Energy Levels of Light Nuclei $A = 8$

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Abstract: An evaluation of $A = 5$–10 was published in *Nuclear Physics* 78 (1966), p. 1. This version of $A = 8$ differs from the published version in that we have corrected some errors discovered after the article went to press. Figures and ntroductory tables have been omitted from this manuscript. Reference key numbers have been changed to the TUNL/NNDC format.

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^{8}He
(Not illustrated)

GENERAL: See (1960GO1B, 1960ZE03, 1961BA1C, 1961LO07, 1961YA04, 1964GO25, 1965BA1A).

Mass of ^{8}He : From the systematics of neutron binding energies (1960GO36) and from the calculated mass excess of ^{7}He, the mass excess of ^{8}He is estimated as 31.6 to 32.4 MeV. It is thus stable against ^{6}He $+$ 2n by 1.3 to 2.1 MeV and should exhibit β^{-}-decay to ^{8}Li*(0.98) with E_{β}(max) $= 9.7$ to 10.5 MeV (1965DE08).

1. ^{8}He(β^{-})^{8}Li* $\qquad Q_{\rm m} \approx 10$

An activity with half-life 30 ± 20 msec, E_{β}(max) $= 13 \pm 2$ MeV, observed in ^{11}B + γ (320 MeV), is ascribed to ^{8}He (1963NE07). See also (1965PO03).

2. ^{11}B(γ, 3p)^{8}He $\qquad Q_{\rm m} \approx -45$

At E_{γ}(max) $= 320$ MeV, the production cross section is > 6 μb (1963NE07).

^{8}Li
(Figs. 11 and 14)

GENERAL: See (1955LA1D, 1956KU1A, 1957FR1B, 1960TA1C, 1962IN02, 1963LO1E, 1963NA1E, 1964BE1N, 1964GR1J, 1964LO1F, 1964ST1B).

Ground state :

$\mu = +1.6532 \pm 0.0008$ nm: see ^{7}Li(n, γ)^{8}Li, (1965FU1G).

1. ^{8}Li(β^{-})^{8}Be $\qquad Q_{\rm m} = 16.002$

The beta decay leads mainly to ^{8}Be*(2.9): see ^{8}Be. Reported half-lives are listed in Table 8.2; taking $\tau_{1/2} = 0.849$ sec and $Q = 16.002 - 2.90$, $ft = 4.14 \times 10^{5}$ (1966BA1A). The distribution of recoil momenta indicates $J^{\pi} = 2^{+}$ (see ^{8}Be).

The asymmetry of the β-decay has been exploited as an indicator of ^{8}Li nuclear polarization: see ^{7}Li(n, γ)^{8}Li.

Table 8.1: Energy levels of ^{8}Li

E_x (MeV ± keV)	$J^\pi; T$	Γ (keV)	Decay	Reactions
g.s.	$2^+; 1$	$\tau_{1/2} = 849 \pm 4$ msec	β^-	1, 2, 3, 9, 10, 12, 14, 19, 20, 21
0.975 ± 12	$1^+, 2^+; 1$	$\tau < 0.2$ psec	γ	2, 9, 12
2.258 ± 3	$3^+; 1$	31 ± 5	γ, n	3, 4, 9
3.21	$(1^\pm, 2^+); 1$	≈ 1000	n, n_1	5
(5.0)	$(2^-); 1$	broad	n	4
(6.4)		≈ 2000	n	4
6.53 ± 20	$T = 1$	< 40		16
(8.9 ± 400)	$(1^-, 2^-)$	≈ 4000		14

Table 8.2: The half-life of ^{8}Li

$\tau_{1/2}$ (sec)	Reference
0.89 ± 0.02	(1947HU06)
0.825 ± 0.02	(1951RA12)
0.89 ± 0.01	(1953BU35)
0.875 ± 0.02	(1953BR1B)
0.85 ± 0.016	(1952SH44)
0.84 ± 0.04	(1954WI25)
0.841 ± 0.004	(1954KL36)
0.84 ± 0.02	(1959FA02)
0.88 ± 0.03	(1959IM04)
0.82 ± 0.02	(1962NE14)
0.87 ± 0.02	(1965BE1P)
0.849 ± 0.004	weighted mean

2. ^{6}Li(t, p)^{8}Li $Q_m = 0.803$

Ground-state protons have been observed with E_t up to 3.3 MeV: see (1952MO19, 1952PE02, 1954AL35, 1955CU17).

At $E(^{6}\text{Li}) = 4.5$ MeV, the 0.98 MeV γ-ray has been observed. Doppler shift measurements give $\tau < 0.2$ psec for ^{8}Li*(0.98). The transition is thus dipole in character, with a maximum E2 admixture of 2×10^{-3} in intensity (1965MO1P).

3. ^{7}Li(n, γ)^{8}Li $Q_m = 2.033$

The thermal capture cross section is 37 ± 4 mb (1964ST25); capture γ-rays of energy $E_\gamma = 2.02$, 1.06 and 0.96 MeV are reported with intensity ratios 0.8/0.2/0.3 (1961JA19; prelim. values). See also (1959BO1C).

The cross section for capture radiation has been measured for $E_n = 40$ to 1000 keV: it decreases from 50 μb at $E_n = 40$ keV to 5 μb at 1000 keV. A maximum in the cross section appears at $E_n = 250$ keV corresponding to the known resonance in ^{7}Li(n, n); $\Gamma_\gamma = 0.07 \pm 0.03$ eV (1959IM04).

Measurement of the asymmetry of β-decay of ^{8}Li produced by capture of polarized neutrons indicate that the thermal capture takes place $> 80\%$ in the $J_c = 2$ channel (1959CO68, 1961WA03, 1962AB01). An NMR determination yields $g = 0.8265 \pm 0.0004$ nm/$\hbar$, or with $J = 2$, $\mu = +1.653 \pm 0.0008$ nm (1959CO68, 1962CO08). Shell model calculations give this value with $a/K = 2.1$ (1959KU1E).

4. ^{7}Li(n, n)^{7}Li $E_b = 2.033$

Total cross sections for Li and for ^{7}Li are reported in (1960HU08, 1964ST25). Recent measurements of the total cross section have been reported for $E_n = 1$ to 390 keV (1964HI04), 10 to 155 keV (1959BI19), 0.2 to 2.2 MeV (1961LA1A, 1964LA19), 1.5 to 7.5 MeV (1963BA50), 14 MeV (1964AR25), and 18 to 28 MeV (1960PE25). Angular distribution information is summarized in (1963GO1M). See also (1964LA19). A measurement at $E_n = 96$ MeV (1960SA25) has been analyzed in terms of the optical model by (1960HO14). See also (1962BA1W, 1963LU10). The thermal cross section is 1.07 ± 0.04 b (1960HU08); the coherent scattering length (thermal, bound) is $a = -2.1$ fm (1964ST25). See also (1961ME02). A pronounced resonance is observed at $E_n = 256$ keV with $J = 3^+$, formed by p-waves (Table 8.3). Polarization measurements confirm the assignment and indicate that the background s-wave scattering is contributed mainly by channel spin $J_c = 2$ (1961DA04, 1962EL01: see also (1961LA1A)) in agreement with earlier results of (1956TH06) but in conflict with (1956WI04). In this case, the coherent scattering length in the $J_c = 1$ channel is $a_1 = [+1.2]$, $a_2 = [-3.6]$ fm, suggesting an s-wave, $J^\pi = 2^-$, resonance at positive neutron energy (1956TH06, 1960LA1C). A good account of the polarization is given by

Table 8.3: ^{7}Li(n, n)^{7}Li resonance parameters [a]

	(1956WI04)	(1956TH06, 1960HU08)
E_{res} (keV)	256	258 ± 3 [c]
Γ (keV)	32	32 [d]
$\Gamma_n(E_r)$ (keV)	35.8	
Γ_γ (eV)(cm)	0.07 ± 0.03 [b]	
γ_n^2 (keV)	351	307
E_λ (keV)	-49	-43
radius (fm)	4.08	4.0
σ_{max} (b)	11.2 [e]	12.0

[a] Energies in laboratory system, except for Γ_γ.
[b] (1959IM04).
[c] $E_{res} = 275$ keV, $\sigma_{max} = 7.0 \pm 0.2$ b (1956GO62).
[d] 35 ± 5 keV (1960HU08).
[e] (1961LA1A).

the assumption of levels at $E_n = 0.25$ and 3.4 MeV, with $J^\pi = 3^+$ and 2^-, together with a broad $J^\pi = 3^-$ level at higher energy (1964LA19). It is noted that the polarization near the $J = 3^+$ resonance is similar in shape to that of ^{7}Li(p, n)^{7}Be at the presumptive mirror level, but opposite in sign (1962EL01). A broad maximum centering at $E_n \approx 5$ MeV may indicate a level at $E_x \approx 6.4$ MeV (1956GO62, 1960HU08, 1963BA50, 1964ST25).

See also (1960PE02, 1962FO1E, 1962OT01, 1963AL1J, 1963GL1E, 1963HA1G, 1963WE20).

5. ^{7}Li(n, n′)^{7}Li* $\qquad E_b = 2.033$

The excitation function for 0.48 MeV γ-rays shows an abrupt rise from threshold (indicating s-wave formation and emission) and a broad maximum ($\Gamma \approx 1$ MeV) at $E_n = 1.35$ MeV. The rise above threshold indicates the existence of a $J = 1^-$ level, which may be identified with the 1.35 MeV resonance, if a strong d-wave contribution is included. Other odd parity assignments to this resonance lead to excessive reduced widths. A good fit is obtained with either $J = 1^-$ or 1^+, $\Gamma_{lab} = 1.14$ MeV, $J^\pi = 2^+$ is not excluded (1955FR10). In the range $E_n = 1.5$ to 4 MeV, the cross section for emission of 0.48 MeV γ-rays remains constant at first and then increases to 280 mb at $E_n = 4$ MeV (1963BA50). The cross section for emission of 0.48 MeV γ-rays is ≈ 80 mb (± 12%) over the range $E_n = 13.6$ to 14.3 MeV (1962BE35). See also (1963GO1M, 1963MA61).

6. ^{7}Li(n, 2n)^{6}Li $Q_m = -7.253$ $E_b = 2.033$

The cross section is 27 ± 15 mb at $E_n = 10.2$ MeV and 56 ± 5 mb at 14.1 MeV (1963AS01). See also (1964ST25).

