the resolution of these experiments (~10 kev). No decision could be made as to which isotope of chlorine is responsible for the two resonances observed. It appears worthwhile to investigate manganese, titanium, and potassium at high resolution inasmuch as resonance structure is very likely present in these elements.

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Energy Levels of B^9 and O^{15}†

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Energy levels of B^9 have been investigated by the $B^{10}(He^3,\alpha)B^9$ reaction. Alpha-particle groups leading to the ground, 2.37-Mev and 2.83-Mev states of B^9 have been found. There is no evidence for any well-defined state between the ground state and 2.37-Mev state of B^9. The $O^{16}(He^3,\alpha)O^{15}$ reaction has been studied in the neighborhood of 5-Mev excitation in O^{15} and excited states have been found at 5.247- and 5.195-Mev energy in O^{15}.

INTRODUCTION

THE energy levels of Be^9 have been the subject of many recent studies.[1] It is of interest to compare the level structure of the mirror nuclei Be^9 and B^9, especially because of the unusual properties of the 1.75-Mev state in Be^9. Prior to the present investigation, the ground state and a state near 2.33 Mev in B^9 had been firmly established,[2–5] while a state in the vicinity of 1.4 Mev had been suggested.[4]

The energy level scheme of N^{15} is well known from precise measurements of the $N^{14}(d,p)N^{15}$ reaction,[1] while the O^{15} levels below the threshold for $N^{14}+p$ have been studied only by $N^{14}(d,n)O^{15}$ and by gamma-ray cascades[1] which do not provide resolution comparable to the (d,p) work. From a comparison of the N^{15} and O^{15} energy-level schemes it would be expected that there should be two levels in O^{15} just above 5 Mev corresponding to the 5.276- and 5.305-Mev states in N^{15}. The $O^{16}(He^3,\alpha)O^{15}$ reaction was employed in order to resolve these levels.

THE B^9 MEASUREMENTS

For both experiments singly charged He^3 ions were accelerated by the Kellogg Radiation Laboratory 3-Mv electrostatic accelerator and were selected in energy by an electrostatic analyzer. The reaction products were analyzed by a 16-inch double-focusing 180° magnetic spectrometer and detected by a 0.003-inch thick CsI (Tl) scintillator.

In the B^9 experiment a 96% enriched B^{10} target approximately 20 $\mu g/cm^2$ thick, evaporated on a tantalum backing, was used. An observation angle of 131° in the laboratory system was chosen in order to reduce the alpha-particle energy below the 10-Mev limit of the magnetic spectrometer. Alpha-particle spectra were taken at 2, 2.5, and 3 Mev He^3 energy, of which the 3-Mev spectrum shows the most pronounced structure (Fig. 1). Alpha-particle groups were found leading to the ground state and to excited states of B^9 at 2.37 ± 0.02-Mev and 2.83 ± 0.03 Mev (based on the assumed ground-state calibration). The shift of these excited-state groups with angle is consistent with their assignment to a level in B^9. A possible contribution of alpha particles in the region of the 2.83-Mev state from the $B^{11}(He^3,\alpha)B^{10}$ reaction due to B^{11} contamination of the target was excluded by the measurement of an alpha spectrum with a B^{11} target. The B^{11} reaction does not show any yield in this region. The width of the 2.37-Mev state was measured separately with improved resolution and was found to be 80 ± 15 kev, while the 2.83-Mev state width is about 300 kev. There is no indication of a level between the ground and 2.37-Mev states. To investigate excitation energies of B^9 between 4 and 7 Mev, the alpha spectrum was taken with the spectrometer at 90°. No sharp level was observed in this region.

