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 $\pm$ 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 $\pm$ 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 $\pm$ 0.7 keV for the N^{15} doublet and 30.3 $\pm$ 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.

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MASS OF Na^{20} †

P. F. Donovan

Bell Telephone Laboratories, Murray Hill, New Jersey, and Brookhaven National Laboratory, Upton, New York

and

P. D. Parker

Brookhaven National Laboratory, Upton, New York

(Received 31 December 1964)

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 $\pm$ 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 $\pm$ 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

60-inch cyclotron and a 2-cm-diameter gas target with a 3.8×10^{-3}-mm Havar steel window.[6] Charged particles were measured with a semiconductor-detector telescope having an angular resolution of ±1.6° and containing a 50-μ silicon wafer (ΔE detector[7]) and a 3-mm lithium-drifted device (E detector). The signals from these two detectors were added to give $E+\Delta E$, the total energy of the particle, and were multiplied[8] to generate an output pulse of the form $(E+E_0+k\Delta E)\times\Delta E$, which was used to identify the particle as a p, d, t, He^3, or He^4. The $E+\Delta E$ pulse was routed to one of three 512-channel analyzers, depending on whether the particle was identified as (1) a deuteron, (2) a triton, or (3) a He^3 or a He^4.

Figure 1 shows the triton spectra obtained at laboratory angles of 20° and 25° using a natural neon target. The kinematic behavior of the observed triton peaks, as measured by similar spectra taken at 70° and 150°, makes it clear that all six of these peaks are due to the reaction $Ne^{20}(He^3, t)Na^{20}$ and not to the reaction $Ne^{22}(He^3, t)Na^{22}$.

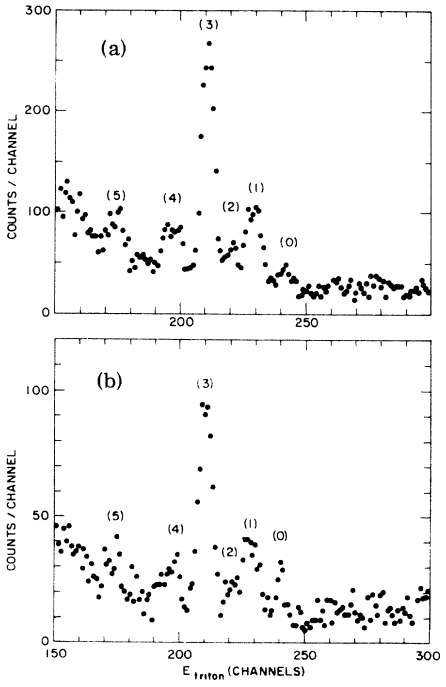

FIG. 1. Triton spectra obtained by bombarding a pure neon gas target with 32-MeV He^3 ions. The dispersions are very nearly 70 keV/channel. The beam integration was different for each of these runs so that a yield comparison is not possible. (a) Spectrum obtained at a laboratory angle of 20°. (b) Spectrum obtained at a laboratory angle of 25°.

As a reference for the energy calibration of our triton spectra, we used the ground-state triton group from the reaction $C^{12}(He^3, t)N^{12}$. [The mass excess of N^{12} has recently[9] been measured to be +17.349 ± 0.009 MeV, so that the Q value for the reaction $C^{12}(He^3, t)N^{12}$ is now known to be −17.367 ± 0.009 MeV.] The triton spectra from the reactions $Ne^{20}(He^3, t)Na^{20}$ and $C^{12}(He^3, t)N^{12}$ were precisely compared by making a measurement using a mixture of neon and methane in the gas target. Since this technique allowed us to measure both spectra simultaneously and under identical conditions, we were able to eliminate energy uncertainties caused by gain shifts, and to reduce target-thickness corrections and beam-energy uncertainties to second-order effects. Figure 2 shows the resulting triton-energy spectrum obtained at a laboratory angle of 20°, indicating the locations of groups corresponding to the ground state and 1.00-MeV first excited state of N^{12} and of group (3) from the reaction $Ne^{20}(He^3, t)Na^{20}$. The location of the Na^{20} ground-state group is obscured by the increase in background due to the presence of the methane; however, from this spectrum the Q value for the Na^{20} (3) group was determined to be −15.85 ± 0.04 MeV. From a series of six runs on pure neon targets yielding spectra similar to those in Fig. 1, the excitation of the Na^{20} (3) group above the ground-

