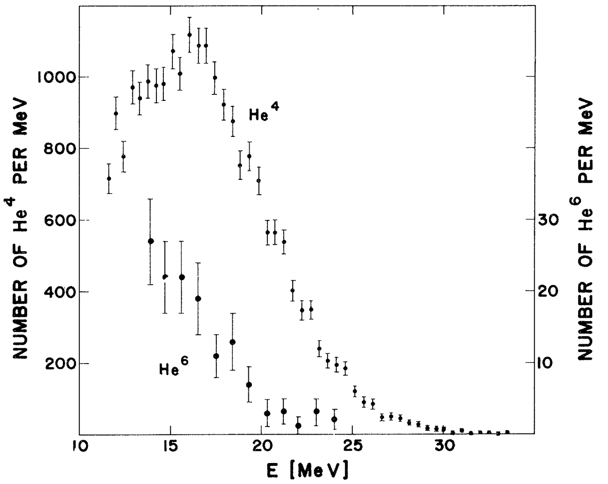

FIG. 2. Energy spectra of long-range He^4 and He^6 particles spontaneously emitted from Cf^{252}. Energies have been corrected for energy loss in the absorber foil. The spectra are shown only for energies high enough for the particles to penetrate to the E detector, so that the identification of the particle species is unambiguous.

masking these apparently rather rare particles. Evidence has also been reported in channeling studies for the occasional loss of somewhat more than the expected energy in a transmission detector.[9] This effect or the Landau effect could conceivably disperse He^4 particles into the vicinity of the He^6 locus. Neither of these effects, however, to our knowledge, could produce the relatively clean separation between the He^4 and He^6 events that is obtained. The absence of any events immediately above the H^3 locus toward the He^4 locus is further evidence that the He^6 events we observe are real.

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*On leave from Department of Chemistry, Princeton University, Princeton, New Jersey.

†Work performed under the auspices of the U. S. Atomic Energy Commission.

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Li^4 AND THE EXCITED LEVELS OF He^4†

Joseph Cerny, Claude Détraz,* and Richard H. Pehl
Department of Chemistry and Lawrence Radiation Laboratory, University of California, Berkeley, California
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There is a continuing interest in a characterization of such nuclei as H^4 and Li^4; in addition, a determination of the mass of either should aid in locating the lowest $T=1$ state of He^4, which is the subject of considerable current speculation. To accomplish this we have again[1] utilized the technique of simultaneous observation of (p,t) and (p,He^3) transitions to analog final states—here applied to the $(T=1)$ reactions Li$^6(p,t)$Li^4 and Li$^6(p,\text{He}^3)$He^{4*}. The latter reaction and the reaction Li$^7(p,\alpha)$He^4 also allow the investigation of the $T=0$ states of He^4.

Some of the recent data concerning the two lowest excited states of He^4 are summarized in Table I.[2-8] Since state I ($\approx$20 MeV, probably $0^+, T=0$) lies just above the p-t threshold at 19.81-MeV excitation and state II ($\approx$22 MeV, probably 1^- or $2^-, T=0$), above the n-He^3 threshold at 20.58 MeV, their exact nature is uncertain. Besides these two states, Vlasov and Samoilov suggest[9] the possibility that the lowest $T=1$ state lies at 24 or 25 MeV. This would require Li^4 to be unbound by 4.5 to 5.5 MeV.

We have used 43.7-MeV protons from the Berkeley 88-in. cyclotron to induce (p,t) and (p,He^3) reactions on Li^6 and (p,α) reactions on Li^7. Targets of separated isotopes were used; the general experimental setup was reported previously.[1]

Figure 1 presents a Li$^6(p,t)$Li^4 spectrum

Table I. Evidence for the first two excited levels of He^4.

