Energy Levels of Light Nuclei
$A = 6$

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Abstract: An evaluation of $A = 5$–10 was published in *Nuclear Physics A*320 (1979), p. 1. This version of $A = 6$ differs from the published version in that we have corrected some errors discovered after the article went to press. Figures and introductory tables have been omitted from this manuscript. Reference key numbers have been changed to the TUNL/NNDC format.

(References closed in 1978)

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^{6}n

(Not illustrated)

^{6}n has not been observed in the interaction of 700 MeV protons or of 400 GeV protons with uranium: the cross section is $< 1.1 \times 10^{-3}$ μb (1977TU02; 700 MeV), < 9 μb (1977TU1B; 400 GeV). See also (1977DE08) [and footnote 10 in (1977TU1B) and (1976GO1C, 1978SA1E; theor.).

^{6}H

(Not illustrated)

^{6}H has not been observed in the interaction of π^{-} and ^{14}N: see (1972AG01).

^{6}He

(Figs. 4 and 7)

GENERAL: (See also (1974AJ01).).

Model calculations: (1974GH01, 1974IR04, 1975FI1C, 1975FI1D, 1975VE01, 1976CE03, 1976IR1B).

Astrophysical questions: (1976VI1A).

Electromagnetic interactions: (1975VE01).

Special reactions: (1974BO08, 1975FE1A, 1975ZE01, 1976BO08, 1976VA29, 1977FE1B, 1977YA1A).

Muon and neutrino capture and reactions: (1973MU1B, 1974CA04, 1975DO1F, 1976WA02, 1977PR1B, 1978DE15, 1978HW01).

Pion capture and reactions (See reaction 10 in ^{6}Li. See also reaction 5 here.): (1974CA24, 1974DE1C, 1974KO27, 1975BE1G, 1975MO22, 1976AL1F, 1976CA20, 1976TR1A, 1976TZ1A, 1977AR1C, 1977AU02, 1977BA1Q, 1977CO1E, 1977DO06, 1977RA1A, 1977SH1C).

Other topics: (1973DZ1A, 1974GH01, 1974IR04, 1974KA1E, 1974MC04, 1975KU08, 1976IR1B, 1976RO1D, 1978PA02).

Ground state properties: (1974GH01, 1975BE31, 1976BE1G, 1976HA1E).

Mass of ^{6}He: The mass excess of ^{6}He is 17593.7 ± 1.1 keV [see ^{7}Li(d, ^{3}He)^{6}He] (1978RO01). Including previous values of the mass excess, the adopted mass excess of ^{6}He is 17594.0 ± 1.1 keV.

1. ^{6}He(β^{-})^{6}Li $\qquad Q_{\mathrm{m}} = 3.507$

Table 6.1: Energy levels of ^{6}He

E_x (MeV $\pm$ keV)	$J^\pi; T$	$\tau_{1/2}$ or $\Gamma_{c.m.}$	Decay	Reactions
g.s.	$0^+; 1$	$\tau_{1/2} = 808.1 \pm 2.0$ msec	β^-	1, 4, 5, 6, 7, 9, 10, 12, 13, 14, 15, 18, 20
1.797 ± 25	$(2)^+; 1$	$\Gamma = 113 \pm 20$ keV	n, α	4, 5, 7, 10, 12, 13, 14, 15, 18, 20
(13.6 ± 500)		broad		12, 13
(15.5 ± 400)		broad	γ	5, 12, 13
(23.2 ± 700)		broad	γ	5, 12

The decay proceeds to the ground state of ^{6}Li($J^\pi = 1^+$) and is a super-allowed Gamow-Teller transition. The half-life is 808.1 ± 2.0 msec (1974WI14): see Table 6.2 in (1966LA04) for a listing of earlier determinations. Using Q_m and this $\tau_{1/2}$, $\log ft = 2.910 \pm 0.002$: see (1974WI14, 1978RO01).

The internal bremsstrahlung spectrum has been measured by (1965BI09). The electron-neutrino correlation results are in good agreement with pure axial vector interaction. An upper limit to the possible admixture of tensor interaction is 0.4% (1963JO15). See also (1974AJ01, 1978CA1H) and (1974KU06, 1974VE02, 1975BE42, 1975CA35, 1975DO05, 1975KR14, 1976BE1E, 1976KU07, 1976WA02, 1977AZ02, 1977KL09, 1977SA1G, 1977TE1B, 1977WA1F, 1978PA02; theor.).

2. (a) ^{3}H(t, n)^{5}He $\quad Q_m = 10.44 \quad E_b = 12.305$

(b) ^{3}H(t, 2n)^{4}He $\quad Q_m = 11.3321$

(c) ^{3}H(t, d)^{4}H $\quad Q_m = -9.2$

(d) ^{3}H(t, 3n)^{3}He $\quad Q_m = -9.2457$

The cross section for neutron production (reactions (a) and (b)) rises monotonically from 40 keV to 2.2 MeV: see (1974AJ01). The zero-energy cross section factor $S_0 \approx 300$ keV $\cdot$ b (1964PA1A). At $E_t = 1.90$ MeV, the total cross section for production of α-particles is 106 ± 5 mb (1958JA06). The cross section for reaction (b) increases monotonically for $E_t = 34$ to 160 keV (1977SE11). For a review of a_{nn} determinations see (1972KU08). See also (1974LA02). (1977BA23) find that the cross section for the reaction ^{3}H(t, d)^{4}He + e^{-} + $\overline{\nu}$ is $\leq$ 0.3 nb/sr at $E_t = 1.4$ MeV: see also reaction 1 in ^{6}Be. For the earlier work on these reactions see (1974AJ01). See also (1975KU1C), (1975FO19; astrophysical questions) and (1974DE18, 1974NE1B; theor.).

3. ^{3}H(t, t)^{3}H $\quad E_b = 12.305$

Differential cross sections have been measured for $E_t = 1.58$ to 2.01 MeV: see (1974AJ01). See also (1975AB1C; theor.).

4. ^{4}He(t, p)^{6}He $\qquad Q_m = -7.509$

At $E_t = 22$ (1971ST05) and 23 MeV (1978AJ02), angular distributions of the protons to ^{6}He*(0, 1.80) have been measured. No other states are observed with $E_x \lesssim 4.2$ MeV (1971ST05). See also (1974LA1A).

5. ^{6}Li(π^-, γ)^{6}He $\qquad Q_m = 13.060$

The excitation of ^{6}He*(0, 1.8) and possibly of (broad) states at $E_x = 15.6 \pm 0.5$, 23.2 ± 0.7 and 29.7 ± 1.3 MeV is reported by (1973BA62) from E_γ measurements using a pair spectrometer. (4.4 ± 0.6)% of stopped pions were absorbed radiatively: the branching ratios of ^{6}He*(0, 1.8) are (0.31 ± 0.04)% and (0.15 ± 0.03)% respectively (1973BA62). (1978RE05) find (0.34 ± 0.03)% and (0.11 ± 0.01)%, respectively.

6. ^{6}Li(n, p)^{6}He $\qquad Q_m = -2.725$

Angular distributions have been measured at $E_p = 4.71$, 5.24 and 6.77 MeV (1977RO01: p_0). At $E_n = 14$ MeV the p_0 angular distribution is similar in shape to the angular distributions in ^{6}Li(p, p′)^{6}Li*(3.56) and in ^{6}Li(p, n)^{6}Be$_{g.s.}$. The ratios of the cross sections for these isobaric analog transitions are consistent with charge independence (1972ME05). For measurements at 800 MeV see (1977RI07). See also (1976KI1D, 1976MI1C), (1976SL2A) and ^{7}Li.

7. ^{6}Li(t, ^{3}He)^{6}He $\qquad Q_m = -3.489$

The ground state angular distribution has been studied at $E_t = 17$ MeV. The weighted average of the experimental ratio of the differential cross sections at twelve angles ($\theta_{c.m.} \approx 28° \rightarrow 72°$) for population of ^{6}He$_{g.s.}$ to that for population of the analog state, ^{6}Li*(3.56), reached in the (t, t′) reaction [see ^{6}Li] is 2.28 ± 0.16, rather than 2 as predicted by geometrical isospin considerations. Corrections based on a microscopic DWBA calculation of charge exchange and inelastic scattering do not appear to account for the difference (1976SH14). At $E_t = 22$ MeV only ^{6}He*(0, 1.80) are populated with $E_x \lesssim 8.5$ MeV (1971ST05).

8. ^{6}Li(^{3}He, 3p)^{6}He $\qquad Q_m = -10.442$

See (1970BA41; $E(^3\text{He}) = 53.2$ MeV).

9. ^{6}Li(^{6}Li, ^{6}Be)^{6}He $\qquad Q_m = -7.795$

Angular distributions have been studied at $E(^6\text{Li}) = 32$ and 36 MeV for the reactions involving the ground states of ^{6}He and ^{6}Be and for the inelastic scattering of ^{6}Li to ^{6}Li*(3.56) [see reaction 18 in ^{6}Li]: these three states in ^{6}He, ^{6}Li and ^{6}Be are analog states. At 32 MeV the ratios of the differential cross sections for populating ^{6}Li*(3.56) to those for populating $^6\text{He}_{\text{g.s.}}$ varies with angle from 0.17 to more than 1.65. These variations indicate that charge dependent effects are important and that additional analysis would require a better knowledge of the wave functions of these isospin multiplet states than is currently available (1974WH01, 1974WH02, 1974WH07, 1975WH01).

10. ^{7}Li(γ, p)^{6}He $\qquad Q_m = -9.976$

At $E_\gamma = 60$ MeV, the proton spectrum shows two prominant peaks attributed to ^{6}He*($0 + 1.8$, 18 ± 3) (1973GA16, 1976MA34). (1974DE52) using bremsstrahlung radiation ($E_{\text{bs}} \leq 28$ MeV) suggest states at $E_x = 2.5$ and 8.5 MeV in ^{6}He, in addition to ^{6}He*(0, 1.8). See also (1975MA1E).

11. ^{7}Li(e, ep)^{6}He $\qquad Q_m = -9.976$

See ^{7}Li.

12. ^{7}Li(n, d)^{6}He $\qquad Q_m = -7.751$

At $E_\gamma = 60$ MeV, the proton spectrum shows two prominant peaks attributed to centered at $E_x = 13.6$, 15.4 and 17.7 MeV (± 0.5 MeV) and a possible state or states (populated with an l-transfer ≥ 2) at $E_x = 23.7$ MeV. DWBA analyses of the d_0 and d_1 groups lead to $S(1p_{3/2}) = 0.62$ for $^6\text{He}_{\text{g.s.}}$ and to $S(1p_{3/2}) = 0.37$ and $S(1p_{1/2}) = 0.32$ for ^{6}He*(1.8) (1977BR17). See (1974AJ01) for earlier measurements.

