GAMMA-RAY TRANSITIONS FROM THE 5-MeV DOUBLET LEVELS IN N^{15} AND O^{15}†

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(Received 30 December 1964)

One of the first applications of the lithium-drifted germanium gamma-ray detector to nuclear-reaction gamma rays was the observation[1,2] of gamma-ray two-escape peaks following the 4-MeV deuteron bombardment of N^{14}. Two sharp lines, each of which had a half-width of 8.3 keV, were observed in the vicinity of 5.3-MeV gamma-ray energy. These lines were assigned to the ground-state transitions from the 5.270-5.299-MeV doublet levels in N^{15} as formed in the reaction $N^{14}(d,p)N^{15}$. Since the 5.299-MeV transition is known to be predominantly $E1$, whereas the 5.270-MeV transition is an $M2, E3$ mixture,[3] it was surprising that at least the upper member of the doublet did not exhibit Doppler broadening. The Weisskopf estimate for the lifetime of the 5.299-MeV $E1$ transition is $\sim 10^{-17}$ sec, which is much less than the nuclear slowing-down time of $\sim 5\times 10^{-13}$ sec. Thus, at $E_d = 4$ MeV one would expect a Doppler broadening of the $E1$ line of about 80 keV if the state is populated directly. Alexander[4] has recently studied the gamma rays emitted in the reaction $O^{16}(t,\alpha)N^{15}$ and has observed that the 5.299-MeV transition is indeed Doppler broadened, as would be expected from the lifetime estimate.

In the present work we have shown that in $N^{14}+d$ there is actually a quartet of gamma-ray lines in the 5.3-MeV region, and that the two sharp members are the $M2, E3$ transitions from the mirror pair of levels in N^{15} and O^{15} populated by (d,p) and (d,n) reactions, while the two $E1$ lines are Doppler broadened to such an extent that they blend into the background.

Gamma rays produced by the deuteron bombardment of ZrN and C^{14} targets and by the He^3 bombardment of a quartz target were detected by observations of two-escape peak spectra with a lithium-drifted germanium gamma-ray detector having a sensitive volume of 3 cm^3. The detector was placed 15 cm from the target at 90° to the incident beam. A pulse-height dispersion of 3 keV per channel was achieved by the use of a post-bias amplifier and a 1024-channel pulse-height analyzer.

Curve A of Fig. 1 is a partial spectrum from the bombardment of the ZrN target with 3.0-MeV deuterons, and it shows the two-escape peaks for the region of 5.3-MeV gamma-ray energy. The two sharp peaks are similar to those in the previous work,[1,2] except for slightly different relative intensities at our lower beam energy. There is also in curve A some evidence for two broad underlying peaks, one on either side of the sharp doublet.

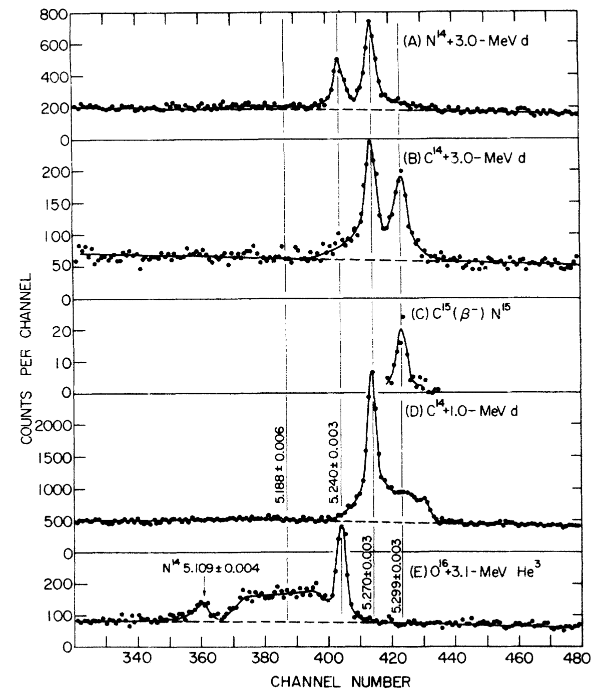

FIG. 1. Li-Ge two-escape peak gamma-ray spectra, as described in the text. The N^{14} 5.109-MeV line in curve E arises from the contaminant reaction $C^{12}(He^3,p)N^{14}$. The resolution of the detector for the two-escape peak of a 5.3-MeV gamma ray is about 11 keV. Transition energies are given in MeV, and they are based on an excitation energy of 5.299 ± 0.0026 MeV for the second excited state of N^{15}.

