Charged Particles from the Bombardment of Li^7 by He^3

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A $(Li^7)_2SO_4$ target was bombarded with He^{3++} ions at 720 kev, and the energies of the charged particles emitted were analyzed by means of a NaI spectrometer. The spectrum was found to consist in part of particles smoothly distributed in energy; and in part of relatively sharp groups of particles of defined energies. Evidence is presented that the five highest pulse height groups of charged particles consist of protons corresponding to defined energy states in Be^9. The observed proton energies are 10.51 ± 0.03, 8.9 ± 0.2, 8.3 ± 0.2, 7.6 ± 0.1, and 6.1 ± 0.10 Mev. In addition, group of particles were barely discernible at the lower half of the pulse height scale used for the protons. Although these groups of particles are not positively identified, it seems relatively certain that they are α-particles corresponding to Li^6 in its various energy states. A special attempt to identify groups of deuterons failed, indicating that for some reason the formation of Be^8 is discriminated against in this reaction.

INTRODUCTION

SOME time ago it was reported[1] that when Li^7 was bombarded by He^3 a pulse spectrum was observed in NaI which would correspond to particles, some of which were grouped and others of which were smoothly distributed in energy. Because of the very low counting rates, it was possible to say only that the spectrum was roughly consistent with the breakup of B^{10} into Be^9 and a proton, into Be^8 and a deuteron, and into the multi-body breakups of two α's and a deuteron, and of two α's and a neutron plus a proton.

More recently with a multi-channel pulse analyzer available, it became feasible to seek to establish the identity of the particle groups just referred to in accordance with Be^8 having a broad level at 3 Mev and Be^9 having a narrow level at 2.43 Mev, in addition to the respective ground states. It will be seen in what follows that considerably more work will be required before definite conclusions can be drawn from the study to date. However, it seems reasonable to present, at this stage of the work, the body of evidence which indicates that each of the "relatively" sharp groups of particles arises from protons corresponding to associated states in Be^9.

EXPERIMENTAL APPARATUS AND PROCEDURE

As in previous studies with the He^3 beam, the spectrometer used to study the energy spectra of the reaction products consisted of a NaI crystal 2 mm thick coupled to a 5819 photomultiplier. A cut-away view of the essential features of this spectrometer and associated target arrangement is given in a previous paper.[2] The energy resolution of the spectrometer for 14.7-Mev protons was a little over 3 percent. Precision aluminum foils served to assist in spectrometer calibration and particle identification.

The Li^7 target consisted of $(Li^7)_2SO_4$ fused onto a tantalum backing. The Li^7 was of 99 percent purity with respect to Li^6. Spectral analysis showed that the $(Li^7)_2SO_4$ contained, in addition to sulfur and oxygen, only trace amounts of relatively high-Z elements. There was further assurance that the target was free from contamination and also that the beam contained no unwanted components, in the observation that when a $(Li^6)_2SO_4$ target, essentially identical with the $(Li^7)_2SO_4$ target, was bombarded with He^3 in an investigation of Be^8 there was no evidence of target contamination or of unwanted beam components.[3]

The experimental procedure was (a) to calibrate the crystal for pulse response *vs* energy for protons and deuterons, (b) to measure the pulse height spectrum and assign the particle identities on the basis of the expected energies, and (c) to check the particle assignment by measuring the energy loss of the various particles in their passage through aluminum absorbers. In order to obtain the proton and deuteron energy *vs* pulse height characteristic relation, there was mounted, together with the Li^7 target, a zirconium tritide target which contained, in addition, an appreciable amount of deuterium. The lithium and "zirconium" targets were so arranged that it was possible to quickly rotate from the Li^7+He^3 to the $H^2(He^3,p)He^4$ and $H^3(He^3,d)He^4$ reactions. These latter two reactions yield, respectively, 14.7-Mev protons and 9.99-Mev deuterons.

The absorber wheels shown in Fig. 1 of reference 2 were mounted with precision absorbers. These absorbers could be utilized, first, to permit slowing the 14.7-Mev protons and the 9.99-Mev deuterons by an amount which was determined from Aron, Hoffman, and Williams, Range *vs* Energy Charts[4] to obtain the respective pulse height *vs* energy characteristics; and second, to interpose absorbers of known thickness in which the respective energy losses of each of the particle groups in question could be obtained, assuming the particle identities were known. Figure 1 shows the pulse height *vs* energy characteristics for protons and deuterons

* Now at Naval Research Laboratory.
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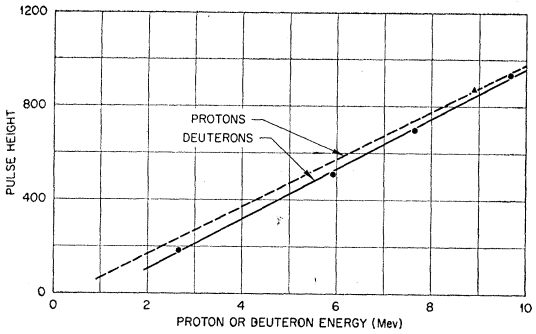

FIG. 1. Curves relating the NaI spectrometer pulse height to energy for protons and deuterons.

obtained from 14.7-Mev protons and 9.99-Mev deuterons in the manner just described.

