Excited State of Be^9 from the $B^{11}(d, \alpha)Be^{9*}$ Reaction†

D. M. VAN PATTER, A. SPERDUTO, K. HUANG, E. N. STRAIT, AND W. W. BUECHNER
Department of Physics and Laboratory for Nuclear Science and Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts

(Received September 25, 1950)

The alpha-particles from boron bombarded by 1.51-Mev deuterons have been investigated with a magnetic spectrometer. Two groups of alpha-particles have been assigned to the reaction $B^{11}(d,\alpha)Be^9$ with Q-values of 8.018 ± 0.007 and 5.596 ± 0.006 Mev, indicating a virtual state of Be^9 at 2.422 ± 0.005 Mev. The previously unreported alpha-particle group corresponding to this excited state had a natural half-width of less than 7 kev. No additional alpha-groups corresponding to excited states of Be^9 were observed for excitations of Be^9 from 0 to 5.0 Mev.

I. INTRODUCTION

At present, only the one excited state of Be^9 at 2.4 Mev is well-established experimentally. This virtual state was first discovered by Davis and Hafner[1] from the inelastic scattering of 4.5- and 7.1-Mev protons. They reported the level at 2.41 Mev with a half-width of less than 100 kev and found no indication of other levels in Be^9 up to 5.4-Mev excitation. This result has been confirmed recently by Rhoderick,[2] who found only one level at 2.39 ± 0.05 Mev from the inelastic scattering of 4.7-Mev protons.

Guth and Mullin[3] have made a theoretical analysis of the experimental cross section of the $Be^9(\gamma,n)Be^8$ reaction which has a pronounced maximum about 100 kev above the reaction threshold. Their results indicated that the $Be^9(\gamma,n)Be^8$ yield can be accounted for by a bound S-state about 100 kev below threshold (at 1.5-Mev excitation of Be^9).

Mullin and Guth[4] have also analyzed the angular distribution of neutrons from this reaction. They find good agreement with the assumption that the ground state of Be^9 is a doublet ^2P-state and that the level at 2.4 Mev is an unresolved ^2D-state.

It is possible to examine the excited states of Be^9 from an investigation of the $B^{11}(d,\alpha)Be^{9*}$ reaction. The ground-state $B^{11}(d,\alpha)Be^9$ alpha-particles have been observed by Cockcroft and Lewis[5] at 0.55-Mev bombarding energy, and they reported[6] a Q-value of 8.13 ± 0.12 Mev. In their results, there was no indication of an alpha-group corresponding to the 2.4-Mev excited state of Be^9; however, if such an alpha-group were much weaker than the ground-state group, it probably would not have been detected. Using 0.55-Mev deuterons and an enriched B^{11} target, Smith and Murrell[7] found the ground-state $B^{11}(d,\alpha)Be^9$ alpha-group to have a range of 4.6 cm. They observed another alpha-group of 2.8-cm range, which was of about equal intensity from both the enriched B^{11} and B^{10} targets and which Smith and Murrell attributed to carbon contamination from the reaction $C^{13}(d,\alpha)B^{11}$. An alpha-group corresponding to the 2.4-Mev excited state of Be^9 would have coincided with the 2.8-cm alpha-group. However, it should have been six times more intense from the enriched B^{11} target (97 percent B^{11}) as from the enriched B^{10} target (15 percent B^{11}).

Since there had been no report in the literature of any alpha-particle groups from the $B^{11}(d,\alpha)Be^{9*}$ reaction corresponding to excited states of Be^9, it was decided to study this reaction. This has been done using a magnetic spectrometer of high resolution in order to investigate both the states of Be^9 and the possibility that some of the states may be closely spaced doublets.

