are consistent with the total cross section evaluation by Seagrave[6] at thermal energies. These scattering length values are $a_2 = 0.15 \pm 0.05$ fm and $a_4 = 6.13 \pm 0.04$ fm. However, due to the large quoted errors in the analyzed phase shifts, it appears as if the phase-shift analysis is equally consistent with the scattering lengths embodied in the theoretical curve of Fig. 2, the present experimental results, and the thermal measurements of Dilg *et al*. These are $a_2 = 0.65 \pm 0.04$ fm and $a_4 = 6.35 \pm 0.02$ fm.

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*Work partially supported by the U. S. Atomic Energy Commission under Contract No. AT(11-1)-3058.

†National Science Foundation undergraduate summer research participant.

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