13. ^{7}Li(p, 2p)^{6}He $\qquad Q_m = -9.976$

The summed proton spectrum at $E_p = 100$ MeV shows ^{6}He*(0, 1.8) and a broad group centered at $E_x \approx 14$ MeV: the angular correlation for $^6He_{g.s.}$ is in quite good agreement with DWIA (1976BH02). In a lower resolution experiment (1967RO06) suggest states at $E_x = (13.4 \pm 0.5)$ MeV [$\Gamma = 1.2$ MeV] and (15.3 ± 0.3) MeV [partially resolved]. See also (1966LA04).

14. ^{7}Li(d, ^{3}He)^{6}He $\qquad Q_m = -4.482$

On the basis of a very accurate measurement of the Q-value of this reaction (1978RO01) find the atomic mass excess of ^{6}He $= 17593.7 \pm 1.1$ keV. The weighted average of this value and of the previous determinations leads to 17594.0 ± 1.1 keV (1978RO01) which we adopt and use in calculating Q_m.

Angular distributions of the ^{3}He ions to ^{6}He*(0, 1.80) have been measured at $E_d = 14.4$ and 22 MeV: they are consistent with $l = 1$ and therefore with $J^\pi = 0^+$, 2^+ for these two states: see (1974AJ01). There is no evidence for any other states of ^{6}He with $E_x < 10.7$ MeV (1971ST05). See also (1974DI1A, 1975DI1B) and reaction 28 in ^{6}Li.

15. ^{7}Li(t, α)^{6}He $\qquad Q_m = 9.838$

The energy of the first excited state is 1.797 ± 0.025 MeV, $\Gamma = 113 \pm 20$ keV (1965AJ01). ^{6}He*(1.80) decays into ^{4}He+2n. The branching ratio Γ_γ/Γ_n is $< 4 \times 10^{-4}$ (1964HU1A), $\Gamma_\gamma/\Gamma_\alpha \leq 2 \times 10^{-6}$ (1966LI1A). Angular distributions of the α_0 and α_1 groups have been measured at $E_t = 13$ and 22 MeV: they are consistent with $l = 1$ pickup and therefore with $J^\pi = 0^+$, 2^+ for ^{6}He*(0, 1.80): see (1974AJ01). No other α-groups are reported corresponding to ^{6}He states with $E_x < 12$ MeV (1965AJ01), $E_x < 24$ MeV (1971ST05: $E_t = 16 \rightarrow 22$ MeV; region between $E_x \approx 13$ and 16 MeV was obscured by presence of breakup α-particles). See also (1975KO1B).

16. ^{7}Li(^{3}He, ^{4}Li)^{6}He $\qquad Q_m = -12.9$

See (1970BA41: $E(^3\text{He}) = 53.2$ MeV). See also (1976WA12).

17. ^{7}Li(^{7}Li, ^{8}Be)^{6}He $\qquad Q_m = 7.281$

See (1968ST12).

18. ^{9}Be(n, α)^{6}He $\qquad Q_m = -0.600$

Angular distributions have been measured at $E_n = 12.2$, 14.1 and 18.0 MeV (1976SM02: α_0, α_1), 13.99 MeV (1974PE06: α_0, α_1) and at 14.4 MeV (1967PA03: α_0). No other states are observed below $E_x \approx 7$ MeV (1974PE06). See also ^{10}Be.

19. ^{9}Be(p, ^{4}Li)^{6}He $\quad Q_m = -24.1$

See (1970DE17).

20. ^{9}Be(t, ^{6}Li)^{6}He $\quad Q_m = -5.383$

At $E_t = 21.5$ and 23.5 MeV, angular distributions have been studied for the transitions to ^{6}He*(0, 1.80) and ^{6}Li*(0, 2.19, 3.56) (1973VO08, 1976VO1A): see discussion in reaction 32 in ^{6}Li. See also (1974CA04, 1975BR1E; theor.).

21. ^{9}Be(^{7}Li, ^{10}B)^{6}He $\quad Q_m = -3.390$

See (1977KE09) and ^{10}B.

22. (a) ^{10}B(^{7}Li, ^{6}He)^{11}C $\quad Q_m = -1.284$

(b) ^{11}B(^{7}Li, ^{6}He)^{12}C $\quad Q_m = 5.982$

See (1968ST12).

23. ^{18}O(^{6}Li, ^{18}F)^{6}He $\quad Q_m = -5.161$

See ^{18}F in (1978AJ03).

^{6}Li
(Figs. 5 and 7)

GENERAL: (See also (1974AJ01).)

Shell model: (1974KA11, 1975DI04, 1975GO1B, 1975VE01, 1976CE03, 1976GH1A).

Collective, rotational and deformed models: (1974BO25).

Cluster and α-particle models: (1972KR1A, 1973DO09, 1973LI23, 1974BA30, 1974GR24, 1974JA1K, 1974KA11, 1974NO03, 1974PA1B, 1974SH08, 1974WO1B, 1975BL1C, 1975GO08, 1975GR26, 1975HA48, 1975KR1A, 1975LE1A, 1975LI1C, 1975MI09, 1975NO03, 1975PA11, 1975RA32, 1975SH05, 1975TH1C, 1975VI08, 1976PL02, 1976RO02, 1976SC34, 1977BO35, 1977CH07, 1977SI10, 1977SM1A, 1977TA1C, 1978BO43, 1978DE1K, 1978HO1E, 1978IO1A, 1978LO1B, 1978OS1D).

Astrophysical questions: (1973TI1A, 1973TR1B, 1973WE1D, 1974AU1A, 1974CA1C, 1974JA11, 1974PA10, 1974RE1A, 1975BR1B, 1975ME1E, 1975TR1A, 1976AU1B, 1976AU1C, 1976BE1C, 1976CL1A, 1976CO1B, 1976EP1A, 1976GI1C, 1976HA1F, 1976SI1C, 1976VI1A, 1977CA1B, 1977MA1H, 1977MO1D, 1977MO1E, 1977SC1D, 1977WE1D, 1978AU1C, 1978DW1A).

Electromagnetic transitions: (1973WE18, 1974HA1C, 1974KU06, 1974MU13, 1974NO03, 1974VE02, 1974VE10, 1974YA01, 1975VE01, 1976KU07, 1977DO06, 1978KI08).

Special levels: (1974DZ07, 1974IR04, 1974KA11, 1974KU06, 1975DI04, 1975DO05, 1975LI20, 1975LO1D, 1975SH01, 1976IR1B, 1976PR07, 1977FA09, 1978FA1C, 1978HO1E).

Applied work: (1975GE1C, 1977BR1H, 1977MO1B, 1978KA1E).

Special reactions: (1973SI38, 1974BA70, 1974BO08, 1974JA11, 1974LA18, 1974PA10, 1974QU01, 1974TI02, 1975BA1G, 1975EC02, 1975KU01, 1975RA14, 1975RA21, 1975ZE01, 1976BE67, 1976BO08, 1976BU16, 1976CR1A, 1976LE1F, 1976LO03, 1976MI13, 1976NA11, 1976OS04, 1976RA1C, 1976RO12, 1977AU1B, 1977BO21, 1977CA22, 1977FE1B, 1977GI08, 1977MO1C, 1977PA27, 1977RE08, 1977RO23, 1977SH1D, 1977ST34, 1977YA1B, 1978BI08, 1978CA15, 1978DI04, 1978FL03, 1978GE1C, 1978GE04, 1978GR1F, 1978LA1F, 1978OT1A).

Muon and neutrino capture and reactions: (1973MU1B, 1974CA04, 1974DO1C, 1974EN10, 1974WA1C, 1974WI01, 1975BE42, 1975CH22, 1975DO1F, 1975FE1B, 1976WA02, 1977BA1P, 1977BA1R, 1977CA1C, 1977MU1A, 1977PR1B, 1977WA1F, 1977WA1G, 1978DE15, 1978HW01, 1978LE04, 1978MI1C).

Pion and kaon and other meson capture and reactions: (1972BA1C, 1973AL1A, 1973AR1B, 1973BA1G, 1973BA1E, 1973BA30, 1973NA20, 1973RO1F, 1973WI1A, 1974AM01, 1974CA24, 1974CL04, 1974DE1C, 1974GO04, 1974HU14, 1974JA1K, 1974KO27, 1974NO03, 1974TA18, 1974VE02, 1975AR02, 1975BA1L, 1975BE1G, 1975BR1D, 1975BU1A, 1975CA32, 1975DE1D, 1975MO22, 1975PN1A, 1975SA01, 1975TA1C, 1975VE05, 1975YA02, 1976AL1F, 1976AS1B,

1976BA1G, 1976BO32, 1976CA20, 1976DU1B, 1976DY1B, 1976HU1C, 1976HU1A, 1976LE1H, 1976LE1G, 1976LI26, 1976PI1B, 1976RO14, 1976TR1A, 1976TZ1A, 1977AB09, 1977AL1C, 1977AL1D, 1977AM1A, 1977AR1C, 1977AU02, 1977BA1Q, 1977BE1L, 1977BO1E, 1977BU25, 1977CO1E, 1977DO06, 1977HA1K, 1977HO1B, 1977MA35, 1977NA08, 1977RA1A, 1977SH1C, 1977SI03, 1977SI10, 1977TE1A, 1977VE05, 1977WA1H, 1978EI1A, 1978KA1C, 1978KI08, 1978MO01, 1978OT1A, 1978RE05, 1978WI1E).

Table 6.2: Energy levels of ^{6}Li

E_x (MeV $\pm$ keV)	$J^\pi; T$	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
g.s.	$1^+; 0$		stable	1, 2, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54
2.185 ± 3	$3^+; 0$	26	γ, d, α	1, 2, 5, 6, 11, 12, 13, 14, 16, 17, 22, 25, 27, 29, 31, 32, 36, 37, 38, 45, 47
3.56289 ± 0.10	$0^+; 1$	< 5	γ	6, 9, 11, 13, 15, 16, 18, 27, 28, 29, 31, 32, 53
4.31 ± 30	$2^+; 0$	1700 ± 200 [a]	γ, d, α	1, 5, 11, 13, 14, 16, 27
5.366 ± 15	$2^+; 1$	540 ± 20	γ	1, 11, 13, 16, 27, 28, 29, 31, 41
5.65 ± 50	$1^+; 0$	1000^{+600}_{-400}	d, α	5, 13
21.0	$2^-; 1$	broad	t, ^{3}He	1
21.5	$0^-; 1$	broad	t, ^{3}He	1
25.0 ± 1000	$4^-; 1$	≈ 4000	γ, n, t, ^{3}He	1
26.6 ± 400	$3^-; 0$	broad	γ, n, t, ^{3}He	1
(31)	(3^+)	broad	d, t, ^{3}He, α	1

[a] See, however, Tables 6.4 and 6.5.

Anti-proton interactions: (1977WE1E).

