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Cross section and angular dependence of the ^{3}H(γ,d)n reaction

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The angular asymmetry and the total cross section for the ^{3}H(γ,d) reaction have been measured. The total cross section measurement agrees with the most recent Faddeev-type calculation but the angular asymmetry departs from the prediction of a simple plane wave calculation that fits the ^{3}He(γ,d) data. In the absence of final state interactions the ^{3}He and ^{3}H asymmetries should be related by $-1/5$ (i.e., the isospin dependence). These data would appear to indicate that the $E2$ final state interaction in the ^{3}H (γ,d) reaction has to be carefully treated.

[NUCLEAR REACTIONS ^{3}H(γ,d), $E=15-36$ MeV. Measured $\sigma(\theta,E)$.]

Photodisintegration studies of the three-body system have for the most part been carried out with ^{3}He, not ^{3}H as the target nucleus. A large body of data[1] with an uncomfortable range of answers exists for the ^{3}He (γ,d) reaction, making difficult a comparison with theory.[2] In contrast, experiments for the ^{3}H (γ,d) reaction total three; the latest from Livermore[3] is one in which the two-body and the three-body total cross sections were simultaneously measured. The two-body data from Livermore agree reasonably well with the low energy data from Zurich[4] but are higher than the Heidelberg[5] data where the measurements just meet, at approximately 20 MeV.

We have measured the ^{3}H(γ,d) and ^{3}H(e,d) cross sections from 15 to 36 MeV, thus overlapping the Livermore and Heidelberg data. In addition, we performed a fore-aft asymmetry measurement to determine the effects of $E2$ strength in the two-body breakup of ^{3}H. These data can be compared to the ^{3}He(γ,d) asymmetry data which are accounted for by direct $E1\cdot E2$ interference, with final state interactions apparently playing an insignificant role.[6] On the basis of a simple effective charge argument, the asymmetry for the ^{3}H(γ,d) reaction should be $-\frac{1}{5}$ that for the ^{3}He(γ,d) reaction. We note that the asymmetry measurements for ^{3}He photodisintegration are in reasonable accord, and the asymmetry measurements that we report here are the first for the ^{3}H(γ,d) reaction and thus provide a new, additional test for theoretical models. Furthermore, since deuteron detection defines the two-body breakup in ^{3}He and ^{3}H, the same experimental setup was used to determine the ratio of these cross sections, which is independent of many of the systematic errors that are apparently a problem in the ^{3}He(γ,d) measurements.[2]

The experimental apparatus consists of the University of Saskatchewan 300 MeV linear electron accelerator and two positive-ion spectrometers.[7] Photon beams are generated by inserting desired radiator foils in front of the target. Cross sections are measured with and without the radiator to determine the contribution from the real photon beam. The radiator can be translated along the beam which allows us to be certain that geometric corrections due to the beam spot size are not a problem. The radiator used in this experiment was a 63 mg/cm^2 Ta foil, and the incident electron energy was 100 MeV. The photon spectrum was calculated using equation 3*BSe* in Koch and Motz.[8] Over the energy range of 15 to 36 MeV, the real photon and virtual photon analyzed data agreed to within 10%. The major source of error in the experiment is the uncertainty associated with the number of target nuclei. The target that we used was a 5 μm tritiated titanium foil. The square density of tritium was approximately

0.2 mg/cm^2 corresponding to 2 Ci of tritium. Since the number of tritons from Ti is very small, we were able to measure the elastic form factor at low momentum transfers. These data allowed us to determine the number of tritium nuclei in the TiT foil by using the constraint that at $q^2=0$, the charge form factor must go to unity. All of the data presented here have been taken with the same target angle orientation with respect to the incident beam. A typical spectrum showing the elastically scattered tritons and the disintegration deuterons with a corresponding Ti background run is shown in Fig. 1. One of the spectrometers was used to continuously monitor the elastic peak to ensure that we were not losing tritium from the target. In addition, we periodically repeated runs at the same angle, magnetic field, and incident electron energy. These runs agreed to within 8%. The major cause for the 8% uncertainty is the slight wrinkling of the Ti foil that occurs when tritium is introduced in the Ti metal. The reproducibility from run to run is affected by not being able to place the beam exactly at the same point on the target (the beam spot is approximately a circle of 1 mm diameter). Future runs will be made with a larger diameter TiT target with a defocused beam in order to minimize this error. Prior to performing the experiment with TiT, we used a normal hydrogenated titanium target. This target was subjected to average currents of approximately 15 μA and no discernable loss of hydrogen was detected when the elastic protons were monitored over several days.

