Energy Levels of Light Nuclei
$A = 8$

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Abstract: An evaluation of $A = 5$–10 was published in *Nuclear Physics A*227 (1974), 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 introductory tables have been omitted from this manuscript. Reference key numbers have been changed to the TUNL/NNDC format.

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

GENERAL: (See also (1966LA04).)

Theoretical and review papers: (1969KR20, 1969SO08, 1970KR1G, 1970RY04, 1971LO13, 1971RY1A, 1971DO1F, 1972PN1A, 1972ST1C).

Experimental papers: (1966DE14, 1966PO09, 1967CO1K, 1967PO1D, 1968BA48, 1968BH1A, 1970CA1M, 1971CA47, 1972CA38, 1972VO06, 1973JU2A, 1973KO1D).

Mass of ^{8}He: The atomic mass excess of ^{8}He derived from the Q of the ^{26}Mg(α, ^{8}He)^{22}Mg reaction is 31.65 ± 0.12 MeV. See also (1968BA48). ^{8}He is then stable to decay into ^{6}He + 2n by 2.1 MeV (1966CE01). See also (1966BA38, 1968CE1A, 1972CE1A).

1. ^{8}He(β^{-})^{8}Li $\quad Q_{\rm m} = 10.70$

The half-life is 122 ± 2 msec. The decay takes place 88% to ^{8}Li*(0.98) [$\log ft = 4.20$; B. Zimmerman, private communication] and 12 ± 1% via ^{8}Li states decaying by neutron emission (1965PO06). See also (1966NE07) and (1973HA49; theor.).

2. ^{11}B(γ, 3p)^{8}He $\quad Q_{\rm m} = -44.85$

See (1966NE07).

3. ^{26}Mg(α, ^{22}Mg)^{8}He $\quad Q_{\rm m} = -45.05$

This reaction has been studied at $E_{\alpha} = 80$ MeV (1966CE01).

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

GENERAL: (See also (1966LA04).)

Shell model: (1966BA26, 1973HA49).

Special levels: (1966BA26, 1970FR1C).

Electromagnetic transitions: (1966BA26, 1972EV03, 1973HA49).

Table 8.1: Energy levels of ^{8}Li

E_x (MeV ± keV)	$J^{\pi}; T$	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
g.s.	2^+; 1	$\tau_{1/2} = 842 \pm 6$ msec	β^-	1, 2, 3, 10, 11, 14, 17, 18, 19, 20, 21, 23, 24, 25, 26, 27
0.9808 ± 0.1	1^+; 1	$\tau_m = 12 \pm 4$ fsec	γ	2, 3, 10, 13, 14, 15, 17, 18, 19, 21, 24, 25, 26
2.261 ± 2	3^+; 1	$\Gamma = 31 \pm 5$	γ, n	3, 4, 10, 14, 17, 18, 19, 25
3.21	1; 1	≈ 1000	n	5, 14
5.4	$(2^+, 3^+)$; 1	≈ 650	n	4, 5
6.1 ± 100		≈ 900	n	4
6.530 ± 20		< 40	(n)	4, 19
7.1 ± 100		≈ 350	n	4
(9.)		≈ 6000		14, 17

Special reactions: (1965AF1A, 1966BA1R, 1966KL1C, 1967AU1B, 1967GO1F, 1968GR1E, 1970AZ1A, 1971AG01, 1971DH1A, 1971KA1K, 1972VO06, 1973KO1D, 1973WI15).

Pion and kaon reactions: (1967ZE1A, 1968BA1M, 1968BE1R, 1968BH1A, 1969BA1L, 1970AG1B, 1970BA44, 1971DH1A, 1971VA1E, 1971VA19, 1972WE20, 1972BA1C, 1973GE1K).

Astrophysical questions: (1967MI1C, 1970BA1M).

Other topics: (1966TO04, 1967DI1B, 1971BA2Y, 1972AN05, 1972GA1L, 1972PN1A, 1973JU2A).

Ground state properties: (1966BA26, 1969PE1D, 1972VA36, 1973EN1B, 1973MA1K, 1973SU1B).

$J = 2$ (1973NE10);

$\mu = +1.65335 \pm 0.00035$ nm (1973HA12);

$\mu = +1.6532 \pm 0.0008$ nm (1959CO68, 1962CO08);

$\mu = +1.6530 \pm 0.0008$ nm (1967GU14). See also (1967SH14, 1969FU11, 1971SH26).

1. ^{8}Li(β^-)^{8}Be $\qquad Q_m = 16.006$

The β-decay leads mainly to ^{8}Be*(2.9): see ^{8}Be. Measurements of the half-life of ^{8}Li include $\tau_{1/2} = 841 \pm 4$ msec (1954KL36), 848 ± 5 msec (1960JA12), 844.0 ± 0.7 msec (1966CL02),

854 ± 8 msec (1968DA12), 838 ± 6 msec (1971WI05): $\tau_{1/2} = 842 \pm 6$ msec is adopted. [For other measurements see Table 8.2 in (1966LA04)]. See also (1968BO32). Taking $\tau_{1/2} = 842$ msec and $Q = 16.006 - 2.94$, $\log ft = 5.61$ (B. Zimmerman, private communication). See also (1966BA1A, 1969BA43). The distribution of recoil momenta indicates $J^\pi = 2^+$ (see ^{8}Be).