7. ^{7}Li(n, d)^{6}He $Q_m = -7.755$ $E_b = 2.033$

At $E_n = 14$ MeV, the cross section is 9.8 ± 1.1 mb (1953BA04), 14 ± 1.5 mb (1963BA56).

8. ^{7}Li(n, t)^{4}He + n $Q_m = -2.467$ $E_b = 2.033$

The cross section rises to 450 mb at $E_n \approx 8$ MeV and thereafter decreases slowly to 300 mb at 15 MeV (1964ST25). The large cross section, comparable to the geometric value, supports the hypothesis that ^{7}Li may be described as an (α + t) cluster (1962RO12). See also (1963AL1J, 1963BA50, 1963BR28, 1964VA19).

9. ^{7}Li(d, p)^{8}Li $Q_m = -0.192$

Observed proton groups indicate levels at 974 ± 15 (1955LE24), 977 ± 20 keV (1955KH35) and at 2.28 MeV (1955LE24, 1960HA14). At $E_d = 3.5$ MeV, no excited states are observed below the 0.97 MeV level with an intensity $> \frac{1}{160}$ of the ground-state group (1961ER01). At $E_d = 15$ MeV, no states observed in the region $2.28 < E_x < 8$ MeV: a limit of 0.6 mb/sr is placed on groups with widths $\lesssim 100$ keV ($\theta = 10°$, $14°$ and $25°$) (1960HA14). See also (1965WA12).

Angular distributions at $E_d = 14$ to 15 MeV have been analyzed by PWBA: see Table 8.4. At low bombarding energies, $E_d = 0.5$ to 4 MeV, angular distributions show striking agreement with simple PWBA theory. The applicability of the theory in this range is ascribed to the proximity of a pole in the stripping cross section when Q and E_d are small (1960SE08, 1960WA1G, 1963SE1F). Analysis in both PWBA and DWBA is reported by (1961HA1G): the latter leads to nearly ten times larger θ_n^2.

The cross section for ^{7}Li(d, p)^{8}Li*(γ)^{8}Li has been measured for $E_d = 1.9$ to 3.3 MeV: no resonances appear. The γ-ray angular distribution, very nearly isotropic for $E_d > 2.3$ MeV, indicates that stripping dominates. If the transition is M1 (see ^{6}Li(t, p)^{8}Li), the 0.97 MeV state has $J = 1^+$ or 2^+: $E_\gamma = 980 \pm 10$ keV (1962CH14).

The polarization of recoil ^{8}Li nuclei has been studied at $E_d = 10$ MeV (1963LE1K).

See also (1959BO1C, 1959HA29, 1959SE1A, 1960PR1D, 1960SE13, 1963AL19, 1963GL1C, 1963SE1G).

Table 8.4: Reduced widths from ^{7}Li(d, p)^{8}Li

E_x in ^{8}Li (MeV)	J^{π}	l	r_0 [a] (fm)	θ_n^2 [a]	r_0 [b] (fm)	θ_n^2 [b]	θ_n^2 [c]	θ_n^2 [d]
0	2^+	1	3.8	0.066	4.2	0.053	$0.038 - 0.07$	$0.49 - 0.60$
0.97	(1^+)	1	3.5	0.040	4.2	0.028		
2.28	3^+	1	3.0	0.012	4.0	0.015		

[a] (1960HA14): PWBA.
[b] (1960MA32): PWBA.
[c] (1961HA1G): PWBA.
[d] (1961HA1G): DWBA.

10. ^{7}Li(t, d)^{8}Li $\qquad Q_m = -4.225$

See (1965AJ01).

11. ^{7}Li(α, ^{3}He)^{8}Li $\qquad Q_m = -18.546$

Not reported.

12. ^{9}Be(γ, p)^{8}Li $\qquad Q_m = -16.885$

At $E_{\text{brems.}} = 32$ MeV, transitions are observed to the ground and first excited states of ^{8}Li (1962CU05). See also (1958CH31, 1962NE14, 1963NE02, 1965AL02, 1965KO1B).

13. ^{9}Be(n, d)^{8}Li $\qquad Q_m = -14.660$

Not reported.

14. ^{9}Be(p, 2p)^{8}Li $\qquad Q_m = -16.885$

At $E_{\mathrm{p}} = 138$ MeV, the cross section of production of 0.98 MeV γ-rays is 2.4 ± 0.4 mb (1961CL09). The summed proton spectrum shows two peaks, corresponding to pickup of protons with binding energies of $\approx 16.7 \pm 0.3$ MeV and 25.8 ± 0.4 MeV ($1p_{\frac{3}{2}}$ and $1s_{\frac{1}{2}}$, respectively) (1958MA1B, 1958TY49, 1962GA23, 1964TI02, 1966TY01). See also ^{9}Be.

15. ^{9}Be(d, ^{3}He)^{8}Li $\qquad Q_{\mathrm{m}} = -11.391$

See (1954WI25).

16. ^{9}Be(t, α)^{8}Li $\qquad Q_{\mathrm{m}} = 2.930$

At $E_{\mathrm{t}} = 12.98$ MeV, α-particle groups are observed to the ^{8}Li ground state, to the states at 0.98 and 2.26 MeV and to a state at 6.530 ± 0.020 MeV. The width of the 6.53 MeV state is < 40 keV (1965WA12).

17. ^{9}Be(^{7}Li, ^{8}Be)^{8}Li $\qquad Q_{\mathrm{m}} = 0.367$

See ^{9}Be.

18. ^{10}B(n, ^{3}He)^{8}Li $\qquad Q_{\mathrm{m}} = -15.754$

Not reported.

19. ^{10}B(p, 3p)^{8}Li $\qquad Q_{\mathrm{m}} = -23.472$

See (1965BE1P).

20. ^{11}B(γ, ^{3}He)^{8}Li $\qquad Q_{\mathrm{m}} = -27.210$

See (1963NE07).

21. ^{11}B(n, α)^{8}Li $\qquad Q_{\mathrm{m}} = -6.632$

See (1959SA04) and ^{12}B.

^{8}Be

(Figs. 12 and 14)

GENERAL: See (1956KU1A, 1957FR1B, 1958WI1E, 1959BA1F, 1959BA1D, 1959BR1E, 1959WI1B, 1960BI1E, 1960KU05, 1960PE11, 1960PH1A, 1960PH1C, 1960TA1C, 1961BA1E, 1961CL10, 1961VA17, 1962IN02, 1962IN1A, 1962IW1A, 1963BR1N, 1963BU1C, 1963DA1C, 1963FR1G, 1963KU03, 1963MA1E, 1963MO1H, 1963NA1E, 1963SH1G, 1964AM1D, 1964BA1Y, 1964BE1N, 1964BE1M, 1964BR1H, 1964DA1G, 1964DU1D, 1964GR1J, 1964MA1G, 1964VO1B, 1965BA2H, 1965BE1H, 1965MA2B, 1965MA1G, 1965NE1C, 1965TR1B, 1965YU1D).

Table 8.5: Energy levels of ^{8}Be

E_x (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	$J^\pi; T$	Decay	Tables	Reactions
g.s.	6.8 ± 0.6 eV	$0^+; 0$	α	6, 8	1, 4, 12, 13, 14, 15, 16, 23, 24, 25, 26, 28, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 42, 45, 46, 50, 51
2.90 ± 30	1450 ± 60	$2^+; 0$	α	6, 8, 9	4, 13, 14, 15, 16, 23, 24, 26, 28, 29, 30, 31, 32, 33, 34, 37, 39, 42, 44, 45, 50
11.4 ± 300	≈ 7000	$4^+; 0$	α	8	4, 13, 14, 23, 32, 34
16.628 ± 5	97 ± 11	2^+	α	6, 8, 11, 16	4, 13, 15, 23, 29, 30, 32, 34, 39, 45
16.923 ± 6	83 ± 10	2^+	α	6, 8, 11	4, 13, 15, 23, 34, 39, 45
17.638 ± 2	10.7 ± 0.5	1^+	p, γ	6, 11, 12, 14, 16	13, 15, 16, 18, 23, 24, 34, 45
18.153 ± 5	147	1^+	p, γ	6, 12, 14, 16	15, 16, 18, 19, 23
18.9	> 500	2^-	p, n	13	17, 32
19.05 ± 20	270 ± 20	(3)	p, γ	6, 12, 14	16, 18, 27
19.22	190	3^+	p, n	13, 14	17, 18
19.9	≈ 1000	2^+; (0)	p, α	15	22
(19.9)	> 1000	(1^+)	p, n	13	17
20.36	1160	(1^-)	p, n	13	17
20.9 ± 200	1570 ± 180	4^-	p	14	19
21.5	1000	(3^+)	p, n	13	17
21.6	≈ 5000	(1^-)	p, γ	6, 12	16
22.5	(800)	2^+; (0)	p, d, α, (n), (γ)	10, 12, 14, 15	6, 7, 11, 15, 16, 18, 22

Table 8.5: Energy levels of ^{8}Be (continued)

E_x (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	$J^{\pi}; T$	Deacy	Tables	Reactions
23.		(4^+)	p, α	15	22, 32
23.6	≈ 5000	$(1^-, 2^-)$	p, γ	6, 12	16
(24.0)	(1360)	$(0^-; 0)$	d, α	10	11
25.2	(270)	2^+	d, α, p	10, 15	7, 11, 22
(28.5)	$\approx$ 20 MeV	6^+; (0)	α	8	3
(57)	$\approx$ 73 MeV	8^+; (0)	α	8	4

1. ^{8}Be $\rightarrow$ ^{4}He + ^{4}He $\qquad Q_m = 0.095$

The weighted mean of direct Q determinations to 1957 is $Q = 94.1 \pm 0.7$ keV (1957VA11). Reported widths are 4.5 ± 3 eV (1956RU41), 6.8 ± 0.6 eV (1962BA1C), ≤ 3.5 eV (1956HE57), > 0.1 eV (1955TR03): see Table 8.8. (1966BE05) find $Q = 92.12 \pm 0.05$ keV, $\Gamma = 6.8 \pm 1.7$ eV.

2. ^{4}He(α, n)^{7}Be $\qquad Q_m = -18.991 \qquad E_b = -0.095$

At $E_\alpha = 39$ MeV, $\sigma < 0.7$ mb (1952WA31).

