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Energy Levels of Light Nuclei
$A = 7$

F. Ajzenberg-Selove [a] and T. Lauritsen [b]

[a] *University of Pennsylvania, Philadelphia, Pennsylvania 19104-6396*
[b] *California Institute of Technology, Pasadena, California*

Abstract: An evaluation of $A = 5$–24 was published in *Nuclear Physics* 11 (1959), p. 1. This version of $A = 7$ 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.

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^{7}He
(Not illustrated)

Not observed: see (1955AJ61).

^{7}Li
(Fig. 5)

GENERAL:

Theory: See (1955AU1A, 1955DA1A, 1955LA1D, 1956AB1A, 1956FE1A, 1956KU1A, 1956ME1A, 1957FE1A, 1957FR1B, 1957LE1E, 1957MA57, 1957MA1E, 1957SO1A, 1958HA1D, 1958SK1A).

1. ^{3}H(α, γ)^{7}Li $\qquad Q_{\rm m} = 2.465$

For $E_\alpha = 0.5$ to 1.9 MeV, capture radiation is observed to ^{7}Li(0) and ^{7}Li*(0.48), with intensity ratio 5 : 2. The smooth rise of the cross section suggests a direct capture process. The angular distribution is not isotropic, indicating $l > 0$ (1958RI34); see also (1958LI1A). In the range $E_\alpha = 0.48$ to 1.13 MeV, the cross section increases from 0.6 to 1.2 μb (1959HO03).

2. ^{4}He(t, t)^{4}He $\qquad E_{\rm b} = 2.465$

Differential cross sections have been measured for $E_{\rm t} = 1.2$ to 2.2 MeV (1956HE16). At $E_{\rm t} = 1.677$ MeV, $\theta = 30°$, dσ/dΩ (lab) = 875 mb/sr (1958AL05).

3. ^{4}He(α, p)^{7}Li $\qquad Q_{\rm m} = -17.347$

At $E_\alpha = 38.5$ MeV, two groups of protons are observed, corresponding to the ground and 0.48-MeV states of ^{7}Li. Absolute c.m. differential cross sections are given as $(1.53 \pm 0.09) + (1.93 \pm 0.15)\cos^2\theta$ and $(1.32 \pm 0.07) + (0.66 \pm 0.23)\cos^2\theta$ mb/sr for the ground state and excited state groups, respectively. The cross sections are in fair agreement with those calculated from ^{7}Li(p, α)^{4}He by the principle of detailed balancing. The partial inelastic cross sections are estimated to be 11 ± 1 mb for s-waves, 33 ± 3 mb for d-waves (1958BU38).

4. ^{6}Li(n, γ)^{7}Li $\qquad Q_{\rm m} = 7.252$

Table 7.1: Energy levels of ^{7}Li

E_x in ^{7}Li (MeV)	J^π	τ_m (sec) or Γ (keV)	Decay	Reactions
0	$\frac{3}{2}^-$		stable	1, 3, 4, 9, 10, 17, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 30, 31
0.4780 ± 0.0003	$\frac{1}{2}^-$	$\tau_m = (0.9 \pm 0.1) \times 10^{-13}$	γ	1, 3, 4, 9, 10, 16, 17, 19, 23, 24, 25, 28, 30, 31
4.630 ± 0.01	$(\leq \frac{7}{2}^-)$	93 ± 8	t, α	9, 18, 19, 23, 30, 31
6.54 ± 0.02	$(\frac{1}{2}^+, \frac{3}{2}^+)$	broad	t, α	(5), 9, 18, 19
7.47 ± 0.01	$\frac{5}{2}^-$	141 ± 20	n, α, t	5, 6, 9, 18, 19, 30
(9.6)			γ, n, t, α	12, 15, 18, 19
(10.8)			γ, n, t, α	12, 15
12.4			γ, n	12
14.0			γ, n	12
16.2			γ, t, α	15
17.5			γ, n	12, 19
(21.5)			γ, t, α	15, 19
(23.5)			γ, t, α	15

Two γ-rays with $E_\gamma = 7.26 \pm 0.03$ and 6.78 ± 0.05 MeV, and relative intensities 10 and 7.5 ± 2.0, corresponding to transitions to the first two states of ^{7}Li are observed. The total radiative capture cross section is 28 ± 8 mb (1957BA18).