The coefficient for the angular correlation between β^-, $\bar{\nu}_e$ and α-particles, $b = -0.88 \pm 0.08$ (1965GR25), -1.01 ± 0.07 (1966EI02), in substantial agreement with $b = -1$, expected from axial vector coupling.

See also (1970SC34) and ^{8}Be.

2. ^{6}Li(t, p)^{8}Li $\quad Q_m = 0.801$

Transitions to ^{8}Li*(0, 0.98) have been observed: see (1966LA04). See also (1968CO1H).

3. ^{7}Li(n, γ)^{8}Li $\quad Q_m = 2.0327$

$Q_0 = 2032.78 \pm 0.15$ keV (E.T. Jurney, private communication);

$Q_0 = 2032.8 \pm 1$ keV (1967RA24).

The thermal capture cross section is 45.4 ± 3 mb. Neutron capture γ-rays are observed with $E_\gamma = 980.6 \pm 0.2$, 1052.0 ± 0.2 and 2032.5 ± 0.28 keV, with intensities of 10.6 ± 1, 10.6 ± 1 and 89.4 ± 1 γ/100 neutrons: $E_x = 980.7 \pm 0.2$ keV for the first excited state (E.T. Jurney, private communication). The cross section for capture radiation has been measured for $E_n = 40$ to 1000 keV: it decreases from 50 μb to 5 μb over that interval. The cross section shows the resonance corresponding to ^{8}Li*(2.26): $\Gamma_\gamma = 0.07 \pm 0.03$ eV (1959IM04). See also (1967GU14), (1966LA04) and (1970AU1B; astrophys. calculations).

4. ^{7}Li(n, n)^{7}Li $\quad E_b = 2.0327$

The thermal cross section is 1.07 ± 0.04 b (1960HU1A); the coherent scattering length (thermal, bound) is -2.1 ± 0.1 fm (1969BA1P, 1973MU14). Total cross-section measurements have recently been reported at $E_n = 0.010$ to 1.236 MeV (1968HI1E), 0.10 to 1.50 MeV (1970ME1C), 1.12 to 2.30 MeV (1968KN1B), 2.5 to 15.0 MeV (1971FO1A), 3.35, 4.83, 5.74 and 7.5 MeV (1968HO03: also σ_{el}), 10 MeV (1967CO01) and 0.6 to 30.0 MeV (C.A. Goulding, private communication, and (1973GO2B)). See also (1968EN1A, 1972PR03). Polarization measurements at $E_n = 4.4$ MeV are reported by (1966ST09; n_0). For earlier references see (1966LA04). See also (1966DA1B, 1972LA1F) and (1966AG1A, 1966SE1E, 1967BE1F, 1967HO1F; theor.). For angular distribution measurements see ^{7}Li and (1970GA1A).

Table 8.2: Resonance parameters for ^{8}Li*(2.26) (1970ME1C) [a,b]

$E_{\rm res}$ (keV)	261.2
$E_{\rm x}$ (MeV) [c]	2.261
Γ (keV)	35 ± 5 [d]
$\Gamma_{\rm n}(E_{\rm r})$ (keV)	36.5
Γ_γ (eV) [c]	0.07 ± 0.03 [e]
$\gamma_{\rm n}^2$ (keV)	594
θ^2	0.091
radius (fm)	3.30
$\sigma_{\rm max}$ (b)	12.0 [f]
J^π	3^+
$l_{\rm n}$	1

[a] See also (1956TH06, 1956WI04, 1960HU1A).
[b] Energies in laboratory system except for those labeled [c].
[c] Energies in c.m. system.
[d] (1960HU1A).
[e] (1959IM04).
[f] See also (1968HI1E).

A pronounced resonance is observed at $E_{\rm n} = 261$ keV with $J^\pi = 3^+$, formed by p-waves (Table 8.2) (1970ME1C). A good account of the polarization is given by the assumption of levels at $E_{\rm n} = 0.25$ and 3.4 MeV, with $J^\pi = 3^+$ and 2^-, together with a broad $J^\pi = 3^-$ level at higher energy (1964LA19). Broad peaks are reported at $E_{\rm n} = 4.6$ and 5.8 MeV (± 0.1 MeV) [^{8}Li*(6.1, 7.1)] with $\Gamma \approx 1.0$ and 0.4 MeV, respectively, and there is indication of a narrow peak at $E_{\rm n} = 5.1$ MeV [^{8}Li*(6.5)] with $\Gamma \ll 80$ keV and of a weak, broad peak at $E_{\rm n} = 3.7$ MeV (1971FO1A: D.G. Foster and C.A. Goulding, private communications). See also reaction 5.