Other topics: (1973DZ1A, 1974DZ07, 1974IR04, 1974KU06, 1974MU13, 1974RE1B, 1974SE1B, 1975BL1C, 1975DO05, 1975ER09, 1975GO1B, 1975GO08, 1975HE09, 1975KU01, 1975KU08,

1975LI1C, 1975LI20, 1975LO1B, 1975NO03, 1975RA32, 1975SH01, 1976GH1A, 1976IR1B, 1976MA04, 1976MI1B, 1976MI1E, 1976PR07, 1977BL1B, 1977BU1D, 1977FA09, 1978DE1K, 1978FA1C, 1978FR1E, 1978JE1B, 1978LE05, 1978PA02).

Ground state properties: (1974BL1B, 1974DE1E, 1974DZ07, 1974KU06, 1974MU13, 1974PA1B, 1974SHYR, 1974VE02, 1974WO1B, 1974YA01, 1975BE31, 1975CA32, 1975DO05, 1975GO04, 1975JO1A, 1975RA32, 1976FU06, 1976GH1A, 1976RO02, 1977AN21, 1977BO35, 1977BU09, 1977DU01, 1977FA09, 1977MA35, 1978AN07, 1978BO43, 1978FA1C, 1978LE05, 1978ZA1D).

$$\mu = 0.8220467\ (6)\ \text{nm (1974BE50)},$$

$$Q = -0.644\ (7)\ \text{mb (V. Shirley, private communication)}.$$

1. (a) ^{3}He(^{3}H, γ)^{6}Li	$Q_m = 15.7940$	$E_b = 15.7940$
(b) ^{3}He(^{3}H, p)^{5}He	$Q_m = 11.20$	
(c) ^{3}He(^{3}H, p)^{4}He + n	$Q_m = 12.0959$	
(d) ^{3}He(^{3}H, n)^{5}Li	$Q_m = 10.13$	
(e) ^{3}He(^{3}H, d)^{4}He	$Q_m = 14.3205$	
(f) ^{3}He(^{3}H, ^{3}H)^{3}He		
(g) ^{3}He(^{3}H, dn)^{3}He	$Q_m = -6.2573$	
(h) ^{3}He(^{3}H, p2n)^{3}He	$Q_m = -8.4820$	
(i) ^{3}He(^{3}H, 2d)^{2}H	$Q_m = -9.5263$	
(j) ^{3}He(^{3}H, pd)^{3}H	$Q_m = -5.4936$	

Capture γ-rays (reaction (a)) to the first three states of ^{6}Li [γ_0, γ_1, γ_2] have been observed for E(^{3}He) $= 0.5$ to 25.8 MeV, while the yields of γ_3 and γ_4 have been measured for E(^{3}He) $= 12.6$ to 25.8 MeV: see (1974AJ01). The γ_2 excitation function does not show resonance structure. However, the γ_0, γ_1, γ_3 and γ_4 yields do show broad maxima at E(^{3}He) $= 5.0 \pm 0.4$ [γ_0, γ_1], 20.6 ± 0.4 [γ_1], ≈ 21 [γ_3] and 21.8 ± 0.8 [γ_4] MeV. The magnitude of the ground state capture cross section is well accounted for by a direct capture model; that for the γ_1 capture indicates a non-direct contribution above E(^{3}He) $= 10$ MeV, interpreted as a resonance due to a state with $E_x = 25 \pm 1$ MeV, $\Gamma_{c.m.} = 4$ MeV, $T = 1$ (because the transition is E1, to a $T = 0$ final state) [the E1 radiative width $|M|^2 \gtrsim 5.2/(2J+1)$ W.u.], $J^\pi = (2, 3, 4)^-$, α + p + n parentage (1973VE09, 1973VE1B). The γ_4 resonance is interpreted as being due to a broad state at $E_x = 26.6$ MeV with $T = 0$. $J^\pi = 3^-$ is consistent with the measured angular distribution (1973VE1B). The ground and first excited state reduced widths for ^{3}He + t parentage, $\theta_0^2 = 0.8 \pm 0.2$ and $\theta_1^2 = 0.6 \pm 0.3$ (1971VE10, 1973VE09, 1973VE1B).

Elastic scattering (reaction (f)) angular distributions have been measured at $E(^3\text{He}) = 5.00$ to 32.3 MeV and excitation functions have been reported for $E(^3\text{He}) = 4.3$ to 33.4 MeV: see (1974AJ01) and (1977VL01). At the lower energies the elastic yield is stuctureless and decreases monotonically with energy (1968IV01). Polarization measurements are reported for $E_{\vec{t}} = 9.02$ to 17.02 MeV (1977HA17) and $E(^3\text{He}) = 19.9 \rightarrow 33.3$ MeV (1977KA10, 1977VL01). A strong change occurs in the analyzing power angular distributions at $E_{\vec{t}} = 15$ MeV (1977HA17). A phase-shift analysis by (1977VL01) [single level R-matrix formalism, $L \leq 4$] yields P-states [0^-, 2^-; $T = 1$] at $E_x \approx 21.5$ and 21.0 MeV and F-states [3^-, 4^-; $T = 1$] at $E_x \approx 26.7$ and 25.7 MeV. There is some indication also of $T = 0$, 3^-, 5^- and 3^+ states at $E_x \approx 25$, 29.5 and 31.5 MeV whose decay is presumably primarily by $\text{d} + \alpha$ (1977VL01).

For reactions (b) and (c) see ^{5}He and ^{5}Li and (1966LA04, 1974AJ01). See also (1975SC1F). The angular distribution and polarization of the neutrons in reaction (d) have been measured at $E(^3\text{He}) = 2.70$ and 3.55 MeV. The excitation function for $E(^3\text{He}) = 0.7$ to 3.8 MeV decreases monotonically with energy (1971KL04). The excitation function for n_0 has been measured for $E(^3\text{He}) = 2$ to 6 MeV (1975AB11) and for $E(^3\text{He}) = 14$ to 26 MeV (1974CH15: $\theta = 20°$); evidence for a broad structure at $E(^3\text{He}) = 20.5 \pm 0.8$ MeV is reported [^{6}Li*(26.1)]. Since reaction (d) is not restricted to $T = 0$ or $T = 1$ the structure could correspond to both ^{6}Li*(25.0, 26.6) (1974CH15). See (1973NO07) for suggestions of ^{6}Li states at≈ 16.2 and ≈ 17 MeV.

Angular distributions of deuterons (reaction (e)) have been measured for $E_t = 1.04$ to 3.27 MeV and at $E(^3\text{He}) = 0.29$ to 0.80 MeV: see (1974AJ01). Recent measurements are reported at $E(^3\text{He}) = 4.25$ to 9.85 MeV (1975SC1F) and 32 MeV (1974RO01). (1977HA42) have studied the polarization in this reaction at $E_{\vec{t}} = 9.02$, 12.86 and 17.02 MeV and report an excitation function at $\theta_{\text{c.m.}} = 90°$ for $E_t = 9.02$ to 17.27 MeV. The angular distributions show marked deviations from the antisymmetric shape predicted by a simple particle-transfer model incorporating charge symmetry (1977HA42). An excitation curve for $E(^3\text{He}) = 17$ to 33 MeV shows resonant behavior at about $E_x = 31$ MeV, corresponding to the 3^+, $T = 0$ state suggested in the elastic scattering (1978EN1A; prelim.).

For reaction (c) see (1972KU08, 1975SC1F). For reactions (c), (i) and (j) see (1973SL03, 1974AL01). See also (1974RE1C), (1975FO19; astronomical considerations), (1974LO1B, 1974SL04, 1976CO1E, 1976HA1C) and (1973KO14, 1973SL1C, 1974BR30, 1975KU09, 1975SH1B, 1975TA1A, 1977KA1D, 1977KA1G, 1978FE1C; theor.).

2. ^{3}H(α, n)^{6}Li $\qquad Q_m = -4.7839$

Neutron groups corresponding to ^{6}Li*(0, 2.19) have been detected: see ^{7}Li (1967SP10). See also ^{7}Li.

3. ^{4}He(d, γ)^{6}Li $\qquad Q_m = 1.4735$

Searches for γ-rays from resonant capture by ^{6}Li*(3.56) [$J^\pi = 0^+$; $T = 1$] have been unsuccessful: the upper limit for its parity-forbidden heavy particle width, $\Gamma_{d\alpha}$, is 1.7×10^{-2} eV (1975BA06), 8×10^{-4} eV (1975BE44). The radiative capture has been observed at seven energies in the range $E_\alpha = 5.4$ to 25 MeV (1978RO1E; prelim.). See also (1974AJ01, 1977BI1D).

4. (a) ^{4}He(d, n)^{5}Li	$Q_m = -4.19$	$E_b = 1.4735$
(b) ^{4}He(d, p)^{5}He	$Q_m = -3.12$	
(c) ^{4}He(d, np)^{4}He	$Q_m = -2.2246$	
(d) ^{4}He(d, t)^{3}He	$Q_m = -14.3205$	
(e) ^{4}He(d, d)p + ^{3}H	$Q_m = -19.8140$	
(f) ^{4}He(d, d)^{2}H^{2}H	$Q_m = -23.8467$	

The proton yield gives no evidence of states in ^{6}Li with $6.5 < E_x < 8.7$ MeV (1964OH01). Polarization measurements at $E_d = 8.5$, 10 and 11 MeV (1971KE16) indicate scattering through the first two states of ^{5}He. See also ^{5}He and ^{5}Li and (1974AJ01).

Reaction (c) has been studied at $E_d = 8.9$ MeV (1977SA21) to determine the n-α FSI [see ^{5}He]; at $E_\alpha = 14.99$ MeV (1977KO18) to determine the n-p FSI and the sequential decay via states of ^{6}Li; and at $E_{\vec{d}} = 6.78$ MeV (1977NO1C), 8.7, 11.4 and 14.4 MeV (1975WA1G, 1976LI1V; $\vec{n}$), and 15 MeV (1978NA08), $E_\alpha = 18$ MeV (1976SA29, 1978SA07), 27.2 MeV (1977KO42), 39.4 MeV (1975KN02) and 100 MeV (1977LE18) and $E_d = 50$ MeV (1977LE18) for polarization and angular distribution measurements, most analyzed by the modified impulse approximation (MIA). (1976SA29) report destructive interference between the MIA matrix elements and the n-p FSI for $E_{np} \lesssim 0.6$ MeV. For other measurements to $E_\alpha = 165$ MeV see ^{5}He, reaction 5(b) in (1974AJ01) and (1977FO07).

Studies of the t and ^{3}He differential cross sections (reaction (d)) at $E_d = 45.8$ MeV (1974RO01), $E_\alpha = 48.3$ MeV (1971WA20), 49.9, 64.3 and 82.1 MeV (1970GR07, 1972GR07) and 166 MeV (1974BA09), and of the vector analyzing power at $E_{\vec{d}} = 32.41$ MeV (1976DA1C), show pronounced deviations from $90^\circ_{\text{c.m.}}$ symmetry which are angle and energy dependent [the asymmetry is appreciably less at 166 MeV (1974BA09)]. These deviations appear to be reproduced by (1974WE13) who used an exact finite-range multi-interaction DWBA analysis which includes all appropriate one-particle transfer reaction mechanisms, and Coulomb and other effects. See also (1974BA09).

