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Alpha Spectrum in the Decay of Li^8†

R. T. FROST* AND S. S. HANNA
Department of Physics, The Johns Hopkins University, Baltimore, Maryland

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The alpha-particle spectrum in the successive beta-alpha decay of Li^8 was observed with magnetic analysis from 1 to 6.5 Mev, corresponding to excitation energies in Be^8 from 2 to 13 Mev. The only definite structure in the spectrum corresponds to the well-known broad state at 2.9 Mev.

IN the many reactions in which the unstable Be^8 nucleus is produced by the emission of a heavy particle, the large recoil momentum imparted to the Be^8 nucleus seriously alters the observed alpha-particle spectrum in the $Be^8(\alpha)\alpha$ disintegration.[1] In the beta decay of Li^8, however, the alpha spectrum can be studied without excessive distortion. In addition, since the half-life of the Li^8 nucleus is 0.85 sec,[1] it is possible to produce Li^8 nuclei and then observe the $Li^8(\beta)Be^8(\alpha)\alpha$ decay without interference from competing reactions or modes of decay.

Previous investigations of the alpha spectrum,[2] employing range analysis, have been conducted in two ways. In one, a study is made of the spectrum of one of the decay alpha particles emitted from a target in which Li^8 nuclei are embedded; in the other, the ranges of both alpha particles are measured in a cloud chamber or emulsion. The former method is subject to the intrinsic loss of resolution discussed below, while with the latter technique the task of obtaining good statistics is formidable. Because of the current interest in the existence of states of Be^8 above 3 Mev, we have examined the "single alpha" spectrum in some detail with good instrumental resolution. The loss of resolution inherent in the method of producing the alpha particles is less serious in the high-energy region of the spectrum. The analysis is based on the observation of some 7×10^4 particles.

TABLE I. Effect of target and center-of-mass motion on the energy and resolution in the alpha spectrum.

E_α Mev	Recoil broadening Mev	Target Av loss Mev	Target Broadening[a] Mev	Total broadening Mev
1.5	±0.07	0.23	±0.11	±0.18
3.5	±0.07	0.14	±0.05	±0.12
6.0	±0.05	0.09	±0.03	±0.08

[a] This calculation takes into account the shape of the "line" already produced by the recoil effect, and gives the additional broadening introduced by the target.

A convenient method of preparing Li^8 nuclei is with the $Li^7(d,p)Li^8$ reaction. Thin targets of natural lithium, deposited on nickel foils, were bombarded with a beam of deuterons of 0.68-Mev energy. At this energy the Li^8 nuclei are emitted at forward angles between 0° and 32° in the laboratory system. As the Li^8 nuclei come to rest at various depths in the target, set at 45°, the emitted alpha particles are degraded in energy by various amounts with a resulting loss of resolution. By assuming an isotropic emission of Li^8 nuclei[3] (in the center-of-mass system) and extrapolating a range-energy curve for Li^8 particles[4] to low energies, the average loss in energy and the effective broadening were computed for various alpha energies, with the results given in Table I.

The distortion of the spectrum arising from the disintegration in flight of the Be^8 nuclei may also be described in terms of an effective broadening or loss of resolution. For an isotropic beta-neutrino correlation[3] and an isotropic beta-alpha correlation,[5] the values in Table I are obtained.

The "prompt" radiations from the $Li+d$ reactions were excluded from observation by means of a rotating shutter, designed so as to expose the target periodically to the beam, and in opposite phase the target to the alpha detector. The period of rotation was 2 sec. The delayed alpha particles were observed at 90° to the deuteron beam.

The spectrum was studied with a magnetic analyzer which has been used previously.[6] With recording in nuclear emulsions, no attempt was made to detect alpha particles much below 1.0 Mev. Four exposures were made covering the following energy intervals: 0.9–2.0, 1.1–2.3, 2.0–4.1, and 3.1–6.4 Mev. The energies were obtained from the known calibration of the instrument. The chief uncertainty in the actual energy scale of the alpha spectrum arises from the loss is energy in the target (Table I). In reading the plates in the microscope, the distribution in track length was measured

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* Now at Knolls Atomic Power Laboratory, Schenectady, New York.

[1] For a summary of these reactions, see F. Ajzenberg and T. Lauritsen, Revs. Modern Phys. **24**, 321 (1952).

[2] W. A. Fowler and C. C. Lauritsen, Phys. Rev. **51**, 1103 (1937); Rumbaugh, Roberts, and Hafstad, Phys. Rev. **51**, 1106 (1937), Phys. Rev. **54**, 657 (1938); C. L. Smith and W. Y. Chang, Proc. Roy. Soc. (London) **A166**, 415 (1938); Bonner, Evans, Malich, and Risser, Phys. Rev. **73**, 885 (1948); C. W. Li and W. Whaling, Phys. Rev. **81**, 661 (1951) (this investigation employs magnetic analysis); Frye, Armstrong, and Rosen, Phys. Rev. **98**, 241(A) (1955); F. C. Gilbert, Phys. Rev. **93**, 499 (1954).

[3] The results of the computation are not very sensitive to this assumption.

[4] Neuendorffer, Inglis, and Hanna, Phys. Rev. **82**, 75 (1951); W. H. Barkas, Phys. Rev. **89**, 1019 (1953).