5. ^{7}Li(n, n$'$)^{7}Li* $\qquad E_{\rm b} = 2.0327$

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 $E_{\rm n} = 1.35$ MeV. A good fit is obtained with either $J^\pi = 1^-$ or 1^+ (2^+ not excluded), $\Gamma_{\rm lab} = 1.14$ MeV (1955FR10). At higher energies a prominent peak is observed at $E_{\rm n} = 3.8$ MeV ($\Gamma_{\rm lab} = 0.75$ MeV) and there is some indication of a broad resonance ($\Gamma_{\rm lab} = 1.30$ MeV) at $E_{\rm n} = 5.0$ MeV. Between $E_{\rm n} = 6.0$ and 9.0 MeV, the cross section decreases monotonically. The two resonances are interpreted as being due to states with $J^\pi = 2^+$ or 3^+ [^{8}Li*(5.4)] and $J^\pi = 3^+$ or 3^- [^{8}Li*(6.4)] [(1972PR03: Γ_λ, γ^2_λ and θ^2_λ are listed for these two states under various assumptions)]. Cross-section measurements have also recently been reported for $E_{\rm n} = 3.35$, 4.83, 5.74 and 7.5 MeV (1968HO03; n_1, n_2), 10 MeV (1967CO01; n_2) and 19.0 to 21.0 MeV (1972PR03; γ_1). See also (1965DE1G, 1972CO1K), and (1966LA04) for a listing of earlier references.

6. ^{7}Li(n, 2n)^{6}Li $\quad Q_{\rm m} = -7.251 \quad E_{\rm b} = 2.0327$

See (1963AS01, 1964ST25).

7. (a) ^{7}Li(n, p)^{7}He $\quad Q_{\rm m} = -10.42 \quad E_{\rm b} = 2.0327$
(b) ^{7}Li(n, p)^{4}He + 3n

At $E_{\rm n} = 19$ MeV, the upper limit for reaction (b) is 10 mb (1971KO24). See also ^{7}He and (1973LI02).

8. ^{7}Li(n, d)^{6}He $\quad Q_{\rm m} = -7.753 \quad E_{\rm b} = 2.0327$

See (1967VA12, 1973LI02) and (1966LA04).

9. ^{7}Li(n, t)^{4}He + n $\quad Q_{\rm m} = 2.4668 \quad E_{\rm b} = 2.0327$

The cross section rises to 450 mb at $E_{\rm n} \approx 8$ MeV and thereafter decreases slowly to 300 mb at $E_{\rm n} = 15$ MeV (1964ST25). The large cross section, comparable to the geometric value, is understood in terms of the (α + t) cluster nature of ^{7}Li (1962RO12). Cross sections for this reaction have recently been reported at $E_{\rm n} = 3.35$, 4.83, 5.74 and 7.5 MeV (1968HO03) and at 10 MeV (1967CO01). See also (1967VA12, 1971AN1M, 1973LI02) and ^{5}He, and (1966JE1B).

10. ^{7}Li(d, p)^{8}Li $\quad Q_{\rm m} = -0.1919$
$Q_0 = -188 \pm 7$ keV (1967SP09).

Proton groups have been observed to ^{8}Li*(0, 0.98, 2.26): see (1966LA04). At $E_{\rm d} = 15$ MeV, no states are observed in the region $2.3 < E_{\rm x} < 8$ MeV: a limit of 0.6 mb/sr is placed on groups with widths $\lesssim$ 100 keV ($\theta = 10°$, $14°$, $25°$) (1960HA14). Angular distributions of the p_0 and p_1 groups [$l_{\rm n} = 1$] at $E_{\rm d} = 12$ MeV have been analyzed by DWBA: $S_{\rm exp.} = 0.87$ and 0.48, respectively for ^{8}Li*(0, 0.98) [$S_{\rm exp.}/S_{\rm theor.} = 0.84$, 1.09] (1967SC29). For PWBA analyses, see (1966LA04).

The first excited state decays by emitting a 980 ± 10 keV γ-ray. The transition is M1 (1962CH14). The lifetime of ^{8}Li*(0.98) is 10.1 ± 4.5 fsec (1971TH02). See also (1966TH1B, 1968FI1F).

11. ^{7}Li(t, d)^{8}Li $\qquad Q_{\rm m} = -4.2249$

See (1970CH1Q) and ^{10}Be. See also (1970JA1J; theor.).

12. ^{7}Li(α, ^{3}He)^{8}Li $\qquad Q_{\rm m} = -18.546$

Not reported.

13. ^{8}He(β^-)^{8}Li $\qquad Q_{\rm m} = 10.70$

^{8}He decays with $\tau_{1/2} = 122 \pm 2$ msec to ^{8}Li*(0.98) with an 88% branch [$\log ft = 4.20$; B. Zimmerman, private communication] and to neutron unstable states with a 12 ± 1% branch. The allowed decay supports the assignment $J^{\pi} = 1^{+}$ to ^{8}Li*(0.98) (1965PO06).

14. ^{9}Be(γ, p)^{8}Li $\qquad Q_{\rm m} = -16.888$

See (1962CU05, 1966DE13, 1968AD09). See also (1966LA04).

15. ^{9}Be(e, ep)^{8}Li $\qquad Q_{\rm m} = -16.888$

See (1969BA1F; theor.). See also ^{9}Be.