3. ^{4}He(α, p)^{7}Li $\qquad Q_m = -17.347 \qquad E_b = -0.095$

See ^{7}Li.

4. ^{4}He(α, α)^{4}He $\qquad E_b = -0.095$

Reported differential cross section measurements are cited in Table 8.7. The course of the derived phase shifts with increasing energy from $E_\alpha = 0.15$ to 120 MeV is exhibited in (1956RU41, 1958NI05, 1960JO03, 1963TO02, 1965DA1A).

The s-wave phase shift, δ_0, decreases smoothly from $180°$ at 0.3 MeV. The absence of measurable effects in the range $E_\alpha = 0.15$ to 0.2 MeV yields an upper limit of 3.5 eV on the width of the ground state (1956HE57). Analysis of the $0 - 6$ MeV data leads to $\Gamma(\text{g.s.}) = 4.5 \pm 3$ eV (1956RU41), 6.8 ± 0.6 eV (1962BA1C): see Table 8.8.

Table 8.6: Electromagnetic transitions in ^{8}Be

Transition	Remarks	References
$16.6 \rightarrow 2.9$ $16.9 \rightarrow 2.9$	$\Gamma(\text{M1}) = 1.9 \pm 0.6$ eV	(1962NO02: (^{8}Li, ^{8}B))
$17.6 \rightarrow$ g.s.	$\Gamma(\text{M1}) = 16.7$ eV	(1949FO18, 1961ME10)
$17.6 \rightarrow 2.9$	$\Gamma(\text{M1}) = 8.2$ eV, $\Gamma(\text{E2}) = 0.15$ eV	(1961ME10)
$17.6 \rightarrow 16.6$	$\sigma(\text{p}, \gamma) = 6.5\ \mu$b	(1965WI07, 1965WIZZ)
$17.6 \rightarrow 16.9$	$\sigma(\text{p}, \gamma) = 0.4\ \mu$b	(1965WI07, 1965WIZZ)
$18.15 \rightarrow$ g.s.	$\Gamma \approx 1.8$ eV	(1954KR06, 1960MA23)
$18.15 \rightarrow 2.9$	$\Gamma \approx 3.6$ eV	(1954KR06, 1960MA23)
$19.05 \rightarrow 2.9$		(1957NE22, 1963PE15)
$21.6 \rightarrow$ g.s.	E1 giant res.: $\int \sigma \mathrm{d}E = 22$ MeV · mb	(1963MI08, 1963RE09)
$23.6 \rightarrow 2.9$	E1 giant res.	(1963MI08, 1963RE09)

Table 8.7: Measurements of dσ/dΩ in ^{4}He(α, α)^{4}He

E_α (MeV)	References	E_α (MeV)	References
$0.15 - 3.0$	(1956HE57)	$23 - 38$	(1959BR71)
$3.0 - 6.0$	(1956RU41)	$23 - 51$	(1964SH19)
$4.0 - 12.0$	(1963TO02)	30	(1951GR45, 1952GR1A)
$5.0 - 9.0$	(1960JO03)	33.5, 35.5	(1961CH09)
$6.4 - 7.8$	(1960BE05, 1961DU01)	38.5	(1957BU13)
$10 - 20$	(1964WE1C)	$37 - 47$	(1960CO04, 1964CO1D, 1964CO27)
$12.3 - 22.9$	(1956NI20)	51	(1964VA1J)
$12.9 - 21.6$	(1953ST52)	$53 - 120$	(1965DA1A)
20, 20.4	(1951BR92, 1951MA1B)		

The d-wave phase shift becomes appreciable for $E_\alpha > 2.5$ MeV and passes through resonance at $E_\alpha = 6$ MeV ($J = 2^+$, $E_x = 3.18$ MeV, $\Gamma = 1.5$ MeV). The g-wave shift rises from $E_\alpha \approx 11$ MeV and indicates a broad $J^\pi = 4^+$ level at $E_x = 11.4$ MeV. The $l = 6$ and $l = 8$ phase shifts become active above $E_\alpha \approx 30$ and 50 MeV respectively. Dispersion formula fits are somewhat unsatisfactory, but indicate $J^\pi = 6^+$ and 8^+ levels at $E_x \approx 28$ and ≈ 57 MeV respectively. Both the excitation energies and the reduced widths for all five levels are approximately proportional to $J(J + 1)$ (1965DA1A).

Sharp oscillations in the excitation functions at $15°$ and $45°$ are observed corresponding to ^{8}Be*(16.6) and (16.9). Since no oscillations were observed at $27.8°$, these states are assigned $J^\pi = 2^+$ (1964SH19).

Optical model analysis of α-α scattering is discussed by (1960IG02, 1965DA1A); analysis in terms of two-nucleon forces is given by (1959VA1F, 1961SC1B). See also (1959BU07, 1959WI1F, 1960BI1E, 1961GO1T, 1961SH1F, 1962IG1B, 1962SH1F, 1963WI1H, 1964EN1C, 1965OK1B).

5. ^{6}Li(d, γ)^{8}Be $\qquad Q_m = 22.280$

Not observed: (1953SA1A, 1954SI07).

6. (a) ^{6}Li(d, n)^{7}Be $\qquad Q_m = 3.384 \qquad E_b = 22.280$

(b) ^{6}Li(d, n)^{4}He + ^{3}He $\qquad Q_m = 1.797$

The yield curve has been measured for $E_d = 0.06$ to 5.5 MeV (1952BA64, 1954HI34, 1956NE13, 1957SL01). A broad s-wave resonance is indicated at $E_d = 0.41$ MeV, $\Gamma = 0.45$ MeV (1952BA64, 1956NE13). The forward cross section rises from ≈ 22 mb/sr at $E_d = 1.1$ MeV to ≈ 57 mb/sr at 5.5 MeV without sharp resonances (1957SL01). Above $E_d = 0.6$ MeV, angular distributions indicate a strong admixture of stripping process (1956NE13).

Comparison of the yields n_0/n_1 (^{7}Be(0) and ^{7}Be*(0.43)) and p_0/p_1 (^{7}Li(0) and ^{7}Li*(0.48)) over the energy range $E_d = 0.4$ to 3.2 MeV shows that the angular distributions are closely similar for n and p. The yield ratios are also closely equal over this range, consistent with the assumption of charge symmetry. The ratio n_0/n_1 increases rapidly as E_d falls below 0.8 MeV, suggesting a change in the reaction mechanism there (1957WI24, 1963BI27, 1963CR08).

7. (a) ^{6}Li(d, p)^{7}Li $\qquad Q_m = 5.028 \qquad E_b = 22.280$

(b) ^{6}Li(d, p)^{4}He + ^{3}H $\qquad Q_m = 2.561$

Cross sections and angular distributions have been measured for $E_d = 30$ keV to 5.4 MeV (1959AJ76, 1963BI27, 1963ME09, 1964PA06). A broad maximum near $E_d = 1.0$ MeV is interpreted as indicating a level at $E_d = 0.4$ MeV (1950WH02). In the range $E_d = 1$ to 5 MeV there

Table 8.8: ^{8}Be parameters from ^{4}He(α, α)^{4}He

E_x (MeV)	J^π	$\Gamma_{c.m.}$	R (fm)	θ^2	References
g.s.	0^+	4.5 ± 3 eV [a]	5.7	0.15	(1956RU41)
			4.4	[0.40]	(1958NI05)
		6.8 ± 0.6 eV	3.5	1.7	(1962BA1C)
		$\lesssim 3.5$ eV			(1956HE57)
		6.8 ± 1.7 eV			(1966BE05)
2.9	2^+	2 MeV	5.0	0.7	(1956RU41)
3.1			3.5	1.32	(1960JO03)
3.18		1.5 MeV	3.5	1.27	(1963TO02)
3.13		1.8 MeV	3.5	2.46	(1962BA1C)
11.8	4^+		4.4	1.3	(1958NI05)
11.4 ± 0.3					(1959BR71)
11.3 ± 0.4					(1962CE01) [b]
≈ 14					(1960IG02)
16.6	2^+				(1964SH19)
16.9	2^+				(1964SH19)
≈ 28.5	6^+	≈ 20 MeV	≈ 4.5	≈ 1.8	(1964DA12, 1965DA1A)
≈ 57	8^+	≈ 73 MeV	4.5	≈ 4.1	(1964DA12, 1965DA1A)

[a] See also (1962BA1C).
[b] From ^{6}Li(α, d)^{8}Be.

is evidence for both direct interaction and compound nucleus formation (1963BI27, 1963ME09, 1964PA06): at back angles the (d, p_1) data show evidence of the $E_d = 3.7$ MeV resonance (see ^{6}Li(d, α)^{4}He). See also ^{6}Li(d, n)^{7}Be and (1964FE01).

8. ^{6}Li(d, d)^{6}Li $\qquad E_b = 22.280$

Excitation functions have been measured for $E_d = 2$ to 4.8 MeV; they do not show any clear resonance behavior (1964PA06). See also ^{6}Li.

9. ^{6}Li(d, t)^{5}Li $\qquad Q_m = 0.595 \qquad E_b = 22.280$

Table 8.9: Parameters of ^{8}Be*(2.9) [a]

E_x (MeV)	$\Gamma_{c.m.}$ (MeV)	R (fm)	γ^2 (MeV)	θ^2 [b]	Reaction	Reference
(3.18)	1.5	3.5	3.36	1.27	^{4}He(α, α) [c]	(1963TO02)
		4.48	2.65	3.4	^{7}Li(p, $\gamma\alpha$)	(1960GE07)
2.6 ± 0.15	0.7 ± 0.1				^{7}Li(p, γ)	(1963BA58)
3.1 ± 0.1	1.75 ± 0.1				^{7}Li(d, n)	(1964JO04)
	1.6 ± 0.4				^{7}Be(d, p)	(1959SP1A)
2.90 ± 0.06	1.53 ± 0.04	5.75	0.60	0.64	^{7}Be(d, p)	(1960KA17)
2.8 ± 0.1	0.8				^{9}Be(d, t)	(1955CU16)
	1.35 ± 0.15	5		0.082	^{9}Be(d, t)	(1959VL24)
2.90 ± 0.04	1.35 ± 0.15				^{9}Be(^{3}He, α)	(1963DO08)
3.06		5.5	0.62	0.60	^{10}B(d, α)	(1963PU02)
2.88 ± 0.08		4.48	3.0	≈ 2	^{10}B(d, α)	(1953TR04)
2.895 ± 0.028	1.45 ± 0.06				mean	

[a] Spectra from several reactions – e.g. ^{8}Li(β^-, α), ^{8}B(β^+, α), ^{11}B(p, α), ^{9}Be(p, d) – are reported "consistent with phase shifts of ^{4}He(α, α) scattering" and so support the parameters of Table 8.8.
[b] Units of $\frac{3}{2}(\hbar^2/\mu R^2)$.
[c] See Table 8.8.