5. ^{6}Li(n, n)^{6}Li $\qquad E_b = 7.252$

The total cross section has been measured from $E_n = 4$ eV to 10 MeV (1954JO17, 1954NE1A, 1955HU1B, 1956GO62, 1957HU1D, 1957KA1B, 1958HU18), from $E_n = 7$ to 14 MeV by (1958BR16) and at 14 MeV by (1952CO1B, 1957KA1B). A pronounced resonance occurs at $E_n = 255$ keV (see Table 7.2) with a peak cross section of 10.3 b (1954JO17). Angular distributions for $E_n = 0.2$ to 0.4 MeV have been studied by (1956WI04): all observations are consistent with p-wave formation of a $J = \frac{5}{2}^-$ level, ^{7}Li*(7.47). The s-wave potential scattering has a statistical channel spin mixture with negative phase shift (1956WI04). Resonance parameters are compared with those of the mirror level (^{7}Be*) in Table 7.2. The 7.47-MeV level has been assumed to be the upper member of the $^2F_{7/2,\ 5/2}$ doublet of which ^{7}Li*(4.6) is the lower. It is pointed out by (1956ME1A, 1957MA57, 1957SO1A) that it may in fact be a component of the ^{4}P multiplet and that the $F_{5/2}$ is to be found at a lower energy. This assumption would explain the large values of θ_p^2

and θ_n^2 and would make the large difference of θ_α^2 for the mirror levels less disturbing (1957MA57). See also (1954LA1A, 1956DA1A, 1958HA1D; theor.).

No other clearly defined resonance is observed, although the cross section exhibits a broad maximum near $E_n = 5$ MeV (1954JO17, 1957HU1D, 1958HU18).

The large coherent thermal scattering length suggests the existence of at least one bound s-level (1954LA1A).

6. ^{6}Li(n, α)^{3}H $\quad Q_m = 4.787 \quad E_b = 7.252$

The isotropic thermal capture cross section is 945 b (1958HU18); up to $E_n \approx 70$ eV, the cross section varies as $1/v$. Cross sections and angular distributions are summarized in (1955HU1B, 1956HU1A, 1957HU1D, 1958HO1C, 1958HU18). A strong resonance is observed at $E_n = 0.25$ MeV with a peak cross section of 2.9 b, attributed to p-wave formation of a $J = \frac{5}{2}^-$ level (see ^{6}Li(n, n)^{6}Li and Table 7.2). In the range $E_n = 9$ to 90 keV the cross section is higher than the $1/v$ law would indicate (1956GO1E, 1959BA1H). Above the resonance, the cross section appears to exhibit a broad hump, $\sigma \approx 250$ mb, at $E_n = 1.5$ to 2 MeV, and then decreases smoothly to 26 mb at 14 MeV. The decrease at 2 MeV is attributed to competing reactions (1956RI34, 1958MU07; see, however, (1958HO1C)). (1958KE30) find an almost linear decrease from 34.3 mb at $E_n = 12.5$ MeV to 17.5 mb at $E_n = 18.3$ MeV. For $E_n \gtrsim 2$ MeV the reaction appears to proceed by a pickup process. See ^{6}Li(n, t)^{4}He in ^{6}Li. See also (1955PE1B, 1956DA1A, 1957BE71, 1957EL1C, 1957KO1A) and (1959BA1H).

7. ^{6}Li(n, p)^{6}He $\quad Q_m = -2.753 \quad E_b = 7.252$

The cross section at $E_n = 14$ MeV is 6.7 mb (1953BA04, 1954FR03).

8. ^{6}Li(n, d)^{5}He $\quad Q_m = -2.429 \quad E_b = 7.252$

The total cross section is about 200 mb at $E_n = 5.5$, 6.5 and 14 MeV (1956RI34). For the ^{5}He ground-state peak, $\sigma = 89$ mb for the continuum, $\sigma = 77$ mb at $E_n = 14$ MeV (1954FR03). The reaction appears to proceed by pickup: see ^{6}Li(n, d)^{5}He in ^{6}Li.

9. ^{6}Li(d, p)^{7}Li $\quad Q_m = 5.027$

The weighted mean value of the excitation energy of the first excited state is 477 ± 2 keV (see (1955AJ61)). Levels are also observed at $E_x = 4.630$ MeV, $\Gamma = 93 \pm 8$ keV (1957BR97), $4.61 \pm$

Table 7.2: Resonance parameters for $7.2 - 7.5$ MeV level in ^{7}Li-^{7}Be

	^{6}Li(n, n)^{6}Li, ^{6}Li(n, α)^{3}H				^{6}Li(p, α)^{3}He	
	(1951BA79)	(1954JO17)	(1956WI04)	(1956MA91)	(1951BA79)	(1956MA91)
E_r (keV, lab) [a]	250	255	255		1820	1850
Γ (keV, lab)	100	100	100		500	
E_λ (keV above g.s.)	7540	7700	6640 [b]	7680	7310	7800
$\Gamma_{n,p}(E_r)$ (keV, c.m.)	50	114	82	114	400	670
radius (n, p) in 10^{-13} cm	4.0	2.54	3.94	4.08	4.0	4.08
$\gamma^2_{n,p}$ (10^{-13} MeV-cm)	2.4	11.8	3.5 [b]	4.6	2.6	4.2
$\theta^2_{n,p}$	[0.13]	0.42	0.19 [b]	0.26	[0.14]	0.24
$\Gamma_\alpha(E_r)$ (keV, c.m.)	36	60	43	64	30	50
radius (α) in 10^{-13} cm		3.5		4.39		4.39
γ^2_α (10^{-13} MeV-cm)		0.4 [c]	0.12 [b]	0.14		0.79
θ^2_α		[0.04]	0.014 [b]	0.017 [d]		0.095 [d]