The radiations from $C^{14}+d$ were next investigated, since the levels in N^{15} are formed without interference from the O^{15} levels. At $E_d = 3.0$ MeV the spectrum in curve B shows the two-escape peaks of the 5.270-5.299-MeV doublet. In this case the sharp 5.299-MeV line arises from the beta decay of C^{15} formed in the reaction $C^{14}(d,p)C^{15}$, and it obscures the Doppler-broadened 5.299-MeV line from the reaction $C^{14}(d,n)N^{15}$. This was demonstrated by measuring the spectrum of delayed C^{15} gamma rays after turning off the beam, with the results shown in curve C, and then by lowering the beam energy to 1.0 MeV, which is below the threshold for forming C^{15}, and observing the spectrum shown in curve D. The latter shows the same sharp 5.270-MeV line, but reveals the Doppler-broadened 5.299-MeV line. From a comparison of curves B and C it is apparent that C^{15} decays to the 5.299-MeV upper member of the N^{15} doublet, in agreement with two previous investigations.[5,6] The total width of the 5.299-MeV line in curve D is 48 ± 6 keV, compared to the maximum value of 60 keV allowed by the kinematics.

In the reaction $O^{16}(He^3,\alpha)O^{15}$, the O^{15} levels are formed without interference from the N^{15} levels. The spectrum obtained from the quartz target at $E_{He^3} = 3.1$ MeV is shown in curve E. It is clear that the 5.19-MeV line is Doppler broadened, while the 5.24-MeV line is sharp. This is as expected since the level order in O^{15} is inverted[7] from that in N^{15}. The 5.19-MeV line in curve E has a total width of 80 ± 8 keV, compared to a maximum allowed value of 75 keV.

From the positions and shapes of the various peaks we conclude that in $N^{14}+d$ a quartet of lines occurs near 5.3 MeV, the components of which are represented approximately by the N^{15} and O^{15} spectra in curves D and E, respectively. The sharp central lines in curve A arise from the O^{15} 5.24-MeV and N^{15} 5.270-MeV $M2, E3$ transitions, while the broad components on either side are the O^{15} 5.19-MeV and N^{15} 5.299-MeV $E1$ transitions, arising from the reactions $N^{14}(d,n)O^{15}$ and $N^{14}(d,p)N^{15}$, respectively. We obtain energy separations of 29.1 ± 0.7 keV for the N^{15} doublet and 30.3 ± 0.7 keV for the two $M2, E3$ lines. From the observed widths of the four lines we can set an upper limit of 3×10^{-13} sec for the mean lifetimes of the N^{15} 5.299-MeV and the O^{15} 5.19-MeV levels, and a lower limit of 5×10^{-12} sec for the mean lifetimes of the N^{15} 5.270-MeV and the O^{15} 5.24-MeV levels. These results are consistent with the known properties of these levels, and in particular the lifetime allowed for the 5.299-MeV $E1$ transition in N^{15} is considerably easier to understand than that allowed by the lifetime limit inferred from the earlier conclusions of Ewan and Tavendale.[1,2]

†Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] G. T. Ewan and A. J. Tavendale, Nucl. Instr. Methods 26, 183 (1964).

[2] G. T. Ewan and A. J. Tavendale, Can. J. Phys. 42, 2286 (1964).

[3] E. K. Warburton, J. S. Lopes, R. W. Ollerhead, A. R. Poletti, and M. F. Thomas, Phys. Rev. (to be published).

[4] Private communication quoted in reference 2.

[5] D. E. Alburger, A. Gallmann, and D. H. Wilkinson, Phys. Rev. 116, 939 (1959).

[6] D. E. Alburger, C. Chasman, K. W. Jones, and R. A. Ristinen, Phys. Rev. 136, B913 (1964).

[7] T. Lauritsen and F. Ajzenberg-Selove, Nuclear Data Sheets, compiled by K. Way et al. (Printing and Publishing Office, National Academy of Sciences, National Research Council, Washington 25, D. C., 1962), Sets 5 and 6.

MASS OF Na^{20} †

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There has recently been a considerable amount of interest in the mass of Na^{20} since calculations on the $A=20$ multiplet by a number of authors[1-4] have predicted a mass excess for Na^{20} of +6.8 to +7.0 MeV, in contrast to the value of +8.28 ± 0.30 MeV measured by Alvarez.[5] To try to resolve this apparent contradiction, we have redetermined the mass of Na^{20} by measuring the Q value for the reaction $Ne^{20}(He^3,t)Na^{20}$. Our results now give Na^{20} a measured mass excess of +6.83 ± 0.06 MeV, in good agreement with the multiplet calculations.

Our measurements on the reaction $Ne^{20}(He^3, t)Na^{20}$ were made using the magnetically analyzed 32-MeV He^3 beam from the Brookhaven