[5] Hanna, LaVier, and Class, Phys. Rev. **95**, 110 (1954).

[6] D. R. Inglis, Phys. Rev. **78**, 104 (1950); R. W. Gelinas and S. S. Hanna, Phys. Rev. **89**, 483 (1953).

at various positions on the plates. Throughout the spectrum, a well-defined peak in the track length distribution was obtained with negligible background.

Each exposure was corrected for the variation with particle momentum of the solid angle of the spectrograph. The observed α^{++} yield was converted to the total $\alpha^{+}+\alpha^{++}$ yield, using data from the literature.[7] This correction is small and is applicable only in the low-energy region. Since the exposures were not all made with the same target, and because of uncertainties in the monitoring introduced by the pulsing arrangement, no attempt was made to obtain absolute normalizations. Instead, the spectra were joined together by matching intensities in the regions of overlap. Finally, the complete momentum spectrum was converted to an energy spectrum.

The spectrum is shown in Fig. 1. The peak corresponding to the familiar 2.9-Mev state in Be^8 is prominently displayed, but shifted to lower energy because of the average energy loss in the target (Table I).

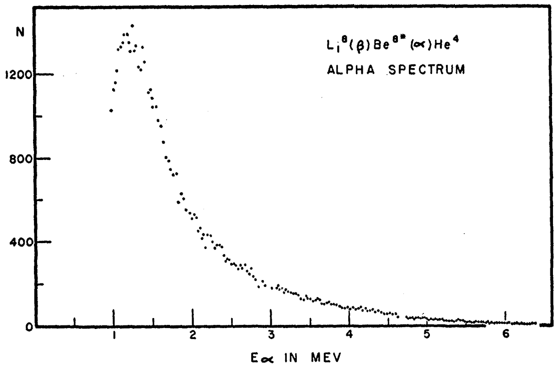

FIG. 1. Alpha spectrum from $Li^8(\beta)Be^{8*}(\alpha)He^4$. The vertical intensity scale is arbitrary. The numbers given indicate approximately the actual number of particles counted for the points below 3 Mev. Above 3 Mev the actual count is about twice that indicated by the numbers.

Other structure is not apparent in the spectrum. Considering the resolution as given in Table I and the statistical uncertainty in the data, it is estimated that a fairly sharp group in the vicinity of $E_\alpha = 2.0$, 4.0, or 6.0 Mev would have been detected if its intensity was greater than 2.5, 1.0, or 0.5 percent, respectively, of the total observed intensity which can be attributed principally to the 2.9-Mev state. Very broad states would, of course, be more difficult to observe.

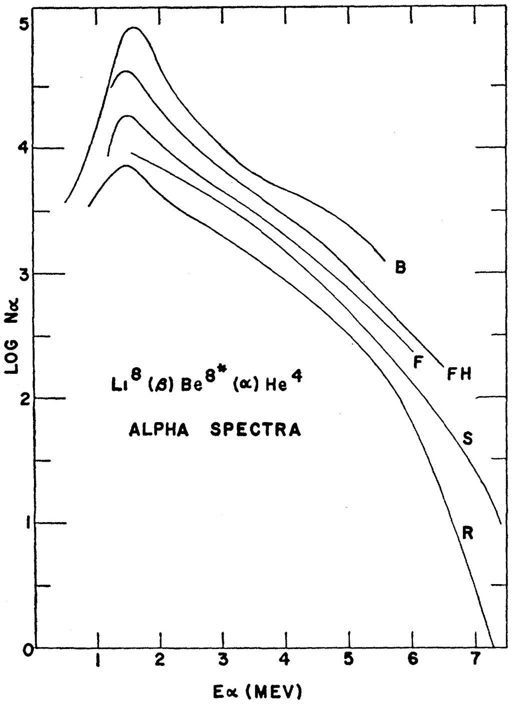

FIG. 2. Logarithmic plot of the curves of various authors. B = Bonner *et al.* FH = present authors. F = Fowler and Lauritsen. S = Smith and Chang. R = Rumbaugh, Roberts, and Hafstad. The vertical displacement of the curves is of course arbitrary.

In order to compare the present results with earlier measurements, the various spectra are plotted on a logarithmic scale in Fig. 2. Wherever necessary, the earlier data have been converted from a range to an energy spectrum, and the energy scale has been adjusted to compensate for an estimated average target loss. The agreement among the various curves is generally good. The discrepancies which appear, for the most part, can be traced to the different techniques employed. In the region of 4.5 Mev in the present data, there is perhaps an indication of very broad structure, but not as much as in the curve of Bonner *et al.*

In this experiment one does not expect to observe all states in Be^8. In detecting the alpha-particle decay, only states of even spin and even parity will be exhibited. In addition, there are limitations imposed by the well-established selection rules of beta decay. For example, the beta transition to the ground state of Be^8 is not detected,[8] which suggests a difference in spin between this state and the one at 2.9 Mev. One might reasonably expect, however, to detect states in Be^8 having the same spin and parity as the 2.9-Mev state.

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[7] G. H. Briggs, Proc. Roy. Soc. (London) **114**, 431 (1927).

[8] W. F. Hornyak and T. Lauritsen, Phys. Rev. **77**, 160 (1950).