Magnetic Analysis of the $Li^6(He^3,t)Be^6$ Reaction*

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The triton spectrum from the reaction $Li^6(He^3,t)Be^6$ has been measured in a 61-cm double-focusing magnetic spectrometer at He^3 bombarding energies of 10, 11, and 12 MeV, and at observation angles of 1.7° and 10°. A triton group corresponding to the Be^6 ground-state transition was seen. The Q value for the ground-state transition is (-4.306 ± 0.006) MeV, leading to a Be^6-Li^6 mass difference of 4.288 ± 0.006 MeV, in good agreement with the values from the $Li^6(p,n)Be^6$ threshold. The width of the ground state of Be^6 is (89 ± 6) keV.

INTRODUCTION

OUR present knowledge of the width and mass of the ground state of Be^6 is based on neutron spectra and neutron threshold measurements of the $Li^6(p,n)Be^6$ reaction, measurements which are subject to some uncertainty in interpretation when the final state is as broad as the Be^6 ground state. The $Li^6(He^3,t)$-Be^6 reaction provides another method for determining the properties of this state with the precision afforded by magnetic spectroscopy of the tritons. This paper reports an examination of the triton spectrum covering the energy region up to 2.8-MeV excitation in Be^6.

EXPERIMENTAL METHOD

The ONR-CIT tandem accelerator provided a $(He^3)^{++}$ beam of mean energy (10.990 ± 0.004) MeV. The uncertainty in the mean beam energy (±4 keV) is composed of two parts: ±3 keV from the uncertainty in the energy of the Th C' alpha line [(8.7841±0.0028) MeV][1] against which the beam analyzing magnet is calibrated, and ±3 keV corresponding to $\pm\frac{1}{4}$ of the full exit slit width to allow for uncertainty in the mean beam position in the exit slits. The energy spread of the beam, which contributes to the observed width of the ground state, is taken to be 13 keV as defined by the full width (1 mm) of the exit slits of the 90° beam analyzing magnet of 86.36-cm radius.

The triton energy was measured in the 180° double-focusing magnetic spectrometer of 60.96-cm radius set at 0° with respect to the incoming He^3 beam. Horizontal and vertical slits at the entrance of the spectrometer defined a square aperture with sides displaced 2° from the beam axis, and a square beam catcher with sides 1.1° off the beam axis prevented the He^3 beam from entering the spectrometer and permitted the usual integration of the He^3 beam current. The average angle of observation computed for this entrance aperture between the square at 1.1° and the square at 2° is 1.73°.

Targets of metallic lithium, enriched to 99.3% mass 6, were evaporated in the spectrometer target chamber on 5×10^{-6} cm Ni supporting foils. The target thickness, between 10 and 35 $\mu g/cm^2$ for various targets used, was determined by measuring with the spectrometer the energy loss of He^3 ions passing through the target. The targets were set normal to beam axis, and the observed particles as well as the incident beam passed through the target.

Particles deflected in the spectrometer were detected in an array of 16 Au-Si surface-barrier solid-state detectors located in the focal plane. Slits just in front of each counter defined a momentum window $\Delta P=P/720$, and the momentum interval between adjacent counters was $P/400$. An energy measurement for each particle was obtained from 64 channels of pulse-height analysis of the output of each detector. Given the energy and magnetic rigidity of a particle, one can compute the $(charge)^2/mass$ ratio and thereby count tritons in the presence of other charged particles of the same magnetic rigidity. To separate singly charged He^3 ions from tritons, an aluminum foil of thickness 2.6 mg/cm^2 was placed in front of the counters. In passing through this foil the He^3 loses about four times the energy lost by a triton of the same energy, and the energy discrimination provided by the solid-state counters enabled us to count tritons without interference from the $(He^3)^+$ ions.

RESULTS

The momentum spectrum from which the ground-state Q-value and width measurements were made is shown in Fig. 1 for a He^3 bombarding energy of 11 MeV and observation angle 1.7°. The experimental yield at each value of $B\rho$ has been divided by $B\rho$ to convert the spectrum to a constant momentum interval. The solid curve shows the triton group leading to the ground state of Be^6, the dashed curve is a deuteron group from the reaction $Li^6(He^3,d)Be^{7*}$ (0.432 MeV). The deuteron energy scale appears at the top of the figure, the triton energy scale appears at the bottom.

The triton energy at the peak of the ground-state group in Fig. 1 is 3.365 MeV, at the middle of the half-width it is 3.361 MeV, and we have taken (3.363 ± 0.003) MeV as the triton energy for the ground-state transition, to which another 2 keV must be added to allow for the triton-energy loss in the target. The Q value corresponding to this triton energy is -4.306 MeV.

