Magnetic Analysis of $Be^9(d,\alpha)Li^7$ and $Be^9(d,p)Be^{10}$ Reactions

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The alpha-particle and proton groups arising from the deuteron bombardment of beryllium targets have been studied with a high resolution magnetic spectrometer. Except for the well-known one at 480 kev, no evidence has been found for energy levels in Li^7 between 3.4 Mev and the ground state. The Q-value for the $Be^9(d,\alpha)Li^7$ reaction has been measured as 7.145±0.024 Mev. Studies of the proton groups indicate that there are no levels in Be^{10} between the ground state and one at 3.375±0.010 Mev. The Q for the $Be^9(d,p)Be^{10}$ reaction has been found to be 4.576±0.012 Mev.

I. INTRODUCTION

When beryllium is bombarded with deuterons, a wide variety of reactions that lead to the emission of gamma-rays, alpha-particles, protons, tritons, and neutrons are observed. Since beryllium consists of a single isotope, the various reactions are readily identified. Studies of the energies of the gamma-radiation and particle groups yield information regarding the masses and energy levels of the residual nuclei produced in the reactions. The alpha-particle groups are associated with the formation of Li^7, which is known to have excited states at 0.480 and 7.38 Mev.[1] The proton groups are associated with the formation of Be^{10}, for which the lowest excited level appears to be at 3.37 Mev. In view of the recent interest in the character of the excited states of Li^7 and because of the success of the mirror-nucleus picture in correlating the ground states of Be^{10} and C^{10} with excited levels in B^{10},[2] the alpha-particles and protons have been studied in some detail with a high resolution magnetic spectrometer. The object of the present experiment was to measure the energies released in the reactions and to investigate the possibility of additional energy levels in Li^7 and Be^{10}. The various reactions that lead to the formation of these two nuclei are shown in Figs. 1 and 2, which are taken from the summary by Lauritsen.[1] The particular reactions that form the basis of our observations are indicated on the figures by the symbol #.

II. APPARATUS AND EXPERIMENTAL ARRANGEMENT

The experimental arrangement was essentially the same as that previously described.[3] Most of the measurements were made on thin targets of beryllium evaporated onto platinum sheets, although thin beryllium-foil targets[4] were also used, particularly for the purpose of checking upon the effects of contaminants. These foils were supplied to us by Professor T. Lauritsen.

As in our previous work, the energies of both the incident and the emergent particles from the reactions were measured in terms of the magnetic field strengths required to bring them onto the photographic plates used as detectors. The sensitivity of the balance-type flux meter has recently been increased by a factor of more than ten so that the principal uncertainty in the energy determination for the particles arises from the uncertainty in the energy of the polonium alpha-particles used for calibration purposes and the uncertainties in the values of the fundamental physical constants that must be employed in calculating the $H\rho$ to energy conversion. Unfortunately in these experiments, there is an additional experimental error that must be considered when the measured particle energies are used for determining the reaction energies. This arises from an uncertainty with regard to the angle of observation with respect to the direction of the incident beam; this angle is essentially 90 degrees. Because of slight spreading of the beam in the target region and other geometrical factors, the angle between the beam and the median plane of the magnet gap is not known to closer than a quarter of a degree. In addition, there is a finite collection angle for the photographic plates, which are 1 centimeter wide placed approximately 100 centimeters from the target. As a result, the value of the reaction energy is uncertain by an amount $\Delta Q = 2(M_1, M_2, E_1, E_2)^{\frac{1}{2}}\delta/M_3$, where δ is the uncertainty in angle with respect to the 90-degree position and M_1, M_2, E_1, and E_2 are the masses and energies of the incident and emitted particles, respectively, and M_3 is the mass of the residual nucleus formed in the reaction.[5] This error is particularly important in the reactions of the light nuclei which have a high Q, as is the case here, and is approximately the same as that caused by the other factors mentioned above. The other experimental errors, such as those associated with the readings of the photographic plates, reproducibility of the flux meter, and so forth, are considerably smaller.

III. RESULTS

The various proton and alpha-particle groups that have been observed to result from the deuteron bombardment of beryllium targets are shown in Fig. 3.

[1] T. Lauritsen, Preliminary Report No. 5, National Research Council, Nuclear Science Series (1949).
[2] Scherr, Meuther, and White, Phys. Rev. **75**, 282 (1949).
[3] Buechner, Strait, Sperduto, and Malm, Phys. Rev. **76**, 1543 (1949).
[4] H. Bradner, Rev. Sci. Inst. **19**, 662 (1948).
[5] M. S. Livingston and H. A. Bethe, Rev. Mod. Phys. **9**, 245 (1937), Eq. (770).