16. ^{9}Be(n, d)^{8}Li $\qquad Q_{\rm m} = -14.664$

See (1969SC05) in ^{10}Be.

17. ^{9}Be(p, 2p)^{8}Li $\quad\quad Q_{\rm m} = -16.888$

The summed proton spectrum at $E_{\rm p} = 156$ MeV shows peaks corresponding to ^{8}Li(0) and ^{8}Li*($0.98 + 2.26$) [unresolved]. In addition s-states [$J^{\pi} = 1^{-}$, 2^{-}] are suggested at $E_{\rm x} = 9$ and 16 MeV, with $\Gamma_{\rm c.m.} \approx 6$ and 8 MeV: the latter may actually be due to continuum protons (1967RO06). See also ^{9}Be and (1966LA04) [(1965TY1A) has now been published as (1966TY01)]. See also (1971GR1K), (1965CO1E) and (1967KO1B, 1968JA1D, 1973AS02; theor.).

18. ^{9}Be(d, ^{3}He)^{8}Li $\quad\quad Q_{\rm m} = -11.395$

At $E_{\rm d} = 38$ MeV, differential cross sections have been obtained for the ^{3}He groups corresponding to ^{8}Li*(0, 0.98, 2.26) (1966GA21: see ^{9}Be(d, t)^{8}Be).

19. ^{9}Be(t, α)^{8}Li $\quad\quad Q_{\rm m} = 2.926$

At $E_{\rm t} = 12.98$ MeV, α-particle groups are observed to ^{8}Li*(0, 0.98, 2.26) and to a state at $E_{\rm x} = 6.530 \pm 0.020$ MeV with $\Gamma_{\rm c.m.} < 40$ keV (1965WA12). For angular distributions to these four states, see (1968AJ01): the distribution of the α-particles to ^{8}Li*(6.53) is rather featureless and does not involve a forward maximum, suggesting $l > 1$. A large l-transfer is consistent with the narrow width of this unbound state (1968AJ01). At $E_{\rm t} = 20$ MeV these four ^{8}Li states were also observed. ^{8}Li*(6.53) was found to have $\Gamma_{\rm c.m.} = 40 \pm 10$ keV. No other groups corresponding to sharp states of ^{8}Li ($\Gamma \lesssim 100$ keV) with $E_{\rm x} \lesssim 16$ MeV were observed at $\theta = 15°$, $25°$ and $35°$ (F. Ajzenberg-Selove and O. Hansen, private communication). The α_0 angular distribution has also been measured at $E_{\rm t} = 2.10$ MeV (1970CO04) and 0.52 to 1.31 MeV (1969NA04; also α_1 at $E_{\rm t} = 0.52$ to 1.67 MeV).

The mean lifetime, $\tau_{\rm m} = 14 \pm 5$ fsec for ^{8}Li*(0.98): $E_{\rm x} = 980.80 \pm 0.10$ keV (1972CO09). See also ^{12}B in (1975AJ02).

20. ^{9}Be(^{7}Li, ^{8}Be)^{8}Li $\quad\quad Q_{\rm m} = 0.368$

See (1966LE10) and (1968TO1C; theor.).

21. ^{10}Be(d, α)^{8}Li $\quad\quad Q_{\rm m} = 2.372$

This reaction has been observed for $E_d = 0.7$ to 3.0 MeV: see ^{12}B (1970GO11, 1973GO09).

22. ^{10}B(n, ^{3}He)^{8}Li $Q_m = -15.755$

Not reported.

23. ^{11}B(γ, ^{3}He)^{8}Li $Q_m = -27.211$

See (1963NE07).

24. ^{11}B(n, α)^{8}Li $Q_m = -6.633$

Angular distributions have been obtained at $E_n = 14.1$ MeV for the α_0 and α_1 groups (1973BO26). See also (1966JA1C) and ^{12}B in (1975AJ02).

25. ^{12}C(α, ^{8}B)^{8}Li $Q_m = -41.445$

At $E_\alpha = 129$ MeV, ^{8}B groups are observed to ^{8}Li*(0, 0.98, 2.26) (1968MC02).

26. ^{13}C(^{7}Li, ^{12}C)^{8}Li $Q_m = -2.914$

At $E(^7\text{Li}) = 34$ MeV angular distributions have been measured for the transitions to $^8\text{Li}_{\text{g.s.}} + {}^{12}\text{C}_{\text{g.s.}}$, $^8\text{Li}^*_{0.98} + {}^{12}\text{C}_{\text{g.s.}}$, $^8\text{Li}_{\text{g.s.}} + {}^{12}\text{C}^*_{4.4}$ and $^8\text{Li}^*_{0.98} + {}^{12}\text{C}^*_{4.4}$ (1973SC26).

27. ^{18}O(^{7}Li, ^{17}O)^{8}Li $Q_m = -6.014$

See (1969NE1E).

^{8}Be
(Figs. 12 and 14)

GENERAL: (See also (1966LA04).)

