Alpha Spectrum in the $Li^7(p,\gamma)Be^{8*}(\alpha)He^4$ Reaction†

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The alpha-particle spectrum in the $Li^7(p,\gamma)Be^{8*}(\alpha)He^4$ reaction was observed with magnetic analysis from 1.0–5.5 Mev, corresponding to excitation energies in Be^8 from 2–11 Mev. In addition to the well-known structure at $E_{ex}=2.9$ Mev, very broad structure in the region of $E_{ex}=10$ Mev was observed. No evidence was obtained for the existence of levels between 3 and 10 Mev.

TRANSITIONS to the ground and first excited states of Be^8 have been well established[1,2] in the $Li^7(p,\gamma)Be^{8*}(\alpha)He^4$ reaction. Recently, experimental evidence has been reported for states at 4.1, 5.3, and 7.5 Mev.[3] We have investigated the spectrum of charged particles from the proton bombardment of Li^7 using magnetic analysis at a bombarding energy of 0.44 Mev, and at angles of observation of 70° and 90°. The $Li^7(p,\gamma)$ process is resonant at 0.44 Mev with a width of 12 kev.

In a study of the alpha spectrum in this reaction, it is necessary to consider the effect of the recoil imparted to the Be^8 nucleus by the radiation. Six hypothetical cases are illustrated in Fig. 1. The solid lines show the calculated shape of the alpha spectrum in the laboratory frame of reference, assuming the natural line shape shown by the dashed lines. For narrow levels the recoil broadening is about ±0.2 Mev, in alpha energy, while for broader levels the effect is relatively much less significant.

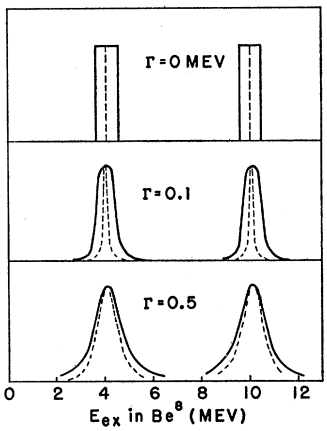

FIG. 1. Recoil broadening of alpha groups from $Li^7(p,\gamma\alpha)He^4$ for six hypothetical levels in Be^8. An isotropic gamma emission is assumed. Γ is the full width at half-maximum of the level measured in alpha energy.

Targets of Li^7(99.8 percent)[4] metal deposited on aluminum backings were bombarded with proton beams of 1 to 2 microamperes. The resonance reaction was monitored by recording the high-energy gamma rays with a NaI scintillation counter. As sharp structure was not anticipated in the alpha spectrum, the entrance slit of the spectrograph was widened to 0.10 or 0.15 inch[5] in order to increase the observed yield. The lithium targets used ranged from 25–60 kev thick for the protons. The instrumental and target broadening can be judged from the $Li^6(p,\alpha)He^3$ peaks which arise from the small residual amount of Li^6 in the target. Actually, structure from the $Li^7(p,\gamma\alpha)He^4$ reaction should be considerably less broadened by target thickness because of the sharp resonance response of the reaction.

The data are presented in Fig. 2 ($\theta=90°$) and Fig. 3 ($\theta=70°$). The reaction products were recorded in nuclear emulsions, each exposure in the spectrograph

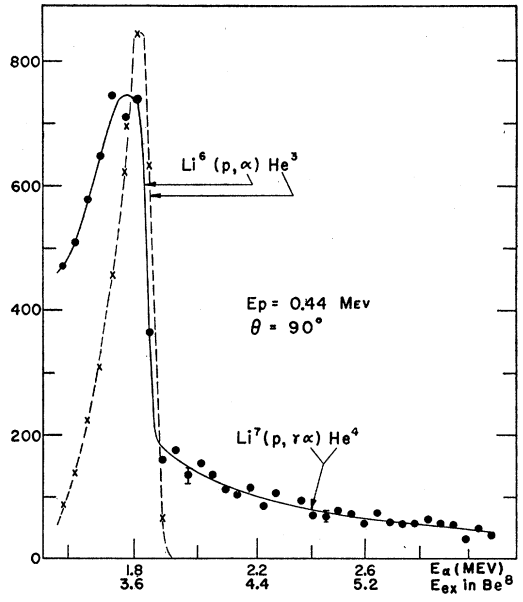

FIG. 2. Spectrum at $\theta=90°$. The circles represent the He^4 count; the crosses the He^3 count.

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[1] The evidence is summarized in F. Ajzenberg and T. Lauritsen, Revs. Modern Phys. **27**, 77 (1955).
[2] W. E. Burcham and J. M. Freeman, Phil. Mag. **41**, 921 (1950), have studied the alpha spectrum up to $E_\alpha=2.2$ Mev with magnetic analysis.
[3] E. K. Inall and A. J. F. Boyle, Phil. Mag. **44**, 1081 (1953). E. K. Inall, Phil. Mag. **45**, 768 (1954).
[4] Obtained from the Isotopes Division, Atomic Energy Commission, Oak Ridge National Laboratory.
[5] R. W. Gelinas and S. S. Hanna, Phys. Rev. **89**, 483 (1953). For a 0.10-inch slit the geometric solid angle is about 10^{-3} sterad.