A more precise measurement of the Q value is obtained by reading from Fig. 1 the ratio of triton energy

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

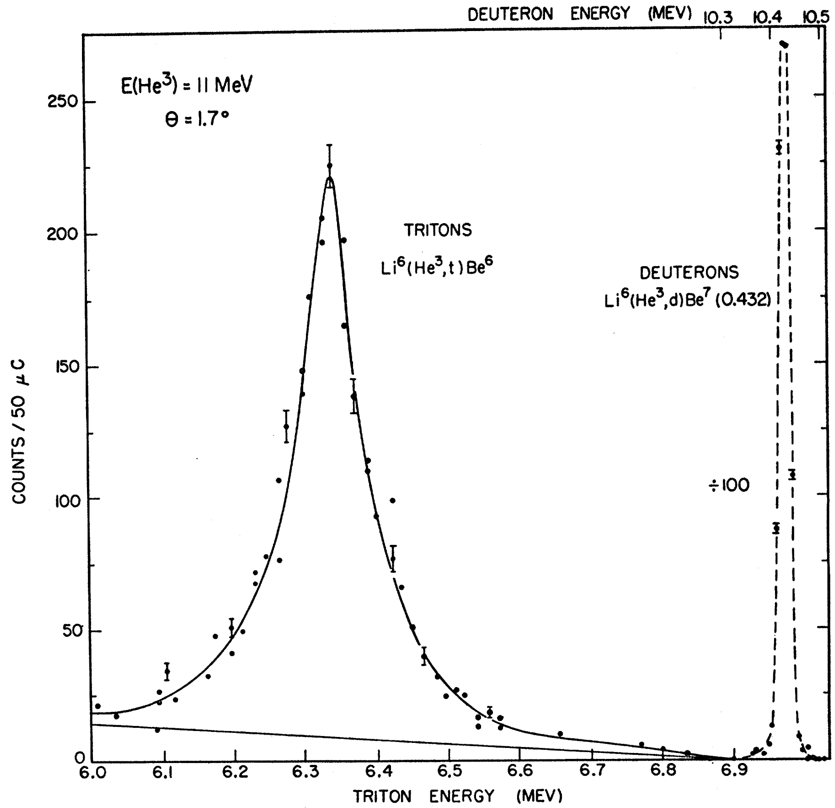

FIG. 1. Momentum spectrum of tritons and deuterons from Li^6+He^3 at $E_{He^3}=11$ MeV. The mean observation angle is 1.7°. The deuteron yield has been divided by 100. The yield at each value of $B\rho$ has been divided by $B\rho$ to present a momentum spectrum with constant momentum interval.

to deuteron energy, a procedure which is equivalent to calibrating the spectrometer energy scale in terms of the deuteron line from $Li^6(He^3,d)Be^{7*}$ [(0.432±0.003) MeV].[2] Calculation of the $Li^6(He^3,t)Be^6$ Q value in terms of this energy ratio yields the same Q value, −4.306 MeV, but with a smaller uncertainty of ±0.006 MeV, since the uncertainty in the bombarding energy and angle of observation are of less significance when the energy ratio is measured. This Q value corresponds to a Be^6-Li^6 mass difference of (4.288±0.006) MeV, in good agreement with earlier measuerments listed in Table I. The mass scale is $C^{12}=12$.

The triton yield does not approach zero on the low-energy side of the ground-state group, as may be seen also in Fig. 2, and some allowance must be made for this background in order to find the width at half-maximum. We have subtracted the background indicated by the straight line in Fig. 1. The resultant width at half-maximum is 110 keV, to which we assign an uncertainty of ±7 keV, largely of statistical origin.

TABLE I. Properties of Be^6 ground state.

Mass difference Be^6–Li^6 (MeV)	Γ (keV)	Reference
4.27 ±0.2	≤150	a
4.30 ±0.04	140±40	b
4.289±0.009	95±28	c
4.39 ±0.07	···	d
4.288±0.006	89±6	this experiment

[a] F. Ajzenberg-Selove, C. F. Osgood, and C. P. Baker, Phys. Rev. **116**, 1521 (1959).
[b] M. Gulyamov, B. V. Rybakov, and V. A. Sidarov, Zh. Eksperim. i Teor. Fiz. **44**, 1829 (1963) [English transl.: Soviet Phys.—JETP **17**, 1230 (1963)].
[c] J. L. Honsaker, Bull. Am. Phys. Soc. **9**, 627 (1964).
[d] Reference 4.

[2] R. B. Day and T. Huus, Phys. Rev. **95**, 1003 (1954).

The width of the deuteron group displays the instrumental resolution, a trapezoidal window of half-width determined by the collector slit width δr_c, and baseline determined by δr_c and the energy spread of the incident He^3 beam. In terms of triton energy, this trapezoid has a half-width of 17.5 keV and a baseline of 30.5 keV. By folding this trapezoidal window into a resonance curve of width Γ, we find that $[\Gamma^2+(\text{base width})^2]^{1/2}$ is a good approximation to the observed width, and we have therefore removed the instrumental resolution from the observed width quadratically. The resultant laboratory width is 106±7 keV. The corresponding width of the Be^6 ground state is (89±6) keV.

An energy spectrum taken at 10° with 11-MeV bombarding energy is shown in Fig. 2. The beam catcher is no longer present, and the entrance aperture is defined by the rectangular aperture of 4°×4°. The experimental yield has been divided by $(B\rho)^2$ to convert the spectrum to a constant energy interval. The triton energy scale appears at the bottom of the figure, the Be^6 excitation energy at the top.