[a] $E_r = 265$ keV, $\sigma = 9.5 \pm 0.2$ b (1956GO62); see also (1958HU18, 1959BA1H).
[b] With same convention as other references, $E_\lambda = 7580$ (H.B. Willard, private communication).
[c] $\gamma^2_n/\gamma^2_\alpha = 30$; see (1956MA91: footnote, p. 1406).
[d] Corrected value: see (1957MA57).

0.02 MeV (1952GE07), 4.46 ± 0.02 MeV (1955KH35) and $E_x = 6.54 \pm 0.02$ MeV (1955KH31, 1955KH35), 6.56 MeV (1955LE24: see, however, (1958HA22)) and $E_x = 7.457$ MeV, $\Gamma = 91 \pm 8$ keV (1957BR97). A search for a level at 5.5 MeV was unsuccessful at $\theta = 30°$, $70°$ and $90°$, $E_d = 7.0$ and 7.5 MeV (1957BR97). Angular distributions of the protons to the ground state and the 0.48-MeV level, at $E_d = 8$ MeV (1953HO48) and $E_d = 14.5$ MeV (1955LE24), analyzed by stripping theory, show odd parity, $J \leq \frac{5}{2}$ for both states: see also (1954NI1A). The ratio of reduced widths θ^2(g.s.)/θ^2(0.48) $= 0.69$ and 0.66 from these two experiments (1956RE04); θ^2(g.s.)≈ 0.060 (1957FR1B). The angular correlation between the protons and the 0.48-MeV γ-rays is isotropic (see (1955AJ61)) indicating $J = \frac{1}{2}$ for ^{7}Li*. The mean life of this state as determined in the present reaction and in ^{9}Be(d, α)^{7}Li is $(7.7 \pm 0.8) \times 10^{-14}$ sec (1956BU83). At $E_d = 15$ MeV, the angular distribution of the protons to the 4.6-MeV state has been measured for $\theta = 30°$ to $100°$ and can be reasonably accounted for by stripping theory with $l_n = 2$, $J \leq \frac{7}{2}^-$ (1956HA90); on the other hand, (1958HA22) report the distribution nearly isotropic at $E_d = 15$ MeV. At $E_d = 24$ MeV the distribution is in poor agreement with stripping theory (1957CO68). For the 7.5-MeV level, the proton distribution at $E_d = 15$ MeV indicates $l_n = 1$ and a reduced width equal to that of the ground state (1958HA22). A search for 4.1 MeV γ-rays from a possible $(4.6 \rightarrow 0.48)$ transition was unsuccessful: at $E_d = 1.8$ MeV, $I_{4.1} < 0.1$ $(I_{0.48})$ (1957WI24). See also ^{8}Be, (1955AU1A, 1955LA1D, 1957FR1B; theor.) and (1952AJ38).

10. ^{6}Li(t, d)^{7}Li $\quad Q_m = 0.994$

$Q_0 = 0.986 \pm 0.007$ (1954AL35).

At $E_t = 240$ keV, the reaction has been observed to the ground state and to the 0.48-MeV level (1954AL35). See also (1955CU1A).

11. ^{6}Li(α, ^{3}He)^{7}Li $\quad Q_m = -13.325$

Not reported.

12. ^{7}Li(γ, n)^{6}Li $\quad Q_m = -7.252$

The total cross section for neutron production (including the (γ, np) and (γ, 2n) processes) has a broad maximum ($\sigma = 2.3$ mb) at $E_\gamma = 16.8$ MeV, $\Gamma = 9.3$ MeV (1958RY77: $^{\rm nat}$Li). For the (γ, n) process alone, the peak cross section is estimated as ≈ 2.7 mb at $E_\gamma \approx 14$ MeV (1954GO1A). Discontinuities reported in the integral yield curve are listed in Table 7.3. Integrated cross sections are tabulated by (1954GO39). See also (1953MO1B, 1955HE51, 1958BE1C, 1958TI1A) and (1953PE1A, 1957BA1H; theor.). (It is to be noted that the total cross section in ^{6}Li(n, n)^{6}Li exhibits no evidence of sharp structure in the region $E_x = 9$ to 12 MeV: see (1954JO17, 1957HU1D, 1958HU18).)

