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Energy of the $^{14}N(d, \gamma_0)^{16}O$ Resonance in the Giant-Dipole Region of ^{16}O

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The 90° yield from the reaction $^{14}N(d,\gamma_0)^{16}O$ has been measured between 2.1 and 2.9 MeV to accurately determine the location of the strong resonance previously observed in this region. Two separate measurements were made. It is found that the resonance occurs at $E_d = 2.40 \pm 0.05$ MeV, moving it with respect to the dip $^{15}N(p,\gamma_0)^{16}O$ and $^{16}O(\gamma, n_0)^{15}O$. This result brings into question interpretations of the fine structure of the ^{16}O giant dipole resonance made on the basis of earlier experimental work.

The fine structure seen in the giant dipole resonance of ^{16}O has been explained by Giller, Melkanoff, and Raynal[1] as an interference effect between the 1p-1h configurations responsible for the gross dipole-resonance phenomenon and 2p-2h, 3p-3h, etc. configurations. Measurements by Suffert[2] of the reaction $^{14}N(d,\gamma_0)^{16}O$ indicate a strong resonance at an energy corresponding to 22.7 ± 0.05-MeV excitation in ^{16}O, while the ^{16}O dipole-resonance fine structure as seen in the reactions $^{16}O(\gamma, n_0)^{15}O$ [3] and $^{15}N(p, \gamma_0)^{16}O$ [4] shows large peaks at ^{16}O excitation energies of about 22.3 and 23.0 MeV. The valley between these peaks is interpreted[1] as resulting from interference with the $T = 1$, 2p-2h configuration responsible for the observed resonance. Recent theoretical work by Shakin and Wang,[5] who emphasize, instead, the 3p-3h configurations, presents an alternative to the Gillet work; a careful evaluation of the experimental evidence is thus called for. We have remeasured the $^{14}N(d, \gamma_0)$ excitation function in the vicinity of the reported resonance, using two different types of targets. We find that the resonance occurs at a deuteron laboratory energy of 2.40 ± 0.05 MeV, corresponding to an ^{16}O excitation of 22.84 ± 0.05 MeV. With this 0.14-MeV upward correction, the position of the $^{14}N(d, \gamma_0)^{16}O$ resonance no longer provides convincing evidence to support the Gillet conjecture that 2p-2h configurations are important in producing the dipole-resonance fine structure.

The yield of γ rays from the radiative capture of deuterons by ^{14}N was measured at 90° to the incident beam for deuteron bombarding energies between 2.2 and 2.9 MeV. In our first measurement, the nitrogen target, in the form of tantalum nitride, was prepared by heating a 0.13-mm-thick tantalum disk to approximately 1000°C and then exposing it to nitrogen gas at 1 atm for about 30 sec. The distribution of nitrogen in the target was determined by an observation of the resonance in the reaction $^{15}N(p, \alpha\gamma)^{12}C$ at $E_p = 1.21$ MeV.[6] The 4.43-MeV γ ray from this reaction on nitrogen of natural isotopic composition is sufficiently intense to provide a conveniently observable resonance shape. By unfolding the resonance width of 20 keV from the observed yield curve, we determined that the nitrogen concentration decreases approximately linearly from the surface inward such that the centroid of the nitrogen distribution was at a depth of 60 keV for 1.21-MeV protons (or 2.42-MeV deuterons). The deuteron bombarding energies quoted below have been shifted accordingly to correspond to energies at the centroid of the nitrogen distribution. A further observation of the $^{14}N(d, n_5)$ threshold at 2.044 MeV [7] confirmed the fact that there was no nitrogen-free layer at the surface of the target which could adversely affect our determination of bombarding energies. The absolute energy of the deuteron beam from the University of Florida 4-MV Van de Graaff accelerator was determined by observing the $^{16}O(d, n_0)$ threshold at 1.829 MeV.[8] The over-all uncertainty in deuteron bombarding energy, including beam energy calibration and target energy-loss corrections, is estimated as ±20 keV.

