Magnetic Analysis of the $Be^9(p,\alpha)Li^6$ Reaction*

D. E. Groce† and W. Whaling
California Institute of Technology, Pasadena, California
(Received 1 August 1963)

The momentum spectrum of the alpha particles from the $Be^9(p,\alpha)Li^6$ reaction has been measured in a magnetic spectrometer at 30° with 10-MeV incident proton energy. The discrete alpha-particle groups observed correspond to states in Li^6 at 0-, 2.19-, 3.55-, 4.40-, and 5.32-MeV excitation energy. Higher excited states are obscured at all angles of observation by the continuous alpha spectrum from the breakup in flight of Be^8, Li^{6*}, Be^{9*}, and B^9.

INTRODUCTION

THE energy spectrum of the alpha particles from the reaction $Be^9(p,\alpha)Li^6$ provides a simple and direct method for investigating the excited states of Li^6. States with both isotopic spins, 0 and 1, are excited in this reaction, and stable targets are available in thin self-supporting foils of high purity. Earlier precision measurements of the alpha-particle spectrum by magnetic analysis revealed transitions only to the ground state and first two excited states.[1] We have repeated this experiment at a higher bombarding energy, with observations at a number of laboratory angles, to search for transitions to other excited states in Li^6.

EXPERIMENTAL ARRANGEMENT

A 10-MeV proton beam was obtained from the ONR-CIT tandem accelerator. The magnetic analyzer for the beam energy was calibrated against the $Al^{27}(p,n)Si^{27}$ threshold[2] at 5.800±0.008 MeV. Entrance and exit slits of the beam-analyzing magnet were set to limit the momentum spread of the incident-proton beam to $P/\Delta P=450$, where ΔP is the full width at

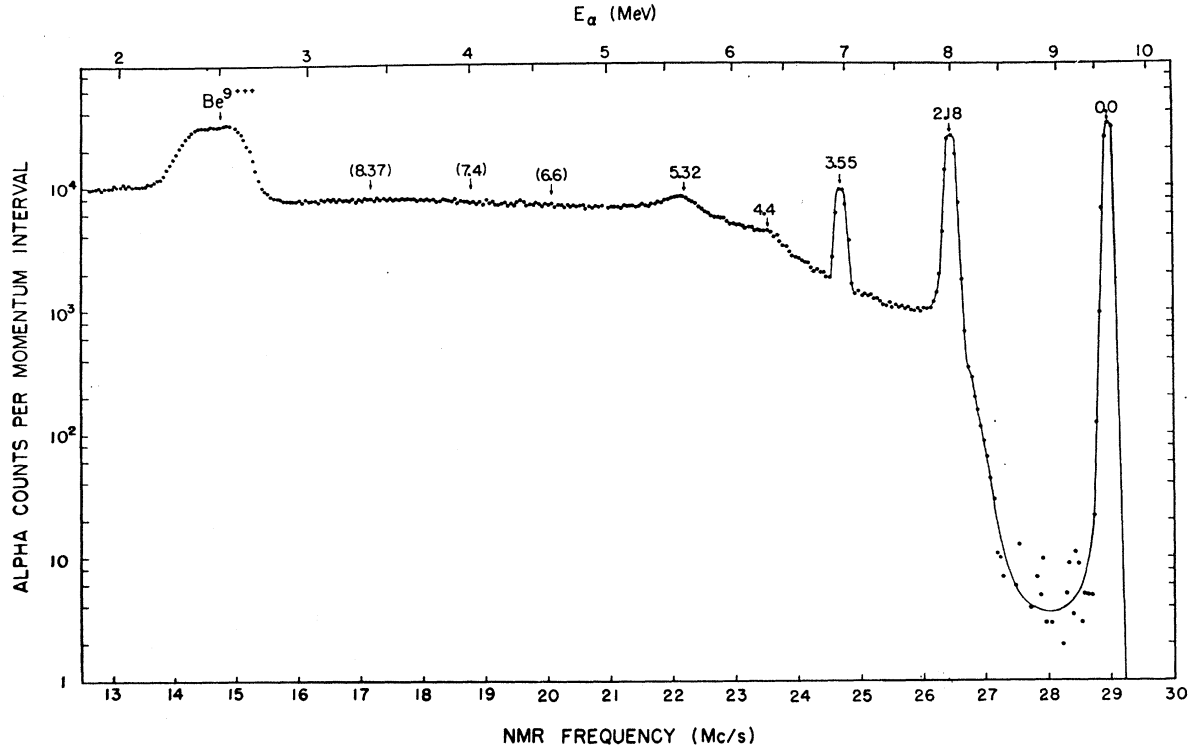

FIG. 1. Momentum spectrum of alpha particles from $Be^9(p,\alpha)Li^6$ at 30° laboratory angle, 10-MeV incident proton energy. The momentum interval ΔP is $P/360$. The arrows indicate the location of alpha groups corresponding to the excited states of Li^6. The excitation energies in parentheses, for states not seen in this experiment, are taken from Ref. 5. The $(Be^9)^{+++}$ ions are from elastic scattering of H in the target.

* Supported by the U. S. Office of Naval Research.
† Present address: Department of Nuclear Physics, Australian National University, Canberra, A.C.T., Australia.
[1] C. P. Browne and C. K. Bockelman, Phys. Rev. **105**, 1301 (1957).
[2] D. A. Bromley, A. J. Ferguson, H. E. Gove, J. A. Kuehner, A. E. Litherland, E. Almqvist, and R. Batchelor, Can. J. Phys. **37**, 1514 (1959).

half-maximum of the momentum distribution. The proton beam of 0.3–1 μA passed through the thin self-supporting beryllium foil target and then into a cup which stopped the beam and permitted a measurement of the total charge of protons hitting the target. The foil thickness, determined from the energy loss of alpha particles passing through the foil, varied between 35 and 200 $\mu g/cm^2$ for the different targets used.