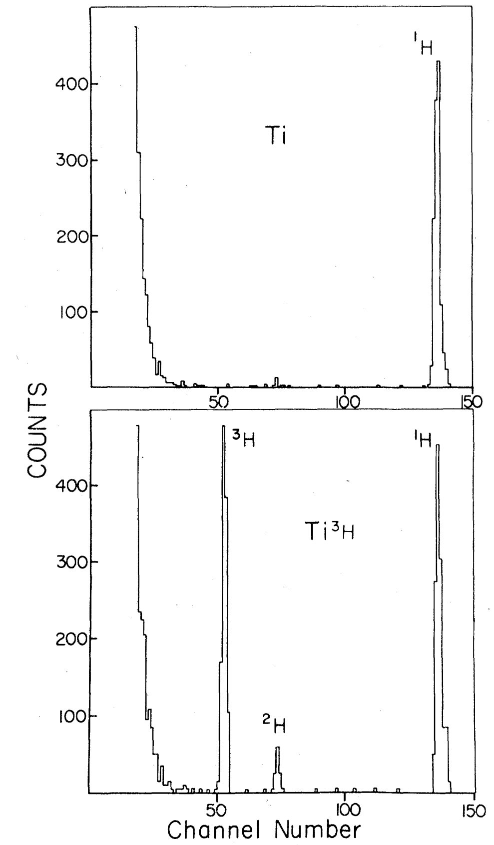

FIG. 1. A pulse-height spectrum that shows the elastically scattered tritons and deuterons produced by the photon or electron beam. The latter define the two-body breakup of ^{3}H. The background from the normal Ti target is also given and it is seen that the Ti contributes very little to the number of counts in the relevant peak regions.

The most recent theoretical work dealing with ^{3}H is that of Rahman *et al.*,[9] and that of Gibson and Lehman.[10] The latter authors consider both ^{3}H and ^{3}He photodisintegration and take into account final state interactions as well as Coulomb effects. They predict that the two-body cross sections from ^{3}He and ^{3}H are essentially the same except for the shift due to different thresholds.

Our total cross section measurements are shown in Fig. 2. Although the uncertainties in the higher

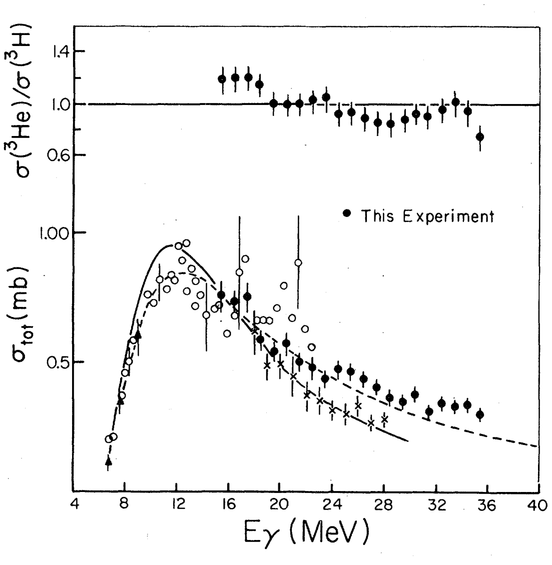

FIG. 2. Total cross sections for the two-body disintegration of ^{3}H. The data are Ref. 3 —○, Ref. 4 —▲, Ref 5 —×, and this work — ●. Only statistical errors are shown for the previous data. Using Eq. (2), the total cross section for our data is determined from the relation $\sigma=2\pi[\sigma(\theta_f)+\sigma(\theta_b)]$. We have folded into the data, in percent quadrature, the systematic error for our experiment. Thus our error bars represent the total uncertainty for our experiment. The statistical errors were typically 2%. The curves give the theory of Ref. 9 — solid line, and Ref. 10 —dashed line.