13. ^{7}Li(γ, p)^{6}He $\quad Q_m = -10.005$

According to (1953TI02) and (1954TI16), the cross section in the range $E_\gamma = 12$ to 20 MeV exhibits a single broad maximum at ≈ 15.6 MeV with a width of ≈ 4 MeV. At $E_\gamma = 14.8$ MeV the cross section is 2.2 ± 0.25 mb; according to (HA55A), the integrated cross section is 11 MeV-mb. There appears to be some disagreement on the shape of this excitation function. It is suggested that a γ-emitting state of ^{6}He at ≈ 1.6 MeV could account for the discrepancy between the Canberra and Saskatoon results (1954TI16, 1955TI1A). Some evidence for fine structure is reported by (HA55A). See also (1953TU1A, 1954RU27, 1954TU1A, 1958SM1A, 1958ST1A, 1958TI1A, 1958WH1A).

14. ^{7}Li(γ, d)^{5}He $\quad Q_m = -9.681$

See (1958BA1C, 1958PA1B, 1958TI1A, 1958WH1A).

Table 7.3: Levels of ^{7}Li (MeV) from ^{7}Li(γ, t)^{4}He and ^{7}Li(γ, n)^{6}Li

(γ, t)				(γ, n)
(1953TI02)	(1953ST27)	(1954ST89)	(1955MI55)	(1954GO39)
		4.7		
	5.25	5.5		
		6.8		
	7.25		7.6	
			8.6	
9.3	(9.25)		9.6	9.6 [a]
			11.7	10.8
				12.4
			(13.5)	14.0
(16.7)			16.2	
				17.5
(21.5)				
(23.5)				

[a] 9.96 ± 0.04 MeV (1958RY77).

15. ^{7}Li(γ, t)^{4}He $\qquad Q_{\rm m} = -2.465$

Reported peaks in the excitation function are listed in Table 7.3. Observations are made in nuclear emulsions, mainly under continuous-spectrum irradiation. It is pointed out by (1953PE1A) that $T = \frac{3}{2}$ levels of ^{7}Li will not be observed in the present reaction in the region 0 to 15 MeV above threshold: compare ^{7}Li(γ, n)^{6}Li. See also (1952NA1A, 1953TI1A, 1953TU1A, 1954ER1A, 1954TU1A, 1955TI1A, 1958TI1A) and (1955CZ1A, 1956CZ1A; theor.).

16. ^{7}Li(γ, γ')^{7}Li*

Measurement of resonance scattering and absorption in Li yield τ(mean) $= (1.1 \pm 0.3) \times 10^{-13}$ sec (1958BE10), $(1.15 \pm 0.14) \times 10^{-13}$ sec (1958SW65, 1959SW63) for the 0.48-MeV state.

17. ^{7}Li(e, e)^{7}Li

Elastic and inelastic (0.47-MeV state) scattering have been studied at $E_e = 187$ MeV by (1955ST85). Elastic scattering results indicate an r.m.s. radius of about 2.1×10^{-13} cm (1957HO1E: see also (1956HO93, 1957ME1B)).

18. ^{7}Li(n, n′)^{7}Li* → ^{3}H + ^{4}He $\quad Q_m = -2.465$

At $E_n = 14$ MeV, there is evidence for ^{7}Li states at 4.6 ± 0.25, $\approx 6.5 \pm 0.25$, 7.5 ± 0.25 and 9.25 (?) MeV (1954AL24: Li-loaded photoplates). See also (1954FR03).

19. ^{7}Li(p, p′)^{7}Li*

Elastic scattering at $E_p > 10$ MeV is characterized by direct interaction processes: see (1956KI54, 1957HI56). Inelastic proton groups corresponding to the states at 0.48, 4.63, 6.54 and 7.46 MeV have been observed at bombarding energies up to 18.3 MeV: see (1952AJ38). A careful check on the isotropy of the 477-keV radiation from the $J = \frac{1}{2}^-$ level yields $W(\theta) = 1 + \alpha \cos\theta$, with $\alpha = (2.9 \pm 6.2) \times 10^{-4}$; the result implies an upper limit for the intensity of a parity non-conserving part of the wave function $F^2 < 1 \times 10^{-4}$ (1958WI38).