Shell model: (1965CO25, 1965VO1A, 1966BA26, 1966GU06, 1966HA18, 1966PA15, 1967BA1K, 1967BO1C, 1967HS1A, 1967PA10, 1967ST1C, 1967SV1A, 1968BA1L, 1968FA1B, 1968GO01, 1969AB1D, 1969GU1E, 1969GU03, 1969IK1A, 1969KU1F, 1969SV1A, 1970BA75, 1970BO1J, 1970CO1H, 1970DE1F, 1970GU11, 1970KO04, 1970KR1D, 1970NO1C, 1970RU1A, 1970TU01, 1970WO12, 1970ZO1A, 1971BO22, 1971BO29, 1971CO28, 1971GU20, 1971HA1U, 1971NO02, 1972AB12, 1972BO38, 1972HA05, 1972LE1L, 1973BO07, 1973HA05, 1973HA49, 1973JO1K).

Collective and deformed models: (1962MO1B, 1965VO1A, 1967LA09, 1967PA10, 1969AB05, 1969RU04, 1970BO41, 1970GO1Q, 1971BO22, 1971BO29, 1971HO19, 1972AB1C, 1972BO38, 1972HA05, 1972HO56, 1973BO07, 1973HO40, 1973KO1F, 1973KU13, 1973PE08).

Cluster and α-particle model: (1965IN1A, 1965NE1B, 1966KA1A, 1966PA15, 1966WE1C, 1969AB1B, 1969AB1D, 1969IK1A, 1969KU1C, 1969KU1F, 1969ME1C, 1969TA1C, 1970BA75, 1970YU1B, 1971AB07, 1971AB1B, 1971FR06, 1971KH06, 1971LE1N, 1971NO02, 1972AB1C, 1972AB19, 1972AK10, 1972BA59, 1972FR1B, 1972GR42, 1972HA05, 1972HI16, 1972HO56, 1972IK1A, 1972LE1L, 1972VA45, 1973HO40, 1973VA1N).

Special levels: (1966BA26, 1966BR1H, 1966DA02, 1966GU06, 1966PA15, 1966ST1D, 1967BA1N, 1967HO03, 1967HS1A, 1967MA1B, 1967ST1C, 1968GO01, 1968LA1B, 1969BA43, 1969GU03, 1969HA1G, 1969HA1F, 1969SH1A, 1970BO1J, 1970KI1D, 1970PE18, 1970RU1A, 1971AN03, 1971CO28, 1971GU20, 1971NO02, 1972BE1E, 1972HA1R, 1973AS02, 1973BO07, 1973FE1J, 1973HO40, 1973MA1K, 1973ST1Q, 1973VA1N).

Electromagnetic transitions: (1965CO25, 1966BA26, 1966PA15, 1966WA1E, 1967HS1A, 1968LA1B, 1969AB05, 1969HA1G, 1969HA1F, 1971BO22, 1972AB12, 1972BO38, 1972HA05, 1972NA05, 1973AS02, 1973BO07, 1973HA49, 1973HA1Q).

Special reactions: (1966ME1D, 1967GO1F, 1968CH1F, 1969BA1Q, 1969DE1M, 1969VI1C, 1970RA1J, 1972BI10, 1972CR1F, 1972HA2F, 1973JO07, 1973KO1P).

Other topics: (1965CO25, 1965VO1A, 1966DA02, 1966GU06, 1966HA18, 1966PA15, 1966TO04, 1966YO1B, 1967BA1K, 1967BA12, 1967BA1M, 1967BO1G, 1967BO1C, 1967BR1E, 1967CA17, 1967DI1B, 1967LA09, 1967LA1G, 1967PA10, 1967SV1A, 1968BA1L, 1968FA1B, 1968GO01, 1968LA1B, 1968NE1C, 1969AB05, 1969GU03, 1969KU1F, 1969HO1M, 1969KE1B, 1969NA1E, 1969NA1L, 1969RU04, 1969SH1A, 1969SV1A, 1970BA75, 1970BO1J, 1970CO1H, 1970HO1J, 1970KO04, 1970KR1D, 1970NO1C, 1970PE18, 1970RU1A, 1970TU01, 1970ZO1A, 1971AN03, 1971DE1V, 1971GR1L, 1971GR2C, 1971HO19, 1971JE1B, 1971SO11, 1971ZA1D, 1972AB12, 1972AN05, 1972EL1C, 1972FR1B, 1972HA05, 1972HA57, 1972LE1L, 1972LE23, 1972PN1A, 1972ST1C, 1972VA45, 1973HA05, 1973JO1K, 1973JU2A, 1973KO26, 1973NA26, 1973RA1E, 1973RO1R, 1973ST1Q).