II. APPARATUS AND EXPERIMENTAL PROCEDURE

The apparatus and experimental procedure were essentially the same as those described in a previous paper,[8] except for some improvements in stabilization and in the analysis of results. A beam of deuterons in the energy range of 1.2 to 1.8 Mev was obtained from an electrostatic accelerator. This beam was then defined in space, direction, and momentum by means of a deflecting magnet and slit arrangement. The target was located between the pole faces of a large annular magnet. A fraction of the charged particles emitted from the target at right angles to the incident beam was deflected through 180 degrees and focused in the uniform field of the annular magnet. The charged particles were recorded on Eastman NTA plates, each plate being exposed successively and each covering a range of 10 percent in energy. During the course of the experiments to be described, an improvement was made in the stabilization of the magnetic field of the annular magnet. With the slit arrangement used, charged-particle groups were measured with an energy spread at half-maximum of as low as 0.21 percent.

Measurements of the magnetic field and radii of curvature of the charged particles determined the momentum of the particles. The magnetic field was

† This work has been assisted by the joint program of the ONR and AEC.

[1] K. E. Davis and E. M. Hafner, Phys. Rev. **73**, 1473 (1948).
[2] E. H. Rhoderick, Proc. Roy. Soc. **A201**, 348 (1950).
[3] E. Guth and C. J. Mullin, Phys. Rev. **76**, 234 (1949).
[4] C. J. Mullin and E. Guth, Phys. Rev. **76**, 682 (1949).
[5] J. O. Cockcroft and W. B. Lewis, Proc. Roy. Soc. **A154**, 246 (1936).
[6] Corrected by M. S. Livingston and H. A. Bethe, Rev. Mod. Phys. **9**, 3 (1937).
[7] C. L. Smith and E. B. M. Murrell, Proc. Cambridge Phil. Soc. **35**, 298 (1939).
[8] Buechner, Strait, Stergiopoulos, and Sperduto, Phys. Rev. **74**, 1569 (1948).

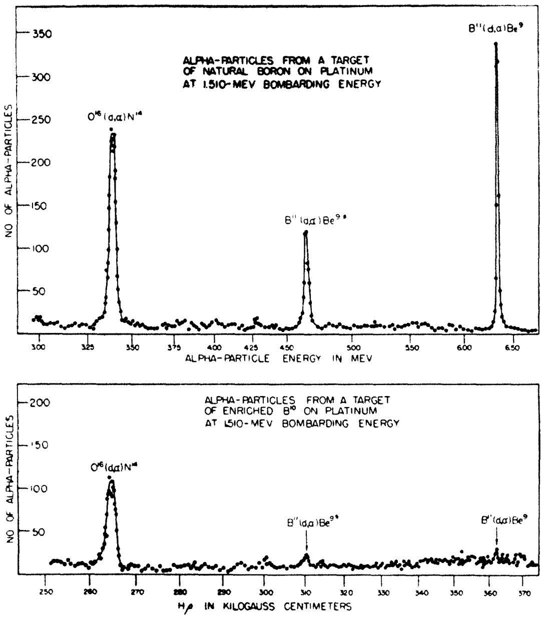

FIG. 1. Alpha-particle spectrum from natural boron and enriched B^{10} targets in the energy interval 3.0 to 6.7 Mev. The incident deuteron energy is 1.510 Mev.

measured by a balance-type fluxmeter which was described in a previous paper.[9] The calibration constant for the fluxmeter was determined from the measured radius of curvature of polonium alpha-particles in the magnetic field of the annular magnet. The value of Hr for polonium alpha-particles used as an absolute standard was computed from Briggs' value[10] for the Hr of RaC′ alpha-particles and from Lewis and Bowden's value[11] for the ratio of velocities of RaC′ alpha-particles and polonium alpha-particles. From these measurements, the value of Hr for polonium alphas is 3.3159×10^5 gauss-cm (absolute emu), accurate to 1 part in 5000.

The radii of curvature of the charged-particle groups were determined by measuring with a microscope the track-density distribution on the nuclear-track plates relative to a fixed index mark. The background track density for a given peak was determined at points sufficiently far removed so that the contribution from the reaction peak was negligible. In the case where several peaks were only partly resolved, an analytic resolution of the peaks was made taking into account the peak shape.