At $E_p = 12$ MeV, the angular distribution of the protons leaving ^{7}Li in the 4.63-MeV state can be accounted for by a mixture of direct interaction with $l = 0$, and compound nucleus formation, indicating $J = \frac{1}{2}^-, \frac{3}{2}^-$, or $\frac{5}{2}^-$. It is also possible to fi t the data under the assumption of compound nucleus formation with s, p, and d-waves, permitting $J = \frac{7}{2}^-$ (1957CO53). Angular distributions at $E_p = 17.5$ MeV are reported by (1957MA04). The relative intensities observed in this work for protons leading to the 4.6, 6.6, and 7.5-MeV states are consistent with assignments ^{22}F$_{7/2}$, ^{22}F$_{5/2}$, ^{24}P$_{5/2}$; it is presumed that the 6.6-MeV state in question here is not the broad even-parity state at 6.54 MeV (1957LE1E). At 31.8 MeV, angular distributions of protons leading to the 4.6-MeV and 6.6-MeV levels fi t the direct interaction theory with $l = 1$ ($J = \frac{1}{2}^+, \frac{3}{2}^+, \frac{5}{2}^+, \frac{7}{2}^+$). A weak group to a 9.6-MeV level is also reported (1957SI1A). Levels at 18 ± 1.4 (?) and 22 ± 1.4 (?) MeV are observed with 96-MeV protons (1956ST30). See also (1957TY35, 1958CH26, 1958MA1B, 1958TY46, 1958TY49).

20. ^{7}Li(p, d)^{6}Li $\quad Q_m = -5.026$

The ground-sate reduced width $\theta_n^2 = 0.05$ and 0.035 for ^{6}Li(0) and ^{6}Li*(2.2), respectively: see ^{6}Li.

21. ^{7}Li(d, t)^{6}Li $\quad Q_m = -0.994$

$\theta^2_n = 0.11$ and 0.061 for ^{6}Li(0) and ^{6}Li*(2.2), respectively: see ^{6}Li.

22. ^{7}Li(d, ^{3}He)^{6}He $\qquad Q_m = -4.512$

$\theta^2_p = 0.055$ and 0.017 for ^{6}He(0) and ^{6}He*(1.7), respectively: see ^{6}He.

23. ^{7}Li(d, d′)^{7}Li*

Inelastic deuteron groups have been observed to the states at 0.48 and 4.6 MeV: see (1952AJ38) and (1955KH31, 1955KH35). (1955LE24) report $Q = -4.62 \pm 0.04$, $\Gamma = 0.3 \pm 0.1$ MeV, for the latter state; $\theta^2_\alpha = 0.5 \pm 0.2$ (1957MA57). At $E_d = 14.4$ MeV, the angular distribution of the deuterons corresponding to the 0.48-MeV state is moderately well accounted for by the theory of (1952HU1B), with $l = 2$ (1955LE24). Some discrepancies appear to exist between reported angular distributions of deuterons corresponding to the 4.6-MeV level at $E_d = 14$ to 15 MeV: compare (1955LE24) and (1956HA90). See also (1956SO21, 1956SO33).

24. ^{7}Li(α, α')^{7}Li*

^{7}Li states at 0.48 and 4.6 MeV have been observed at various energies up to 48 MeV: see (1955AJ61). At $E_\alpha = 31.8$ and 48 MeV, the angular distribution of the α-particles to the 4.6-MeV state exhibits a prominent peak in the forward direction, suggesting a direct interaction process (1956CO61, 1957SI1A). (1954ZH1A) finds $E_\gamma = 478 \pm 2$ keV and a lifetime for the first excited state $< 1.3 \times 10^{-13}$ sec (see also ^{6}Li(d, p)^{7}Li and ^{9}Be(d, α)^{7}Li). At $E_\alpha = 1.9$ MeV, the angular distribution of the 0.48-MeV radiation is isotropic within 10% (1954LI48). See also (1955BR1A, 1957NE1B).

25. ^{7}Be(ϵ)^{7}Li † $\qquad Q_m = 0.863$

† The symbol (ϵ) denotes orbital electron capture.

The decay proceeds to the ground and 0.48-MeV states. The fraction to the excited state is 0.115 ± 0.01 (see (1955AJ61)). The γ-ray energy is 477.8 ± 0.3 keV (weighted mean of values quoted in (1955AJ61), including the value 477.3 ± 0.4 reported by (1957DU37)). The weighted mean value of the half-life is 53.37 ± 0.11 days (1949SE20, 1953KR16, 1956BO36, 1957WR37), $\log ft = 3.25$ for the ground state transition and 3.44 for the excited state. Both transitions are super-allowed (1954MA1D, 1956CH1B). A measurement of the internal conversion coefficient for the 0.48-MeV γ-radiation indicates that the radiation is 55% to 100% M1 (1958LE20). See also (1955LA1D; theor.).

26. ^{7}Be(n, p)^{7}Li $\qquad Q_{\rm m} = 1.646$

See ^{8}Be.

27. (a) ^{9}Be(γ, d)^{7}Li $\qquad Q_{\rm m} = -16.693$
(b) ^{9}Be(γ, np)^{7}Li $\qquad Q_{\rm m} = -18.919$

See (1955AJ61) and ^{9}Be.

28. ^{9}Be(n, t)^{7}Li $\qquad Q_{\rm m} = -10.435$

See (1957SC12, 1957VA12) and ^{10}Be.