The cross section for tritium production rises rapidly to 190 mb at 1 MeV, then more slowly to 290 mb near 4 MeV. There is evidence of deviation from isotropy near 0.4 MeV (1955MA20). See also ^{5}Li.

10. ^{6}Li(d, ^{3}He)^{5}He $\qquad Q_m = 0.839 \qquad E_b = 22.280$

See ^{5}He.

11. ^{6}Li(d, α)^{4}He $\qquad Q_m = 22.375 \qquad E_b = 22.280$

Cross sections and angular distributions have been measured for $E_d = 0.03$ to 12 MeV (1948HE01, 1950WH02, 1962HA15, 1962JE02, 1963AN10, 1963ME09, 1964MA2D, 1964PA06, 1965MA13). Maxima are observed at $E_d = 0.8$ MeV, $\Gamma_{lab} \approx 0.8$ MeV, and $E_d = 3.75$ MeV,

Table 8.10: Levels of ^{8}Be from ^{6}Li(d, α)^{4}He [a]

E_{res} (MeV)	E_λ(c.m.) (MeV)	E_x (MeV)	$\Gamma_{c.m.}$ [b] (MeV)	J^π	θ^2_d	θ^2_α
0.8	0.26	22.54	0.80	2^+	0.23	0.003
	1.74	24.02	1.36	0^+	0.75	0.09
3.75	2.95	25.23	0.27	2^+	0.025	0.022

[a] (1965FR02).

[b] Partial width, $\Gamma_{\lambda\lambda}$.

$\Gamma_{lab} \approx 1.4$ MeV. Analysis of the angular distributions in terms of two-level interference favors $J^\pi = 2^+$ for the upper level, and $J^\pi = 0^+$ or 2^+ for the lower (1963ME09, 1964PA06). The upper level appears to have a large deuteron width, $\theta^2_d \approx 0.2$, and small $\theta^2_\alpha \approx 0.025$ and $\theta^2_p < 0.005$ (1964PA06). A more elaborate analysis appears to require that both levels, $E_x = 22.54$ and 25.23 MeV, have $J^\pi = 2^+$ and that a third broad $J^\pi = 0^+$ level exist at $E_x = 24.02$ MeV (1965FR02): see Table 8.10. The same parameters give a good account of the data up to $E_d = 9.5$ MeV. There is no evidence of further resonances (1965MA13). See also (1959HA29, 1960HA14, 1963EL1D, 1963FR1G, 1964FE01).

12. ^{6}Li(t, n)^{8}Be $\qquad Q_m = 16.023$

See (1959AJ77, 1962SE1A).

13. ^{6}Li(^{3}He, p)^{8}Be $\qquad Q_m = 16.787$

At $E(^3\text{He}) = 1.2$ to 2 MeV, proton groups are reported corresponding to ^{8}Be(0), ^{8}Be*(2.9) and possibly ^{8}Be*(12.3) (1956MO19, 1956SC01). At $E(^3\text{He}) = 3.5$ to 4.2 MeV, groups with $Q = 0.163$, -0.143 and -0.854 MeV (± 10 keV) are observed, corresponding to the 16.6, 16.9 and 17.6 MeV states (1961ER01): see Table 8.11.

The differential cross sections for ground-state protons show backward peaking at $E(^3\text{He}) = 5$, 6 and 7 MeV, forward peaking at $E(^3\text{He}) = 13$ and 17 MeV, and both forwards and backward peaks in the intermediate region (1963MA02). Analysis of the angular distribution of protons leading to the $E_x = 16.6$ MeV level indicates stripping, with $L = 0$ and a large deuteron width (1963MO1K, 1964MO1L). See also (1963WE1B, 1965KA1F, 1965RO1R, 1965YO1D).

14. ^{6}Li(α, d)^{8}Be $\qquad Q_m = -1.567$

Table 8.11: ^{8}Be levels near 16 MeV

E_x [a] (MeV ± keV)	Γ (keV)	Reaction	Reference
16.624 ± 10	95 ± 20	^{6}Li(^{3}He, p)^{8}Be	(1961ER01)
16.627 ± 15	105 ± 30	^{9}Be(^{3}He, α)^{8}Be	(1961ER01)
16.635 ± 15	96 ± 20	^{9}Be(^{3}He, α)^{8}Be	(1963DO08)
16.623 ± 10	95 ± 20	^{10}B(d, α)^{8}Be	(1961ER01)
16.64 ± 15		^{7}Li(d, n)^{8}Be	(1960DI02)
16.67	190	^{7}Li(d, n)^{8}Be	(1957SL01)
16.4 ± 200	< 400	^{12}C(γ, α)^{8}Be	(1955GO59)
16.628 ± 5	97 ± 11	mean	
16.930 ± 10	85 ± 20	^{6}Li(^{3}He, p)^{8}Be	(1961ER01)
16.914 ± 12	88 ± 25	^{9}Be(^{3}He, α)^{8}Be	(1961ER01)
16.930 ± 15	80 ± 15	^{9}Be(^{3}He, α)^{8}Be	(1963DO08)
16.919 ± 10	85 ± 20	^{10}B(d, α)^{8}Be	(1961ER01)
16.9 ± 50		^{7}Li(d, n)^{8}Be	(1960DI02)
16.8 ± 200	< 300	^{12}C(γ, α)^{8}Be	(1955GO59)
16.923 ± 6	83 ± 10	mean	
17.641 ± 10	< 20	^{6}Li(^{3}He, p)^{8}Be	(1961ER01)
17.636 ± 10	< 15	^{9}Be(^{3}He, α)^{8}Be	(1961ER01)
17.641 ± 10		^{9}Be(^{3}He, α)^{8}Be	(1963DO08)
17.61	< 20	^{7}Li(d, n)^{8}Be	(1957SL01)
17.639 ± 6		mean	

[a] Based on listed Q_m.

At $E_\alpha = 43$ MeV, deuteron groups corresponding to ^{8}Be(0) and ^{8}Be*(2.9) are reported (1959ZE1A); at $E_\alpha = 48$ MeV, an additional group ascribed to ^{8}Be*(11.3 ± 0.4) is observed (1962CE01). Angular distributions of d_0 and d_1 show forward peaking, with that of d_0 exhibiting pronounced oscillatory characteristics. Attempts to fit the observations with direct interaction theory are only moderately successful (1959ZE1A, 1962CE01). See also (1959ST30, 1962KO13, 1963BL20, 1963DE1G, 1963DE29, 1963WE1B, 1964DE1K).

15. ^{6}Li(^{6}Li, α)^{8}Be $\qquad Q_m = 20.808$

In addition to α-groups to the ground and 2.9 MeV states, there is evidence for a cluster reaction mechanism in which ^{6}Li combines with a deuteron cluster to produce a state of ^{8}Be at 20.95 ± 0.3 MeV, $\Gamma = 3.4$ MeV. At E(^{6}Li) $= 1.9$ MeV, the cross section is 1.3 mb, or 23 times that for ground-state alpha particles (1963KA20). On the other hand (1964QU01) find that the α-particle spectrum is consistent with the involvement of a ^{8}Be level near 22 MeV, with $\Gamma \approx 0.4$ MeV. See also (1962CO05). The ^{8}Be state decays by proton and α emission: $\Gamma_p/\Gamma_\alpha = 1.64$ (1962GA21). At E(^{6}Li) $= 3.2$ MeV, alpha groups corresponding to ^{8}Be* $= 16.6$, 16.9, (17.6), 18.15 MeV are reported (1964CA1G). See also (1960SH01, 1962CO21, 1963LE19, 1963TA1B, 1964GA1E, 1964SH05, 1965MA2A, 1965NO1A).

16. ^{7}Li(p, γ)^{8}Be $\qquad E_b = 17.252$

Cross sections and angular distributions have been reported from $E_p = 30$ keV to 14.5 MeV. Two γ-rays are observed, γ_0 to the ground state and γ_1 to the broad, 2^+, excited state at 2.9 MeV: $E_\gamma = (17.2,\ 14.3) + \frac{7}{8}E_p$. Resonances for both γ_0 and γ_1 occur at $E_p = 0.44$ and 1.03 MeV, and for γ_1 alone at 2 MeV (see, however, (1963PE15)): see Table 8.12. In the range $E_p = 2.5$ to 9 MeV, broad resonances are reported at $E_p \approx 5$ MeV (γ_0), $\Gamma \approx 5$ MeV (1959GE33, 1963MI08, 1963PE15 ($\Gamma = 5.5$ MeV)), at $E_p \approx 7.3$ MeV (γ_1), $\Gamma \approx 8$ MeV, and possibly at $E_p \approx 6$ MeV (γ_1). The $E_p \approx 5$ MeV resonance ($E_x \approx 21.6$ MeV) is presumed to represent the giant dipole resonance based on ^{8}Be(0), while the γ_1 resonance, 2.0 ± 0.5 (1963MI08), 3 ± 0.5 MeV (1963RE09) higher is similarly related to ^{8}Be*(2.9). Angular distributions from $E_p = 2.0$ to 7.5 MeV are approximately isotropic (except at 2.59 MeV), suggesting $l = 0$ capture (1963MI08, 1963PE15). The integrated (γ, p) cross section, determined by reciprocity is 22 ± 4 MeV · mb (1963RE09), 20 MeV · mb (1964TA05). See also (1965TA1E).

Angular distributions near the $E_p = 0.44$ MeV resonance show strong $\cos\theta$ interference terms which vanish at resonance. At resonance the radiation is nearly isotropic, consistent with p-wave formation, $J^\pi = 1^+$, with channel spin ratio $\sigma(J_c = 2)/\sigma(J_c = 1) = 5$. A detailed study of the angular distributions of γ_0 and γ_1 yields a small $\cos^2\theta$ term for γ_0: $A_2 = 0.067 \pm 0.025$ (1961ME10), $A_2 = 0.028 \pm 0.003$ (1958NE17, 1961BR02), while γ_1 is isotropic: $A_2 = -0.004 \pm 0.008$ (1961ME10); see, however, (1958NE17, 1961BR02). Analysis of these data together with γ-α correlations leads to Γ(E2)/Γ(M1) for $\gamma_1 = 0.018 \pm 0.009$ (1961ME10), 0.044 ± 0.014 (1960GR21).