The incident deuteron energy was determined from the measurement of the energy of deuteron groups scattered elastically from targets consisting of a thin layer of natural boron evaporated onto a thin film of Formvar. It was found possible to resolve the deuteron groups scattered from B^{10}, B^{11}, C^{12}, and O^{16} nuclei contained in the target and backing.

As will be described in a forthcoming paper, the determination of Q-values was made more precise by an accurate measurement of the median angle of observation as a function of the magnetic field of the annular magnet. This angle varied from $(\frac{1}{2}\pi - 0.0029)$ radians at zero field to $(\frac{1}{2}\pi - 0.0015)$ radians at maximum field. The appropriate corrections were applied to the observed Q-values calculated for a 90-degree angle of observation. In addition, a correction was made for the finite solid angle of observation as well as for the approximation of using the nonrelativistic Q-equation for calculation.

The targets used for the initial survey of the $B^{11}(d,\alpha)Be^9$ reaction were prepared by the evaporation of metallic boron from a carbon crucible onto platinum backings 0.010-in. thick. Both natural boron and boron enriched to 96 percent B^{10} (obtained from Oak Ridge) were used. These targets had an effective thickness for the $B^{11}(d,\alpha)Be^9$ ground-state reaction of less than 13 kev. In addition, targets were made consisting of a thin layer of natural boron evaporated onto a thin film of Formvar. From these latter targets, it was possible to observe deuteron groups elastically scattered from the B^{10} and B^{11} nuclei in the natural boron.

III. RESULTS

A survey was first made of the alpha-particle groups with energies between 3.0 and 6.7 Mev emitted from the natural boron and enriched B^{10} targets on platinum when bombarded by 1.51-Mev deuterons. The results of this survey are shown in Fig. 1. The survey was not extended to lower energy alpha-particles because of the presence of deuterons scattered from platinum. The yields of the alpha-particles from the two targets have been normalized to the same beam bombardment and area counted on the nuclear-track plates. The relative thickness of the two targets was determined from a comparison of the yield of the $B^{10}(d,p)B^{11}$ protons from each target. When corrected for the isotopic abundance of B^{10} in the two targets, the thicknesses of the natural boron and enriched B^{10} targets were found to be equal to within 10 percent.

In Fig. 1, the prominent alpha-group from the natural boron target (81 percent B^{11}) at 6.37 Mev was assigned to the ground-state reaction $B^{11}(d,\alpha)Be^9$. This assignment was made on the basis of the following evidence. From the enriched B^{10} target (four percent B^{11}), a weak alpha-group at this position could barely be distinguished from the continuous distribution of alpha-particles from the reaction $B^{10}(d,\alpha)2\alpha$. The yield of this group increased by a factor of approximately 25 when the natural boron target was substituted for the enriched B^{10} target. Since there is a difference of a factor of 20 in the relative abundances of B^{11} in the two targets, this result is in agreement with the assumption that the 6.37-Mev alpha-group originates from the B^{11}

[9] Buechner, Strait, Sperduto, and Malm, Phys. Rev. **76**, 1543 (1949).
[10] G. H. Briggs, Proc. Roy. Soc. **A157**, 183 (1936).
[11] W. B. Lewis and B. V. Bowden, Proc. Roy. Soc. **A145**, 250 (1934).

The preliminary Q-value for this group was found to be 8.02 Mev, in close agreement with the value of 8.03 Mev calculated from masses[12] and in fair agreement with the previous experimental value[6] of 8.13±0.12 Mev. The above results indicate that the assignment of this alpha-group to the $B^{11}(d,\alpha)Be^9$ reaction is correct.

