# NEW ISOTOPE OF HELIUM: $^{7}$He

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Energy spectra have been measured at 15 scattering angles for $^{3}$He ions arising from the triton bombardment of $^{7}$Li. A peak which appeared in the spectra at all scattering angles is attributed to the ground state of $^{7}$He. The $Q$ value of the reaction $^{7}$Li($t$, $^{3}$He)$^{7}$He corresponds to $^{7}$He being unbound to neutron decay by $0.42 \pm 0.06$ MeV. The width of the state was determined to be $0.17 \pm 0.04$ MeV.

The question of location and possible particle stability of $^{7}$He has been a subject of interest for many years. An unsuccessful attempt to observe the formation of $^{7}$He through the reaction $^{7}$Li($n,p$)$^{7}$He was reported[1]; however, experimental conditions precluded a positive result unless $^{7}$He were bound by >3 MeV. The existence of a particle-stable $^{7}$He nucleus has been advanced[2,3] as a possible explanation of $\beta$ activity ($\tau = 80$ msec) of unknown origin resulting from the negative-pion bombardment of carbon.[4] Early evidence from the reactions $^{7}$Li($\gamma,n$)$^{6}$Li and $^{7}$Li($\gamma,t$)$^{4}$He suggested that the $T=\frac{3}{2}$ level in $^{7}$Li occurred at an excitation energy of either 10.8 or 12.4 MeV.[5] If the former value were correct, the particle stability of $^{7}$He remained an open question,[6,2] whereas the assumption of the latter energy led to the conclusion that the last neutron in $^{7}$He was unbound by >1 MeV.[7] The situation with regard to the $T=\frac{3}{2}$ state in $^{7}$Li (and $^{7}$Be) has recently been clarified by an experiment at Berkeley.[8] In this experiment the controversial level was found at an excitation energy of 11.13 MeV in $^{7}$Li, and the ground state of $^{7}$He was predicted to be unbound by 0.36 MeV. In the experiment discussed in the present paper the formation of the ground state of $^{7}$He was observed directly through the reaction $^{7}$Li($t$, $^{3}$He)$^{7}$He and was found to be unbound to neutron decay by $0.42 \pm 0.06$ MeV.

The experiment was performed using a 22-MeV triton beam from the Los Alamos three-stage tandem accelerator. After energy analysis in a 90° magnet, the triton beam was collimated and allowed to strike a self-supporting $^{7}$Li target of thickness 0.40 mg/cm$^{2}$. The target was made by evaporation of isotopically pure (99.99%) $^{7}$Li. $^{3}$He particles from the reaction $^{7}$Li($t$, $^{3}$He)$^{7}$He were detected in a $\Delta E$ gas proportional counter (90% Ar, 10% Co$_2$) followed by a surface-barrier $E$ detector. Pulses from the $\Delta E$ and $E$ detectors were used with an analog pulse multiplier to identify $^{3}$He pulses. The $E+\Delta E$ spectrum was recorded with a 400-channel pulse-height analyzer. The analyzer was gated by pulses from a coincidence circuit requiring a triple coincidence of signals from the $E$ and $\Delta E$ detectors and the pulse multiplier. An energy calibration of the detection system was obtained using a 0.05-mg/cm$^{2}$ carbon target and observing $^{3}$He particles from the ground-state reaction $^{12}$C($t$, $^{3}$He)$^{12}$B.

$^{3}$He spectra from the reaction $^{7}$Li($t$, $^{3}$He)$^{7}$He were taken at 15 angles between $\theta_{\rm lab} = 6°$ and 40° in each of two series of runs. A well-defined peak was observed in all spectra. Spectra taken at laboratory angles 10°, 15°, and 20° are shown in Fig. 1. The width of the 10° peak stated in the figure has been converted to the $^{7}$He center-of-mass system. After subtraction of a smooth background, a $Q$ value and width were obtained from the mean energy of each peak and from the second moment about the mean energy, respectively. The average value of $Q$ obtained by this procedure