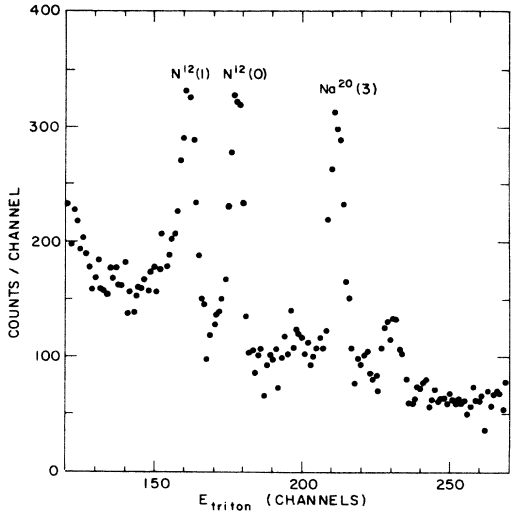

FIG. 2. Triton spectrum obtained at a laboratory angle of 20° by bombarding a mixed neon-methane gas target with 32-MeV He^3 ions. The dispersion is very nearly 70 keV/channel.

state peak was determined to be 1.96 ± 0.04 MeV, yielding a Q value of -13.89 ± 0.06 MeV for the Na^{20} ground-state group and a mass excess of $+6.83 \pm 0.06$ MeV for Na^{20}.

As a check on these results a different reference for the energy calibration of the triton spectra was chosen; for the runs on pure neon gas the Na^{20} ground-state Q value was determined directly by a comparison of the triton spectra to the deuteron spectra which were stored simultaneously from the reaction $Ne^{20}(He^3, d)Na^{21}$. Analyses of these data yield a Na^{20} ground-state Q value of -13.9 ± 0.1 MeV. This result matches perfectly the value determined by reference to the N^{12} ground-state triton group, but is less accurate due to the fact that the groups being compared are much further separated in energy, making their relative energies more sensitive to an exact knowledge of the beam energy and the analyzer dispersion.

Using our value of $+6.83 \pm 0.06$ MeV for the mass excess of Na^{20}, the value of[10] $+3.229 \pm 0.009$ MeV for the mass excess of the first $T=1$ state in Ne^{20}, and the value of[11] -0.0135 ± 0.004 MeV for the mass excess of F^{20}, we have recalculated the coefficients for the quadratic mass formula,[12]

$$M = a + bT_z + cT_z^2,$$

with the following results:

$$b = -3.42 \pm 0.03 \text{ MeV},$$

$$c = +0.18 \pm 0.03 \text{ MeV}.$$

These coefficients agree within the experimental errors with the coefficients calculated for the lowest $T=2$ members of the $A=20$ multiplet using the data of Garvey, Cerny, and Pehl[2] for the $T=2$ levels in F^{20} and Ne^{20}, and using a mass excess of[11] $+3.792 \pm 0.015$ MeV for O^{20},

$$b = -3.70 \pm 0.35 \text{ MeV},$$

$$c = +0.36 \pm 0.15 \text{ MeV}.$$

Finally, with regard to the level structure of Na^{20}, the excitations of the levels corresponding to the observed triton groups may be listed as follows: (0), ground state; (1), 0.76 ± 0.05 MeV; (2), 1.3 ± 0.1 MeV; (3), 1.96 ± 0.04 MeV; (4), 2.89 ± 0.05 MeV; and (5), 4.33 ± 0.1 MeV. It should be noted, however, that groups (1), (4), and (5) are considerably broader than our energy resolution of ~350 keV. Since the threshold for breakup into $Ne^{19} + p$ lies at 2.22 MeV, group (1) is bound, and hence must correspond to an unresolved multiplet. Pehl and Cerny[13] have, in fact, reported that they have resolved group (1) into four groups separated by ~100 keV. Groups (4) and (5), however, may be broad either because they correspond to unresolved multiplets or because they are unbound to proton emission.

It is a pleasure to thank Dr. V. I. Goldanskii for suggesting this problem, Dr. J. F. Mollenauer for his assistance in the construction and maintenance of the gas target, and Professor D. H. Wilkinson, F.R.S., for writing the computer program used in the isobaric-parabola fitting. Thanks are also due to Dr. R. Pehl and Professor J. Cerny for communication of their data prior to publication, and to Dr. C. P. Baker and the 60-inch cyclotron crew for performing the irradiations.

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

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