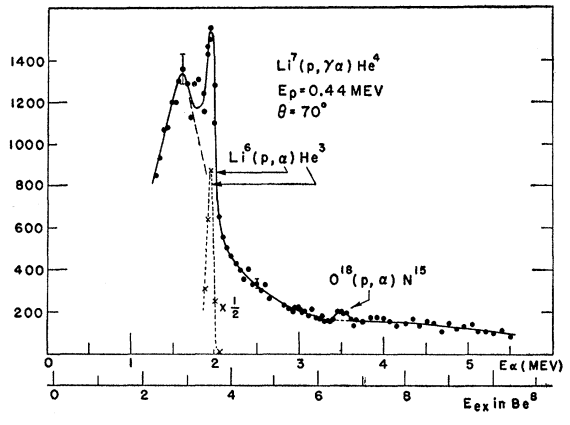

FIG. 3. Spectrum at $\theta=70°$. Below $E_\alpha=1.8$ Mev the actual count is about one quarter that indicated by the given scale. Above 3.7 Mev the count is about one and a half times that indicated.

covering a range from E to about $2E$. The spectrum in Fig. 3 was obtained in three exposures. Some 3×10^4 alpha particles were accumulated in about 70 hours of bombardment. The region around $E_{ex}=3$ Mev, which has been observed before,[2] was not studied in very great detail. There is, moreover, evidence of a small contribution from the $Al^{27}(p,\alpha)Mg^{24}$ reaction, from the target backing, which makes the data around $E_\alpha=1.7$ Mev quantitatively unreliable. All the data were corrected for the variation with energy of the acceptance angle of the spectrograph and for the increasing loss of α^{++} particles toward lower energies because of electron capture. The spectrum in Fig. 3 (but not that in Fig. 2) has been converted to a linear energy scale.

The α and He^3 peaks attributed to $Li^6(p,\alpha)He^3$ are identified with certainty, since He^3 particles can be distinguished from α particles by range in emulsion following magnetic analysis. The target is known to contain approximately 0.2 percent Li^6. The assignment made to the $O^{18}(p,\alpha)N^{15}$ reaction was substantiated by an exposure at a bombarding energy of 1.0 Mev. The same target was used, except that it had been allowed to oxidize thoroughly in air for several days. Not only was the yield in this peak greatly enhanced over the $Li^7(p,\gamma\alpha)He^4$ yield, but the energy of the group was changed by the proper amount for identification with the O^{18} reaction.

TABLE I. Comparison of results on states in Be^8. ΔE_α is a half-width at half-maximum measured in alpha energy.

	Inall[a]		Present experiment	
E_{ex} in Be^8 Mev	Observed ΔE_α Mev	Observed intensity percent	ΔE_α expected in laboratory Mev	Min. observable intensity percent
4.1	0.04	1.8±0.3	0.20	1.0
5.3	0.07	1.7±0.3	0.21	0.5
7.5	0.07	1.0±0.3	0.21	0.5

[a] See reference 3.

The appearance of these impurity peaks makes it possible to estimate quite accurately the intensity of a group from $Li^7(p,\gamma\alpha)He^4$ which would be just discernible in the alpha "background." The O^{18} peak falls in the region of overlap between two exposures and the structure, which is somewhat outside statistics, was recognized immediately in both runs. The intensity of this peak is 0.10 percent of the total $Li^7(p,\gamma\alpha)He^4$ alpha intensity, including the ground-state transition.[6] The prominent $Li^6(p,\alpha)He^3$ peak is 1.9 percent of the total intensity. Using these percentages as a guide and allowing for greater expected peak widths, the figures in Table I were estimated for the minimum observable intensities of alpha groups corresponding to levels at $E_{ex}=4.1$, 5.3, and 7.5 Mev. For comparison the intensities reported by Inall[3] are included in the table. Level widths obtained from his data were used to estimate the widths expected in the present experiment (see Fig. 1).

In the method used by Inall the alpha particles were detected in coincidence with the gamma rays, and an integral spectrum was obtained by means of absorbing foils. Hence an observed level width contains, in addition to the natural width, the experimental broadening from the absorbing foils and from the detector, and a small amount of recoil broadening because of the non-zero solid angles employed. We have not attempted to estimate the magnitude of these effects, since the widths expected in the present experiment are very insensitive to these corrections and in any event an upper limit is obtained by neglecting them.