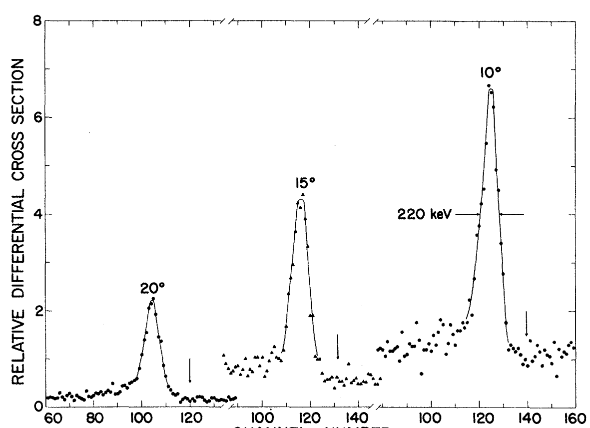


FIG. 1. A portion of the $^{3}$He energy spectra from the reaction $^{7}$Li($t$, $^{3}$He)$^{7}$He taken at laboratory angles 10°, 15°, and 20°. The width shown with the 10° spectrum is given in the $^{7}$He center-of-mass system. The arrows indicate the position of the threshold for $^{6}$He$+n$ breakup.

was −11.16 MeV. This $Q$ value corresponds to a mass excess of 26.09 ± 0.06 MeV ($^{12}$C scale) which has the consequence that $^7$He is unbound to neutron decay by 0.42 ± 0.06 MeV. After correction for the energy resolution of the apparatus (0.15 MeV), a width of 0.17 ± 0.04 MeV was obtained for the ground state of $^7$He. Although the peaks are slightly asymmetric, in each case the mean energy was within ~15 keV of the energy at maximum yield, and the width as determined above was within ~20 keV of the full width at half-maximum of the peak. The 15 measurements of $Q$ in each series of runs were distributed about the mean value with a standard deviation of approximately 29 keV; the standard deviation of the width measurements was about 15 keV.

In Fig. 2 the laboratory energy of the observed groups (solid points) is plotted as a function of laboratory angle. The heavy solid line associated with the points was calculated from the average $Q$ value determined from the data. Also shown in Fig. 2 is the energy variation with angle of several possible target-impurity groups. In the cases of $^{14}$N and $^6$Li impurities, the dashed lines do not correspond to known levels in the residual nuclei. If such levels should occur in these nuclei, the shape of their laboratory energy versus scattering angle curve would be sufficient to distinguish them from $^7$He. The only contaminant group observed in the experiment resulted from the reaction $^1$H($t$, $^3$He)$n$ due to hydrocarbon buildup on the target.

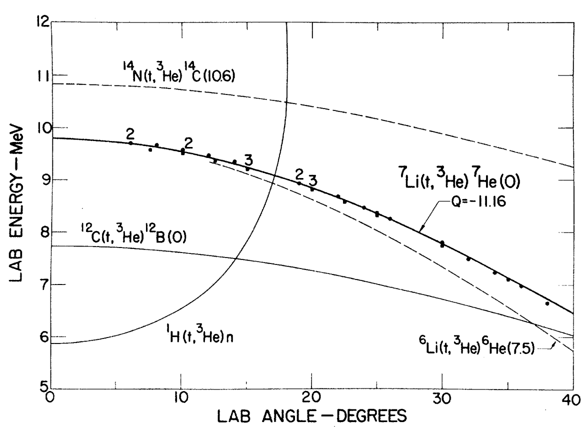


FIG. 2. Diagram showing the variation of laboratory energy with angle for several reactions at a triton bombarding energy of 22 MeV. The experimental data are indicated by the solid circles and squares; the numbers associated with the points represent overlapping data. The dashed lines indicate that there is no level known in the residual nuclei at the energies given.

In runs taken with the mass identification system set to detect alpha particles, evidence of carbon and a trace of oxygen were observed, although these impurities were not present in sufficient quantity for detection in the $^3$He spectra.

With our location of the ground state of $^7$He, the masses of three members of the lowest $M=7$, $T=\frac{3}{2}$ quartet are now known. If we use the quadratic isobaric mass formula[9]

$$M=a+bT_z+cT_z^2,$$

together with the Berkeley results[8] for the energies of the lowest $T=\frac{3}{2}$ states in $^7$Li and $^7$Be, the ground state of $^7$B is estimated to have a mass excess of 27.66 ± 0.20 MeV. The uncertainty of 0.20 MeV is obtained from a quadratic combination of the errors associated with the three known members. Within quoted errors this result for $^7$B agrees with a prediction made from the $T=\frac{3}{2}$ state in $^7$Be after correction for the neutron-proton mass difference and for the Coulomb energy difference.[8]