Table 8.3: Energy levels of ^{8}Be

E_x (MeV ± keV)	$J^\pi; T$	$\Gamma_{c.m.}$	Deacy	Reactions
g.s.	0^+; 0	6.8 ± 1.7 eV	α	1, 4, 12, 13, 14, 15, 22, 23, 24, 25, 27, 30, 31, 32, 33, 34, 36, 37, 38, 39, 40, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 60, 62, 64
2.94 ± 30 [a]	2^+; 0	1.56 ± 0.03 MeV	α	4, 13, 14, 15, 22, 23, 24, 25, 27, 28, 29, 30, 31, 32, 33, 36, 37, 38, 39, 40, 42, 44, 45, 46, 47, 48, 49, 50, 51, 52, 55
(6.0 ± 3000)	0^+; 0	$(9 \pm 4$ MeV)	α	4
(10.0 ± 3000)	2^+; 0	$(12^{+4}_{-2}$ MeV)	α	4, 29
11.4 ± 300	4^+; 0	≈ 3.5 MeV [d]	α	4, 14, 22, 24, 31, 32, 33, 38, 42, 49, 51
16.627 ± 4 [b]	$2^+; 0+1$	107 ± 3 keV	(γ), α	2, 4, 13, 15, 22, 23, 24, 28, 29, 33, 37, 38, 42, 46, 49
16.911 ± 4 [b]	$2^+; 0+1$	77 ± 3 keV	(γ), α	2, 4, 13, 15, 22, 23, 24, 31, 32, 33, 37, 38, 42, 46, 49
17.642 ± 1.5 [b,c]	1^+; 1	10.7 ± 0.5 keV	γ, p	13, 16, 18, 22, 23, 31, 32, 33, 38, 42
18.154 ± 4 [b,c]	1^+; 0	138 ± 6 keV	γ, p	13, 16, 18, 22, 31, 33, 38, 42
18.91 [c]	2^-; 0	48 ± 20 keV	γ, n, p	13, 16, 17, 18, 22, 31, 32, 42
19.06 ± 20 [c]	3^+	270 ± 20 keV	γ, p	13, 16, 18, 22, 31, 32, 42
19.22	3^+; (1)	208 ± 30 keV	n, p	13, 17, 18, 22, 31, 33, 38
19.4	1^-	≈ 650 keV	n, p	13, 17, 18
19.9	4^+; 0	< 1 MeV	α	4, 13, 24, 32, 33

Table 8.3: Energy levels of ^{8}Be (continued)

E_x (MeV ± keV)	$J^\pi; T$	$\Gamma_{c.m.}$ (keV)	Deacy	Reactions
20.1	$2^+; 0$	≈ 1.1 MeV	n, p, α	4, 17, 18, 21, 32
20.2	$0^+; 0$	< 1 MeV	α	4
20.9 ± 200	4^-	1.6 ± 0.2 MeV	p	18
21.5 ± 300	(3^+)	1 MeV	γ, p, n	16, 17, 31
22.0	$1^-; 1$	$4 - 5$ MeV	γ, p	16
22.2	$2^+; 0$	≈ 0.8 MeV	n, p, d, α	4, 6, 7, 11, 15, 18, 21, 33
23.6			γ, p	16
24.0	$1^-, 2^-$	≈ 8 MeV	γ, p	16
25.2	$2^+; 0$	≈ 1 MeV	p, d, α	4, 7, 11, 21
25.5	$4^+; 0$		α	4
27.483 ± 10	$0^+; 2$	10 ± 3 keV	p, d, α	7, 11
(28.6)		broad	γ, p	16

[a] See also Table 8.4.
[b] See also Table 8.5.
[c] See also Table 8.7.
[d] We are greatly indebted to Prof. F.C. Barker for enlightening discussions concerning the width of ^{8}Be*(11.4).

Ground state: (1965CO25, 1965VO1A, 1966BA26, 1966TO1B, 1967BO1G, 1967BR1E, 1967LA1G, 1967PA10, 1968BA1L, 1968BO19, 1968FA1B, 1969AB05, 1969GU03, 1969KE1B, 1969KU1F, 1970KO04, 1970KR1D, 1970TU01, 1971BO29, 1971GR1L, 1971GR2C, 1971RU14, 1972AB12, 1972GR42, 1972LE1L, 1973KO26, 1973MA1K, 1973VA1N).

Adjusted mass excess [†] of ^{8}Be: 4941.87 ± 0.13 keV (1972WA1G).

1. $^8\text{Be} \rightarrow {}^4\text{He}^4\text{He}$ $\quad Q_m = 0.09189$

$Q_0 = 92.6 \pm 0.8$ keV (1966RE02).

In α-α scattering (reaction 4) the Q_0 is found to be 92.12 ± 0.05 keV, $\Gamma_{c.m.} = 6.8 \pm 1.7$ eV (1968BE02). See also (1966LA04) for earlier values.

[†] Not used in Q_m calculations in this paper.

2. ^{4}He(α, γ)^{8}Be $\qquad Q_{\rm m} = -0.09189$

Radiative widths have been measured for ^{8}Be*(16.6, 16.9): see (1974NA1H: $E_\alpha = 31$ to 35 MeV).

3. (a) ^{4}He(α, n)^{7}Be $\qquad Q_{\rm m} = -18.9921 \qquad E_{\rm b} = -0.09189$
(b) ^{4}He(α, p)^{7}Li $\qquad Q_{\rm m} = -17.348$

For reaction (a) see (1952WA31). For reaction (b) see ^{7}Li.