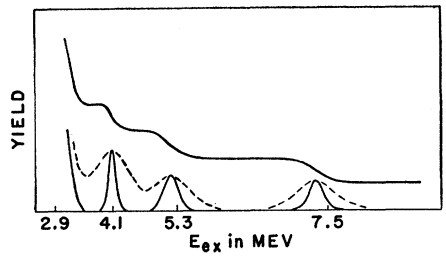

FIG. 4. Conversion of the integral curve of Inall to a differential spectrum (schematic). The dashed curve takes account of the recoil broadening anticipated when the alpha particles are observed irrespective of the direction of emission of the associated gamma rays.

On the basis of intensity alone the failure to observe these alpha groups is perhaps not decisive. The discrepancy is highlighted, however, if the integral curve presented by Inall is converted to a differential spectrum as is done schematically in Fig. 4. Even after allowing for recoil broadening, in the manner indicated by the dashed curve, the spectrum differs from the results in Figs. 2 and 3 in a fundamental fashion, especially with

[6] The intensity ratio of the excited-state to the ground-state transition was taken to be 1:2. R. L. Walker and B. D. McDaniel, Phys. Rev. 74, 315 (1948).

regard to the breadth and over-all extent of the 2.9-Mev level. In Fig. 4 this level does not contribute to the yield above $E_{ex}=3.5$ Mev. This is contrary to the evidence in Figs. 2 and 3, unless one attributes the entire yield above $E_{ex}=3.5$ Mev to the presence of levels which are very much broader than those observed by Inall.

The logarithmic plot of the data in Fig. 5 serves to emphasize some very broad structure in the region of $E_{ex}=10$ Mev. A level in Be^8 in this vicinity has been observed through other reactions. There is an indication of similar structure in the alpha spectrum of the $Li^8(\beta)Be^{8*}(\alpha)He^4$ decay.[7] Recently Moak and Wisseman[8] with the $Li^6(He^3,p)Be^8$ reaction, and Nilson and Jentschke[9] from alpha-alpha scattering, have given evidence for a level at about 12 Mev. Some older measurements locate a level at 11 Mev.[1] In view of the great breadth of the level and the incomplete coverage of it in the present experiment, it is probable that the same level is involved in all these experiments.

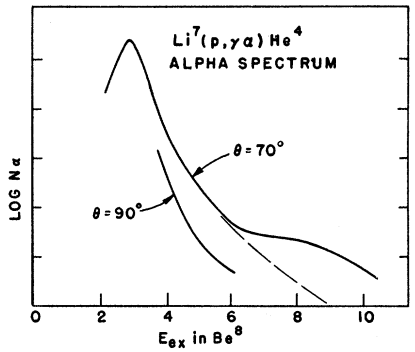

FIG. 5. Semilogarithmic plot of the spectra. The vertical displacement of the curves is, of course, arbitrary. The dashed line is merely a visual extrapolation.

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Atomic Masses of Ni^{58} and Ni^{60}†

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Mass spectrographic measurements are reported of the mass differences $C_2H_4O_2-Ni^{60}$ and $C_3H_6O-Ni^{58}$. These results are used, together with existing data, to discuss certain discrepancies between transmutation and mass spectroscopically determined masses in the Fe-Ni-Zn section of the atomic mass table.

I. INTRODUCTION

IT has been pointed out[1,2] that in the Fe-Ni-Zn section of the atomic mass table there exist discrepancies between mass spectroscopic and transmutation data. Further, these differences suggest that the masses of the nickel isotopes, as determined by mass spectroscopic methods, may be too low by ~0.6 mmu. If such an error indeed be present in these mass values, its correction would cause the disappearance of most of the discrepancies in this region. With this in mind, some new mass studies of nickel isotopes were undertaken in this laboratory, and are reported herein.

II. EXPERIMENTAL

The masses of Ni^{58} and Ni^{60} have been redetermined using only hydrocarbons as comparison and dispersion lines. The hydrocarbons C_4H_9 and C_3H_6O, came from pump oil vapor, while $C_2H_4O_2$ was obtained from glacial acetic acid, introduced into the source region through a slow leak from a variable temperature reservoir. Nickel ions were obtained from $NiCl_2$ in the crucible of a modified Shaw source.[3] The mass spectrograph was a Dempster double-focusing instrument[4] possessing a resolution of about 1 part in 7000.

The effect on the doublet spacing of pressure changes in the analyzer section of the mass spectrograph has also been investigated, and will be reported in the *Canadian Journal of Physics*.

III. MASS OF Ni^{58}

Several photographs of the $Ni^{58}-C_3H_6O$ doublet were obtained in March, 1955 and May, 1955. From these were chosen the eight best-matched, low-pressure doublets, which were then measured by four individual observers. After routine statistical analysis, the following mass difference was obtained: $C_3H_6O-Ni^{58}=106.52\pm15$ mmu. From this, the Ni^{58} mass is calculated to be 57.95380 ± 15 amu. C^{12} and H^1 were taken to be

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