energy Livermore data are too large for a very meaningful comparison, our data tend to overlap their error bars. At still higher photon energies our data tend to lie a bit higher than the Heidelberg data. For energies below 15 MeV, the energy loss correction to the data[7] exceeds 10 – 15 %, the level that has been experimentally checked. Also shown are the theoretical calculations for this reaction. Our data agree best with the calculation of Gibson and Lehman. Over the same energy range we show the ratio of ^{3}He to ^{3}H two-body, 90° differential cross sections. The ^{3}He cross sections were taken from our earlier work,[11] and from additional data taken during the ^{3}H runs. This served as a cross check on the absolute magnitude of the earlier data. No disagreement was found. The ratio of these data is independent of any photon spectrum (real or virtual) and the only important systematic error that does not cancel in the ratio is that associated with determining the number of target nuclei. From these data we obtain a mean value of 0.99 ± 0.03. Hence averaged over the energy range of 15 to 36 MeV, the ratio of the ^{3}He to ^{3}H cross sections agrees with the theoretical prediction. There is, however, a tendency for the ^{3}He cross section to be somewhat larger than the ^{3}H cross section at lower photon energies, which is not consistent with the available theory for the ratio of these cross sections.

The angular dependence of the cross section was determined by measuring the cross section at the center-of-mass angles of 55° and 125°. For these angles it can be shown that the asymmetry is given by

$$\beta = \frac{1}{P_1(\cos\theta_f)} \left[\frac{\sigma(\theta_f) - \sigma(\theta_b)}{\sigma(\theta_f) + \sigma(\theta_b)} \right] , \qquad (1)$$

where

$$\sigma(\theta) = \sum_l A_l P_l(\cos\theta) \text{ and } A_4 << 1 \ . \qquad (2)$$

These data are given in Fig. 3, along with the existing data for the ^{3}He(γ,d) reaction. Note that we have plotted only the magnitudes of the asymmetries. Our data from ^{3}He and ^{3}H give the proper sign difference, i.e., neutrons from the ^{3}H(γ,n) reaction are backward peaked, while protons from the ^{3}He(γ,p) reaction are forward peaked. Clearly the magnitude of the ^{3}H asymmetry is not $\frac{1}{5}$ that for ^{3}He, rather it is slightly lower and has the same approximate dependence on E_γ, suggesting direct $E1 \cdot E2$ interference. No calculation exists for the ^{3}H(γ,d) asymmetry in which final state interactions are taken into account. For that reason we have computed a plane wave asymmetry using an Irving-Gunn ground state wave function for ^{3}He and ^{3}H. The model predicts the ^{3}He asymmetry quite well, which, as pointed out earlier, was taken as an indication that final state interactions are not important in explaining the interference between the $E1$ and $E2$ transition amplitudes. The ^{3}H asymmetry, using the same model, is also shown. It clearly does not explain the experimental results. Since these data are most likely mainly sensitive to $E1$ and $E2$ interference they should provide the means to test various model predictions about the importance of $E2$ absorption and perhaps shed some light on the question of differences in final state interactions in ^{3}He and ^{3}H.

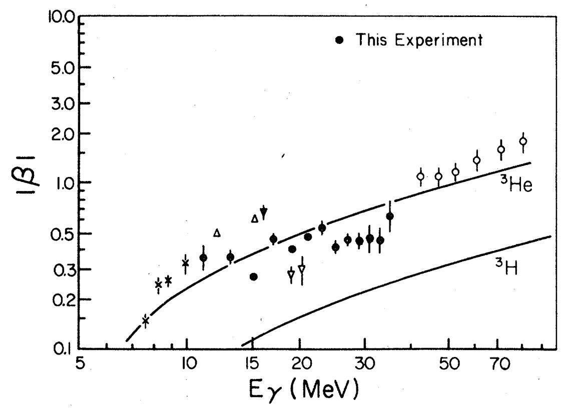

FIG. 3. Angular asymmetry data for ^{3}He and ^{3}H. The ^{3}He data are from Ref. 12 —○, Ref. 13 —∇, Ref. 6 —▼, Ref. 14 —Δ, and Ref. 15 —×. Shown are the plane wave asymmetry calculations for the ^{3}He(γ,d) and ^{3}H(γ,d) reactions. The ^{3}He data are fit reasonably well (perhaps surprisingly) up to 70 MeV by this model. The ^{3}H data are not well described by this model, which may indicate that the effects of final state interactions are markedly different for ^{3}H.

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