A second prominent alpha-group of 4.69-Mev energy was observed from the natural boron target. A weak group of the same energy was observed from the enriched B^{10} target, the yield being about a factor of 10 smaller. If this group were assigned to the $B^{11}(d,\alpha)Be^{9*}$ reaction, it would correspond to an excited state of Be^9 at 2.42 Mev, agreeing with the position of an excited state already established by inelastic proton scattering. However, the ratio of the yields from the two targets was a factor of 2 smaller than expected. In addition, at 1.51-Mev bombarding energy, the position of this 4.69-Mev alpha-group agreed within a few kev with the position of the alpha-group from the $C^{13}(d,\alpha)B^{11}$ reaction with a Q-value of 5.16 Mev. Prior to these experiments, the $C^{13}(d,\alpha)B^{11}$ group had been observed from other targets subjected to long bombardments and had evidently originated from a surface contamination of natural carbon which contains 1.1 percent of C^{13}. It was therefore necessary to eliminate the possibility that the observed alpha-group from the natural boron target was entirely due to the $C^{13}(d,\alpha)B^{11}$ reaction.

To accomplish this purpose, the relative intensities of the $C^{13}(d,\alpha)B^{11}$ and $C^{13}(d,p)C^{14}$ groups were measured at 1.811-Mev bombarding energy from a target of $KC^{13}N$, enriched to 60 percent C^{13}. The ratio of the yields was found to be 5:1. Then, the ratio of the possible $B^{11}(d,\alpha)Be^{9*}$ alpha-group and the $C^{13}(d,p)C^{14}$ proton group was measured from the natural boron target at the same bombarding energy. This ratio was found to be 62:1. This indicated that only eight percent of the alpha-group from the natural boron target could be attributed to the $C^{13}(d,\alpha)B^{11}$ reaction, and the remainder was evidently due to the $B^{11}(d,\alpha)Be^{9*}$ reaction. This also explained the fact that the ratio of the yield of this group from the natural boron and the enriched B^{10} targets was lower than predicted from the abundance of B^{11} in the two targets, inasmuch as part of the weak group from the enriched B^{10} target was evidently due to the $C^{13}(d,\alpha)B^{11}$ reaction.

In the above work, the energy of the $B^{11}(d,\alpha)Be^{9*}$ alpha-group was measured at 1.812-Mev bombarding energy. Combining this result with the original measurements made at 1.510-Mev bombarding energy, it was possible to determine the shift in energy of this alpha-group for a change in deuteron bombarding energy of 302±3 kev. At an angle of observation of 90 degrees, the change of energy of a disintegration particle, ΔE_{out}, due to a change of bombarding energy, ΔE_{in}, is given by:

$$\Delta E_{\text{out}}=[(M_{\text{res}}-M_{\text{in}})/(M_{\text{res}}+M_{\text{out}})]\Delta E_{\text{in}},$$

where M_{res} is the mass of residual nucleus, M_{in} is the mass of bombarding particle, and M_{out} is the mass of disintegration particle.

In the case of the $B^{11}(d,\alpha)Be^{9*}$ reaction, the energy of an alpha-group would change 162±2 kev for a change in bombarding energy of 302±3 kev. For the $C^{13}(d,\alpha)B^{11}$ reaction, the expected change would be 181±2 kev. The observed change in the energy of the alpha-group was 161±4 kev, in agreement with the assignment of this group to the $B^{11}(d,\alpha)Be^{9*}$ reaction. In fact, this result ruled out any target mass other than 11, since a target mass of 10 or 12 would have given an alpha-energy shift of 151 or 172 kev, both of which are outside the limit of error on the measurement. These results indicated that the 4.69-Mev alpha-group from the natural boron target could be assigned unambiguously to the $B^{11}(d,\alpha)Be^{9*}$ reaction.

In the light of this evidence, the results of Smith and Murrell[7] were reexamined. Using enriched B^{11} (97 percent B^{11}) and B^{10} (15 percent B^{11}) targets, they found a 2.8-cm alpha-group that they assigned to carbon contamination on the basis that the yield of this group was about the same from the two targets. The possibility cannot be ruled out that part of the group which they observed was actually due to the $B^{11}(d,\alpha)Be^{9*}$ reaction, but it is evident that they also observed particles from the $C^{13}(d,\alpha)B^{11}$ reaction.