29. ^{9}Be(p, ^{3}He)^{7}Li $\qquad Q_{\rm m} = -11.200$

Not observed.

30. ^{9}Be(d, α)^{7}Li $\qquad Q_{\rm m} = 7.152$

A number of α-groups have been observed with deuteron energies of up to 14 MeV. These correspond to levels at 480 ± 2 keV (1948BU31, 1953CO02), 4.62 ± 0.02 MeV (1953GE01: see also (1951GO47, 1952AS1A, 1956JU1D)), and 7.5 ± 0.17 (?) MeV (1951GO47). There is no evidence in this reaction of a state at 5.5 MeV suggested in ^{7}Li(γ, t)^{4}He (see (1955AJ61)): at $E_{\rm d} = 0.5$ and 0.7 MeV ($\theta = 70°$), the intensity of a group leading to such a state is less than 5% of the intensity of the ground-state alpha group (1956GE1A: see also (1955CU16, 1956JU1D)). Observation of the continuous distribution of alpha-particles and tritons indicates production and breakup of ^{7}Li levels at 4.6 and 6.6 MeV (1955CU16, 1956JU1D).

The (α, γ) angular correlation has been observed for $E_{\rm d} = 0.40$ and 0.84 MeV (1953UE01, 1954CO17). There is no significant departure from isotropy, in agreement with $J = \frac{1}{2}$ for the 0.48-MeV level. The mean life of this state is $(7.7 \pm 0.8) \times 10^{-14}$ sec (1956BU83: Doppler shift; mean of observations in this reaction and in ^{6}Li(d, p)^{7}Li); compare ^{7}Li(γ, γ)^{7}Li. This value is considerably shorter than that given by a shell-model calculation (1955LA1D). Se also ^{10}B(p, α)^{7}Be in ^{7}Be.

See also (1956GR37, 1956TU1A) and ^{11}B.

31. ^{10}B(n, α)^{7}Li $\qquad Q_{\rm m} = 2.793$

With thermal neutrons, two groups of α-particles are observed, corresponding to ^{7}Li*(0, 0.48); the fraction of transitions leading to the ground state is about 6%; see (1952AJ38, 1954DE1C, 1958BU02) and ^{11}B. The γ-ray energy is 478.5 ± 1.5 keV (1948EL1A), 478 ± 4 keV (1956DA23); the mean life is $(7.5 \pm 2.5) \times 10^{-14}$ sec (1949EL07). The (α-γ) correlation is isotropic (1950RO1A: pile neutrons). See also (1955JA18).

For neutrons in the range $E_{\rm n} = 5.6$ to 19.5 MeV, the reaction appears to proceed mainly through the 4.6-MeV level or through direct three-body disintegration (1956FR18). See also (1955AJ61).

32. ^{11}B(γ, α)^{7}Li $\qquad Q_{\rm m} = -8.670$

Not reported.

^{7}Be

(Fig. 6)

GENERAL:

Theory: See (1957FR1B, 1957MA57, 1958SK1A).

1. ^{7}Be(ϵ)^{7}Li $\quad Q_{\rm m} = 0.863$

The decay is complex; see ^{7}Li.

2. ^{4}He(^{3}He, γ)^{7}Be $\quad Q_{\rm m} = 1.584$

In the range $E(^3\text{He}) = 0.48$ to 1.32 MeV, the capture cross section increases from 0.04 to 1.2 μb. At $E(^3\text{He}) = 1.32$ MeV, about 50% of the transitions involve the 0.43-MeV state (1959HO03). See also (1958BA59, 1958HE1F). The significance of this reaction for energy generation in stars is discussed by (1958CA1C, 1958FO1A).

3. ^{4}He(^{3}He, ^{3}He)^{4}He $\quad E_{\rm b} = 1.584$

Elastic scattering studies for $E(^3\text{He}) = 3$ to 5.5 MeV ($\theta = 54°$ to $126°$) indicate a prominent resonance at $E(^3\text{He}) = 5.17$ MeV, $\Gamma = 0.180$ MeV (^{7}Be* $= 4.53$ MeV, $\Gamma_{\rm c.m.} = 0.102$ MeV). Phase-shift analysis indicates that the state is $F_{7/2}$, with $\gamma_\alpha^2 = 3.0 \times 10^{-13}$ MeV-cm, $\theta_\alpha^2 = 0.36$, $R = 4.4 \times 10^{-13}$ cm. The behavior of the p-wave phase shifts suggests that the ground state, and possibly ^{7}Li*(0.48), have widths which approach $\theta_\alpha^2 = 1$. The s-wave phase shift is consistent with hard-sphere scattering, with $R = 2.8 \times 10^{-13}$ cm (1958MI92). See also (1958CH35).