Table 8.12: ^{8}Be levels from ^{7}Li(p, γ)^{8}Be

E_{res} (keV)	Γ_{lab} (keV)	^{8}Be*	l_p	J^{π}	σ_{max} (mb)	γ_0/γ_1	$w\Gamma_\gamma$ (eV)	References
441.4 ± 0.5 [a]	12.2 ± 0.5	17.64	1	1^+	6.0	1.9	9.4	(1949FO18, 1956BU27)
1030 ± 5	168	18.15	1	1^+		0.54	2	(1954KR06, 1960MA33, 1963RI09)
2060 ± 20	310 ± 20	19.05		(-) [d]	γ_1 only			(1957NE22, 1963PE15, 1963RI09)
5000	≈ 5000	21.6	(0)	(1^-)	0.05 [b]	0.5	[c]	(1959GE33, 1963MI08, 1963PE15)
(6000)		(22.5)			(γ_1)	0.3		(1963MI08)
7300	≈ 5500	23.6	(0)	$(1^-, 2^-)$	(γ_1)	0.2		(1963MI08, 1963PE15)

[a] See (1959AJ76).
[b] γ_0 only (1964TA05).
[c] $\int \sigma(\mathrm{p}\gamma_0) = 0.37 \pm 0.15$ MeV · mb (1963RE09).
[d] (1964SC19).

With $\Gamma_\gamma = 25$ eV, one obtains $\Gamma(\gamma_0) = 16.7$ eV, $\Gamma(\gamma_1$, M1$) = 8.15 \pm 0.07$ eV, $\Gamma(\gamma_1$, E2$) = 0.15 \pm 0.07$ eV. The observed E2 strength is about 15 times smaller than predicted by intermediate coupling shell model (1961ME10). See (1957KU58). The channel spin mixture $\sigma(2)/\sigma(1)$ is 3.2 ± 0.5 (1961ME10), 4.1 ± 0.1 (1958NE17).

The relative intensity of γ_0/γ_1 at resonance is 2.0 (1961ME10), 2.3 ± 0.04 (1960MA23: $\theta = 90°$), 1.8 ± 0.2 (1963BA58); the ratio falls rapidly above resonance and is approximately constant at 0.54 ± 0.08 for $E_p = 0.8$ to 1.0 MeV (1960MA23: see also (1961BR02)). There is evidence for an increase in the ratio at $E_p = 1.03$ MeV (1964SC19). At $E_p = 5.4$, 6.5, 7.5 and 8.6 MeV, the ratios are 0.5 ± 0.07, 0.3 ± 0.04, 0.2 ± 0.04 and 0.2 ± 0.04, respectively (1964TA05). Angular distributions in the range $E_p = 0.2$ to 1.1 MeV indicate interference with s-wave and d-wave non-resonant radiation (1960MA33: see also (1961BR02)); at $E_p = 1.03$ MeV the resonant radiation is isotropic, suggesting p-wave, $J = 1^+$, $\sigma(2)/\sigma(1) = 5$ (1960MA33).

Angular distributions from $E_p = 0.8$ to 1.7 MeV appear to require interference of the $E_p = 0.44$ and 1.03 (1^+) MeV levels with at least two odd-parity levels, possibly those at $E_p = 2.1$ and 5.8 MeV (1964SC19).

A pair-spectrometer measurement yields $E_\gamma = 17.647 \pm 0.015$ MeV for γ_0 at the $E_p = 440$ keV resonance: from the spectrum of γ_1 an excitation energy of $E_x = 2.6 \pm 0.15$, $\Gamma = 0.7 \pm 0.1$ MeV is obtained for the first excited state (1963BA58). See Table 8.9.

At $E_p = 440$ keV, α-particles from ^{8}Be*(16.63) are observed, indicating the existence of the γ-transition ^{8}Be*($17.64 \rightarrow 16.63$). The total resonant cross section is 6.45 ± 0.7 μb (1965WIZZ). The coincidence spectrum at resonance shows the 1.02 MeV γ-ray ($17.64 \rightarrow 16.63$), and a weak branch (5.9 ± 2)% (1965WI07), (7.5 ± 2)% (1965KO05), to the 16.92 MeV state. There is no indication of resonance in the yield of α-particles from ^{8}Be*(16.6) at $E_p = 1.03$ MeV (1965WI07). Evidence from this and other reactions involving ^{8}Be*(16.6) and (16.9) indicates that neither has a pure isospin character (1965KO05, 1965MA1G). See also (1964PA13).

A careful study of γ-α coincidence spectra at $E_\mathrm{p} = 441$ keV reveals only the 2.9 MeV level in the range $E_\mathrm{x} = 2$ to 7 MeV; the α-spectra can be matched with a single-level dispersion formula with $E_\lambda = 5.95$ MeV, $\gamma_\alpha^2 = 11.9$ MeV $\cdot$ fm, $\theta^2 = (1.7)$, $R = 4.48$ fm (1960GE07). A report of other γ-α groups by (1962CA13) is ascribed to contamination (1964MA25, 1964MI10, 1964PR04, 1964WE1C).

For a review of earlier work, see (1959AJ76). See also (1960SI10, 1960SI1D, 1963FE03, 1963SC1N, 1963TR08)

17. ^{7}Li(p, n)^{7}Be $\qquad Q_\mathrm{m} = -1.644 \qquad E_\mathrm{b} = 17.252$

This reaction is widely used as a source of monochromatic neutrons: see summary by (1960GI1A). The threshold is $E_\mathrm{p} = 1880.36 \pm 0.22$ keV (1963MA1R: see ^{7}Be); a second threshold, for neutrons leading to ^{7}Be*(0.43), occurs at $E_\mathrm{p} = 2376 \pm 2$ keV (1960MA1G), and above $E_\mathrm{p} = 7$ MeV, neutrons corresponding to ^{7}Be*(4.55) may be produced (1963BO06).

Reaction cross sections and angular distributions have been reported by (1948TA16: to 2.55 MeV), (1964BU08: 2.4 to 3.0 MeV; n$_1$), (1957NE22, 1958MA07: to 5.5 MeV), (1959GA08: to 3.25 MeV), (1961BE05: 2.6 to 4.2 MeV; n$_0$ and n$_1$ groups separately), (1961NI04: 2.7 to 3.5 MeV), (1963BO06: 3 to 13 MeV; n$_0$, n$_1$, n$_2$), (1964BA16: 4 to 14 MeV) and by (1960HI04: 8 to 14 MeV; n$_0$, n$_1$, n$_2$). See also (1959AJ81, 1960GI1A, 1962AU01, 1963PA1K). The yield of ground state neutrons (n$_0$) rises steeply from threshold and shows pronounced resonances at $E_\mathrm{p} = 2.25$ ($\sigma \approx 0.57$ b) and 4.9 MeV ($\sigma \approx 0.36$ b) (1963BO06). The yield of n$_1$ also rises steeply from threshold (1964BU08) and exhibits a broad maximum near $E_\mathrm{p} = 3.5$ MeV (1961BE05).

The behavior of the cross section near the n$_0$ threshold indicates a broad resonance with $J^\pi = 2^-$, $T = (0)$, $(l = 0)$ at $E_\mathrm{p} = 1.9$ MeV with $\gamma_\mathrm{n}^2/\gamma_\mathrm{p}^2 \approx 5.0$ (Table 8.13). The structure at $E_\mathrm{p} = 2.25$ MeV is ascribed to a 3^+, $T = (1)$, $l = 1$ resonance with $\Gamma_\mathrm{n} \sim \Gamma_\mathrm{p}$ and $\gamma_\mathrm{n}^2/\gamma_\mathrm{p}^2 = 3$ to 10 (1957NE22, 1958MA07, 1959WE1A, 1960GI1A, 1961BE05). The broad peak at 4.9 MeV can be fitted by $J^\pi = 3^{(+)}$ with $\Gamma = 1.1$ MeV, $\gamma_\mathrm{n}^2 \sim \gamma_\mathrm{p}^2$ (1963BO06). An additional resonance at $E_\mathrm{p} = 3.0$ MeV may be indicated (1957NE22, 1961BE05). The behavior of the n$_1$ cross section can be fitted in terms of a single level with $J^\pi = 1^-$ at $E_\mathrm{p} = 3.55$ MeV (1964BU08).

Polarization of the neutrons has been measured by (1961DA04, 1962EL01: 2.0 to 2.4 MeV), (1959CR84: 3.5 to 5 MeV), (1961AU02: 2 to 3 MeV), (1965MO1L: 3.1 to 3.3 MeV), (1965AN09: 3.0 to 4.0 MeV), (1959BA34, 1960BA27: 3 to 6 MeV), (1963MI01, 1963MI06, 1963MI20, 1964MI14: 4 to 5 MeV), (1962BE11: 4 to 10 MeV) and others (1959AJ76, 1963HA1G). Dominant effects are ascribed to the narrow 3^+ level at $E_\mathrm{p} = 2.25$ MeV and a broad 2^- background level. At least one level is needed near threshold, and at the higher energies ($E_\mathrm{p} > 2.6$ MeV) two additional levels are indicated (1961AU02).

Neutron spectra and polarizations have been measured at $E_\mathrm{p} = 143$ MeV by (1962BO33, 1963BO1N). Some contribution from quasi-free scattering is indicated: see (1963VA1C, 1965VA23).