The remaining prominent alpha-group in Fig. 1 of energy 3.42 Mev from the natural boron target was only a factor of 2.5 more intense than the corresponding group from the enriched B^{10} target. This factor was considerably smaller than the factor of 20 for the relative amounts of B^{11} in the two targets and indicated that this alpha-group should not be attributed to the $B^{11}(d,\alpha)Be^{9*}$ reaction. In addition, the Q-value of this group, if assigned to the reaction $O^{16}(d,\alpha)N^{14}$, agreed within 10 kev with the Q-values measured for the same reaction when a target of Formvar (containing oxygen but no boron) was used. However, it was still necessary to rule out the possibility that part of this group could come from the $B^{11}(d,\alpha)Be^{9*}$ reaction. In order to do this, the following experiments were made:

(1) The ratio of intensities of the $O^{16}(d,\alpha)N^{14}$ and $O^{16}(d,p)O^{17}$ groups from a thin Formvar target was measured at 1.510-Mev bombarding energy and was found to be 0.8:1. Then, the ratio of the 3.42-Mev alpha-group and the $O^{16}(d,p)O^{17}$ proton group from the natural boron target was measured at the same bombarding energy and was found to be 1:1. These ratios were considered in agreement with the accuracy of measurement.

(2) The relative yield of this prominent alpha-group from the natural boron target at 1.81- and 1.51-Mev bombarding energy was measured as 3.0:1. The same relative yield was measured from the enriched B^{10}

[12] W. F. Hornyak and T. Lauritsen, Revs. Modern Phys. 20, 191 (1948).

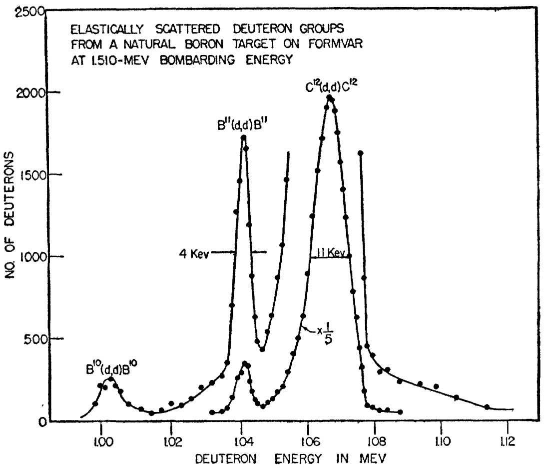

FIG. 2. Spectrum of elastically scattered deuteron groups from a natural boron target on Formvar at 1.510-Mev bombarding energy.

target (four percent B^{11}) and was found to be 3.7:1, in agreement within the error of measurement.

(3) Precise measurements were made on the energy shift of the prominent alpha-group from the natural boron target when the deuteron bombarding energy was changed from 1.203 to 1.811 Mev. The expected change in energy for a $B^{11}(d,\alpha)Be^{9*}$ alpha-group would be 327 ± 2 kev for a change of 608 ± 3 kev in bombarding energy, while that for a $O^{16}(d,\alpha)N^{14}$ group would be 405 ± 2 kev. The observed change in energy was 403 ± 3 kev, in agreement with the assignment of this group to the $O^{16}(d,\alpha)N^{14}$ reaction.

In addition, the observation of the $O^{16}(d,\alpha)N^{14}$ group at a bombarding energy of 1.203 Mev precluded the possibility that a small $B^{11}(d,\alpha)Be^{9*}$ alpha-group might be hidden under the $O^{16}(d,\alpha)N^{14}$ group at 1.510-Mev bombarding energy. From 1.510- to 1.203-Mev bombarding energy, the $O^{16}(d,\alpha)N^{14}$ group shifted 40 kev more than would a possible $B^{11}(d,\alpha)Be^{9*}$ group. Since the half-width of the $O^{16}(d,\alpha)N^{14}$ group was 40 kev at 1.510-Mev bombarding energy, a small $B^{11}(d,\alpha)Be^{9*}$ group would have been resolved from the $O^{16}(d,\alpha)N^{14}$ group at 1.203-Mev bombarding energy.