Some three hours were required to run the entire Li^7+He^3 spectrum with 5 percent counting statistics, and consequently the possibility of instrumental drifts of the order of a few percent could not be ignored. However, such drifts could easily be kept negligible, if necessary, since with the high yields from the $H^2(He^3,p)He^4$, and $H^2(He^3,d)He^4$ reactions, a check on the calibration could be made in a matter of seconds. Likewise, in the data that will be given, the measurement of the shift in pulse height that accompanied the introduction of aluminum absorber was bracketed by a check on the calibration in the following way: The pulse height produced by the 9.99-Mev "calibration deuterons" was noted, the pulse height of a particular peak in question was then measured without absorber; after this the absorber was introduced and the new pulse height in question was redetermined followed by a recheck of the calibration with zero absorber. At one time a low-energy point on the deuteron pulse height *vs* energy characteristic was also rechecked and found to check well the earlier calibration characteristic. Finally, it should be noted that the high-energy proton group from Li^7+He^3 falling at 10.55-Mev constituted a proton calibration and this peak remained constant in pulse height for a fixed position of the 9.99-Mev calibration deuteron pulse height. The employment exclusively of the 9.99-Mev deuteron for instrumental checks obviated the changing of gain positions that would have been necessary had the 14.7-Mev proton been employed.

RESULTS AND CONCLUSIONS

In Fig. 2 is shown the pulse spectrum as it was obtained with a 0.1-mil absorber of nickel in order to identify the group at pulse height 340. Comparison of the pulse height of 340 with the corresponding pulse height at zero mils absorber showed the group in question to be α particles from the breakup of B^{10} into $Li^6+\alpha$. On the zero absorber spectrum there also appeared as just perceptible above the continuum, two other groups of particles in addition to the group just mentioned, presumably α particles associated with the excited states of Li^6. Lack of information on the pulse height *vs* energy characteristic of the crystal to α particles does not permit more to be said about the spectrum below pulse height 400.

Consider now the five highest energy groups in Fig. 2. The energy assignments will, as can be seen from Fig. 1, depend upon the identity of the particles. Let the groups be designated T_0, T_1, T_2, T_3, and T_4, respectively, from highest to lowest energy. Then group T_0 is identified with the breakup of B^{10} into a proton and Be^9 in its ground state by virtue of the fact that the measured energy of T_0, compared with the 14.7-Mev "calibration" proton, agrees well with the energy expected for the Be^9 ground state plus proton mode of breakup from mass values. In exactly analogous fashion T_2 is found to correspond to the state in Be^9 at 2.43-Mev.

The group of particles T_1 does not correspond to any well known state in Be^9 and hence is a logical choice for

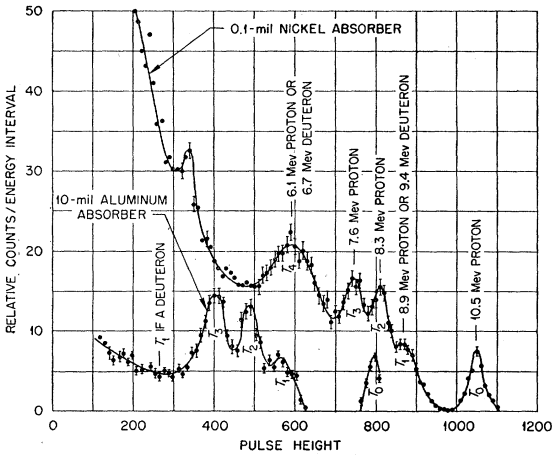

FIG. 2. Pulse spectrum produced in NaI by the reaction products from Li^7+He^3 for both a thick and a very thin absorber.

the deuteron corresponding to the breakup of B^{10} into Be^8 in its ground state and a deuteron. The other deuteron group corresponding to Be^8 at 3-Mev excitation would be expected to be broad in energy spread, and indeed group T_4 is just such a group. However, two irregularities occur, namely: (a) that while groups T_0 and T_2 are identified as the expected protons, and T_1 and T_4 may be the expected deuterons, T_3 is unaccounted for, and (b) that the measured energy interval for T_1 and T_4 is 2.7-Mev. This figure of 2.7-Mev in the laboratory system corresponds to 3.4-Mev in Be^8, and this latter figure is to be compared with 2.95-Mev from other experiments.[3,5–7] The statistical uncertainty in the present experiment is less than 10 percent and it seems unlikely that so large a discrepancy as that just indicated can exist.

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[6] R. Malm and D. R. Inglis, Phys. Rev. **92**, 1326 (1953).
[7] C. C. Trail and C. H. Johnson, Phys. Rev. **95**, 1363 (1954).