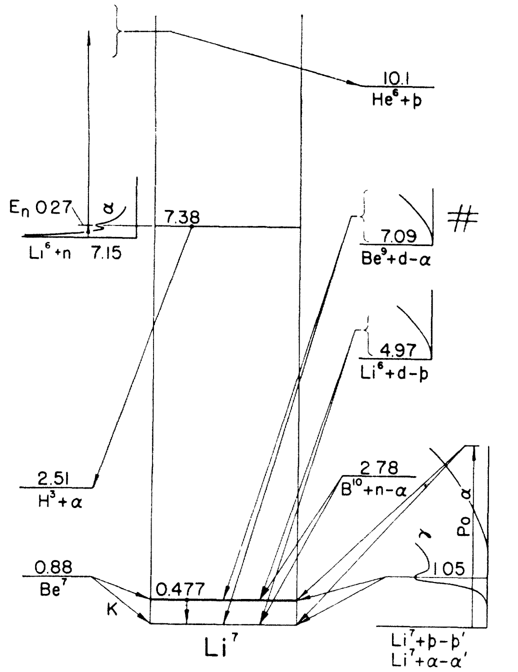

FIG. 1. Energy levels of Li^7.

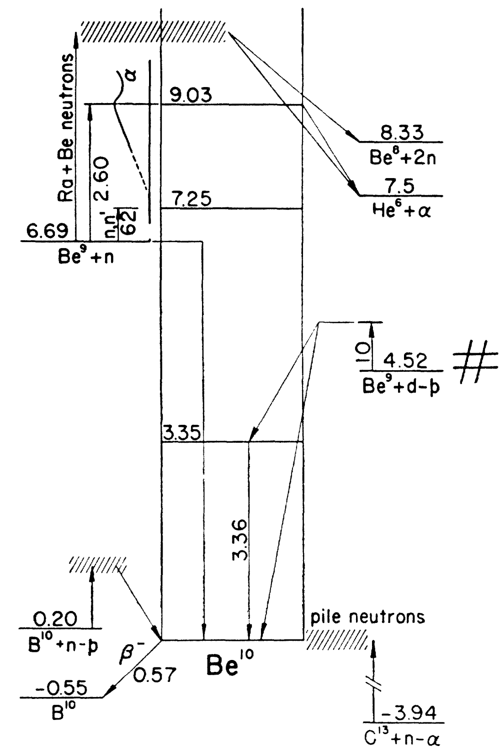

FIG. 2. Energy levels of Be^{10}.

The proton groups due to carbon contamination have not been included, since they are very sharp and are well removed from the groups that are of interest in this experiment. The curves shown in Fig. 1 were obtained with a bombarding energy of 1.396 Mev.

The two alpha-particle groups shown in the figure are from the reaction in which Li^7 is formed. Since, for the same $H\rho$, the range of alpha-particles in the photographic emulsion is less than that for deuterons, it has not been convenient in these experiments to search for alpha-particle groups that have an $H\rho$ of less than approximately 220 kilogauss-centimeters. At this point, a rather heavy background of deuterons that have been elastically scattered from the support for the beryllium targets is encountered. A careful search in the region above this has shown no evidence for additional alpha-particles and indicates that, except for the well-known one at 480 kev, there are no energy levels in Li^7 between the ground state and 3.4 Mev. The possibility that any weak groups might have been obscured at the particular bombarding energy shown in the figure by the groups from carbon and oxygen has been eliminated by studies in which the bombarding energy was varied over the range from 1 to 2 Mev. Also, no evidence of structure in the alpha-particle groups has been found.

Previous work in this Laboratory[6] on the energy difference between the two alpha-particle groups from the Be$^9(d,\alpha)$Li^7 reaction has given 482$\pm$0.003 Mev for this energy level in Li^7. In the present experiment, careful studies have been made on the energies of the groups, and these measurements give 7.145$\pm$0.024 Mev for the Q-value of the reaction which results in the formation of Li^7 in the ground state. Of the factors that enter into the stated error, 17 kev is due to the geometrical factor discussed previously; 16 kev, to uncertainties in the constants employed; and 5 kev, to other errors of experimental origin. This reaction was also studied by Graves,[7] the energy of the alpha-particles being determined from their range. A value of 7.093$\pm$0.022 Mev was obtained from these measurements.

The various proton groups observed have been studied extensively in order to identify those that are

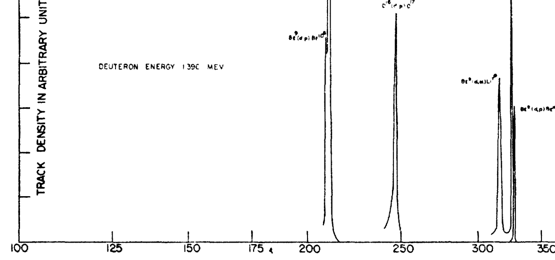

FIG. 3. Alpha-particle and proton groups from beryllium target bombarded with deuterons.