18. ^{7}Li(p, p)^{7}Li $\qquad E_\mathrm{b} = 17.252$

Table 8.13: ^{8}Be levels from ^{7}Li(p, n)^{7}Be

E_p (keV)	Γ_{lab} (keV)	^{8}Be*	l_p	J^π	σ_{max} (b)	γ_n^2/γ_p^2	References
1900	> 500	18.91	0	2^-		≈ 5.0	(1957NE22, 1961BE05)
2250	220	19.22	1	3^+	0.57	5.2	(1957NE22, 1961BE05)
(3000)	> 1000	(19.9)	(1)	(1^+)	(n_0)	(5)	(1957NE22, 1961BE05)
3550	1300	20.36	(0)	(1^-)	(n_1)	5.2	(1961BE05, 1964BU08)
4900	1100	21.5		$3^{(+)}$	0.36	≈ 1	(1959GI47, 1963BO06)

Absolute differential cross sections are reported for $E_p = 0.4$ to 12 MeV (1953WA27, 1956MA12, 1965GL03) and for $E_p = 14.5$, 20.0 and 31.5 MeV by (1956KI54). Anomalies appear at $E_p = 0.44$, 1.03, 1.88, 2.1, 2.5, 4.2 and 6.0 MeV (see Table 8.14). Both the 0.44 and 1.03 MeV resonances are ascribed to p-waves, $J = 1^+$, with channel spins 1 and 2 in a ratio of 1 to 5 (1953CH1A, 1955LI1B: compare ^{7}Li(p, γ)^{8}Be). The structure at $E_p = 2.1$ MeV may indicate a state with $J^\pi \leq 3^+$ (1956MA12), 3^- (1957NE22). The $E_p = 4.2$ MeV resonance is ascribed to an almost pure single-particle level in ^{8}Be at 20.9 MeV (1965GL03).

The polarization of 14.5 and 40 MeV protons scattered from ^{7}Li has been studied by (1962RO20) and (1963HW01). See also (1961RO20).

See also (1961JO17, 1961JO18, 1965AN12) and (1959AJ76).

Table 8.14: ^{8}Be levels from ^{7}Li(p, p)^{7}Li and ^{7}Li(p, p$'$)^{7}Li*

E_p (keV)	Γ_{lab} (keV)	^{8}Be*	l_p	J^π	$\Gamma_{p'}$ (keV)	References
441	12.2 [b]	17.64	1	1^+		(1953CH1A, 1953WA27)
1030 ± 5	168	18.15	1	1^+	≈ 6	(1954MO04, 1955LI1B)
1880 [a]						(1956MA12, 1957NE22)
2100	≈ 0.4	19.0		(3) [c]	small	(1956MA12, 1957NE22)
2250		19.22		3^+	small	(1956MA12, 1957NE22)
4200 ± 200	1800 ± 200	20.9		4^-	(res)	(1965GL03)
5600		22.2				(1965GL03)

[a] (p, n) threshold.
[b] $\theta_p^2 = 0.064$.
[c] (1957NE22: 3^-), (1956MA12: ≤ 3).

19. ^{7}Li(p, p′)^{7}Li* $E_b = 17.252$

A pronounced resonance appears in the yield of inelastically scattered protons (1951BR10, 1954MO04) and 0.48 MeV γ-rays (1954KR06) at $E_p = 1.03$ MeV (see Table 8.14); it is an s- or p-wave resonance interfering with a non-resonant wave of opposite parity (1954MO04: see also (1955LI1B)). Excitation functions for the proton group to the 0.48 MeV state have been measured for $E_p = 2.3$ to 12 MeV: a peak is observed at 5.6 MeV (1965GL03). See also (1964FA08). The yield of 0.48 MeV γ-rays rises smoothly from $E_p = 1.5$ to 3.0 MeV except for a pronounced cusp at 1.881 MeV (1955HA34, 1957NE22). See also (1962CA13).

20. ^{7}Li(p, d)^{6}Li $Q_m = -5.028$ $E_b = 17.252$

See ^{6}Li.

21. ^{7}Li(p, t)^{5}Li $Q_m = -4.433$ $E_b = 17.252$

See ^{5}Li.

22. ^{7}Li(p, α)^{4}He $Q_m = 17.347$ $E_b = 17.252$

Excitation functions and angular distributions have been reported by (1962LU01: 0.4 to 3.3 MeV), (1948HE01: 0.5 to 3.8 MeV), (1958CO62: 0.1 to 0.6 MeV), (1963SA10: 3.0 to 5.5 MeV), (1962CA12: 1.5 to 4.8 MeV), (1960AL18: 12 MeV), (1961HA27: 2.8 to 12 MeV), (1962TE04, 1962TE07: 3.3 to 6.6 MeV), (1964MA51: 4 to 12 MeV), (1962MA40: 15, 18.6 MeV) and (1962CA13, 1963CA1K: 0.5 to 2.5 MeV; see, however, (1964MA25, 1964MI10)). Polarization effects have been studied by (1964AN08: 0.5 to 2.0 MeV), (1962BE14: 1 to 3.2 MeV), (1964AS04: 2 to 3.5 MeV), (1965BO07: 3.2 to 5.3 MeV).

A broad resonance occurs at $E_p = 3.0$ MeV, $\Gamma \approx 1$ MeV, $\sigma_{max} \approx 90$ mb (1948HE01): see Table 8.15. A second prominent peak appears at $E_p = 5.6$ MeV, $\Gamma \approx 1$ MeV (1961HA27, 1962TE04, 1964MA51). Some structure is reported near $E_p = 6.0$ to 6.5 MeV, and a further peak occurs at $E_p = 9.0$ MeV (1964MA51).

An earlier suggestion that a $J = 0$ resonance near $E_p \approx 0$ is involved appears to be contradicted by polarization data (1962BE14). The states at $E_x = 19.9$ MeV and 22.1 MeV ($E_p = 3.0$ and 5.5 MeV resonances) appear to have $J = 2^+$ (1959AJ76, 1961HA27, 1962TE04, 1962TE07, 1965FR02) and to have ^{6}Li + d parentage (1962TE01, 1965FR02). Levels at $E_x = 23$ MeV ($E_p = 6.5$ MeV) and 25.2 MeV ($E_p = 9.0$ MeV) are assigned $J^\pi = 4^+$ and 2^+, respectively (G. Temmer, private communication).

See also (1960BO13, 1962PE20, 1962WE13, 1963AN09, 1964MA2D).

Table 8.15: ^{8}Be levels from ^{7}Li(p, α)^{4}He

$E_{\rm res}$ (MeV)	Γ (MeV)	^{8}Be*	$J^{\pi}; T$	References
3.0	≈ 1	19.9	$2^{+}; 0$	(1948HE01)
5.6	≈ 1	22.1 [a]	(2^{+})	(1961HA27, 1962TE04, 1964MA51)
6.5		23	(4^{+})	(1961HA27, 1964MA51)
9.0		25.1	(2^{+})	(1964MA51)

[a] Possibly same as $E_{\rm x} = 22.5$ seen in ^{6}Li(d, α): see (1965FR02).

Table 8.16: Slow neutron thresholds in ^{7}Li(d, n)^{8}Be (1957SL01)

$E_{\rm d}$ (MeV)	$\Gamma_{\rm c.m.}$ (MeV)	^{8}Be* (MeV)
1.35	0.31	(16.08)
2.10	0.19	16.66
3.32	< 0.02	17.61
4.08	0.23	18.20

23. ^{7}Li(d, n)^{8}Be $\qquad Q_{\rm m} = 15.028$

For $E_{\rm d} = 3.6$ to 7.3 MeV, neutron time-of-flight spectra indicate states in ^{8}Be at 0, 2.9, 16.64 ± 0.015, 16.9 ± 0.05, 17.64 and 18.15 MeV. Angular distribution of neutrons corresponding to the 16.6, 17.6 and 18.15 MeV states are strongly forward; $l_{\rm n} = 1$ for the 16.6 MeV state, consistent with $J = 2^{+}$ (1960DI02). At $E_{\rm d} = 2$ MeV, recoil proton spectra show only the ground state and $E_{\rm x} = 2.9$ MeV groups; in the range $E_{\rm x} < 9$ MeV, no others appear with intensity > 10% of the ground-state group. The spectrum yields $E_{\rm x} = 3.1 \pm 0.1$, $\Gamma = 1.75 \pm 0.1$ MeV; comparison with the shape calculated from known α-α phase shifts suggest a considerable contribution of three-body processes (1964JO04). Reported slow neutron thresholds are listed in Table 8.16. See also (1964JO1D, 1964JO1F, 1965DI1F).

Alpha-particle spectra indicate groups corresponding to the break up of ^{8}Be*(16.6) and (16.9) (1963BI22, 1963PA04, 1964GL03). Alpha particles attributed to ^{8}Be*(11.4) are also reported (1963PA04). In the range $E_{\rm x} = 15.0$ to 18.5 MeV, no α-emitting states other than the 16.6 and 16.9 MeV levels are observed (1964GL03). See also (1965BI1F, 1965JO19, 1965MA1G, 1965MA1K).

A large number of additional states with $E_{\rm x} < 16.1$ MeV has been suggested in addition to ^{8}Be*(0, 2.9, 11.4): for a listing of early references, see (1959AJ76, 1964JO04). See also (1958CA1E, 1960AG03, 1960JU04, 1963MI1M, 1964MI1J).

24. ^{7}Li(^{3}He, d)^{8}Be $Q_{\rm m} = 11.759$

At $E(^3$He$) = 24.3$ MeV, angular distributions of deuterons corresponding to the ground and first excited states of ^{8}Be have been measured (1963WE1B). At $E(^3$He$) = 9$ to 10 MeV, excitation of ^{8}Be*(17.6) is observed (1965GR08). See also (1964DU1E).

25. ^{7}Li(α, t)^{8}Be $Q_{\rm m} = -2.562$

The angular distributions of the tritons to the ground state of ^{8}Be have been determined at a number of energies up to 48 MeV; the distributions indicate strong contribution of direct interaction (1959ST1B, 1960GO04, 1960MA15, 1960VL03, 1962MA59, 1963WE1B). At $E_\alpha = 40$ MeV, higher states are also observed (1960VL03).

26. ^{7}Li(^{7}Li, ^{6}He)^{8}Be $Q_{\rm m} = 7.272$

See (1957NO17, 1964CA16).

27. (a) ^{7}Be(n, p)^{7}Li $Q_{\rm m} = 1.644$ $E_{\rm b} = 18.896$
(b) ^{7}Be(n, α)^{4}He $Q_{\rm m} = 18.991$
(c) ^{7}Be(n, $\gamma\alpha$)^{4}He

At thermal energies, the (n, p) cross section is $(5.1 \pm 0.6) \times 10^4$ b (1955HA34), the (n, α) cross section is ≤ 0.1 mb (1962BA1B, 1963BA34) and the (n, $\gamma\alpha$) cross section is 155 mb (1963BA34). These observations are consistent with odd parity of ^{7}Be; the small value of σ(n, α) leads to an estimated $F^2 < 4 \times 10^{-10}$ for the intensity of a positive parity admixture (1963BA34). Comparison of the thermal cross section for reaction (a) with the (p, n) cross section observed in the inverse reaction supports the assignment $J = \frac{3}{2}$ for ^{7}Be(0) (1957NE22). See also (1959AJ76).