For reactions (d) and (e) see (1972LI04). See also (1978MC1D), (1977MO1E; astrophys.), (1972CH1B, 1974NA10, 1975HE1D, 1976HA1C, 1976NA12, 1976SC34, 1977CL1A, 1977CO1B, 1977OS06, 1977OS1B, 1978KO13; theor.).

5. ^{4}He(d, d)^{4}He $\qquad E_b = 1.4735$

Table 6.3: Levels of ^{6}Li from ^{4}He(d, d)^{4}He [a]

E_d (MeV)	1.070 ± 0.003 [b]	4.8 ± 0.1 [c]	6.26 ± 0.05 [d]
$J^\pi; T$	$3^+; 0$	$2^+; 0$	$1^+; 0$
E_x (MeV)	2.185	4.7	5.65
reduced elastic width:			
γ_λ^2, $l = 0$			0.005
γ_λ^2, $l = 2$	0.80	1.6	2.5
reduced width for proton emission:			
γ_λ^2, $l = 1$		1.3	0.8
reduced width for neutron emission:			
γ_λ^2, $l = 1$		1.3	0.8
interaction radius a (fm)	3.5	4.2	4.12

[a] See also Table 6.4 in (1974AJ01).

[b] (1955GA74).

[c] (1972SC14).

[d] (1977HA34); error in E_d is estimated.

Elastic scattering differential cross-section measurements have been carried out at many energies up to $E_\alpha = 166$ MeV: see (1974AJ01). Recent measurements are those of (1978KA11) at $E_d = 7.8$ MeV and (1974WI13) at $E_d = 29.8$, 32.3, 34.8, 37.3 and 39.8 MeV. See also (1974CH1G). Polarization measurements have been carried out for E_d to 45 MeV [see listing in Table 6.3 of (1974AJ01)] and at $E_{\overrightarrow{d}} = 2.38$ to 13.60 MeV (1976SC15), 4 to 5 and 10 to 12.5 MeV (1975GR09, 1975GR10), 6.04 to 7.05 MeV (1977HA34), 2 to 17 MeV (1978BR1F), 15 to 44.9 MeV (1976CO1D, 1976CO1H, 1976ST1D; preliminary results) and 30.6 MeV (1976HE1D; prelim.). See also (1977SE1C, 1978SE01).

Phase shift analyses have been carried out for $E_d = 0.3$ to 27 MeV: see (1974AJ01) and for $E_d = 3$ to 17 MeV by (1975GR09, 1975GR10) [using all available differential cross-section, vector and tensor analyzing power measurements, and $L \geq 4$] and in the vicinity of the $1^+; T = 0$ state ^{6}Li*(5.65) by (1977HA34) [R-matrix analysis: see Table 6.3]. On the basis of these analyses it is found that the d-wave shifts are split and exhibit resonances at $E_x = 2.19$ ($^3D_3$), 4.7 ($^3D_2$) and 5.65 MeV ($^3D_1$): see Table 6.3. The P-wave phase shifts remain small below $E_d = 17$ MeV,a s do the F and G phase shifts (1975GR09, 1975GR10; see also for contour plots of analyzing power) [see, however, (1978BR1F)]. See also (1974DO1D).

The breakup of ^{6}Li with $E = 22.2$ and 23.0 MeV in the bombardment of ^{118}Sn and ^{208}Pb proceeds primarily by the sequential decay via ^{6}Li*(2.19) $\rightarrow \alpha + d$ (1977SC25). Total cross sections are reported at $E = 0.87$ and 2.1 GeV/nucleon by (1975JA1A). See also (1975CA1D, 1978FI1E) and (1973KO14, 1974BL1B, 1974HA21, 1974HE21, 1974TH05, 1975AB1C, 1975BA76, 1975DU09, 1975HA1E, 1975KU09, 1975LI1C, 1975PL1B, 1975TA1A, 1975WI1C, 1976BA1E, 1976CH1C, 1976HA1C, 1976KO21, 1976LE17, 1977CH07, 1977CO1B, 1977EL1B, 1977FL13, 1977FR12, 1978KA1F; theor.).

6. (a) ^{4}He(^{3}He, p)^{6}Li $\qquad Q_{\rm m} = -4.0201$
(b) ^{4}He(^{3}He, n2p)^{4}He $\qquad Q_{\rm m} = -7.7182$

Angular distributions have been measured at $E(^3\text{He}) = 8$ to 18 MeV and $E_\alpha = 42$, 71.7 and 81.4 MeV: see (1974AJ01). At $E_\alpha = 28$, 63.7, 71.7 and 81.4 MeV the α-spectra show that the sequential decay (reaction (b)) involves ^{6}Li*(2.19) and possibly ^{5}Li (1973HA50, 1977KO09). See also ^{7}Be.

7. ^{4}He(α, d)^{6}Li $\qquad Q_{\rm m} = -22.3733$

See (1977KI12; $E_\alpha = 46.7$ to 49.5 MeV) and (1975MA1G; $E_\alpha = 140$ MeV). See also (1974KO1C; astrophys.) and ^{8}Be.

8. ^{6}He(β^-)^{6}Li $\qquad Q_{\rm m} = 3.507$

See ^{6}He.

9. ^{6}Li(γ, γ)^{6}Li

The width, Γ_γ, of ^{6}Li*(3.56) $= 8.1 \pm 0.5$ eV (1969RA20): see Table 6.4; $E_{\rm x} = 3569.0 \pm 1.7$ keV (1977WE1C), 3562.89 ± 0.10 keV (R.G.H. Robertson and J.A. Nolen, private communication).

10. (a) ^{6}Li(γ, n)^{5}Li $\qquad Q_{\rm m} = -5.66$
(b) ^{6}Li(γ, p)^{5}He $\qquad Q_{\rm m} = -4.59$
(c) ^{6}Li(γ, d)^{4}He $\qquad Q_{\rm m} = -1.4735$
(d) ^{6}Li(γ, t)^{3}He $\qquad Q_{\rm m} = -15.7940$
(e) ^{6}Li(γ, pd)^{3}H $\qquad Q_{\rm m} = -21.2875$
(f) ^{6}Li(γ, nd)^{3}He $\qquad Q_{\rm m} = -22.0513$
(g) ^{6}Li(γ, π^+)^{6}He $\qquad Q_{\rm m} = -143.074$

Table 6.4: Levels of ^{6}Li from ^{6}Li(e, e′) and ^{6}Li(γ, γ') [a]

E_x (MeV)	$J^\pi; T$	Γ_{γ_0} (eV)	Multipolarity	Refs.
2.183 ± 0.009 [b]	$3^+; 0$	$(4.40 \pm 0.34) \times 10^{-4}$	E2	(1969EI06)
3.563 ± 0.010	$0^+; 1$	8.31 ± 0.36	M1	(1969EI06)
		8.1 ± 0.5 [c]	M1	(1969RA20)
		8.16 ± 0.19	M1	(1975BE42)
4.27 ± 0.04	$2^+; 0$	$(5.4 \pm 2.8) \times 10^{-3}$	E2	(1969EI06) [d]
5.37 [e]	$2^+; 1$	0.19 ± 0.04 [f]	M1	(1970HU09)

[a] See also Tables 6.5 in (1974AJ01) and 6.6 in (1966LA04).

[b] $B(\text{E2})\uparrow = 21.8 \pm 0.8\ e^2 \cdot \text{fm}^4$ (1974YE01).

[c] From (γ, γ').

[d] $\Gamma = 690 \pm 120$ keV.

[e] $E_x = 5.32 \pm 0.05$ MeV, $\Gamma = 330^{+120}_{-40}$ keV (1969HU05), $E_x = 5.38 \pm 0.02$ MeV, $\Gamma = 530 \pm 30$ keV (1970HU09), $E_x = 5.41 \pm 0.04$ MeV, $\Gamma = 540 \pm 30$ keV (1971NE03), $\Gamma = 440 \pm 100$ keV (1969EI06). The excitation of this state shows a transverse angular dependence (1969EI06).

[f] Probable value but 0.08 ± 0.04 eV cannot be excluded: see (1970HU09).

The (γ, n) and the (γ, xn) cross sections increase from threshold to a maximum at $E_\gamma \approx 12$ MeV then decrease to $E_\gamma = 32$ MeV without clear evidence of additional structure: see (1975BE1F, 1976BE1H).

The cross section for photoproton production (reaction (b)) is generally flat up to 90 MeV with a slight evidence of a hump at $E_\gamma \approx 16$ MeV (1970WO10). The spectra of photoprotons have been studied at $E_{\text{bs}} = 60$, 80 and 100 MeV; angular distributions of the highest energy protons were measured at $E_{\text{bs}} = 60$ MeV. The spectra show a broad asymmetric peak corresponding to the first two states of ^{5}He ($\sigma = 34.1 \pm 1.6\ \mu$b) and another broad peak centered at $E_x \approx 20$ MeV (1976MA34). The cross section for reaction (c) is $\lesssim 5\ \mu$b in the range $E_\gamma = 2.6$ to 17 MeV consistent with the expected inhibition of dipole absorption by isospin selection rules: see (1966LA04). See also (1976SK02).

The $90°$ differential cross section for reaction (d) decreases monotonically for $E_\gamma = 18$ to 70 MeV: reaction (d) contributes $\approx \frac{1}{3}$ of the total cross section for $^6\text{Li} + \gamma$, consistent with a $^3\text{H} + {}^3\text{He}$ cluster description of $^6\text{Li}_{\text{g.s.}}$ with $\theta^2 \approx 0.68$. The agreement with the inverse reaction, ^{3}H(^{3}He, γ) [see reaction 1] is good (1975SH05).

(1974DE1C, 1977AU02) have measured the yield of π^+ (reaction (g)) near threshold and up to 7.2 MeV above it: transitions are observed to ^{6}He*(0, 1.8). See also (1974GO04, AL77Z, 1977AR1C) and (1975BE42, 1976RA42; theor.).

For the earlier work on $^6\text{Li} + \gamma$, see (1974AJ01). See also (1974BU1A, 1975BE60, 1975BE1G, 1975DO05; reviews), (1975FO19; astrophys.) and (1973CI1A, 1974CL01, 1974GH03, 1974SH08,

1974YA01, 1975LO1D, 1975LO1C, 1975NO1A, 1977TA1C; theor.).

11. (a) ^{6}Li(e, e)^{6}Li
    (b) ^{6}Li(e, ep)^{5}He $\quad Q_m = -4.59$
    (c) ^{6}Li(e, ed)^{4}He $\quad Q_m = -1.4735$
    (d) ^{6}Li(e, eπ^+)^{6}He $\quad Q_m = -143.074$

Elastic scattering has been measured at $E_e = 85$ to 600 MeV [see (1974AJ01)] and at 82 to 292 MeV (1977BU09). The diffraction feature in F^2 indicates a lowering of the central charge density (1971LI10). A model independent analysis of the scattering yields $r_{rms} = 2.51 \pm 0.10$ fm (1972BU01).