4. ^{4}He(α, n)^{7}Be $\quad Q_{\rm m} = -18.993$

A search for this reaction at $E_\alpha = 39$ MeV, 0.5 MeV (c.m.) above threshold, led to a negative result; the cross section is < 0.7 mb. This result is consistent with the assumption that ^{7}Be has negative parity (1952WA31).

5. ^{6}Li(p, γ)^{7}Be $\quad Q_{\rm m} = 5.607$

$Q_0 = 5.66 \pm 0.05$ (1956WA03).

Table 7.4: Energy levels of ^{7}Be

E_x in ^{7}Be (MeV)	J^π	τ or Γ (keV)	Decay	Reactions
0	$\leq \frac{3}{2}^-$	$\tau_{1/2} = 53.37 \pm 0.11$ d	ϵ	1, 5, 9, 13, 16, 18
0.431 ± 0.002	$\frac{1}{2}^-$	$\tau_m = (2.7 \pm 1.0) \times 10^{-13}$ sec	γ	5, 9, 13, 18
4.53 ± 0.02	$\frac{7}{2}^-$	102	^{3}He, α	3, 13, 18
6.35 ± 0.1	$(\frac{3}{2}^+)$	≈ 1000	p, ^{3}He, $\alpha(\gamma)$	5, 7, 9, 18
7.18 ± 0.06	$(\frac{5}{2}^-)$	575	p, ^{3}He, α	7, 9, 13, 18
(14.6 ± 0.3)				18

Gamma transitions to the ground state and to the 0.43-MeV state are observed. The yield shows no evidence of resonance for $E_p = 0.4$ to 1.0 MeV, and the branching ratio remains approximately constant at 62 ± 5%, (1955BA59: 65%) to the ground state, 38% to the 0.43-MeV state, (1955BA59: $<$ 4% to the 4.6-MeV state). The $90°$-differential cross section at 750 keV is 0.02 μb/sr (1956WA03). (1955BA59) estimate 0.2 μb/sr from observation of (430 ± 20)-keV radiation. (Because of the extremely low cross section of the present reaction, small amounts of contaminants may have a strong influence; in particular, earlier reports of a resonance at $E_p \approx 1.6 - 1.8$ MeV may be due to ^{10}B(p, α)^{7}Be: see (1956WA03).)

The angular distribution of both γ-rays (to the ground state and the 0.43-MeV level) is the same at $E_p = 750$ keV, $W(\theta) = 1 + (1.05 \pm 0.15)\cos^2\theta$. Neither s- or d-wave capture yields such a distribution, and p-wave, $J = \frac{3}{2}^-$, is indicated; a direct non-resonant capture process seems also possible (1956WA03).

6. ^{6}Li(p, n)^{6}Be $\qquad Q_m = -5.2 \qquad E_b = 5.607$

At $E_p = 9$ MeV, the cross section for production of ground state neutrons is $d\sigma/d\Omega = 0.19 + 0.23\cos\theta + 0.70\cos^2\theta$ mb/sr; $\sigma = 5 \pm 1$ mb (1957BO1F).

7. (a) ^{6}Li(p, α)^{3}He $\qquad Q_m = 4.022 \qquad E_b = 5.607$
(b) ^{6}Li(p, p)^{6}Li

The excitation function follows the Gamow function from $E_p = 19$ to 250 keV (1953SA1A, 1957JA37). The total cross section exhibits two resonances, one at ≈ 1 MeV (broad) and one at 1.83 MeV (1951BA79, 1956MA91). (There is some discrepancy in the reported absolute cross sections.) In the range $E_p = 1.3$ to 3.1 MeV, the elastically scattered protons, $\theta = 164°$, exhibit a single maximum at $E_p = 1.75$ MeV, with $\Gamma = 0.5$ MeV (1951BA79): see Table 7.2. Preliminary results of a study at $\theta = 156°$ for $E_{\rm p} = 0.45$ to 1.8 MeV clearly show the 1.75-MeV anomaly, but no marked effect near 1 MeV (1958MC65). Analysis of α-particle angular distributions in the range $0.6 \leq E_{\rm p} \leq 2.5$ MeV is consistent with $J = \frac{3}{2}^+, \frac{5}{2}^-$ for the two states at 6.35 and 7.18 MeV. A large, non-resonant background may indicate other states or some direct interaction (1956MA91): see also ^{6}Li(p, γ)^{7}Be. At $E_{\rm p} = 15$ and 18 MeV, the angular distributions of ^{3}He-particles are sharply peaked forward (1956LI37: see ^{6}Li). See also (1955SA1C; theor.).

8. ^{6}Li(p, d)^{5}Li $\qquad Q_{\rm m} = -3.269$

See ^{5}Li.