The above results indicated that the assignment of the 3.42-Mev alpha-group to the reaction $O^{16}(d,\alpha)N^{14}$ was correct. It was concluded that both boron targets contained an appreciable amount of oxygen, the natural boron target containing the greater amount.

Except for the $O^{16}(d,\alpha)N^{14}$ and the two $B^{11}(d,\alpha)Be^9$ groups, no other definite group of alpha-particles appeared in the survey shown in Fig. 1. The background between peaks observed from the natural boron target could be accounted for partially by the continuous distribution of alpha-particles from the $B^{10}(d,\alpha)2\alpha$ reaction from the 19 percent of B^{10} in the target. The remainder of the background is considered to come from a certain amount of alpha-particle contamination on the nuclear-track plates, which cannot be completely eliminated from the counting of the track-density distributions. However, this survey indicated that there were no additional alpha-groups with an intensity greater than 0.1 the intensity of the $B^{11}(d,\alpha)Be^{9*}$ group corresponding to the 2.42-Mev level in Be^9. The region of excitation of Be^9 covered in this survey was 0 to 5.0 Mev.

The original survey of the $B^{11}(d,\alpha)Be^9$ reaction indicated that the alpha-group corresponding to the 2.42-Mev level of Be^9 had a half-width of less than 30 kev. However, the contribution of target thickness to this half-width was somewhat uncertain since the elastically scattered deuterons from the platinum backing of the target obscured the deuteron group scattered from the boron. To eliminate this difficulty, a target was prepared by evaporating natural boron onto a thin film of Formvar (containing oxygen and carbon). The spectrum of elastically scattered 1.510-Mev deuterons from this target is shown in Fig. 2. The deuteron groups scattered from B^{10}, B^{11}, and C^{12} are clearly resolved. The intensities of the B^{10} and B^{11} groups are very closely in the ratio of their isotopic abundance in natural boron.

The deuteron group elastically scattered from B^{11} had an observed half-width of 4.6 kev. To calculate the target thickness for the $B^{11}(d,d)B^{11}$ reaction, it was first necessary to subtract the energy spreads caused by the finite solid angle of observation and the geometry of the slit arrangement. As a result, the target thickness was calculated to be 2.8 kev for the $B^{11}(d,d)B^{11}$ reaction and 4.5 kev for the $B^{11}(d,\alpha)Be^{9*}$ reaction.

The $B^{11}(d,\alpha)Be^{9*}$ alpha-group observed from the same target at 1.510-Mev bombarding energy is shown in Fig. 3. This alpha-group had an observed half-width of 14.8 kev. Correcting this energy spread for the finite angle of observation, the half-width was reduced to 11.4 kev. Before an upper limit for the natural half-width of this group could be made, an estimate was required of the energy spread due to the distribution of beam on the target and the aberration of the 180-degree focusing action of the annular magnet. With the improved stabilization of the annular magnet, the narrowest half-width observed from a reaction where the target thickness was negligible had an energy spread of 0.20 percent after correction for the finite solid angle. Most of this spread could be attributed to the distribution of bombarding deuterons on the target. This distribution had a half-width of 0.6 mm, resulting in an energy spread of 0.16 percent.

The above energy spread of 0.20 percent would contribute 9.2 kev to the half-width of the $B^{11}(d,\alpha)Be^{9*}$ peak. Subtraction of this energy spread and the contribution due to target thickness left an upper limit of 5 kev for the natural half-width of the $B^{11}(d,\alpha)Be^{9*}$ alpha-particle group. The upper limit of the natural half-width estimated in this way is probably determined by instrumental factors.