With a view to positively identifying groups T_1 and T_4, therefore, the corresponding portions of the spectrum were run, respectively, with 68-mg/cm² Al and 31.1-mg/cm² Al, and the shift in pulse height carefully noted. The two different values of absorber were chosen so as to optimize in each instance the distinction between deuterons and protons that was being sought. Figures 2 and 3 present the shift in pulse height of the particle groups in question, as produced by the 68-mg/cm² and 31.1-mg/cm² aluminum absorbers. In the instance of both groups T_1 and T_4, which were thought possibly to be deuterons, the groups lost energy in their respective absorbers as protons would. Hence, each of the five highest pulse height charged particle groups appears to consist of protons. Energy considerations show that it is not likely that these protons can arise from the breakup of B^9 subsequent to the decay of B^{10} into B^9 and a neutron, and, hence, must be associated with the alternative decay of B^{10} into Be^9 in various states of excitation and a proton. In Fig. 2 the proton

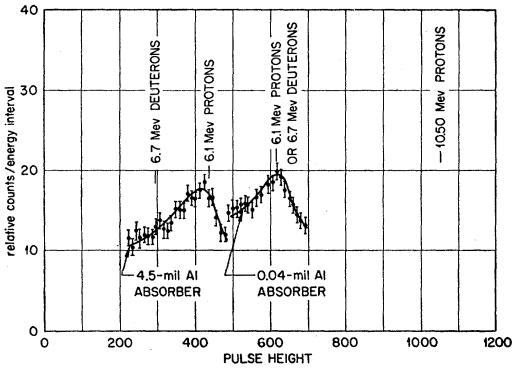

FIG. 3. Shift produced in the pulse height of the "broad peak" by a thick aluminum absorber.

energies are given, respectively, as 10.51, 8.9, 8.3, 7.6, and 6.1 Mev. These particular values were obtained from a single spectral determination in which special attention was given to instrumental stability. The energies obtained from four independent determinations showed a standard error in the determination of the energies of about 3 percent. The Be^9 energy level diagram, Fig. 4, summarizes the present experiment.

The existence of four excited states in Be^9 at excitations below 6 Mev is contradictory to careful experiments involving the reactions $B^{11}(d,\alpha)Be^9$ and $Be^9(p,p')Be^{9*}$.[8–11] The latter reaction, like $Li^7(He^3,p)Be^9$,

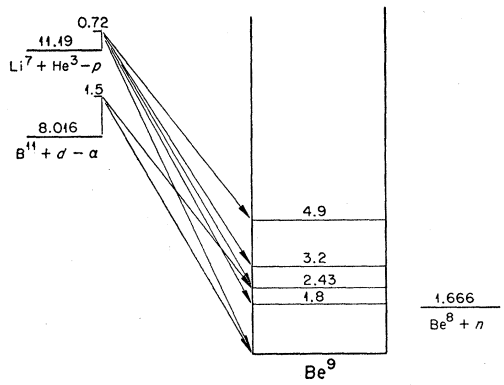

FIG. 4. Energy scheme of Be^9 suggested by the spectrum in Fig. 2.

involves the compound nucleus B^{10}. In spite of the fact that $Li^7(He^3,p)Be^9$ and $Be^9(p,p')Be^{9*}$ both involve B^{10}, the spectra of the B^{10} decay products differ, the first reaction from the second, not only in the absence of deuterons and the presence of more than two groups of protons but also in one other feature. The $Li^7(He^3,p)Be^9$ reaction is accompanied by an approximately equal amount of multi-body breakup such as two α's, a neutron and a proton, whereas, in the $Be^9(p,p')Be^{9*}$ reaction, the multi-body breakup seems of negligible proportions. It is interesting to note that in the neutron spectrum representing the reaction $Be^9(p,n)B^9$ as in the proton spectrum from the $Li^7(He^3,p)Be^9$ reaction, there is a conspicuous abundance of the multi-body process.[12]

In weighing the credibility of the results that the energy scheme for Be^9 is that given in Fig. 4, two other facts are worthy of note. As has already been reported[13] the proton spectrum from $Be^9(He^3,p)B^{11}$ is precisely that expected from knowledge of the well established states in B^{11}. This circumstance, accompanying as it does the fact that the same equipment has been employed for the $Li^7(He^3,p)Be^9$ and $Be^9(He^3,p)B^{11}$ studies, provides additional evidence that the groups observed in Li^7+He^3 are not spurious. Finally, it should be recalled that the yield with energy and the angular distribution of the Be^9 photoneutrons have suggested a state of Be^9 in the neighborhood of the neutron dissociation energy and perhaps other states of higher energies.[14–16]

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[13] Moak, Good, and Kunz, Phys. Rev. **95**, 641 (1954).
[14] Russell, Sacks, Wattenberg, and Fields, Phys. Rev. **73**, 454 (1948).
[15] C. J. Mullin and E. Guth, Phys. Rev. **76**, 382 (1949).
[16] *Note added in proof.*—Dr. K. W. Allen, Nuclear Physics Laboratory, University of Liverpool (private communication), has obtained almost identical results from the bombardment of Li^7 with He^3.