The width of the $^7$He ground state (0.17 ± 0.04 MeV) obtained in the present experiment is somewhat less than that given for the $T=\frac{3}{2}$ states in $^7$Li (0.268 ± 0.030 MeV) and $^7$Be (0.298 ± 0.025 MeV).[8] Referring to the $M=7$, $T=\frac{3}{2}$ energy diagram given in Fig. 3, this result is not surprising since additional particle decay modes are available to $^7$Li and $^7$Be. In particular, both $^7$Li and $^7$Be are unstable to proton emission by >1 MeV and to four-particle breakup as well as to neutron emission. From the assignment[8] given to the $^7$Li and $^7$Be analogs, the $^7$He state has spin and parity $\frac{3}{2}^-$ and is expected to decay by $p$-wave neutron emission. With this assumption of $l_n=1$, a radius of 2.2 F, and the measured width (170 keV) and decay energy (420 keV), the reduced width is computed to be 0.31 of the Wigner limit.

The systematics of neutron binding energies can be extended by use of the experimental value for the mass of $^7$He. The following example is consistent with the independent particle model and its assumption of equal core interaction for all particles in the same orbital state. Consider adding $p_{3/2}$ neutrons to an alpha-particle core and compute $\epsilon$, the mutual interaction energy, defined as the total $p_{3/2}$ neutron binding from all interactions between extra-core neutrons. In going from $^7$He to $^8$He, an argument[10] based on combinations of two-body

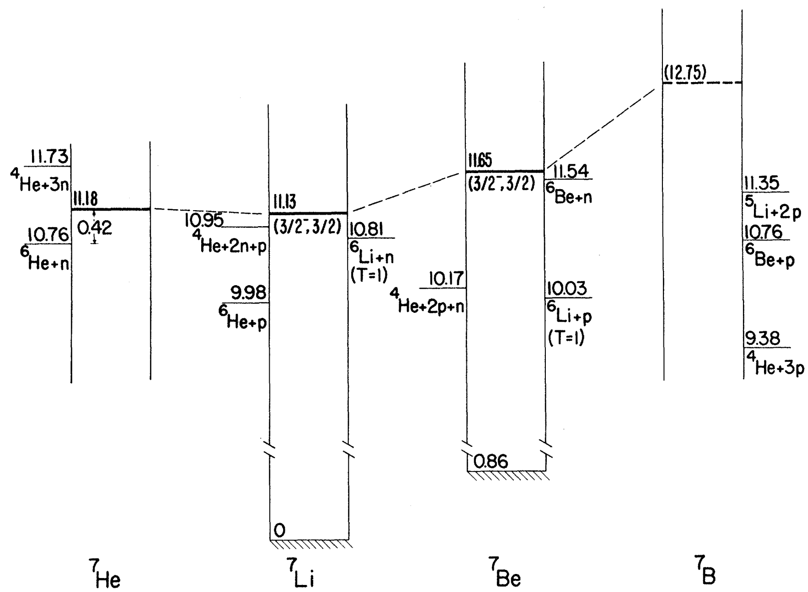


FIG. 3. Energy diagram for the $M=7$, $T=\frac{3}{2}$ quartet. All energies are referred to the ground state of $^7$Li. The decay modes shown are those available for the breakup of $T=\frac{3}{2}$ states with conservation of isospin. The energy of the ground state of $^7$B was calculated as described in the text.

forces shows that the interaction energy should be doubled. We compute $\epsilon$ as follows:

$$\epsilon(^7\mathrm{He}) = \alpha + 3n - {}^7\mathrm{He} - 3(\alpha + n - {}^5\mathrm{He})$$
$$= 3.42 \pm 0.06 \text{ MeV},$$
$$\epsilon(^8\mathrm{He}) = \alpha + 4n - {}^8\mathrm{He} - 4(\alpha + n - {}^5\mathrm{He})$$
$$= 6.89 \pm 0.12 \text{ MeV},$$

where the symbols on the right are atomic masses.[11] The ratio of these is $2.01 \pm 0.05$, in good agreement with the assumption of equal core ir .eraction for all $p_{3/2}$ neutrons.

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[11]Nuclear masses were obtained from J. H. E. Mattauch, W. Thiele, and A. H. Wapstra, Nucl. Phys. 67, 1 (1965), except for the $^8$He mass, which was obtained from J. Cerny, S. W. Cosper, G. W. Butler, R. H. Pehl, F. S. Goulding, D. A. Landis, and C. Détraz, Phys. Rev. Letters 16, 469 (1966).