Table 6.4 summarizes the results obtained in the inelastic scattering of electrons. Form factors have been measured for ^{6}Li*(2.19) (1974YE01; $E_e = 60$ MeV), (1976BE22; $E_e = 107.6$ MeV) and ^{6}Li*(3.56) (1975BE42; $E_e = 124.9$ MeV). Values at $E_e = 40.5$ and 50.5 MeV have also been obtained for ^{6}Li*(5.37) (1977FA02). See (1974AJ01) for the earlier work. (1975BE42) find that the 1p harmonic oscillator radial wave functions do not give a good description of the form factor for ^{6}Li*(3.56). The monopole breakup appears to be predominant near threshold but the influence of ^{6}Li*(4.31) [$J^\pi = 2^+$] becomes important a few MeV above threshold (1976BE22). The inelastic electron groups are superposed on a large quasi-continuous background: see (1974AJ01) and (1974WH05). A study of the scattering at $E_e = 2.5$ and 2.7 GeV finds that a shell model analysis including short range correlations fits the data when a correlation parameter $q_e \approx 250$ MeV/c is used (1974HE20).

Because of the astrophysical implications of a 0^+ state in ^{6}Be near the ^{3}He + ^{3}He binding energy, several attempts have been made to locate the analog state in ^{6}Li at $E_x \approx 15.2$ MeV. The results are negative: e.g., $\Gamma_\gamma < 3$ eV for the M1 width of the $0^+ \rightarrow 1^+$ transition to ^{6}Li$_{g.s.}$ (1973FA04). See also (1974AJ01). At $E_e = 700$ MeV the proton separation spectra (reaction (b)) are similar to those observed in (p, 2p) (1978NA05). See also (1973KU19, 1974HE17, 1975AN11). For reaction (c) see (1974GE10, 1974HE17, 1975GE12, 1976SK02, 1977TA1B). For π^+ production (reaction (d)) see (1977SH1C) and (1977TO20; theor.).

See also (1973BI1A, 1974DE1E, 1975FA1A) and (1973GA19, 1974BA30, 1974BE10, 1974GR24, 1974KU06, 1974ME24, 1974PE08, 1974TO08, 1974WA1C, 1975BA1H, 1975CA32, 1975DO1D, 1975GO30, 1975GR26, 1975JA1B, 1975JA1C, 1975ME27, 1975VI08, 1976BU1B, 1976DU05, 1976TO07, 1976WA02, 1977BR37, 1977KU12, 1977TO03, 1977WA1F, 1977WA1G, 1978BO24; theor.).

12. (a) ^{6}Li(n, n$'$)^{6}Li*
    (b) ^{6}Li(n, nd)^{4}He $\quad Q_m = -1.4735$

Angular distributions have been reported at $E_n = 1.0$ to 14.2 MeV (see (1974AJ01)), 2.3 and 2.8 MeV (1978KN1D; n_0) and at $E_n = 4.0$ to 7.5 MeV (1976KN1D, 1976LA1C; n_0), 7.5 to 14 MeV (1976BI1B, 1976VO1B, 1977HO1A; n_0, n_1) and 14.1 MeV (1974HY01; n_0, n_1). See also (1976KN1C, 1976MI1C, 1978LI1C). For reaction (b) see (1975AN1C) and (1978RI02; $E_n = 800$ MeV; the quasi-elastic and quasi-free yields of deuterons do not show special enhancement from $A^{1/3}$ systematics). See also ^{7}Li and (1978ST05; theor.).

13. (a) ^{6}Li(p, p)^{6}Li

(b) ^{6}Li(p, 2p)^{5}He	$Q_m = -4.59$
(c) ^{6}Li(p, pd)^{4}He	$Q_m = -1.4735$
(d) ^{6}Li(p, p^{3}H)^{3}He	$Q_m = -15.7940$
(e) ^{6}Li(p, pn)^{5}Li	$Q_m = -5.66$
(f) ^{6}Li(p, 2d)^{3}He	$Q_m = -19.8258$

Proton angular distributions have been measured at $E_p = 0.5$ to 600 MeV: see (1966LA04, 1974AJ01) for a listing of the references. Inelastic groups corresponding to excited states of ^{6}Li are displayed in Table 6.5 (1957BR12, 1965HA17, 1975VO04, 1977KI08).

Angular correlations of protons (reaction (b)) are discussed in reaction 14 of ^{5}He (1974BH03). See also (1974MI05, 1975VO04, 1976CO1G, 1977RO1E) and the earlier work described in reaction 12 of ^{6}Li in (1974AJ01).

Reaction (c) has been studied at $E_p = 9$ MeV to 1 GeV: see (1974AJ01) for the earlier work and (1975VO04; 11 MeV), (1976BO1B; $E_p = 28.5$ MeV, (1977BO35; $E_p = 39.8$ MeV), (1974DU10; 40 MeV), (1976RO02, 1977RO02; 100 MeV), (1975KI02; 590 MeV), (1978CH1H, 1978CH1K; 795 MeV) and (1976CO1G; 800 MeV). See also (1974BE46, 1975MI1A, 1978DE1J). At $E_p = 100$ MeV the agreement with DWIA is good: $S_\alpha = 0.58 \pm 0.02$ (1977RO02). A study of reaction (f) indicates dominance, at $E_p = 100$ MeV, of the direct quasi-free reaction process (p+$\alpha \rightarrow$ d+^{3}He): $S_\alpha = 0.52 \pm 0.03$ (1977CO07).

(1975VO04) have compared yields from reactions (b), (c) and (e): by comparing yields in the isospin allowed and forbidden (reaction (c)) channels, they set an upper limit of $\alpha^2 \leq 8 \times 10^{-3}$ for a possible $T = 0$ admixture in the $T = 1$ state, ^{6}Li*(5.37). Reaction (e), at $E_p = 47$ MeV, may proceed by sequential decay involving ^{6}Li*(21, 30) or states in ^{6}Be [see reaction 3 in ^{6}Be] (1977WA05). See also (1974MI05, 1977BO35). Reaction (d), studied at $E_p = 100$ MeV, and compared with the (p, pα) reaction indicates that the ^{3}He + t parentage of ^{6}Li is comparable with the α + d parentage: the quantitative estimates depend strongly on the wave functions used in the estimate (1976RO02). See also (1976CO1G) and (1974AJ01) for the earlier work.

See also ^{7}Be, (1976MO1B, 1977BR33, 1978FR1D), (1973TH1A, 1976SL2A, 1977CO1C, 1978CH1G) and (1973DO09, 1973LI23, 1974GO1G, 1974HA36, 1974JA1F, 1974PR1C, 1974PR10, 1974RA1D, 1974SA09, 1974ZH01, 1975CH1C, 1975HA48, 1975LE1A, 1975PR1A, 1975SA01, 1976GO1E, 1976GO04, 1976OH04, 1978BE1K, 1978KA1C, 1978WO13; theor.).

Table 6.5: Levels of ^{6}Li from ^{6}Li(p, p′), ^{6}Li(d, d′), ^{7}Li(d, t), ^{7}Li(^{3}He, α) and ^{9}Be(p, α) [a]

Reaction	Refs.	E_x (MeV $\pm$ keV)	$\Gamma_{c.m.}$ (keV)
(p, p′), (d, d′), (d, t)	(1957BR12)	2.188 ± 6	26.3
(^{3}He, α)	(1968CO07)	2.17 ± 20	
(p, p′), (p, α)	(1957BR12)	3.560 ± 6	< 5
(p, p′γ), (p, $\alpha\gamma$)	(1977KI08)	3.5629 ± 0.6	
(p, p′)	(1975VO04)	4.40 ± 0.12	1490 ± 150
(d, d′)	(1975BR21)	4.32 ± 0.04	1820 ± 110
(^{3}He, α)	(1975SC31)	4.3 ± 0.1	600 ± 100 [b]
(p, p′)	(1975VO04)	5.33 ± 0.08	560^{+340}_{-100}
(^{3}He, α)	(1968CO07)	5.34 ± 0.02	560 ± 40 [c,d]
(p, p′)	(1975VO04)	5.7	1000^{+600}_{-400} [d]

[a] See also Table 6.6 in (1974AJ01).

[b] See also Table 6.4.

[c] 600 ± 50 keV (1976DE30) [p, α].

[d] See also (1965HA17).

14. (a) ^{6}Li(d, d′)^{6}Li*

(b) ^{6}Li(d, pn)^{6}Li $\qquad Q_m = -2.2246$

(c) ^{6}Li(d, 2d)^{4}He $\qquad Q_m = -1.4735$

(d) ^{6}Li(d, αp)^{3}H $\qquad Q_m = 2.5592$

(e) ^{6}Li(d, αn)^{3}He $\qquad Q_m = 1.7954$

Angular distributions of deuterons have been measured at $E_d = 4.5$ to 19.6 MeV: see (1974AJ01), (1976AB11; $E_d = 4$ to 10 MeV; d$_0$) and (1978FU03; $E_d = 13.6$ MeV; d$_0$). The $T = 1$, 0^+ state, ^{6}Li*(3.56) is not appreciably populated. For a summary of the results on excited states see Table 6.5 (1957BR12, 1975BR21).

At $E_d = 21$ MeV reaction (b) shows spectral peaking (characteristic of $^{1}S_0$ for the pn system [$T = 1$]) when ^{6}Li*(3.56) is formed, in contrast with the much broader shape (characteristic of $^{3}S_1$) seen when ^{6}Li*(0, 2.19) are populated (1972BR03). A study of reaction (c) at $E_d = 52$ MeV shows that the α-clustering probability, $N_{\text{eff}} = 0.12^{+0.12}_{-0.06}$ if a Hankel function is used (1973HA31) [see this reference also for a discussion of other results on momentum distributions and α-clustering probability in ^{6}Li]. The α-particle and the deuteron clusters in ^{6}Li have essentially a relative orbital momentum of $l = 0$. The D-state probabilty of the ground state of ^{6}Li is $\approx$ 5% of the S-state (1973HA31). Quasifree scattering is an important process even for E_d = 6 to 11 MeV (1973MI20). Interference effects are evident in reaction (c) proceeding through ^{6}Li*(2.19, 4.31): this is due to the experiment being unable to determine whether the detected particle was emitted first or second in the sequential decay (1968LE15). Reactions (c) and (d) studied at E_d = 7.5 to 10.5 MeV indicate that the three-body breakup of ^{6}Li at these low energies is dominated by sequential decay processes (1974MI10, 1977MI13). See also (1977BR33, 1977FU1B, 1977TE1A, 1978FU03), (1975GR41, 1975RO1B) and (1972CH1B, 1973JA1B, 1974CH58, 1974WE1B, 1975GO27, 1975KO1A; theor.).