			State I		State II	
Reference	Reaction	Bombarding energy (MeV)	Position (MeV)	Width (MeV)	Position (MeV)	Width (MeV)
a	$d(He^3,p)He^4$	31.8	19.94 ± 0.02	0.140 ± 0.025	21.24 ± 0.2	1.1 ± 0.2
b	$He^4(p,p')He^4$	40	20.46 ± 0.14	~0.3	22.0 ± 0.14	several MeV
c	$He^3(d,p)He^4$	6-10	20.08 ± 0.5	0.2 ± 0.05		
d	$He^4(p,p')He^4$	55			22.4 ± 0.7	1.7 ± 0.5
e	$T(d,n)He^4$	7.83	20.1	0.35 ± 0.05		
f	$T(d,n)He^4$	19			22	
g	$T(p,p)T$	resonance	20.3 ± 0.1			

[a] See reference 2.
[b] See reference 3.
[c] See reference 4.
[d] See reference 5.
[e] See reference 6.
[f] See reference 7.
[g] See reference 8.

at 15°. Such data, taken between 10° and 35° in the laboratory, show a broad state which is unbound by 2.9 ± 0.3 MeV to He^3-p decay. (Though we shall denote this peak as the Li^4 ground state throughout this report, it is probably not a single state.[10]) The width of the unbound Li^4 state is 5.0 ± 0.5 MeV at all angles. Using this Li^4 mass, a Coulomb calculation predicts that the $T = 1$ excited state of He^4 is located at approximately 22.5 MeV (±0.3 MeV). Finally, one predicts that the analog H^4 nucleus is also unbound—by about 2.0 MeV.[11] These masses directly confirm the negative results of previous searches for the β decay of H^4 or Li^4 (see Imhof et al.[12]).

Figure 2 presents spectra from the reactions $Li^6(p,He^3)He^4$ and $Li^7(p,\alpha)He^4$. State I was observed in both of these reactions, appearing at 20.10 ± 0.15 MeV. If its 0^+ assignment is correct, the (p,He^3) transition to this level should correspond to an angular-momentum transfer of $L = 0$ (or 2), while the (p,α) transition would require $L = 1$ transfer. The angu-

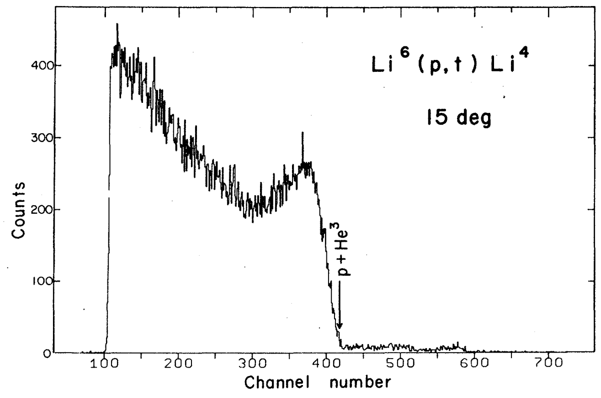

FIG. 1. An energy spectrum of the reaction $Li^6(p,t)Li^4$ at 15° using 43.7-MeV protons. The counts above channel 420 arise from a slight deuteron breakthrough into the triton region of the identifier spectrum.

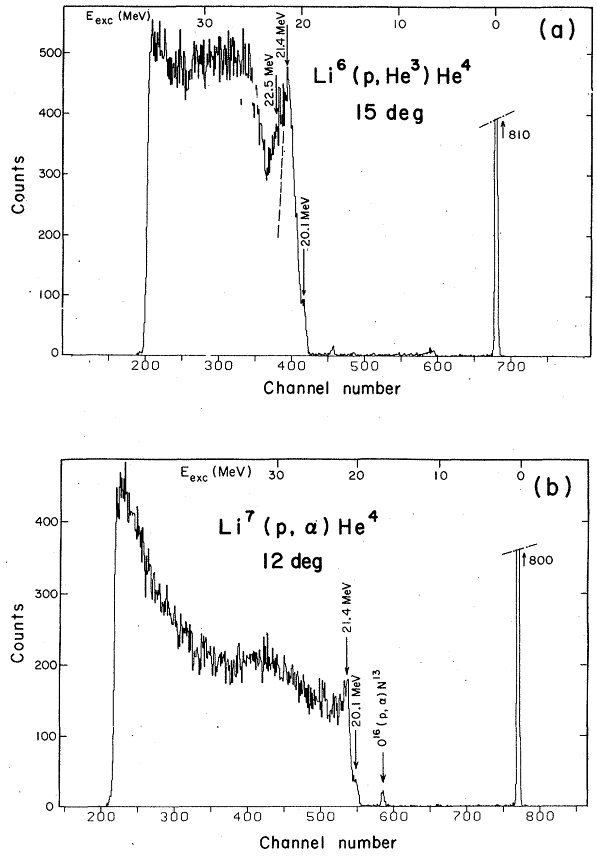

FIG. 2. Typical energy spectra from (a) the reaction $Li^6(p,He^3)He^4$ and (b) the reaction $Li^7(p,\alpha)He^4$ at 43.7 MeV. Part (a) exhibits the analysis of the prominent peak at 21.4 MeV using the width reported by Parker et al.[2]

