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RADIATIVE CAPTURE OF PROTONS BY DEUTERIUM*

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ABSTRACT

An experimental study of the reaction $p + d \rightarrow {}^3\text{He} + \gamma$ between $E_p = 14.0$ and 25.5 MeV gave no indication of a resonance in ${}^3\text{He}$ in the excitation energy range from 14.9 to 22.5 MeV.

INTRODUCTION

Recent measurements¹ of the radiative-capture reaction $H(d, {}^3\text{He})$ showed evidence for a broad resonance in ${}^3\text{He}$ at about 20-MeV excitation. A rise in the 90° excitation function was found where a steady decrease was expected, and in this energy region the cross-section asymmetry about 90° dropped far below its predicted value. However, experiments on the inverse process, two-body photodisintegration² or electrodisintegration²⁻⁵ of ${}^3\text{He}$, did not show these anomalies. A repeat of the capture experiments appeared desirable.

The large gamma-ray detector at Brookhaven was used with the double MP tandem accelerator to measure the $D(p, \gamma)$ excitation function near 90° in $1/2$ -MeV steps for proton energies from 14.0 to 25.5 MeV (E_γ at $90^\circ = 14.8$ to 22.3 MeV). Angular distributions were measured for $E_p = 15.0$, 20.5 , and 22.5 MeV.

EXPERIMENTAL METHOD

The gamma detector system consisted of a 10×10 -inch NaI(Tl) crystal with a plastic-scintillator anticoincidence shield, similar to one described previously.⁶ The target was room-temperature deuterium gas at 0.4 atmosphere contained in a tube, coaxial with the beam, which had entrance and exit windows of 0.0005 -inch Kapton.⁷ The length of the cell was

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chosen to insure that the gamma detector would be well shielded from radiation originating in the windows.

The beam was focussed to pass through a 3/16-inch diameter aperture just before the entrance window. The protons were stopped in a well-shielded Faraday cup. Background in the NaI spectrum was negligible with the gas cell empty.

The angular-distribution data were taken at six angles from 64° to 122° (lab). The 64° point was subject to a greater uncertainty because of background. The measurements were corrected for the extended source geometry and finite solid angle, and were converted to c.m. yields.

For the gamma-ray detector and geometry used in the present experiment, the detection efficiency is expected to decrease somewhat (roughly 10-15%) over the energy range studied. Because this factor is not accurately known at present, we have chosen to omit this correction. This may result in a slightly incorrect slope for our excitation function, but it cannot introduce a false peak or suppress a real one.

RESULTS

Figure 1 shows various results for the 90° excitation function for the inverse process, namely, two-body photodisintegration of ^3He . The capture data were transformed by invoking detailed balance. The present results were taken at 90° lab ($\approx 94^\circ$ c.m.) and 86° lab ($\approx 90^\circ$ c.m.). Each group of points was arbitrarily normalized to match the data of Ref. 1 (open circles) below 16 MeV. The present data show a smooth decrease in yield above $E_\gamma = 14$ MeV.

Fig. 1. Excitation function for $^3\text{He}(\gamma, d)$ at 90° . Data from this experiment ($\bullet$) and Ref. 1 ($\circ$) were converted to photodisintegration by detailed balance. The curve is from Ref. 8. Normalizations were adjusted for best overlap in the 14-16 MeV region.

The curve in Fig. 1 is the result of a calculation of the E1 contribution by Barbour and Phillips⁸ based on the Faddeev approach, in which only S states in ^3He were considered. The scale factor was adjusted to match the data. An extension of the same calculations to include the E2 amplitude was recently published by Barbour and Hendry.⁹ Although there is an increase of a few percent in the total cross section, the yield at 90° is unchanged by the presence of the E2 transitions, as may be seen from the following general expression¹⁰ for the differential cross section:

$$\frac{d\sigma}{d\Omega} = a + b \sin^2 \theta (1 + \beta \cos \theta + \gamma \cos^2 \theta). \quad (1)$$

The first term in the bracket is due to E1 transitions, the third to E2, and the second is a cross term arising from E1-E2 interference. The isotropic term appears if one allows for M1 transitions¹⁰ and/or a D-state admixture in the ^3He wave function.¹¹

The measured angular distribution at $E_p = 15.0$ MeV is shown by the points in Fig. 2. The curve is semiempirical, being a least-squares fit to (1) for data¹² on $\text{H}(d, ^3\text{He})$ at $E_d = 29.6$ MeV (corresponding to $E_p = 14.8$ MeV). It is superposed on the present data with an arbitrary scale factor. The excellent agreement between the data and the curve indicates consistency between the present results and those of Ref. 12.

Fig. 2. Angular distributions for $\text{D}(p, \gamma)$ near 15 MeV. The points are the present results. The curve is from Ref. 12.

Least-squares fits of these data to (1) gave parameters with extremely large uncertainties. However, since the isotropic term contributes only a small fraction of the cross section at these angles and is known¹² to be very small at this energy ($a/b = .008 \pm .003$), a fit was made to (1) with a/b frozen at .008. The resulting value of β was well defined and did not

change when a/b was varied within its limits of uncertainty. As shown in Fig. 3, it is in excellent agreement with the result from Ref. 12. A similar procedure was used for the data at $E_p = 20.5$ and 22.5 MeV since a/b remains small.³ At these energies a/b is less well determined; the dashed extension of the error bars in Fig. 3 indicates the effect of β of the uncertainty in a/b . The curve is a prediction by Barbour and Hendry.⁹ Unlike the data from Ref. 1, the present results are consistent with the curve.

Fig. 3. The asymmetry parameter, β , vs. energy. Experimental values from the present experiment are given by $\bullet$, while $\circ$ represents points from Ref. 12 (12.1 and 15.3 MeV) and Ref. 1 (19.2 and 20.6 MeV).

CONCLUSION

The present measurements of the $D(p, \gamma)$ reaction show a 90° cross section that decreases smoothly with energy and a 90° asymmetry that increases smoothly. We thus find no indication of a resonance in ^3He near 20-MeV excitation, in agreement with experiments on the inverse reaction.²⁻⁵ Our results are consistent with recent theoretical calculations.^{8,9}

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CONCLUSION

The present measurements of the $D(p, \gamma)$ reaction show a 90° cross section that decreases smoothly with energy and a 90° asymmetry that increases smoothly. We thus find no indication of a resonance in ^3He near 20-MeV excitation, in agreement with experiments on the inverse reaction.²⁻⁵ Our results are consistent with recent theoretical calculations.^{8,9}

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