[6] Buechner, Strait, Stergiopoulos, and Sperduto, Phys. Rev. **74**, 1569 (1948).

[7] E. R. Graves, Phys. Rev. **57**, 855 (1940).

associated with the formation of Be^{10}. As can be seen in Fig. 3, the low energy group from beryllium, at bombarding energies of approximately 1.4 Mev, is nearly in coincidence with a low energy proton group from oxygen contamination. It has not been found possible to prepare beryllium targets that are free of oxygen. In order to separate these groups for purposes of positive identification and accurate energy measurements, the bombarding energy has been varied. Figure 4 shows the appearance of these two groups for a deuteron energy of 1.821 Mev. Check runs of this sort have been made for each of the observed groups to guard against the possibility that, at a particular bombarding energy, two groups of different origins might coincide.

These studies give 4.576 ± 0.012 as the Q for the $Be^9(d,p)Be^{10}$ reaction. Here, the experimental errors are as follows: 10 kev due to the uncertainties in the constants, 6 kev due to geometry, and 2 kev from other experimental sources. The measured Q for the $Be^9(d,p)Be^{10*}$ reaction is 1.201 ± 0.007 Mev. From these values, we obtain 3.375 ± 0.010 Mev for the first excited state in Be^{10} which is observed in this reaction. This is in good agreement with the value of 3.359 ± 0.015 Mev which is determined from measurements on the gamma-rays that accompany the reaction.[8] Using the masses of the proton and deuteron as listed by Bainbridge,[9] the value 1.001675 ± 0.000014 is obtained for the $Be^{10}-Be^9$ mass difference.

The recent success of the idea of mirror nuclei in correlating the ground state of C^{10} and Be^{10} with excited states of B^{10} has indicated that, in such mirror nuclei, the equality of the p–p and n–n forces can be assumed and that the entire energy release of the mirror nuclei can be attributed to Coulomb energy and to the neutron-proton mass difference.[10] A correlation between the excited states of Be^{10} and those of B^{10} might then be expected. The excited states in B^{10} have been measured by Rasmussen, Hornyak, and Lauritsen,[8] who measured the energies of the gamma-rays emitted in the $Be^9(d,n)B^{10}$ reaction. These studies show that energy levels in B^{10} occur at 412, 713, 1424, 2138, and 3580 kev. There is also some evidence for an excited state at 5 Mev.[11] The present work indicates that there are no excited states in Be^{10} between the ground level and 3.37 Mev that are excited at the bombarding energies employed in these experiments.

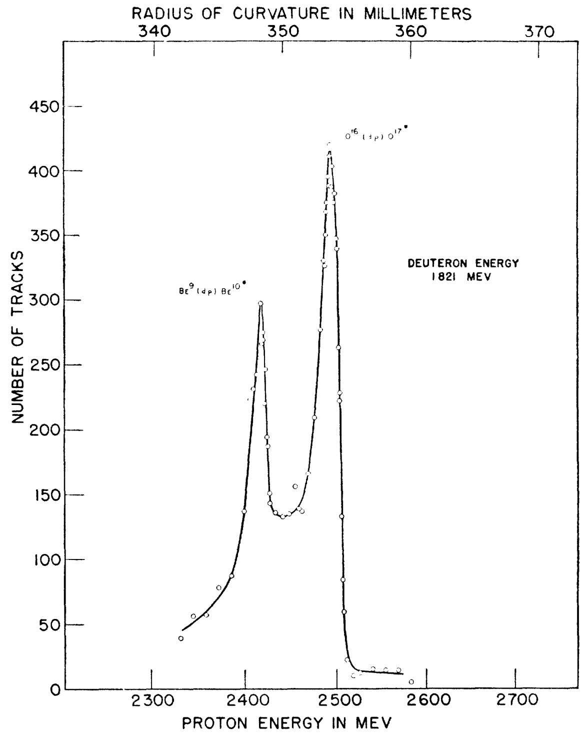

FIG. 4. Low energy proton groups from beryllium and oxygen.

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[8] Rasmussen, Hornyak, and Lauritsen, Phys. Rev. **76**, 581 (1949). We are indebted to Professor Lauritsen for supplying these values and the information in reference 11 prior to publication.

[9] K. T. Bainbridge, Preliminary Report No. 1, Nuclear Science Series, National Research Council (1948).

[10] Sherr, Muether, and White, Phys. Rev. **75**, 282 (1949).

[11] Chao, Lauritsen, and Rasmussen, Phys. Rev. **76**, 582 (1949).