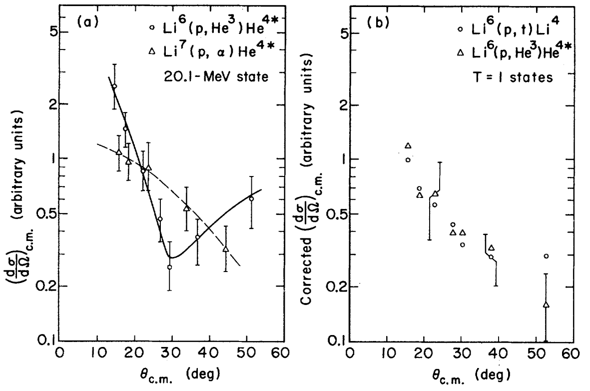

FIG. 3. (a) Angular distributions to the 20.1-MeV excited state of He^4 for the two reactions $\text{Li}^6(p,\text{He}^3)\text{He}^{4*}$ and $\text{Li}^7(p,\alpha)\text{He}^{4*}$. The arbitrary unit, common to both distributions, corresponds roughly to 15-20 μb sr^{-1}. (b) A comparison of the angular distributions of the analog reactions $\text{Li}^6(p,t)\text{Li}^4$ g.s. and $\text{Li}^6(p,\text{He}^3)\text{He}^{4*}$ ($T=1$, 22.5 MeV). The (p,He^3) cross sections have been multiplied by 1.99 to adjust for isospin coupling and phase-space factors. Due to the complexity of the spectra, the relative cross sections have been obtained from only the "corrected" peak heights, assuming comparable widths for these analog states. Probable uncertainties introduced by this procedure are indicated.

lar distributions of Fig. 3(a) are in accord with these expectations and strongly support this 0^+ assignment. First, the (p,He^3) transition is essentially identical to the $\text{Li}^6(p,\text{He}^3)\text{He}^4$ g.s. transition, and both appear to be fairly pure $L=0$, according to our two-nucleon transfer systematics in the light elements[1]; and, second, the limited (p,α) data are consistent with the $\text{Li}^7(p,\alpha)\text{He}^4$ g.s. transition which must have $L=1$ transfer.

It is apparent from Table I that large discrepancies exist in both the location and width of state II as reported from different experiments. These fluctuations and the above Li^4 results lead us to postulate that there are, in fact, at least two states near 22 MeV. We expect one to be a $T=0$ state with a width of about 1 MeV, clearly apparent in the work of Parker *et al.*[2] at 21.2 ± 0.2 MeV, and the other(s) to be the $T=1$ state(s) predicted from our Li^4 mass to appear at 22.5 ± 0.3 MeV. An analysis of the data using the width[13] given by Parker *et al.* for the prominent peak which appears at 21.4 ± 0.25 MeV in the $\text{Li}^6(p,\text{He}^3)\text{He}^4$ spectra [Fig. 2(a)] indicates the presence of an additional, somewhat smaller peak at 22.5 ± 0.3 MeV. As expected, this new peak is broad; however, no width could be obtained due to the complexity of the spectra. This 22.5-MeV level can be postulated as the first $T=1$ excited state of He^4—the analog of the Li^4 ground state.

Further confirmation of this assignment is presented in Fig. 3(b), where both analog transitions, $\text{Li}^6(p,t)\text{Li}^4$ g.s. and $\text{Li}^6(p,\text{He}^3)\text{He}^{4*}$ (22.5 MeV, $T=1$), are shown. The monotonically decreasing angular distributions to these $T=1$ states over the observed angular range are similar to the $\text{Li}^6(p,\text{He}^3)\text{He}^{4*}$ (21.4 MeV, 1^- or 2^-, $T=0$) angular distribution; all three transitions are consistent with the $L=1$ angular-momentum transfer that would be expected to 1^- or 2^- states. Finally—and most importantly—the relative cross sections to these two analog levels, after correcting for isospin coupling and phase space,[14] are quite similar (within the large uncertainties of peak separation and background subtraction), as would be required for transitions proceeding from identical initial to final states through ${}^1S$, $T=1$ pickup of two nucleons.