28. ^{7}Be(d, p)^{8}Be $Q_{\rm m} = 16.672$

For $E_{\rm d} = 0.8$ to 1.7 MeV, proton groups are observed corresponding to the ground state and the 2.9 MeV level: $\Gamma(2.9) = 1.6 \pm 0.4$ (1959SP1A), 1.53 ± 0.04 MeV (1960KA17). A dispersion formula fit yields parameters $E_{\rm x} = 2.90 \pm 0.06$ MeV, $\gamma^2 = 0.60$ MeV, $\theta^2 = 0.64$, $R = 5.75$ fm (1960KA17): see Table 8.9.

Table 8.17: α-β angular correlation coefficients [a] in ^{8}Li, ^{8}B

Nuclide	A/W_β	B/W_β	W_β (MeV)	Reference
^{8}Li		$(5.7^{+2.9}_{-1.9}) \times 10^{-3}$	7.0	(1960KR03)
^{8}Li	$(-8.7 \pm 0.7) \times 10^{-3}$	$(+3.16 \pm 0.6) \times 10^{-3}$	11	(1962NO02)
^{8}Li	$(-8.3 \pm 1.1) \times 10^{-3}$	$(+3.7 \pm 1.0) \times 10^{-3}$	7.5	(1963GR11)
^{8}B	$(-8.7 \pm 0.9) \times 10^{-3}$	$(-3.86 \pm 1.0) \times 10^{-3}$	11	(1962NO02)

[a] $W(\theta) = 1 + A\cos\theta + B\cos^2\theta$.

29. ^{8}Li(β^-)^{8}Be $\qquad Q_{\rm m} = 16.002$

^{8}Li decays mainly to the broad 2.9 MeV, 2^+ level of ^{8}Be, which decays into two α-particles. The β-spectrum, which extends to $\gtrsim$ 14 MeV, has been studied by (1950HO01), (1960FA02) and others, while the α-spectrum, extending to $\approx$ 10 MeV, has been reported by (1938RU01, 1948BO20, 1955FR29, 1960BI10, 1960BI06, 1960FA04, 1961DE1E) and others: see (1955AJ61). The two spectra correspond well, except perhaps for low β-energies (1960GR10). For $E_\alpha \lesssim 5$ MeV, the spectrum is closely matched by a density-of-states derived from the experimental d-wave phase shift of α-α scattering; at higher energies, an increasing excess of α-particles appears which may reflect transition into the tail of the $J^\pi = 2^+$ level at $E_{\rm x} = 16.67$ MeV (1960GR10, 1963AL19, 1963DA05). See also ^{8}B(β^+).

Studies of the distribution of recoil momenta and neutrino-recoil correlation indicate that the decay is at least 90% GT, and that the GT portion is at least 90% axial vector. The observations indicate $J = 2^+$ for ^{8}Li (1958BA1E, 1958LA08, 1959LA11, 1959LA05).

The angular correlations $W(\theta_{\beta\alpha})$ have been measured for the decays of ^{8}Li and ^{8}B as a test of the conserved vector current theory of β-decay. The observed correlation is of the form $W(\theta) = 1 + A\cos\theta + B\cos^2\theta$; reported values of A and B are listed in Table 8.17. With shell model calculations of the matrix element Γ_γ(M1) for ^{8}Be*$(T = 1) \rightarrow {}^8$Be*(2.9 MeV), the CVC theory predicts $\delta \equiv B(^8\text{Li}) - B(^8\text{B}) = (7 \pm 2) \times 10^{-3}\ W_\beta$ (1960KU05, 1960WE1A); conversely, if CVC is assumed correct, the experiment yields Γ(M1) $= 1.9 \pm 0.6$ eV (1962NO02). See also (1963IS04).

See also (1958KE1B, 1959JA1B, 1960NO01, 1960NO05, 1960ST23, 1961FO1C, 1963DA05, 1963HU1G, 1963LE1K, 1964TO1D).

30. ^{8}B(β^+)^{8}Be $\qquad Q_{\rm m} = 17.979$

The decay proceeds mainly to ^{8}Be*(2.9). The α and β spectra correspond closely to those of ^{8}Li, when account is taken of the different Q-values (1960FA04). The ratio $ft(^8\text{B})/ft(^8\text{Li}) = 1.096$

(1964TO1D). Detailed study of the high energy portion of the α-spectrum reveals a maximum near $E_\alpha = 8.3$ MeV, corresponding to transitions to ^{8}Be*(16.62). The observed shape is reproduced with a Breit-Wigner density-of-states function with parameters $E_x = 16.67$ MeV, $\Gamma = 150$ to 190 keV; parameters $E_x = 16.62$, $\Gamma = 95$ keV are less good, but acceptable. With the former set, $\log ft = 2.9$ (using $\tau_{1/2} = 0.774 \pm 0.005$ sec); with the latter, $\log ft = 3.03$. In either case, the low ft-value supports the identification $T = 1$, $J = 2^+$ for ^{8}Be*(16.63) (1964MA35). See, however, (1965MA1G).

See also (1960FA02, 1960GR10, 1963DI17) and see ^{8}Li(β^-)^{8}Be for a discussion of the work on β-α angular correlations.

31. (a) ^{9}Be(γ, n)^{8}Be $\qquad Q_m = -1.665$
(b) ^{9}Be(n, 2n)^{8}Be $\qquad Q_m = -1.665$
(c) ^{9}Be(α, αn)^{8}Be $\qquad Q_m = -1.665$

For reaction (a), see ^{9}Be. The (n, 2n) reaction appears to proceed largely via excited states of ^{9}Be, with subsequent decay to ^{8}Be, mainly ^{8}Be*(2.9) (1959CH1E, 1961MY01, 1963JE05, 1964BO31): see ^{9}Be and ^{10}Be. For reaction (c), see (1962ST12) and ^{9}Be. See also (1959WI41, 1960KO1G, 1961JE01, 1962CU05, 1965LO1K).

32. ^{9}Be(p, d)^{8}Be $\qquad Q_m = 0.559$

At $E_p = 5.2$ MeV, the α-spectrum shows a sharp ground-state group α_0, and a broad group, α_1, corresponding to ^{8}Be*(2.9). A pronounced anomaly appears at $E_x \approx 0.75$ MeV, on the side of the α_1 group, which is apparently a "ghost" of α_0. A quantitative account is given with a density-of-states function derived from α-α scattering phase shifts (1961BE1E: see also (1962BA1C, 1962HA23, 1963AL19)).

At $E_p = 95$ to 155 MeV, ^{8}Be states at 0, 2.9, 11.4, 16.6, 18.8 and (23) MeV are excited (1956SE1A, 1963BA1R, 1963RA01). See also (1959AJ76, 1959FI1B, 1960PH1B, 1964SH07, 1964TO1D, 1964YA1A), ^{9}Be and ^{10}B.

33. (a) ^{9}Be(d, t)^{8}Be $\qquad Q_m = 4.592$
(b) ^{9}Be(d, t)^{4}He + ^{4}He $\qquad Q_m = 4.687$

Angular distributions of ground-state tritons have been measured at a number of energies up to 20 MeV: see (1959AJ76) and (1959VL24, 1960NE09, 1960NE11, 1961RE03, 1962BI11, 1965JA07). The width of the 2.9 MeV state is 0.8 MeV (1955CU16), 1.35 ± 0.15 MeV (1959VL24).

See also (1959FI1B, 1959KU1C, 1959ZA01, 1962HA23, 1963OG1A).

34. ^{9}Be(^{3}He, α)^{8}Be $\qquad Q_{\rm m} = 18.913$

At $E(^3{\rm He}) = 3.0$ and 4.0 MeV, angular distributions of the α-particles to the ground-state of ^{8}Be and to the levels at 2.9, 16.6, 16.9 and 17.6 MeV have been measured. The excitation energy and width of the first excited state are found to be 2.90 ± 0.04 MeV and 1.35 ± 0.15 MeV (1963DO08): see Table 8.9. The parameters of the higher states (from (1961ER01) and (1963DO08)) are given in Table 8.11. The angular distributions are amenable to analysis by direct interaction except in the case of the 16.6 MeV state which appears to involve compound nucleus formation (1963DO08) (compare ^{7}Li(d, n)^{8}Be). For angular distribution data at lower energies, see (1955AJ61) and (1963WE08).

The α-particles corresponding to the 2.9 MeV excited state are superposed on a broad, intense continuum extending to $E_{\rm x} > 16$ MeV. Some part of this spectrum may be ascribed to a broad level at $E_{\rm x} = 12.5$ MeV, with $\Gamma \approx 5$ MeV, but the main contribution appears to be due to a direct 3α breakup (1963DO11: see also (1963WE08)). (1964MO19) find, on the other hand, that the sequential decay, via ^{8}Be*(2.9) and (16.93) dominates the reaction. See, however, (1965MO1M). Angular correlation studies confirm $J^\pi = 2^+$ for ^{8}Be*(16.9) (1964MO19, 1965MO1N).

See also (1962WE1C, 1964BL12, 1965MA1G).

35. (a) ^{9}Be(^{6}Li, ^{7}Li)^{8}Be $\qquad Q_{\rm m} = 5.587$
(b) ^{9}Be(^{7}Li, ^{8}Li)^{8}Be $\qquad Q_{\rm m} = 0.367$

For reaction (a) see (1960MA1H, 1961LE1K). For reaction (b) see ^{9}Be.

36. ^{10}B(γ, d)^{8}Be $\qquad Q_{\rm m} = -6.028$

See ^{10}B and (1955AJ61).

37. ^{10}B(n, t)^{8}Be $\qquad Q_{\rm m} = 0.229$

Angular distributions of the tritons to the ground and 2.9 MeV states of ^{8}Be have been measured at $E_{\rm n} = 14.4$ MeV (1964VA14). See also (1959AJ76, 1964VA1E) and ^{11}B.

38. (a) ^{10}B(p, ^{3}He)^{8}Be $\qquad Q_{\rm m} = -0.534$
(b) ^{10}B(p, pd)^{8}Be $\qquad Q_{\rm m} = -6.028$

See ^{11}C and (1964BA1C).