15. ^{6}Li(t, t′)^{6}Li*

At E_t = 17 MeV angular distributions have been measured for the tritons to ^{6}Li*(0, 3.56) (1976SH14): see also reaction 7 in ^{6}He.

16. (a) ^{6}Li(^{3}He, ^{3}He)^{6}Li

(b) ^{6}Li(^{3}He, t)^{3}He^{3}He $\qquad Q_m = -15.7940$

Angular distributions have been measured at $E(^3\text{He}) = 8$ to 217 MeV [see (1974AJ01)] and at 70 MeV (1975DA1A; abstract; d_0). Reaction (b) has been studied by (1977HA19) at 45 MeV. See also (1974AJ01), (1975GR41) and (1976VR01, 1978HA1H; theor.).

17. (a) ^{6}Li(α, α')^{6}Li*

(b) ^{6}Li(α, 2α)^{2}H $\qquad Q_m = -1.4735$

(c) ^{6}Li(α, αp)^{5}He $\qquad Q_m = -4.59$

Angular distributions (reaction (a)) have been measured at $E_\alpha = 3.0$ to 166 MeV [see (1974AJ01)] and at $E_\alpha = 34.8$, 39.8 and 45.0 MeV (1975BE11; α_0, α_1). In the range $E_\alpha = 12.5$ to 18.5 MeV the optical model gives good agreement with the elastic angular distributions when a target spin-orbit potential is included (1971BI12). At $E_\alpha = 104$ MeV the elastic angular distribution shows a pronounced diffraction pattern (1969HA14) while at 166 MeV there is some backward peaking in addition to a single strong forward peak (1972BA89).

Reaction (b) has been studied at E_α = 50.4, 59.0, 60.5, 70.3 and 79.6 MeV (1969PU01, 1971WA19) and at 700 MeV by (1975DO11). The low energy work, summarized in (1974AJ01), reported a width for the momentum distribution of α particles in ^{6}Li of 29 ± 2 MeV/c, and an effective number of α + d clusters for $^6\text{Li}_{\text{g.s.}}$, $N_{\text{eff}} = 0.08 \pm 0.04$ (1971WA19). On the other hand (1975DO11), using a width parameter of 60.5 MeV/c, find $N_{\text{eff}} = 1.05 \pm 0.12$, and suggest that the lower value reported by (1971WA19) arises from the low energies of the outgoing α-particles in that experiment and consequent nuclear distortions. For other measurements of reaction (b) [$E_\alpha = 23.6$ to 64.3 MeV] see (1974AJ01). See also (1974MA49) and ^{8}Be. For reaction (c) see (1978CA1E).

See also ^{10}B, (1975GR41, 1975RO1B, 1977BR33, 1978CH1G) and (1973LI23, 1974CL03, 1974GR43, 1974HA36, 1974JA27, 1974NO03, 1975BA43, 1975CL01, 1975GO27, 1975MI09, 1975VO1B, 1976AV05, 1976ME20, 1977BE1M, 1977TR1A, 1978JA1C, 1978SU1C; theor.).

18. ^{6}Li(^{6}Li, ^{6}Li)^{6}Li

Angular distributions of ^{6}Li ions have been studied for $E(^6\mathrm{Li}) = 3.2$ to 32 MeV [see (1974AJ01)] and at 32 and 36 MeV for the reaction in which both outgoing ions are excited to ^{6}Li*(3.56) (1974WH01, 1974WH02, 1975WH01). The ratios for populating ^{6}Li*(3.56) and $^6\mathrm{He}_{\mathrm{g.s.}} + {}^6\mathrm{Be}_{\mathrm{g.s.}}$ [the analog states] vary with angle: see reaction 9 in ^{6}He. See also ^{12}C in (1975AJ02), (1975NO1C, 1978NO08) and (1976OG1A).

19. ^{6}Li(^{9}Be, ^{9}Be)^{6}Li

The elastic scattering has been studied at $E(^6\mathrm{Li}) = 4.0$ and 6.0 MeV (1974VO06) and 24 MeV (1968DA20).

20. ^{6}Li(^{10}B, ^{10}B)^{6}Li

The elastic scattering has been studied at $E(^6\mathrm{Li}) = 5.8$ MeV (1976PO02) and 30 MeV (1977KE09).

21. (a) ^{6}Li(^{12}C, ^{12}C)^{6}Li
(b) ^{6}Li(^{13}C, ^{13}C)^{6}Li

The elastic scattering has been studied recently at $E(\overline{^6\mathrm{Li}}) = 9$ MeV (1978DR07) and $E(^6\mathrm{Li}) = 4.5$ to 13 MeV (1976PO02), 36.4 and 40 MeV (1974BI04), 59.8 MeV (1975BI06) and 100 MeV (1977SC1B). For the earlier work, and for inelastic scattering to excited states of ^{12}C, see ^{12}C in (1975AJ02). See also (1975GR41, 1976OG1A, 1978FI1E) and (1975TH1C, 1976AM01, 1977KU07, 1978NO08, 1978PE1C; theor.). For reaction (b) see (1976PO02; 4.5 to 13 MeV) and (1978DR07).

22. (a) ^{6}Li(^{14}N, ^{14}N)^{6}Li
(b) ^{6}Li(^{14}N, ^{14}N)^{4}He + ^{2}H $\qquad Q_{\mathrm{m}} = -1.4735$

See (1977KU06; $E(^{14}\mathrm{N}) = 19.5$ MeV).

23. ^{6}Li(^{16}O, ^{16}O)^{6}Li

Elastic angular distributions have been measured at $E(^6\mathrm{Li}) = 4.5$ to 13 MeV (1976PO02) and at $E(^{16}\mathrm{O}) = 36$ MeV (1971OR02). See also (1975GR41, 1978FI1E) and (1976OH03, 1978PE1C; theor.).

24. ^{6}Li(^{28}Si, ^{28}Si)^{6}Li

See (1976PO02, 1977DE23).

25. ^{7}Li(γ, n)^{6}Li $\qquad Q_\mathrm{m} = -7.251$

The (γ, n$_0$) and (γ, n$_1$) transitions have been studied for $E_\mathrm{bs} = 13$ to 25 MeV (1977FE05): see ^{7}Li.

26. ^{7}Li(n, 2n)^{6}Li $\qquad Q_\mathrm{m} = -7.251$

See ^{8}Li.

27. (a) ^{7}Li(p, d)^{6}Li $\qquad Q_\mathrm{m} = -5.026$
(b) ^{7}Li(p, pn)^{6}Li $\qquad Q_\mathrm{m} = -7.251$
(c) ^{7}Li(p, 2d)^{4}He $\qquad Q_\mathrm{m} = -6.499$
(d) ^{7}Li(p, pd)^{5}He $\qquad Q_\mathrm{m} = -9.62$

Angular distributions of deuterons (reaction (a)) have been studied at $E_\mathrm{p} = 17.5$ to 155.6 MeV: see (1966LA04, 1974AJ01) and at $E_\mathrm{p} = 16.7$ and 17.7 MeV (1977GU14; to ^{6}Li*(0, 2.19, 3.56)) and 185 MeV (1976FA03): to ^{6}Li*(0, 2.19, 3.56, 4.31, 5.37)). A DWBA analysis of the 185 MeV data leads to $C^2S = 0.87$, 0.67, 0.24, (0.05), 0.14, respectively (1976FA03). No other states are seen below $E_\mathrm{x} \approx 20$ MeV (1976FA03). At $E_\mathrm{p} = 800$ MeV ^{6}Li*(2.19) is populated much more strongly than the ground state (1978SH1C). See also (1974KA28) and (1974AJ01). At $E_\mathrm{p} = 12$ MeV (1969CO06) have studied the ratio of the cross section of the (p, d) reaction to that for the (p, $\overline{\mathrm{d}}$) reaction, in which singlet deuterons are formed: σ(p, d)/σ(p, $\overline{\mathrm{d}}) = 41.0$.

For reaction (b) see (1977WA05). A kinematically complete experiment at $E_{\rm p} = 45$ MeV shows that reaction (c) proceeds via low-lying excited states of ^{6}Li (1972FU07). For reaction (d) see (1969DE04).

28. ^{7}Li(d, t)^{6}Li $\qquad Q_{\rm m} = -0.993$

A study at $E_{\rm d} = 23.6$ MeV of the relative cross sections of the analog reactions ^{7}Li(d, t)^{6}Li (to the first two $T = 1$ states at 3.56 and 5.37 MeV) and ^{7}Li(d, ^{3}He)^{6}He (to the ground and 1.80 MeV excited states) shows that ^{6}Li*(3.56, 5.37) have high isospin purity ($\alpha^2 < 0.008$): this is explained in terms if antisymmetrization effects which prevent mixing with nearby $T = 0$ states (1971DE08). See also (1974AJ01) and (1975KU27, 1976KU07; theor.).

29. (a) ^{7}Li(^{3}He, α)^{6}Li $\qquad Q_{\rm m} = 13.327$
(b) ^{7}Li(^{3}He, dα)^{4}He $\qquad Q_{\rm m} = 11.854$
(c) ^{7}Li(^{3}He, tp)^{6}Li $\qquad Q_{\rm m} = -6.487$
(d) ^{7}Li(^{3}He, t^{3}He)^{4}He $\qquad Q_{\rm m} = -2.467$
(e) ^{7}Li(^{3}He, n^{3}He)^{6}Li $\qquad Q_{\rm m} = -7.251$

Angular distributions have been reported at $E(^{3}{\rm He}) = 5.1$ to 18 MeV: see (1974AJ01). At $E(^{3}{\rm He}) = 16$ to 18 MeV, in a region where there are no sharp or strong resonances in the compound nucleus, both the forward and the backward maxima in the α_0 angular distributions are reproduced by conventional DWBA without inclusion of exchange terms. However, the cross section derived from zero-range DWBA is a factor of 25 smaller than the observed cross section. For finite-range analysis no appreciable renormalization is necessary (1971ZA07). Excited states observed in this reaction are displayed in Table 6.5 (1968CO07, 1975SC31). See also (1969LI06). No other states are reported below $E_{\rm x} = 10$ MeV (1968CO07).

Several attempts have been made to look at the isospin decay of ^{6}Li*(5.37) [$J^{\pi} = 2^{+}$; $T = 1$] via ^{7}Li(^{3}He, α)^{6}Li* $\rightarrow$ d + α: the branching is $<$ 2% (1971CO22), $<$ 1% (1973BR20). If $\Gamma(5.37) = 560$ keV, $\Gamma_{\rm d} \leq 12$ keV and $\theta^2_{\rm d}(5.37) \leq 0.5$% (1971CO22). See, however, (1973BR20). $\Gamma_{\rm p}/\Gamma = 0.35 \pm 0.10$ and $\Gamma_{\rm p+n}/\Gamma = 0.65 \pm 0.10$ for ^{6}Li*(5.37) (1973AR05). See also (1976DA24) for reaction (b). For reactions (c), (d), (e) see (1976WA12). See also ^{10}B, (1976ST1B, 1978SM1B) and (1974WE12; theor.).