To summarize, we have observed the unbound ground "state" of Li^4 and predict that H^4 must be unbound by 2 MeV. We have obtained angular distributions to the 20.1-MeV state of He^4 which are consistent with its 0^+ assignment and have identified the lowest $T=1$ "state" of He^4 at an excitation of 22.5 ± 0.3 MeV.

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[*] CNRS and NATO Fellow, visitor from Laboratoire Joliot-Curie de Physique Nicleaire, Orsay, France.

[†] Work performed under the auspices of the U. S. Atomic Energy Commission

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ELASTIC ELECTRON-DEUTERON SCATTERING AND POSSIBLE MESON-EXCHANGE EFFECTS*

C. D. Buchanan and M. R. Yearian

High Energy Physics Laboratory and Department of Physics, Stanford University, Stanford, California

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We have obtained data on elastic electron-deuteron scattering using a two-spectrometer coincidence-detection technique. The electron beam was supplied by the Stanford Mark-III accelerator. Both the electric and magnetic scattering have been measured at values of q^2 of 6, 7, 8, and 12 F^{-2}. ($-q^2$ is the square of the four-momentum transferred.) The accuracy for electric scattering is 6 to 12%; for magnetic scattering, 12 to 20%. Electric scattering was also measured at $q^2 = 20\ \mathrm{F}^{-2}$ with 25% accuracy. Our preliminary analysis of the data has been compared with an impulse-approximation theory and has enabled us to investigate possible meson-exchange and/or relativistic effects.

The measurements were made using a 1.2-cm-thick liquid-deuterium target and two 180°, $n = \frac{1}{2}$, double-focusing magnetic spectrometers. Deuterons were deflected by a 72-in., 1000-MeV/c spectrometer and detected by a six-channel ladder of plastic scintillators. Electrons were deflected by a 36-in., 550-MeV/c spectrometer and detected by a similar five-channel ladder with a liquid Cherenkov backing counter. The solid angle was defined by the 36-in. spectrometer. By demanding a coincidence between counts from each spectrometer, background events from competing inelastic processes were eliminated. Delayed accidental coincidence rates were monitored. These accidental rates were typically less than 20% of the real rate and introduced less than a 2% uncertainty in the final quoted cross sections. About a 20% radiative correction was necessary for the electron detection; less than a 1% correction was necessary for the deuteron detection.

Elastic electron-proton cross sections were also measured and used for normalization purposes, thus reducing possible systematic errors from sources such as solid angle, radiative corrections, target thicknesses, and target density. Our quoted deuteron cross sections were normalized to these proton measurements, using the b' fit of de Vries et al.[1] as an accurate standard; i.e., no error was assigned to the b' fit predictions.

The proton cross sections measured with the two-spectrometer coincidence system were compared with those measured simultaneously using only the 36-in.-spectrometer information. The efficiency of the two-spectrometer system thus obtained was typically $(98.5 \pm 1.5)\%$.

Assuming only a one-photon exchange, one can write

$$\frac{(d\sigma/d\Omega)}{\sigma_{NS}} = A(q^2) + B(q^2)\tan^2(\tfrac{1}{2}\theta),$$

where $d\sigma/d\Omega$ is the experimental cross section. σ_{NS} is the point cross section (including recoil factor), θ is the electron scattering angle in the laboratory, and $A(q^2)$ (referred to as the electric scattering) and $B(q^2)$ (referred to as the magnetic scattering) are functions of q^2 only. For each value of q^2 (except 20 F^{-2}) measurements were made at electron scattering angles of 90°, 120°, and 145°. The values of $A(q^2)$ and $B(q^2)$ were obtained by plotting $(d\sigma/d\Omega)/\sigma_{NS}$ against $\tan^2(\frac{1}{2}\theta)$ and fitting these data with a minimum χ^2 straight line. The χ^2/(de-