γ rays were detected, at 90° to the incident beam, with an anticoincidence-shielded 12.7-cm × 15.2-cm NaI(Tl) spectrometer similar in design to a system described elsewhere.[9] The NaI crystal was positioned 0.4 m from the target. The entire spectrometer was shielded by 10 cm of lead and 30 cm of paraffin loaded with lithium carbonate. A layer of cadmium sheet further reduced the flux of thermalized neutrons reaching the detector. Incident γ radiation was collimated by a 7.6-cm-diam opening in the lead.

The detection electronics were configured to substantially reduce pileup, which had dominated the spectra obtained by Suffert.[2] With a technique similar to that used by Diener *et al.*,[10] fast photomultiplier pulses from the NaI(Tl) detector were timed-clipped and passed through a linear gate prior to any integration, drastically shortening the time within which pulse-distorting pileup could occur. A gating time of 200 nsec was employed with only a slight observable loss in pulse-height resolution. The pulse-height spectrum obtained for $E_d = 2.45$ MeV is shown in Fig. 1. A fast discriminator bias restricts the spectrum to energies above 7 MeV. The initial γ-ray energy calibration was determined with a lower bias to permit observation of the 4.43-MeV γ ray from a PuBe source and the 15.1-MeV line from the $^{11}B(d,n\gamma)^{12}C$ reaction.

Since the anticoincidence shield reduced cosmic-ray background to a negligible level and no contaminants produced γ radiation in the 20-MeV range, determination of the yield was made simply by summing counts above 21 MeV. The resulting excitation function is shown, with triangles for data points, in Fig. 2. These results indicated that the resonance occurs at a deuteron bombarding energy of 2.45 ± 0.05 MeV.

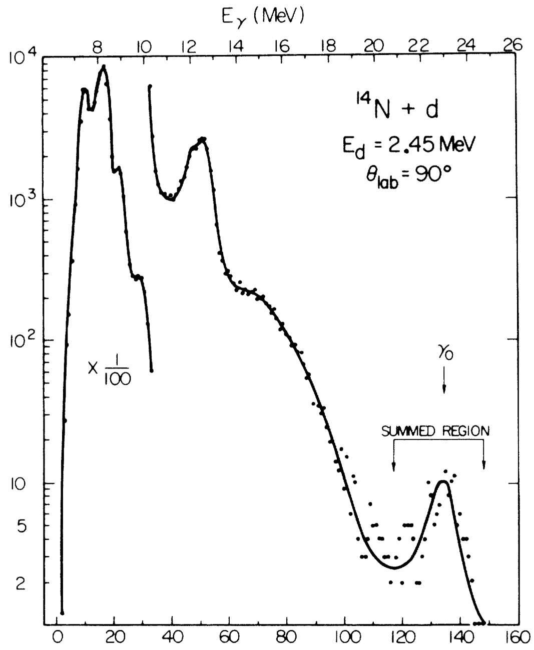

FIG. 1. γ-ray pulse-height spectrum at 90° from the deuteron bombardment of ^{14}N. The low-energy cutoff and spectrum offset of ~7 MeV are introduced in the fast electronics for pileup reduction. This spectrum was obtained from the TaN target using a beam current of 400 nA; the total charge collected was 8000 μC.

Since the earlier measurements had been made using a gas target,[2] we repeated the experiment with this type of target as an additional check. In this case a gas target with a Ni window of 1.27-μm thickness was employed. The pressure in the 1.29-cm-long target cell was maintained at 0.37 atm. A measurement of the $^{16}O(d,n)^{17}F$ threshold was used to obtain the energy of the beam after passing through the foil. The foil thickness was found to be 110 ± 5 keV for 1.8-MeV deuterons. This result was checked by remeasuring the threshold with a foil of half the thickness (0.63 μm) in the