4. ^{4}He(α, α)^{4}He $\qquad E_{\rm b} = -0.09189$

Alpha-α scattering reveals the ground state as a resonance with $Q_0 = 92.12 \pm 0.05$ keV, $\Gamma_{\rm c.m.} = 6.8 \pm 1.7$ eV, [$\tau = (0.97 \pm 0.24) \times 10^{-16}$ sec] (1966BE05, 1968BE02). Effective range theory analysis of higher energy scattering yields widths consistent with this value but subject to considerable uncertainty (1966TO1B). However, (1967KE1B, 1967KE1E) and (1967RA1B) have carried out such analyses yielding $\Gamma = 6.14 \pm 0.04$ eV and $6.4^{+0.8}_{-0.5}$ eV, respectively. Using a three-level, one-channel R-matrix formalism (1968BA2D) find $\Gamma = 5.1 \pm 0.4$ eV for the ground state of ^{8}Be. R-matrix analysis of the s-wave scattering and of the ^{9}Be(p, d)^{8}Be reaction indicates the presence of a second 0^+ state at $E_{\rm x} \approx 6 \pm 3$ MeV, $\Gamma = 9 \pm 4$ MeV ($a_0 = 7$ fm) (1968BA2D). For $E_\alpha = 30$ to 70 MeV the $l = 0$ phase shift shows resonant behavior at $E_\alpha = 40.7$ MeV, corresponding to a 0^+ state at $E_{\rm x} = 20.2$ MeV, $\Gamma < 1$ MeV, $\Gamma_\alpha/\Gamma < 0.5$. No evidence for other 0^+ states is seen above $E_\alpha = 43$ MeV (1972BA83).

The d-wave phase shift becomes appreciable for $E_\alpha > 2.5$ MeV and passes through resonance at $E_\alpha = 6$ MeV ($E_{\rm x} = 3.18$ MeV, $\Gamma = 1.5$ MeV, $J^\pi = 2^+$) (1963TO02). See Table 8.4. Analyses by many-level R-matrix theory of the α-scattering, of the ^{9}Be(p, d)^{8}Be reaction and of the ^{8}Li and ^{8}B β-decays lead to approximately correct values for the $E_{\rm x}$ and Γ of ^{8}Be*(2.9) and suggest a second 2^+ state at $E_{\rm x} \approx 8.5$ MeV, $\Gamma \approx 10.5$ MeV (1969BA43: $a_2 = 6.75$ fm), $E_{\rm x} = 12.0^{-3.0}_{+3.5}$ MeV, $\Gamma = 14^{-3}_{+4}$ MeV (1969CL10: $a_2 = 6.0 \pm 0.5$ fm). Five 2^+ levels are observed from the $l = 2$ phase shifts measured from $E_\alpha = 30$ to 70 MeV: ^{8}Be*(16.6, 16.9) with $\Gamma_\alpha = \Gamma$, and states with $E_{\rm x} = 20.2$, 22.2 and 25.2 MeV. The latter has a small Γ_α (1972BA83). See also reaction 11.

The $l = 4$ shift rises from $E_\alpha \approx 11$ MeV and indicates a broad 4^+ level at $E_{\rm x} = 11.4 \pm 0.3$ MeV (1959BR71). See also (1973CH1W). A rapid rise of δ_4 at $E_\alpha = 40$ MeV corresponds to a 4^+ state at 19.9 MeV with $\Gamma_\alpha/\Gamma \approx 0.96$; $\Gamma < 1$ MeV and therefore $\Gamma_\alpha < 1$ MeV, which is $< 5\%$ of the Wigner limit. A broad 4^+ state is also observed near $E_\alpha = 51.3$ MeV ($E_{\rm x} = 25.5$ MeV) but there is no evidence for a previously reported state at $E_{\rm x} = 27.5$ MeV (1972BA83).

Over the range $E_\alpha = 30$ to 70 MeV a gradual increase in δ_6 is observed (1972BA83). Some indications of a 6^+ state at $E_{\rm x} \approx 28$ MeV and of an 8^+ state at ≈ 57 MeV have been reported

Table 8.4: Parameters of ^{8}Be*(2.9) [a]

E_x (MeV)	Γ_{cm} (MeV)	Reaction	Refs.
2.83 ± 0.20	1.75 ± 0.30	^{6}Li(^{3}He, p), ^{10}B(d, α)	(1969NU01)
	1.2 ± 0.3	^{6}Li(α, d)	(1969BA18)
3.1 ± 0.1	1.75 ± 0.1	^{7}Li(d, n)	(1964JO04)
3.10 ± 0.09	1.74 ± 0.08	^{7}Li(d, n)	(1971RO05)
2.90 ± 0.06	1.53 ± 0.04	^{7}Be(d, p)	(1960KA17)
	1.5 ± 0.1	^{9}Be(p, d)	(1969SU02)
2.90 ± 0.04	1.35 ± 0.15	^{9}Be(^{3}He, α)	(1963DO08)
	1.48 ± 0.07	^{11}B(p, α)	(1971KA21)
2.94 ± 0.03	1.56 ± 0.03	mean	