9. (a) ^{6}Li(d, n)^{7}Be $\qquad Q_{\rm m} = 3.380$
(b) ^{6}Li(d, n)^{3}He + ^{4}He $\qquad Q_{\rm m} = 1.796$

Two neutron groups are reported, corresponding to the ground- and 0.43-MeV states. The γ-ray energy is given as 428.9 ± 2 keV (corrected for Doppler shift): the ^{7}Li*-^{7}Be* difference is 48.5 ± 1.0 keV (1952TH24). At $E_{\rm d} = 3.5$ MeV, the angular distributions of the neutron groups, analyzed by stripping theory indicate $l_{\rm p} = 1$, $J \leq \frac{5}{2}^-$ for both states. Reaction (b) is also observed (1952AJ1B). Pronounced stripping patterns for neutrons leading to the 0.43-MeV state, observed at $E_{\rm d} = 0.6$ to 1.5 MeV, also indicate $l_{\rm p} = 1$. Neutron-gamma correlations, with the neutron counter at a fixed angle, are isotropic; taken together with the stripping results, this observation indicates $J = \frac{1}{2}^-$ for the excited state (1956NE13, 1958NE38, 1958SA17); see also (1951TH1A, 1953TH1B). A search for neutron groups leading to levels of ^{7}Be in the range 0.3 to 2.0 MeV revealed no others with intensities $> 10\%$ of the main group (1956NE13).

Broad maxima observed in the ratio of low energy to high-energy neutrons at $E_{\rm d} = 4.2$ and 5.1 MeV are attributed to ^{7}Be state at 6.5 MeV ($\Gamma_{\rm c.m.} = 1.2$ MeV) and 7.2 MeV ($\Gamma_{\rm c.m.} = 0.5$ MeV). The 4.6-MeV state produces no such effect, presumably because of the high angular momentum of the neutrons (1957SL01): see ^{4}He(^{3}He, ^{3}He)^{4}He. At $E_{\rm d} = 1.8$ MeV, a search for 4.2-MeV γ-rays (from the $4.58 \rightarrow 0.43$ transition) was unsuccessful: I(4.2-MeV γ) < 0.1 I(0.4-MeV γ) (1957WI24). See also (1955CA1A).

10. ^{6}Li(^{3}He, d)^{7}Be $\qquad Q_{\rm m} = 0.113$

Not observed.

11. ^{6}Li(α, t)^{7}Be $\qquad Q_{\rm m} = -14.206$

Not observed.

12. ^{6}Li(^{6}Li, nα)^{7}Be $\quad Q_m = 1.909$

See (1957NO17).

13. ^{7}Li(p, n)^{7}Be $\quad Q_m = -1.646$

A weighted mean of measurements of the ground state threshold gives 1.8811 ± 0.0005 MeV (1954JO10). Using a two-meter absolute electrostatic analyzer, (1958BO76) obtain $E_{\text{thresh.}} = 1.8812 \pm 0.0009$ keV.

The weighted mean value of five independent observations for the energy of the excited state is 431 ± 5 keV; see Table II (7) in (1952AJ38). A neutron threshold determination gives 434 ± 4 keV (1955MA84). At $E_p = 9$ MeV, neutrons corresponding to ^{7}Be*(4.6) are reported by (1957BO1F). At $E_p = 18.3$ MeV, ^{7}Be levels are observed at 4.6 ± 0.2 and 7.1 ± 0.2 MeV (1952TH1C).

14. ^{7}Li(^{3}He, t)^{7}Be $\quad Q_m = -0.881$

Not observed.

15. ^{9}Be(γ, 2n)^{7}Be $\quad Q_m = -20.565$

See ^{9}Be.

16. ^{9}Be(p, t)^{7}Be $\quad Q_m = -12.081$

See (1954CO02) and (1956BE14).

17. ^{9}Be(d, tn)^{7}Be $\quad Q_m = -14.307$

See (1955HE83) and ^{11}B.

18. ^{10}B(p, α)^{7}Be $Q_{\rm m} = 1.147$

The weighted mean of five determinations of the energy of the first excited state gives 430.3 ± 2 keV: see Table III (7) in (1952AJ38), and (1952CR30); $E_\gamma = 432 \pm 3$ keV (1954DA20). The mean lifetime of this state is $(2.7 \pm 1.0) \times 10^{-13}$ sec (1956BU83: Doppler shift). This value agrees with a shell model calculation by (1955LA1D).

At $E_{\rm p} = 18$ MeV, α-groups are reported corresponding to ^{7}Be* $= 0$, 0.49 ± 0.10, 4.72 ± 0.08, 6.27 ± 0.10, 7.21 ± 0.10 and 14.6 ± 0.3 MeV. The last group is ten times as intense as any of the others. It is not completely excluded that it may be due to ^{10}B(p, ^{3}He)^{8}Be (1955RE16).

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(Closed December 01, 1958)

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