The 2.37-Mev energy value for the state in B^9 established in this experiment is in agreement with the 2.33-Mev value[4] for the threshold of the same state, assuming the measured 80-kev width for this state. To

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obtain the energy of a level from threshold measurements, half of the level width should be added.[6] The existence of a broad level in B^9 corresponding[7] to the suggested $\frac{1}{2}^+$, 1.75-Mev level in Be^9 is not completely excluded by these measurements. There is a continuous alpha background which increases smoothly with excitation energy and a broad, weakly-excited state between the ground and 2.37-Mev excited states would be hard to observe. The continuous alpha spectrum may be due to a three-body disintegration, for example as described by Lane and Thomas.[8] This high background also prevents the observation of broad levels of B^9 above 4 Mev. These results are in agreement with similar unpublished work at the Rice Institute.[9]

THE O^{15} MEASUREMENTS

In spite of the negative Q-value of the $O^{16}(He^3,\alpha)O^{15}$ reaction for the region of excitation near 5 Mev in O^{15}, it is possible to separate alpha particles from scattered He^3 nuclei at forward angles. At an incident He^3 energy of 3 Mev and at angles smaller than 45° in the laboratory system, the alpha-particle groups leading to the region of interest have kinetic energies higher than 2.25 Mev, while the scattered He^3 particles have about 3 Mev. Because of the different charge to mass ratio of the He^{3++} and He^{4++} ions, 3-Mev He^3 ions are focused at the same magnetic field as 2.25-Mev He^4 ions. With increasing observation angle the alpha-particle energy drops faster than the scattered He^3-particle energy and the He^3 and He^4 groups overlap.

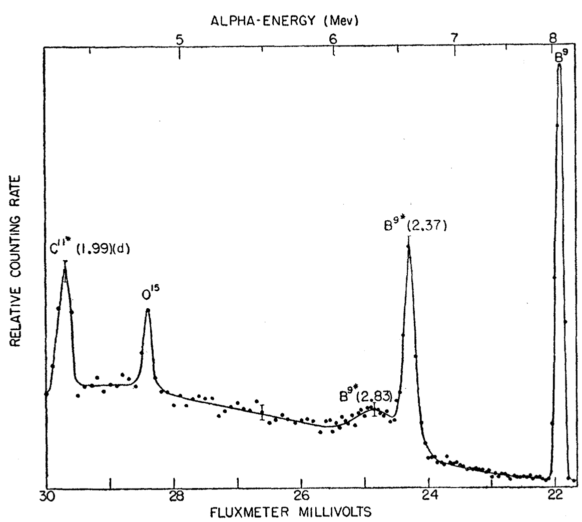

FIG. 1. The alpha-particle spectrum from the $B^{10}(He^3,\alpha)B^9$ reaction at 3-Mev He^3 energy and 131° magnet angle. The groups are designated by the corresponding state of the residual nucleus emitted with the alpha particles. In addition the alpha group from $O^{16}(He^3,\alpha)O^{15}$ and deuteron group from $B^{10}(He^3,d)C^{11}$ reactions are present. The fluxmeter millivolt readings are inversely proportional to momentum/charge.

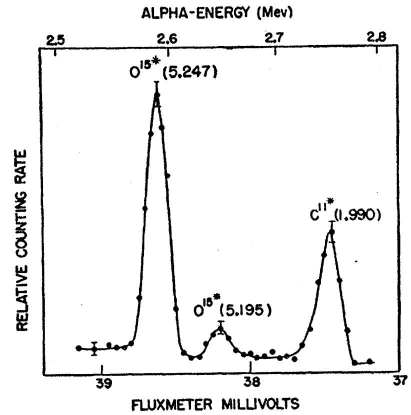

FIG. 2. The alpha-particle spectrum from the $O^{16}(He^3,\alpha)O^{15}$ and $C^{12}(He^3,\alpha)C^{11}$ reactions at 3-Mev He^3 energy and 15° magnet angle. The fluxmeter millivolt readings are inversely proportional to momentum/charge.

A second limitation in choosing the magnet angle is imposed by the $C^{12}(He^3,\alpha)C^{11}$ reaction which is produced in the unavoidable carbon contamination of the target. The alpha-particle group leading to the first excited state of C^{11} has about the same energy as the alpha particles leading to the region of interest in O^{15}. A good separation of the oxygen and carbon groups is possible at angles smaller than 35° in the laboratory system.