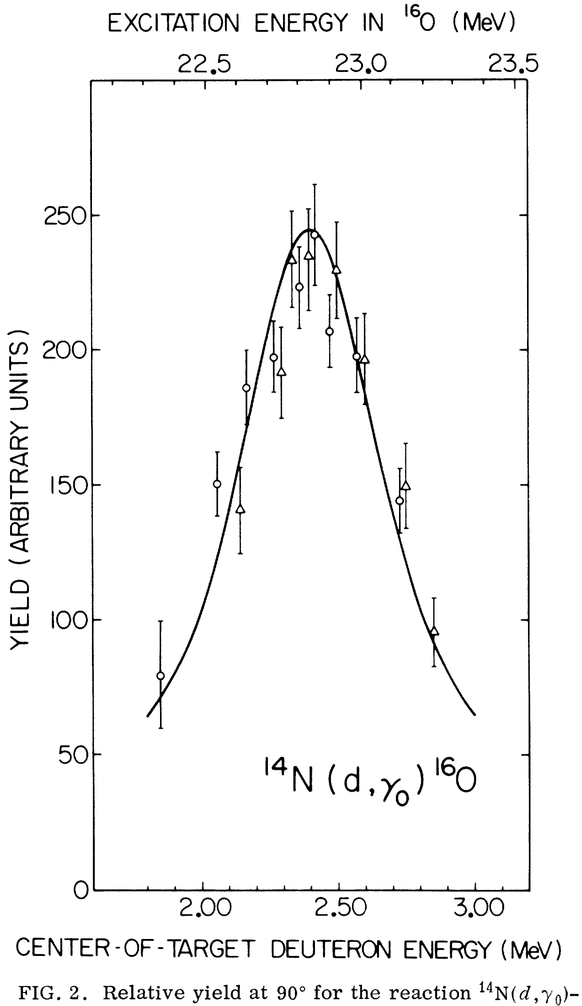

FIG. 2. Relative yield at 90° for the reaction $^{14}N(d,\gamma_0)$-^{16}O. The triangles are data obtained with the tantalum nitride target, while the circles are data obtained with the nitrogen gas target. The deuteron energies have been corrected to correspond to center-of-target energies. The error bars represent the statistical uncertainties for the data points. The curve is a Breit-Wigner shape with Γ(lab) = 700 keV and $E_0 = 2.40$ MeV.

target cell and agrees with the value calculated using the tables of Whaling.[11] The additional energy loss suffered by the deuterons in reaching the center of the nitrogen target was calculated from the tables of Whaling as 50 ± 5 keV for 2.4-MeV deuterons. The resulting yield data as a function of the center-of-target energies are shown as circles in Fig. 2. When only these data are used, the peak of the resonance is found to be 2.38 ± 0.05 MeV. Combining the two runs, a Breit-Wigner shape can be fitted to the data to give 2.40 ± 0.05 MeV as the best estimate of the resonance peak energy, corresponding to an ^{16}O excitation energy of 22.84 ± 0.05 MeV; the width of the resonance is ~600 keV in the center-of-mass system.

In our work two separate measurements provide consistent results which indicate that the peak in the $^{14}\mathrm{N}(d,\gamma_0)^{16}\mathrm{O}$ cross section occurs at a deuteron bombarding energy of 2.40 ± 0.05 MeV rather than 2.24 ± 0.05 MeV as given by Suffert.[2] The ^{16}O excitation energy which corresponds to the peak of the resonance is thus 22.84 ± 0.05 MeV.

Due to the large width (600 keV), the energy dependence of the deuteron penetrability and the level-shift function may shift the observed peak with respect to the true resonance energy. The angular distribution measured by Suffert[2] indicates that the resonance is formed by deuterons having an l value of 1 or greater. If the resonance is fitted with a single-level Breit-Wigner shape assuming $l=1$, penetrability effects would shift the resonance energy down by as much as 50 keV with respect to the position of the maximum in the cross section. Comparable changes in the resonance energy, in either direction, could arise from the shift function, but more detailed information is necessary to reasonably evaluate this function. These effects further reduce the certainty of any conclusions based on the correlation between the experimentally observed $^{14}\mathrm{N}(d,\gamma_0)^{16}\mathrm{O}$ resonance and the structure in the ^{16}O giant dipole resonance. The present results cast serious doubt on the assumption that the $^{14}\mathrm{N}(d,\gamma_0)^{16}\mathrm{O}$ resonance is, in fact, correlated with the interference dip in the $^{16}\mathrm{O}(\gamma,n_0)^{15}\mathrm{O}$ and $^{15}\mathrm{N}(p,\gamma_0)^{16}\mathrm{O}$ cross sections.

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