The targets used for the original survey of the

$B^{11}(d,\alpha)Be^9$ reaction had been subjected to long beam bombardments. From previous experience, it had been found that Q-values calculated for (d,α) reactions from such targets were often of the order of 20 kev too low because of a thick surface layer of carbon that evidently increased with bombardment. In order to eliminate this effect, the Q-values for the two $B^{11}(d,\alpha)$ alpha-particle groups were measured from freshly prepared targets that had not been previously bombarded. The Q-values were calculated to be 8.018 ± 0.007 and 5.596 ± 0.006 Mev, respectively, corresponding to the ground state of Be^9 and an excited state at 2.422 ± 0.005 Mev. Both of these Q-values are an average of two independent measurements which agreed to better than 7 kev. The corrections previously described have been applied to these Q-values, the total corrections being -4.7 and -4.1 kev, respectively. The major part of these corrections, about 80 percent, came from the small deviation from 90 degrees of the median angle of observation. The probable error on this correction was only one-sixth of the correction itself.

The magnetic spectrometer used for these experiments was not designed for the accurate measurement of relative intensities of various particle groups. In most cases, the groups to be compared were recorded on different nuclear-track plates, and it was necessary to assume that the experimental conditions had not changed. However, it was found that the yield of a given particle group from the same target can usually be reproduced to better than a factor of 2. The observation of the deuteron group scattered elastically from the B^{11} nuclei of the natural boron target, as shown in Fig. 3, permitted a comparison of the yield of the $B^{11}(d,d)B^{11}$ process with the yields of the two $B^{11}(d,\alpha)Be^9$ groups. At 1.510-Mev bombarding energy the observed relative intensities of these groups were as follows:

$$B^{11}(d,\alpha)Be^9 : B^{11}(d,\alpha)Be^{9*} : B^{11}(d,d)B^{11} = 1.0:0.6:12.$$

These relative intensities have reproduced several times to better than 20 percent.

In addition, the elastic scattering of both protons and deuterons from B^{10} was observed. At 1.510-Mev bombarding energy, the observed relative intensities of the various scattering processes were:

$$B^{11}(d,d)B^{11} : B^{10}(d,d)B^{10} : B^{10}(p,p)B^{10} = 1.0:1.1:1.8.$$

These values cannot be considered to be reliable to better than a factor of 2. If one assumes Rutherford scattering for 1.510-Mev protons scattered from B^{10} at a laboratory angle of 90 degrees, it is possible to estimate the differential cross section for the $B^{10}(p,p)B^{10}$ process as 57 millibarns per atom per steradian. After applying a correction for the solid angle of observation in center-of-mass coordinates, the differential cross sections for the $B^{11}(d,\alpha)Be^9$ and $B^{11}(d,\alpha)Be^{9*}$ reactions are calculated to be 2.6 and 1.6 millibarns per atom per steradian. The accuracy of the differential cross sections calculated by this method cannot be stated, since the validity of assuming Rutherford scattering is not known. It is probable that this assumption may be considerably in error, but it provides a convenient way of expressing the observed intensities.

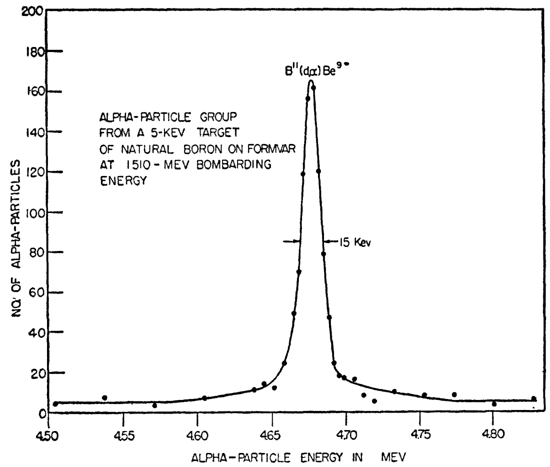

FIG. 3. $B^{11}(d,\alpha)Be^{9*}$ alpha-particle group observed from a 5-kev natural boron target on Formvar.