Because of contamination of the He^3 gas supply and the ion source used in this experiment with hydrogen and deuterium, molecular HD^+ ions were present and these contaminated the He^{3+} singly charged beam even after magnetic and electrostatic analysis. In the target the 3-Mev HD^+ ion breaks into 1-Mev H^+ and 2-Mev D^+ ions. The 2-Mev deuteron group is focused at the same magnetic field as are 4-Mev alpha particles, but because of the high Rutherford scattering at forward angles, the multiply-scattered deuterons form a continuous background over the range of magnetic fields corresponding to alpha particles below 4 Mev. Because pulse-height analysis of the scintillation counter spectrometer did not provide sufficient separation between alpha particles and deuterons to count alpha particles alone, a carbon foil, about 20 $\mu g/cm^2$ thick, was mounted above the electrostatic analyzer in order to produce a clean He^3 beam. Singly charged He^{3+} and HD^+ ions, passing through the foil were thus broken up into H^+, D^+, and He^{3++} ions of different energies, which could easily be separated by the electrostatic analyzer.

In this experiment two different oxygen targets were used: SiO evaporated on a carbon foil[10] and an Al_2O_3-foil target prepared by anodizing aluminum.[11] Both targets were about 20 kev thick for 3-Mev He^3 ions.

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With the clean He^3 beam, alpha spectra were taken at 35°, 25°, and 15° in the laboratory system. The 15° spectrum is shown in Fig. 2. In addition to the alpha group from the $C^{12}(He^3,\alpha)C^{11}$ reaction leading to the first excited state of C^{11}, two closely-spaced groups of alpha particles were observed. The energy shift of the two groups with angle was consistent with the assignment of these two groups to the reaction $O^{16}(He^3,\alpha)O^{15}$, but because of the small permitted change in angle the $N^{15}(He^3,\alpha)N^{14}$ and $O^{17}(He^3,\alpha)O^{16}$ reactions could not be excluded by this measurement. However, the intensity ratio of the two alpha groups from the two different oxygen targets was the same, implying that both alpha groups were due to reaction products of oxygen isotopes. Ascribing the observed alpha groups to the $O^{16}(He^3,\alpha)O^{15}$ reaction, the cross section at 15° in the laboratory system is 0.5 ± 0.2 mb/steradian for the stronger group and 0.06 ± 0.02 mb/steradian for the weaker one. On the other hand, if the observed groups are ascribed to the $O^{17}(He^3,\alpha)O^{16}$ reaction, a cross section of the order of 1 b/steradian is required. Since so large a cross section is very improbable for (He^3,α) reaction at these energies, the identification of these groups as leading to excited states of O^{15} seems established.

The magnetic spectrometer was calibrated by the observation of elastically scattered protons of known energy, and the excitations of the two excited states in O^{15} were found to be 5.195 ± 0.01 Mev and 5.247 ± 0.01 Mev assuming the 4.923-Mev Q-value[1] for the $O^{16}(He^3,\alpha)O^{15}$ ground state. These values are to be compared with 5.276 and 5.305 Mev in N^{15}. The separations are 52 ± 5 kev in O^{15} and 29 kev in N^{15}. Because of the possibility of fairly large level shifts, further work will be necessary to identify corresponding members of the pairs of levels. In addition the excitation of the first excited state of C^{11} was found to be 1.990 ± 0.01 Mev using the same method of calibration.

These results are in agreement with recently reported $O^{16}(He^3,\alpha)O^{15}$ work carried out by the Harwell group.[12]

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Collective and Interparticle Interactions in Even-Even Nuclei*

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A calculation using two equivalent $f_{7/2}$ particles and adding surface effects to the two-body interaction is reported. The effects of increasing the strength of (*a*) the surface interaction and (*b*) the two-particle interaction are computed. The qualitative regularities observed in even-even nuclei in the so-called vibrational region are obtained and the agreement is somewhat better than that with the pure vibrational model. In contrast to earlier calcaulations, these results can give a spin of 2^+ for the second excited state, as often observed. The calculated ratio of $B(E2; 2'\rightarrow 2)$ to $B(E2; 2\rightarrow 0)$ is less than 1.0. The appropriate values of the deformation parameters x are less than 1.0.

I. INTRODUCTION

As more experimental information is obtained, the regularities observed in even-even nuclei are becoming more obvious. In the region $150<A<185$ and $A>225$, these regularities are the especially simple ones characteristic of rotational spectra,[1] and are explained with great accuracy by the Bohr-Mottelson strong-coupling collective model.[2,3] In order to examine the collective behavior which is also exhibited by even-even nuclei outside these two regions,[4–7] the weak-coupling

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