30. ^{9}Be(γ, t)^{6}Li $\qquad Q_{\rm m} = -17.689$

See ^{9}Be.

31. (a) ^{9}Be(p, α)^{6}Li $\quad Q_m = 2.125$

(b) ^{9}Be(p, d)^{4}He^{4}He $\quad Q_m = 0.651$

Angular distributions of α-particles (reaction (a)) have been measured at $E_p = 0.11$ to 45 MeV [see (1974AJ01)] and at 4.6, 4.8 and 5.5 MeV (1974YA1C: α_0, α_1, α_2). At $E_p = 45$ MeV the reaction appears to proceed by a direct process, with a rise at back angles attributed to a pickup process (1972DE01, 1972DE02). ^{6}Li*(3.56) decays by γ-emission consistent with M1 (1954MA26); $\Gamma_\alpha/\Gamma < 0.025$ (1972AR1C) [forbidden by spin and parity conservation]. (1974DU08) report a state of ^{6}Li at 14.0 MeV ($\Gamma < 0.1$ MeV) while (1976DE30) find no evidence for it but report a state at $E_x = 8.2 \pm 0.2$ MeV ($\Gamma = 2.2 \pm 0.2$ MeV). See also Table 6.5 (1977KI08).

At $E_p = 9$ MeV, the yield of reaction (b) is dominated by FSI through ^{8}Be*(0, 2.9) and ^{6}Li*(2.19) with little or no yield from a direct three-body decay (1971EM01).

See also ^{10}B, (1966YO1A, 1976KI1C, 1977KI04), (1978PR1A; applied) and (1974LO1B).

32. ^{9}Be(t, ^{6}He)^{6}Li $\quad Q_m = -5.383$

Angular distributions of $^6\text{He}_{\text{g.s.}} + {}^6\text{Li}_{\text{g.s.}}$, $^6\text{Li}_{\text{g.s.}} + {}^6\text{He}_{\text{g.s.}}$, $^6\text{Li}^*_{3.56} + {}^6\text{He}_{\text{g.s.}}$, and $^6\text{He}_{\text{g.s.}} + {}^6\text{Li}^*_{3.56}$ [the second listed ion being the detected one] have been measured at $E_t = 21.5$ and 23.5 MeV. In the latter two cases the final state is composed of two isobaric analog states: angular distributions are symmetric about $90^\circ_{\text{c.m.}}$, within the overall experimental errors. In the reaction leading to the ground states of ^{6}He and ^{6}Li differences from symmetry of as much as 40% are observed at forward angles. Angular distributions involving $^6\text{He}_{\text{g.s.}} + {}^6$Li*(2.19) and $^6\text{Li}_{\text{g.s.}} + {}^6$He*(1.8) have also been measured. This reaction appears to proceed predominantly by means of the direct pickup of triton or ^{3}He from ^{9}Be (1973VO08, 1976VO1A). See also (1975BR1E; theor.) and ^{12}B in (1980AJ01).

33. ^{9}Be(^{3}He, ^{6}Li)^{6}Li $\quad Q_m = -1.895$

Angular distributions of the ^{6}Li ions have been obtained at $E(^3\text{He}) = 6$ to 10 MeV [see (1974AJ01)]: these and the fairly smooth yield curves [see ^{12}C in (1975AJ02)] seem to suggest that the mechanism of the reaction is essentially direct (1972YO02). See also (1974CA04; theor.).

34. ^{9}Be(^{7}Li, ^{10}Be)^{6}Li $\quad Q_m = -0.439$

See (1977KE09; abstract).

35. (a) ^{10}B(γ, α)^{6}Li $\quad Q_{\rm m} = -4.460$

(b) ^{10}B(n, nα)^{6}Li $\quad Q_{\rm m} = -4.460$

(c) ^{10}B(p, pα)^{6}Li $\quad Q_{\rm m} = -4.460$

(d) ^{10}B(d, dα)^{6}Li $\quad Q_{\rm m} = -4.460$

(e) ^{10}B(α, 2α)^{6}Li $\quad Q_{\rm m} = -4.460$

See (1974AJ01) and ^{10}B here. For reaction (b) see (1977TU1D).

36. ^{10}B(d, ^{6}Li)^{6}Li $\quad Q_{\rm m} = -2.987$

Angular distributions have been measured for the ^{6}Li ions to ^{6}Li*(0, 2.19). The ground state transition in two orders of magnitude greater than predicted by the shell model (1971GU07).

37. ^{10}B(^{3}He, ^{7}Be)^{6}Li $\quad Q_{\rm m} = -2.874$

Angular distributions of the ^{7}Be ions [^{7}Be*(0, 0.43)] corresponding to formation of ^{6}Li*(0, 2.19) have been measured at E(^{3}He) $= 30$ MeV (1970DE12, 1972OH01).

38. ^{10}B(α, ^{8}Be)^{6}Li $\quad Q_{\rm m} = -4.552$

At $E_\alpha = 72.5$ MeV only ^{6}Li*(0, 2.18 ± 0.03) are observed: the latter is excited much more strongly than is the ground state [S_α for the ground state is 0.4 that for ^{6}Li*(2.19)]. The angular distributions for both transitions are flat (1974WO1C, 1976WO11). See also (1974CE1A).

39. ^{10}B(^{16}O, ^{20}Ne)^{6}Li $\quad Q_{\rm m} = 0.270$

See ^{20}Ne in (1978AJ03).

40. ^{11}B(d, ^{7}Li)^{6}Li $\quad Q_{\rm m} = -7.192$

Angular distributions of ^{6}Li ions are reported at $E_{\rm d} = 19.5$ MeV for transitions to ^{7}Li*(0, 0.48) (1971GU07). See also (1974AJ01).

41. ^{11}B(^{3}He, ^{8}Be)^{6}Li $Q_{\rm m} = 4.570$

Angular distributions of ^{6}Li ions are reported at $E(^{3}\text{He}) = 3.0$ and 5.2 MeV. The reaction has been observed to lead to ^{8}Be*(2.9) + ^{6}Li(0) and to ^{8}Be(0) + ^{6}Li*(3.56). It is suggested that ^{6}Li*(3.56) contains a far smaller admixture of the (^{3}He + t) configuration than does ^{6}Li(0) (1964YO06, 1967YO02).

42. ^{12}C(p, ^{7}Be)^{6}Li $Q_{\rm m} = -22.568$

Angular distributions of the ^{6}Li ions corresponding to the transition to ^{7}Be*($0 + 0.43$) have been measured at five energies in the range $E_{\rm p} = 36.0$ to 56.8 MeV and the data have been analyzed using zero-range and finite-range DWBA assuming the pickup of ^{5}He and ^{6}Li clusters as the dominant mechanism (1971HO25). See also (1971BR07) and (1978KU02; theor.).

43. ^{12}C(d, ^{8}Be)^{6}Li $Q_{\rm m} = -5.893$

Angular distributions of ^{6}Li ions are reported at $E_{\rm d} = 19.5$ MeV (1971GU07; transition to ^{8}Be(0)) and at 51.8 MeV (1970EI05; transitions to ^{8}Be*(0, 2.9)).

44. ^{12}C(^{3}He, ^{9}B)^{6}Li $Q_{\rm m} = -11.572$

Angular distributions of ^{6}Li have been obtained at $E(^{3}\text{He}) = 28$ to 40.7 MeV: see (1974AJ01).

45. ^{12}C(α, ^{10}B)^{6}Li $Q_{\rm m} = -23.714$

Angular distributions have been obtained of ^{6}Li and ^{10}B ions corresponding to transitions to ^{6}Li*(0, 2.19) and ^{10}B*(0, 0.72, 2.15) (1972RU03; $E_{\alpha} = 42$ MeV).

46. ^{13}C(p, ^{8}Be)^{6}Li $Q_{\rm m} = -8.615$

At $E_{\rm p} = 45$ MeV, the angular distribution of the ^{6}Li ions corresponding to ^{8}Be*(0, 2.9) have been measured by (1971BR07). The production of ^{6}Li has been studied for $E_{\rm p} = 10$ to 18 MeV (1975OB01). See also ^{14}N in (1976AJ04).

47. (a) ^{14}N(α, ^{12}C)^{6}Li $Q_{\rm m} = -8.799$
(b) ^{14}N(α, αd)^{12}C $Q_{\rm m} = -10.2724$

For reaction (a) see (1975AJ02). Reaction (b), studied at $E_{\alpha} = 22.9$ MeV, appears to involve ^{6}Li*(2.19) (1969BA17).

48. ^{16}O(p, ^{11}C)^{6}Li $Q_{\rm m} = -22.185$

See (1974AJ01).

49. ^{16}O(d, ^{12}C)^{6}Li $Q_{\rm m} = -5.688$

Angular distributions of ^{6}Li ions have been obtained at $E_{\rm d} = 19.5$ MeV corersponding to formation of ^{12}C*(0, 4.4) (1971GU07). See also ^{12}C in (1975AJ02).

50. ^{16}O(^{3}He, ^{13}N)^{6}Li $Q_{\rm m} = -9.239$

Angular distributions of ^{6}Li ions have been measured at $E(^{3}{\rm He}) = 30.0$ and 40.7 MeV (1972OH01).

51. ^{16}O(α, ^{14}N)^{6}Li $Q_{\rm m} = -19.263$

Angular distributions have been obtained of ^{6}Li and ^{14}N ions corresponding to the population of the ground states (1972RU03; $E_{\alpha} = 42$ MeV).

52. ^{19}F(d, ^{15}N)^{6}Li $Q_{\rm m} = -2.540$

See ^{15}N in (1976AJ04).

53. ^{19}F(^{3}He, ^{16}O)^{6}Li $Q_{\rm m} = 4.094$

Angular distributions have been measured at $E(^3\text{He}) = 11$ to 40.7 MeV involving ^{6}Li*(0, 3.56) and various state of ^{16}O: see (1974AJ01). The angular distributions involving $^{16}\text{O}_{\text{g.s.}}$ show pronounced diffraction structure. The direct-reaction mechanism appears to involve coupling ^{3}He and t with $l = 0$ angular momentum to either a singlet or triplet state. The ratio $\sigma_{\text{g.s.}}/\sigma_{3.56} = 2.24 \pm 0.07$ rather than 3 (from the ratios of $2J + 1$) but this is accounted for by the Q-value dependence of the cross sections (1970KL09; $E(^3\text{He}) = 28$ MeV).

54. ^{19}F(α, ^{17}O)^{6}Li $\qquad Q_{\text{m}} = -12.340$

See ^{17}O in (1977AJ02).

^{6}Be
(Figs. 6 and 7)

GENERAL (See also (1974AJ01).)

Model calculations: (1974IR04, 1976CE1B, 1976HE07, 1976IR1B).

Other topics: (1973WE18, 1974DA1B, 1974MC04, 1975BE31, 1975FE01, 1977SI1D).