IV. CONCLUSIONS

The results of this investigation indicate that a previously unreported $B^{11}(d,\alpha)Be^{9*}$ alpha-particle group has been observed, corresponding to an excited state of Be^9 at 2.422 ± 0.005 Mev. The reason that this group was not previously reported is probably because of its close proximity to the alpha-particles from the reaction $C^{13}(d,\alpha)B^{11}$. The position of this excited state is in agreement with the values of 2.41 Mev[1] and 2.39 ± 0.05 Mev[2] previously reported from inelastic proton scattering. The differential cross section for this alpha-particle group is of the order of 2 millibarns, of the same magnitude as the differential cross section of 3 millibarns reported by Davis and Hafner[1] for the inelastic scattering of 4.5- and 7.1-Mev protons leading to the same excited level.

No indication has been found to indicate that other states of Be^9 from 0 to 5 Mev are excited by the $B^{11}(d,\alpha)Be^{9*}$ reaction. This result is in accord with the results of Davis and Hafner[1] from inelastic proton scattering. Recently, the inelastic scattering from beryllium of 14-Mev deuterons has been investigated by the M.I.T. cyclotron group.[13] Only one inelastic deuteron group was found, corresponding to an excited state of Be^9 at 2.4 ± 0.3 Mev, with no indication of other excited states from 0 to 5 Mev. There is therefore no evidence from these investigations that any other state of Be^9 from 0 to 5 Mev, except the 2.42-Mev state, is excited by the $Be^9(p,p')$, $Be^9(d,d')$, and $B^{11}(d,\alpha)$ reactions with an intensity greater than 0.1 to 0.2 the intensity of the 2.42-Mev excited state. The above results are

[13] Preliminary measurements, M. I. T. Cyclotron Group.

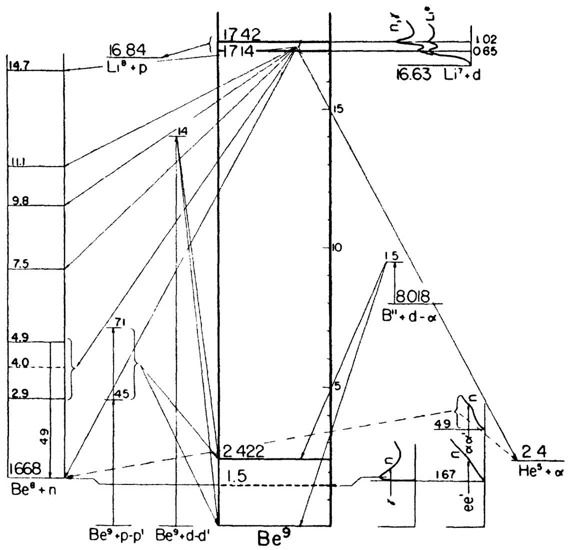

FIG. 4. Energy-level diagram for Be^9. Energies in Mev.

included in the energy-level diagram for Be^9, shown in Fig. 4.

As has been mentioned, it has been proposed that the ground state and the 2.4-Mev excited state of Be^9 may be doublets. The observed half-widths of the $B^{11}(d,\alpha)$ alpha-groups, corresponding to these two states of Be^9, were 20 and 15 kev, respectively. Neither group showed any indication of doublet structure. Analysis of these results indicates an upper limit of 12 and 7 kev for the spacing of possible doublets in the ground state and 2.42-Mev excited state of Be^9, assuming the doublet members to be of about equal intensity.

The upper limit of the half-width of the $B^{11}(d,\alpha)Be^{9*}$ alpha-particle group was calculated to be about 5 kev, corresponding to an upper limit of 7 kev for the natural half-width of the 2.42-Mev excited state of Be^9. This is considerably smaller than the 100-kev upper limit reported by Davis and Hafner.[1] This excited state is virtual, being 0.75 Mev above the threshold for neutron emission. The narrow half-width of this level indicates that neutron emission is improbable and that the state may decay mainly by the emission of gamma-radiation. This result may account for the fact that the 2.42-Mev excited state of Be^9 has not been observed from the $Be^9(\gamma,n)Be^8$ reaction.

We are indebted to Mrs. Cecilia Bryant, Mrs. Hester Sperduto, and Mr. W. Tripp for their assistance in measuring the track-density distributions of the nuclear track plates.