The 180°, double-focusing magnetic spectrometer of 61 cm radius measured the momentum of the alpha particles produced in the reaction. A 6.35-mm collector slit, providing a momentum resolution of $P/\Delta P=360$, was used to survey the spectrum, and a finer resolution of 720 was used to determine the widths and positions of the discrete groups observed. The entrance aperture of the spectrometer was reduced so that the energy spread of the particles entering the spectrometer was equal to the energy interval defined by the collector slit. The spectrometer magnetometer, a nuclear magnetic resonance device, was calibrated with the ThC′ alpha line[3] at 8.7841±0.0028 MeV.

A surface barrier detector with pulse-height analyzer measured dE/dX of the particles passing through the collector slit to provide unambiguous identification of alpha particles in the presence of protons of the same energy. Triply charged Be^9 ions were also detected by this counter; they were recognized by their large energy loss in target and were clearly identified by their energy loss in a thin foil that could be placed in front of the counter.

RESULTS AND DISCUSSION

The momentum spectrum of alpha particles observed at a laboratory angle of 30° is shown in Fig. 1. The continuous spectrum extending up to 8 MeV comes from the breakup in flight of Li^{6*}, Be^8, Be^{9*}, and B^9. Similar spectra were taken at 15°, 45°, 90°, and 150° in an effort to obtain better discrimination between the discrete alpha-particle groups and the continuous background, but, at all angles, the continuous spectrum was equally troublesome. Attempts to observe the recoil Li^6 nucleus in a counter located in the target chamber, in coincidence with the alpha particle detected in the spectrometer, revealed only the transitions to the ground state and the 3.55-MeV state.

The location and widths of the excited states in Li^6 corresponding to the discrete alpha groups are given in Table I. The parameters assigned to the 4.4- and 5.3-MeV states were determined from the energy spectrum shown in Fig. 2. Simple resonance shapes of adjustable width, resonant energy, and strength, were subtracted from the observed spectrum, and the resonant parameters were varied until the residual continuous spectrum was a smoothly varying function of alpha-particle energy. The dashed curves in Fig. 2 show the line shapes and continuous spectrum obtained. The locations of these states are relatively insensitive to any reasonable assumption as to the shape of the continuous spectrum, but the widths of these broad states can be determined only approximately in this experiment since they depend critically on the continuous spectrum that is assumed.

TABLE I. Excited states of Li^6.

Present measurements		Allen *et al.*[a]		Ajzenberg-Selove[b]	
E_R(MeV)	Γ(MeV)	E_R(MeV)	Γ(MeV)	E_R(MeV)	Γ(MeV)
2.19±0.02	<0.035	2.187	<0.1	2.184±0.003	0.021
3.55±0.02	<0.035	3.56 ±0.06	<0.1	3.560±0.006	<0.005
4.40±0.12	0.35±0.15	4.3 ±0.2		4.52 ±0.08	~0.6
5.32±0.06	0.28±0.06	5.35 ±0.07	<0.1		

[a] See Ref. 4. [b] See Ref. 5.

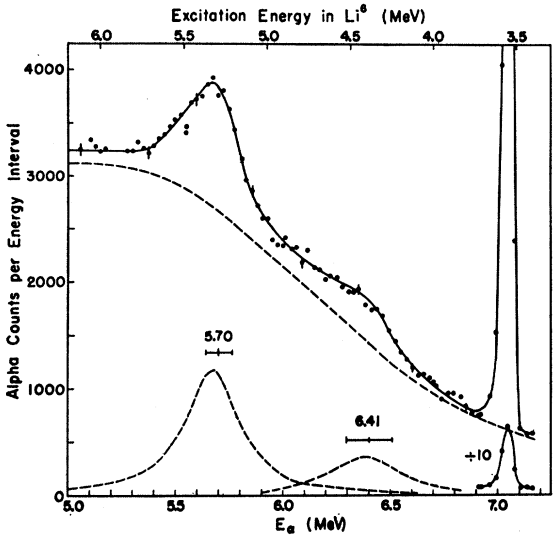

FIG. 2. Energy spectrum of the alpha particles from $Be^9(p,\alpha)Li^6$ at 30° laboratory angle, 10-MeV incident proton energy. The energy interval ΔE is $E/180$, but the observed number of alpha particles of energy E_α has been divided by E_α so that the spectrum shape corresponds to a constant energy interval. Alpha particles of 7-MeV energy lose 45 keV in passing through the beryllium foil target. The observed spectrum (solid line) has been decomposed into discrete groups and a residual continuous spectrum (dashed lines). The bars over the dashed curves indicate the alpha-particle energy, and the uncertainty in the energy, which leads to the excitation energy listed in Table I.

Our values for the positions and widths of the first four excited states of Li^6 are in agreement with the values reported by Allen *et al.*[4] from the alpha-particle spectrum from $Li^7(He^3,\alpha)Li^6$. The excited states at 5.5, 6.6, 7.4, and 8.37 MeV are not seen in the present experiment, but the very strong continuous spectrum obscures the region where groups corresponding to these states would appear. The width of 0.35 MeV for the 4.4-MeV state is less than the value of ~0.6 MeV reported[5] from the He^4+d scattering.

We are indebted to J. H. McNally for help in taking the data.

[3] A. H. Wapstra, Nucl. Phys. **18**, 587 (1960).

[4] K. W. Allen, E. Almqvist, and C. B. Bigham, Proc. Phys. Soc. (London) **75**, 913 (1960).

[5] F. Ajzenberg-Selove and T. Lauritsen, Nucl. Phys. **11**, 1 (1959).