1. (a) ^{3}He(^{3}He, γ)^{6}Be	$Q_{\rm m} = 11.488$	$E_{\rm b} = 11.488$
(b) ^{3}He(^{3}He, p)^{5}Li	$Q_{\rm m} = 10.89$	
(c) ^{3}He(^{3}He, 2p)^{4}He	$Q_{\rm m} = 12.8596$	
(d) ^{3}He(^{3}He, 3p)^{3}H	$Q_{\rm m} = -6.9544$	
(e) ^{3}He(^{3}He, ^{3}He)^{3}He		
(f) ^{3}He(^{3}He, d)^{4}Li	$Q_{\rm m} = -8.4$	
(g) ^{3}He(^{3}He, 2p)^{2}H^{2}H	$Q_{\rm m} = -10.987$	

The yield of γ-rays to ^{6}Be*(1.7) (reaction (a)) increases smoothly from 0.4 to 9.3 μb (assuming isotropy) for $0.86 < E(^3\text{He}) < 11.8$ MeV (90°). No transitions were observed to ^{6}Be(0) [$\sigma < 0.01$ μb at $E(^3\text{He}) = 1.4$ MeV]. This is understood in terms of a direct capture of ^{3}He by ^{3}He in the singlet spin state and with zero angular momentum: the $0^+ \rightarrow 0^+$ γ-transition is forbidden. Reaction (a) is thus of negligable astrophysical importance compared to reaction (c) (1967HA24) [see below]. The capture cross section from $E(^3\text{He}) = 12$ MeV to 27 MeV continues to increase smoothly with energy at first and then shows a broad structure centered at $E(^3\text{He}) = 23 \pm 1$ MeV [$E_{\rm x} = 23.0 \pm 0.5$ MeV], $\Gamma_{\rm c.m.} \approx 5$ MeV (1973VE1B, 1974VE01). This appears to be a ^{33}F cluster resonance which decays by an E1 transition to ^{6}Be*(1.7). The γ-ray angular distributions are coinsistent with $J^\pi = 3^-$ (1974VE01).

For reaction (b) see ^{5}Li and (1976IR02; polarization measurements at $E(^3\text{He}) = 13.6$ MeV).

Measurements of the total cross section section for reaction (c) have been carried out for $E(^3\text{He}) = 60$ to 300 keV (1974DW01) and 0.16 to 2.2 MeV (1969DW1A, 1971DW01). The measurements of (1974DW01), down to $E_{\rm c.m.} = 30$ keV, eliminate the possibility of a resonance [which might help explain the observed absence of solar neutrinos], unless it is extremely narrow ($\Gamma \lesssim 100$ eV): $\theta^2_{\rm p} \approx 3 \times 10^{-6}$ (1974DW01). (1972BB10) has commented that such a high ^{3}He + ^{3}He cluster for a ^{6}Be state at ≈ 11.5 MeV is not expected. The cross section factor $S(E_{\rm c.m.}) = [5.2 - 2.8\ E_{\rm c.m.} + 1.4\ E^2_{\rm c.m.}]$ MeV $\cdot$ b [error in S is $\pm$20% for $E_{\rm c.m.} > 40$ keV] (1974DW01). For the earlier work see (1966LA04, 1974AJ01). For polarization measurements (reaction (c)), see (1976SL1A). The cross section of reaction (c) has been compared with that for ^{3}H(^{3}He, α)d [see reaction 1 in ^{6}Li] at the same c.m. energy (16 MeV). At $E(^3\text{He}) = 13$ MeV a

Table 6.6: Energy levels of ^{6}Be

E_x (MeV $\pm$ keV)	$J^\pi; T$	$\Gamma_{c.m.}$	Decay	Reactions
g.s.	$0^+; 1$	92 ± 6 keV	p, α	2, 3, 4, 5
1.67 ± 50 [a]	$(2)^+; 1$	1.16 ± 0.06 MeV	p, α	1, 2, 3, 4
23	4^-	broad	^{3}He	1, 3
26	2^-	broad	^{3}He	1, 3
27	3^-	broad	^{3}He	1, 3

[a] See Table 6.8 in (1974AJ01).

deviation from the ratio of 2 is observed, which is qualitatively accounted for by a distorted wave zero-range calculation (1974RO01).

The elastic scattering (reaction (e)) has been studied for $E(^3\text{He}) = 3$ to 32 MeV [see (1974AJ01)], at 32 MeV (1974RO01) and at 120 MeV (1977TA1A; also inelastic processes). The optical model fit at 120 MeV appears to be poor (1977TA1A). The excitation function shows a smooth monotonic behavior except for an anomaly at $E(^3\text{He}) = 25$ MeV in the $l = 3$ partial wave corresponding to a broad state in ^{6}Be at $E_x \approx 24$ MeV (1970JE02). Polarization measurements have been reported at $E(^3\text{He}) = 4.33$ to 17.5 MeV: the polarization is consistent with zero at $\theta \approx 63°$, consistent with a description of the scattering which leaves the P- and F-wave phase shifts unsplit (1972BO42, 1972HA64). Polarization measurements have also been carried out at $E(^3\text{He}) = 8.9$ to 34.8 MeV on a polarized ^{3}He target (1974BA1G, 1975BI1C, 1976BA1H; abstracts) and at eight energies in the range $E(\overline{^3\text{He}}) = 17.91$ to 32.9 MeV (1978VL01). A two level R-matrix analysis of the phase shifts $(L \leq 5)$ suggests three broad F-wave states at $E_x \approx 23.4$ (4^-), 26.2 (2^-) and 26.7 MeV (3^-) (1978VL01), in disagreement with the capture γ-ray results described above. Measurements of various of these reactions in order to obtain a total reaction cross section at $E(^3\text{He}) = 17.9$ and 21.7 MeV have been carried out by (1975PO1B; abstract). For reaction (f) see also (1974AJ01). Reaction (g) has been studied at 50 and 78 MeV to look at the quasi-free scattering of the two deuterons. The cross sections are an order of magnitude smaller than those predicted by PWIA (1978AL21).

(1977DA11) have searched at $E(^3\text{He}) = 15$ and 25 MeV for the $^3\text{He} + {}^3\text{He} \rightarrow \text{d} + \alpha + \text{e}^+ + \nu$ reaction [which had been reported by (1975SL01, 1976PI1A, 1977SL1B) to occur with a cross section of 3.4 nb/MeV · sr at $E(^3\text{He}) = 13.6$ MeV]. (1977DA11) find no evidence for this process with a cross section twenty times lower than reported by (1975SL01); thus the cross section for the p + p process at solar energies is not in error and cannot account for the solar neutrino puzzle.

At 120 MeV (1977FU1A) have studied $^3\text{He}+{}^3\text{He} \rightarrow \text{p}+\text{d}+{}^3\text{He}$ and have interpreted the results as possible evidence for a 3N resonance. See also (1971BA1A, 1974UL1B, 1975FE01, 1976BA1J, 1976MC04, 1976NE1A, 1976NO1C, 1978RO1D; astrophysical considerations), (1975TO1A, 1976MI1F, 1978SL1B), (1977MC1C; applied) and (1974DE18, 1976AS05, 1976HE07; theor.).

2. ^{4}He(^{3}He, n)^{6}Be $\qquad Q_m = -9.090$

Neutron groups to ^{6}Be*(0, 1.7) have been observed at $E(^3\text{He}) = 19.4$ to 38.61 MeV: see Table 6.8 in (1974AJ01) for the parameters of the first excited state. There is no evidence for other states of ^{6}Be with $E_x \lesssim 5$ MeV (1966EC01), nor for a state near the ^{3}He threshold at 11.5 MeV: for the latter the differential cross section is $\lesssim 7$ μb/sr at $\theta_{lab} = 7.3°$ (1977MC10; $E(^3\text{He}) = 38.61$ MeV), $\lesssim 7.5$ μb/sr at $\theta = 0°$ (1975VI04; 36.2 MeV).

3. (a) ^{6}Li(p, n)^{6}Be $\qquad Q_m = -5.070$

(b) ^{6}Li(p, pn)^{5}Li $\qquad Q_m = -5.66$

Neutron groups have been observed to ^{6}Be*(0, 1.7) as has the ground state threshold. The width of the ground state is 95 ± 28 keV (1967HO01). The parameters of ^{6}Be*(1.7) are displayed in Table 6.8 of (1974AJ01). Angular distributions have been reported at $E_p = 8.3$ to 49.4 MeV [see (1974AJ01)] and at 14.9 and 17.8 MeV (1974AR05; n_0). For a study at $E_p = 800$ MeV see (1977RI07). In reaction (b) (1977WA05) report, at $E_p = 47$ MeV, some evidence for sequential decay via ^{6}Be*(15.5 ± 2, 24 ± 2). See also (1976SL2A) and (1975FE01; theor.).

4. ^{6}Li(^{3}He, t)^{6}Be $\qquad Q_m = -4.306$

Triton groups have been observed to ^{6}Be*(0, 1.7). The width of the ground state is 89 ± 6 keV (1966WH01). The parameters of the excited state are displayed in Table 6.8 of (1974AJ01). No other excited states have been seen with $E_x < 13$ MeV (1966MA36; $E(^3\text{He}) + 40$ MeV), < 10 MeV (1966RO06; $E(^3\text{He}) = 31$ MeV). An attempt has been made at $E(^3\text{He}) = 25.5$ MeV (1973PA1C) and at 46.3 MeV (1973HA45) to observe the possible ^{6}Be state at $E_x = 11.5$ MeV, of astrophysical interest: $d\sigma/d\Omega \leq 0.19$ μ/sr at $\theta_{c.m.} = 45°$ at the lower energy; $d\sigma/d\Omega \leq 1.6$ μb/sr at $8.4°$ and at 46.3 MeV. Upper limits for the spectroscopic factor are $S \leq 0.006$ (1973PA1C) and ≤ 0.001 (1973HA45). See also (1975CH1D). The ground state angular distribution shows a pronounced oscillatory character, consistent with $l = 0$; that for the 1.7 MeV state is relatively structureless (1966RO06). Angular distributions are also reported by (1972GI07; n_0; 27.0 MeV). The α-spectrum following the $\alpha + p + p$ decay of $^6\text{Be}_{g.s.}$ has been measured by (1977GE02): the yield of low energy α-particles appears to be enhanced compared with calculations based on the available phase space. See also (1977HA19) and (1975FE01, 1978HA1H); theor.).

5. ^{6}Li(^{6}Li, ^{6}He)^{6}Be $\qquad Q_m = -7.795$

See reactions 9 in ^{6}He and 18 in ^{6}Li (1974WH01, 1974WH02, 1974WH07, 1975WH01).

6. ^{9}Be(^{3}He, ^{6}He)^{6}Be $Q_{\rm m} = -9.690$

See (1974AJ01).

^{6}C
(Not illustrated)

See (1976GO1C; theor.).

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(Closed 1978)

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