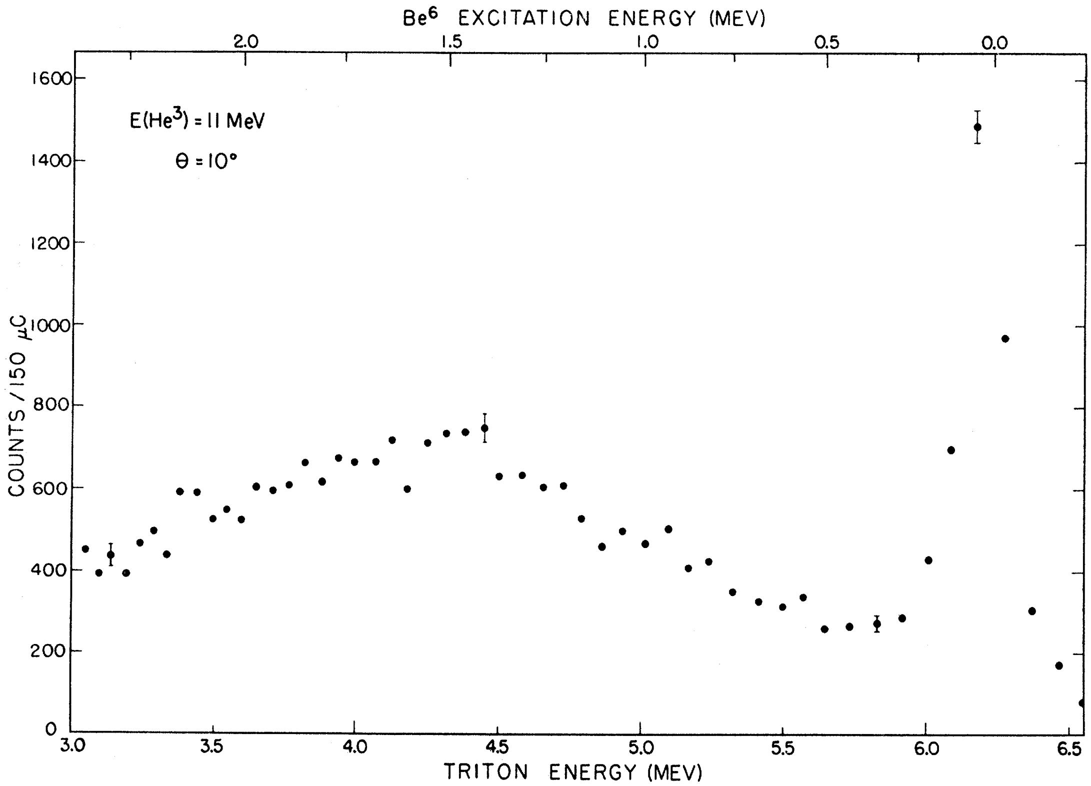

FIG. 2. Energy spectrum of tritons from Li^6+He^3 at $E_{He^3}=11$ MeV. The observation angle is 10°. The experimental points were taken with a momentum window $\Delta P=P/720$, and an interval $P/400$ between adjacent points. As presented in this figure, the yields from three adjacent counters have been summed to improve the statistics, and the yield at each value of $B\rho$ has been divided by $(B\rho)^2$ in order to present an energy spectrum with constant energy interval.

The broad group of tritons of energy 4.4 MeV in Fig. 2 has been observed at 1.7° and 10° in the laboratory, and at He^3 bombarding energies of 11 and 12 MeV; it does not appear in the spectra at 10 MeV. A simple interpretation of this triton group in terms of an excited state of Be^6 is frustrated by its kinematical behavior: As the bombarding energy is increased from 11 to 12 MeV, the peak of this broad group moves from 1.6- to 2.0-MeV Be^6 excitation energy, and the half-width of the group increases from 1.2 to 1.6 MeV, measured in Be^6 excitation energy.

This behavior is not incompatible with the existence of a broad level near 2 MeV in Be^6 which has been reported recently by several authors.[3–6] At a bombarding energy of 11 MeV, tritons populating the Be^6 (2-MeV) state have only 1-MeV energy to penetrate the Be^6 barrier, and the variation of the penetrability across the width of this state will shift the peak toward higher triton energy (lower excitation energy in Be^6). The variation of this shift with bombarding energy reflects the variation of the energy dependence of the triton penetrability with triton energy.

The kinematical energy variation exhibited by the broad group of Fig. 2 may also be understood without invoking a state in Be^6. A two-stage reaction such as $Li^6(He^3,p)Be^{8*}(t)Li^5$ proceeding through one or more states in Be^8 with excitation energy between 23 and 24 MeV can also produce a broad triton peak that behaves as the one we observe here. In our inability to distinguish between these two processes, we are not able to draw any conclusion about excited states of Be^6 from our spectra, other than the observation that there appear to be no narrow states, of width less than about 1 MeV, in the excitation energy region up to 2.8 MeV covered in this experiment.

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[4] C. J. Batty, E. Friedman, P. C. Rowe, and J. B. Hunt, Phys. Letters **19**, 35 (1965).

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