39. (a) ^{10}B(d, α)^{8}Be $\qquad Q_{\rm m} = 17.819$
(b) ^{10}B(d, α)^{4}He + ^{4}He $\qquad Q_{\rm m} = 17.914$

Alpha groups are reported corresponding to ^{8}Be states at 0, 2.9 (1960BE15, 1960BI11, 1961CI02, 1961LE10, 1963PU02, 1964YA1A; and see (1959AJ76)), 16.6 and 16.8 MeV (1961ER01: see Table 8.11). A coincidence study of the α_1 group yields the following parameters for the level shape: $E_{\rm res} = 3.15$ MeV, $\Gamma = 2.04$ MeV, $E_\lambda = 4.00$ MeV, $\gamma^2 = 3.4$ MeV · fm, $\theta^2 = 0.60$, $R = 5.5$ fm (1963PU02: E relative to $E(2\alpha)$). (1953TR04) reports $E_\lambda = 5.29$ MeV (relative to 2α), $\gamma^2 = 13.4$ MeV · fm, $\theta^2 \approx 2$, $R = 4.48$ fm: see Table 8.9.

Arguments are presented for the assignments $J = 2^+$, $T = 1$ for $E_{\rm x} = 16.63$ and $J^\pi = 0^+$ or 2^+, $T = 0$ for $E_{\rm x} = 16.93$ MeV. Comparison of yields with ^{6}Li(^{3}He, p)^{8}Be* indicates gross violation of the isospin selection rule, possibly to be ascribed to intermixture in the compound nucleus stage (1961ER01). See, however, (1965MA1G). There is no evidence for an earlier reported level at $E_{\rm x} = 16.08$ MeV (1961ER01). See also (1961TE02, 1962TE02, 1965LE09).

40. ^{10}B(^{3}He, pα)^{8}Be $\qquad Q_{\rm m} = 12.326$

See (1964ET02, 1965AL1B, 1965ET1A, 1965WA1M) and ^{12}C.

41. (a) ^{11}B(γ, t)^{8}Be $\qquad Q_{\rm m} = -11.226$
(b) ^{11}B(γ, t)^{4}He + ^{4}He $\qquad Q_{\rm m} = -11.132$

See ^{11}B.

42. ^{11}B(p, α)^{8}Be $\qquad Q_{\rm m} = 8.588$

Alpha groups are reported corresponding to the ground and 2.9 MeV state: see (1959AJ76) and (1962AL20). At $E_{\rm p} = 3$ to 5 MeV, the α-spectrum shows an anomaly at $E_{\rm x} \approx 0.75$ MeV, ascribed to successive two-body decays with a final density-of-states related to α-α scattering phase shifts (1961BE1E: see ^{9}Be(p, d)^{8}Be and (1963BR03, 1964BR05, 1964DE1H)). See also ^{12}C and (1959KA12, 1959KA13, 1961KO08, 1962BE21, 1963PH1A, 1964BA1C, 1964YA1A, 1965DU1C, 1965LE09, 1965PH1A, 1965SW1B).

43. ^{11}B(d, nα)^{8}Be $Q_m = 6.363$

See (1965OL01).

44. ^{11}B(^{3}He, ^{6}Li)^{8}Be $Q_m = 4.566$

At $E(^3\text{He}) = 3.0$ MeV, ^{8}Be*(2.9) is produced with an intensity 20 times that of the ground state (1964YO06).

45. (a) ^{12}C(γ, α)^{8}Be $Q_m = -7.369$
(b) ^{12}C(α, 2α)^{8}Be
(c) ^{12}C(p, pα)^{8}Be
(d) ^{12}C(n, nα)^{8}Be

Reaction (a) involves states of ^{8}Be at 0, 2.9, 16.6, 16.9 and (17.6) MeV: see (1955GO59, 1959AJ76, 1964TO1A). See also (1961SE13, 1963SH04, 1964LE1C).

At $E_\alpha = 25.4$ MeV, the four-body breakup ($^{12}\text{C} + \alpha \rightarrow 4\alpha$) is greatly favored over reaction (b) (1962BR14: see also (1961VA38, 1962VA25)). See also (1961GO1T, 1962IG1B, 1963LA02).

Reaction (c) at $E_p = 15$ to 29 MeV proceeds predominantly through the ground state and the 2.9 MeV level. It is not clear whether higher levels of ^{8}Be are involved (1955NE18, 1960VA10, 1962VA1A, 1963VA04). See also (1963JA07, 1964BA1C, 1964KE1F, 1964SY02, 1965YU1C, 1965YU1D).

For reaction (d) see (1955FR35, 1960VA10, 1964BR25).

See also ^{12}C.

46. ^{12}C(d, ^{6}Li)^{8}Be $Q_m = -5.897$

See (1963DR1B, 1964BL1C, 1964DA1B, 1965BE1W, 1965DE1V, 1965SL1C).

47. ^{12}C(^{3}He, ^{7}Be)^{8}Be $Q_m = -5.782$

See (1964PA1K, 1965MA1V).

48. ^{12}C(^{12}C, 6^{4}He) $Q_m = -14.549$

See (1962BE43, 1963BE1U).

49. ^{12}C(^{14}N, ^{18}F)^{8}Be $Q_{\rm m} = -2.953$

See (1965WI1A).

50. (a) ^{16}O(γ, α)^{12}C* $\rightarrow$ ^{8}Be + ^{4}He $Q_{\rm m} = -14.530$
(b) ^{16}O(α, ^{8}Be)^{12}C $Q_{\rm m} = -7.256$

For reaction (a) see (1955AJ61, 1959AJ76, 1964TO1E) and ^{12}C.
For reaction (b) see (1964BR1U) and ^{12}C.

51. ^{16}O(p, p$'$)^{4}He^{4}He^{4}He^{4}He $Q_{\rm m} = -14.436$

See (1962VA1A) and ^{16}O.

52. ^{20}Ne(α, ^{16}O)^{8}Be $Q_{\rm m} = -4.824$

This reaction has not been observed: see (1962LA15).

Table 8.18: Energy levels of ^{8}B

E_x (MeV ± keV)	$J^\pi; T$	Γ (keV)	Decay	Reactions
g.s.	$(2^+); 1$	$\tau_{1/2} = 774 \pm 4$ msec	β^+	1, 2
0.778 ± 7		42 ± 10		2
2.17 ± 50				2

^{8}B

(Figs. 13 and 14)

GENERAL: See (1958FO1C, 1960TA1C, 1962IN02, 1963NA1E, 1964BA1X, 1964BA2A, 1964GR1J, 1964ST1B).

1. ^{8}B(β^+)^{8}Be $\qquad Q_m = 17.979$

The beta decay leads mainly to ^{8}Be*(2.9). Reported half lives are listed in Table 8.19; taking $\tau_{1/2} = 0.774$ sec and $Q = 17.979 - 2.90$, $ft = 4.41 \times 10^5$ (1966BA1A). There is also observed a branch to a ^{8}Be state at ≈ 16.6 MeV; $\log ft = 2.9$ (1964MA35). See also (1964BA1X) and ^{8}Be.

2. ^{6}Li(^{3}He, n)^{8}B $\qquad Q_m = -1.975$

Thresholds for production of slow neutrons are reported at $E(^3\text{He}) = 2.9661 \pm 0.0017$ MeV (1958DU78), 2.974 ± 0.010 MeV (1959FA02), corresponding to the ground state of ^{8}B, and at $E(^3\text{He}) = 4.16 \pm 0.05$ (1958DU78), 4.159 ± 0.030 MeV (1959FA02), corresponding to an excited state at $E_x = 0.789 \pm 0.030$ MeV with $\Gamma_{\text{c.m.}} = 70 \pm 40$ keV. A threshold at 3.9 MeV reported by (1958DU78) is not confirmed by (1959FA02).

Neutron time-of-flight spectra at $E(^3\text{He}) = 4$ to 9 MeV show groups corresponding to ^{8}B(0) and ^{8}B*(0.8), with forward-peaked angular distributions, and to a new state at $E_x = 2.17 \pm 0.05$ MeV (1963DI02). At $E(^3\text{He}) = 4.5$ to 5.3 MeV, time-of-flight spectra locate the first excited state at 0.767 ± 0.012 (1965FA03), 0.783 ± 0.010 MeV (1965MC06: $\Gamma = 40 \pm 10$ keV). See also (1963MO1J).

3. ^{7}Be(p, γ)^{8}B $\qquad Q_m = 0.135$

Table 8.19: Half life of ^{8}B

$\tau_{1/2}$ (sec)	Reference
0.65 ± 0.1	(1950AL57)
0.61 ± 0.11	(1952SH44)
0.78 ± 0.01	(1958DU78)
0.75 ± 0.02	(1958VE20)
0.79 ± 0.02	(1959FA02)
0.774 ± 0.005	(1964MA35)
0.774 ± 0.004	mean

The cross section for proton capture is 0.48 ± 0.18 μb at $E_{\rm p} = 0.80$ MeV and 0.50 ± 0.20 μb at $E_{\rm p} = 1.40$ MeV (1960KA05). The relevance of this reaction in stellar energy production is discussed by (1958FO1C, 1960KA05, 1963BA2D, 1964BA2A, 1964PA1A). See also (1961CH1C).

4. (a) ^{10}B(p, t)^{8}B $\quad Q_{\rm m} = -18.532$
   (b) ^{9}Be(p, 2n)^{8}B $\quad Q_{\rm m} = -20.426$
   (c) ^{12}C(p, nα)^{8}B $\quad Q_{\rm m} = -26.130$

See (1950AL57).

5. (a) ^{10}B(γ, 2n)^{8}B $\quad Q_{\rm m} = -27.014$
   (b) ^{11}B(γ, 3n)^{8}B $\quad Q_{\rm m} = -38.470$
   (c) ^{12}C(γ, p3n)^{8}B $\quad Q_{\rm m} = -54.426$

See (1952SH44).

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(Closed July 01, 1965)

References are arranged and designated by the year of publication followed by the first two letters of the first-mentioned author's name and then by two additional characters. Most of the references appear in the National Nuclear Data Center files (Nuclear Science References Database) and have NNDC key numbers. Otherwise, TUNL key numbers were assigned with the last two characters of the form 1A, 1B, etc. In response to many requests for more informative citations, we have, when possible, included up to ten authors per paper and added the authors' initials.

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