[a] See also Table 8.9 in (1966LA04) and reaction 32 (1973SO08).

by (1965DA1A), with $\Gamma_{c.m.} \approx 20$ and ≈ 73 MeV, respectively. The elastic scattering has been studied at $E_\alpha = 140$ MeV by (1972FR1K). For a listing of the older work see Table 8.7 [(dσ/dΩ)], Table 8.8 [parameters of ^{8}Be states from ^{4}He(α, α)] and Table 8.9 [parameters of ^{8}Be*(2.9)] in (1966LA04). See also (1972FR1J). For studies of inelastic scattering of α-particles from ^{4}He see (1969GR06, 1971HA41) and the review in (1973FI04). See also (1965SL1A, 1967ST30, 1968CO1M).

The bremsstrahlung cross section has been measured at $E_\alpha = 9.35$ MeV and for $E_\alpha = 11.4$ to 13.5 MeV: no significant enhancement is found at the final state energy corresponding to ^{8}Be*(2.9) (1972FR02, 1973FR17). The cross section has also been measured for $E_\alpha = 12.1$ to 18.7 MeV by (1972PE16).

See also (1965PR1A, 1965TA1D, 1966AB1A, 1966AL1G, 1966EN1A, 1966HI1A, 1966OK1A, 1967AB1A, 1967AL1E, 1967BE1N, 1967CH1H, 1967KE1C, 1967KE10, 1967PA1E, 1968BA1H, 1968HA1G, 1968HA1C, 1968KE1E, 1968PA1L, 1968SA1F, 1968SH1G, 1968TA1L, 1968TK1A, 1969AF1B, 1969BA1W, 1969BA1Y, 1969DO03, 1969KE1D, 1969KE09, 1969RE12, 1969SA1D, 1968TH1C, 1969TR1C, 1970CH1P, 1970CH1R, 1970EF01, 1970FE1C, 1970KH1C, 1970KU15, 1970LO1F, 1970PI1B, 1971BR30, 1971KU10, 1971KU22, 1971LE23, 1971MU1H, 1971NE1C, 1971PI1F, 1971RE1F, 1972DE29, 1972GI1G, 1972GO16, 1972GR1R, 1972HI16, 1972KA1K, 1972ME23, 1972OK02, 1973GR1M, 1973HA57, 1973PE08, 1973RA27, 1973YU1A; theor.).

5. ^{6}Li(d, γ)^{8}Be $Q_m = 22.282$

Not observed: (1953SA1A, 1954SI07).

6. (a) ^{6}Li(d, n)^{7}Be $\quad Q_m = 3.382 \quad E_b = 22.282$

(b) ^{6}Li(d, n)^{4}He + ^{3}He $\quad Q_m = 1.795$

The yield curve has been measured for $E_d = 0.06$ to 5.5 MeV [see (1966LA04) and (1966SC26)], and at $E_d = 12$ to 17 MeV (1970GA07: population of ^{7}Be*$(0 + 0.43)$). A broad s-wave resonance is indicated at $E_d = 0.41$ MeV, $\Gamma = 0.45$ MeV (1952BA1A, 1956NE13). Polarization measurements are reported at $E_d = 0.27$ to 0.60 MeV (1966MI06; n_1) and 2.5 to 3.7 MeV (1970TH08; n_0, n_1). The distributions observed by (1970TH08) are quite constant over the range 2.5 to 3.7 MeV, indicating that the predominant reaction mechanism is direct. See also ^{7}Be.

Comparisons of the populations of ^{7}Be*(0, 0.43) and of ^{7}Li*(0, 0.48) have been made at many energies, up to $E_d = 7.2$ MeV. The n/p ratios are closely equal for analog states, consistent with charge symmetry (1957WI24, 1963BI1B, 1963CR08). See also (1966AU1A).

7. (a) ^{6}Li(d, p)^{7}Li $\quad Q_m = 5.026 \quad E_b = 22.282$

(b) ^{6}Li(d, p)^{4}He + ^{3}H $\quad Q_m = 2.559$

Excitation functions have been measured for $E_d = 30$ keV to 5.4 MeV [see (1966LA04) and (1966LO18, 1968BE1P, 1969BL14)]. 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 is evidence for both direct interaction and compound nucleus formation (1963BI1B, 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]. An anomaly is observed in the p_1/p_0 intensity ratio at $E_d = 6.945$ MeV, corresponding to the $J^\pi = 0^+$; $T = 2$ analog of the ground state of ^{8}He: $E_x = 27.483 \pm 0.010$ MeV, $\Gamma = 10 \pm 3$ keV, $\Gamma_{p_0} \ll \Gamma_{p_1}$, $\Gamma_{p_0} < \Gamma_d$ (1969BL14). The parameters of this state have been calculated by (1969BA36).

Polarization measurements have been made at $E_d = 0.6$ and 0.96 MeV (1969NA1J, 1972SE09; p_0, p_1) and at $E_d = 2.1$ to 10.9 MeV (1968DU09, 1968FI07, 1970FI07; p_0, p_1). The latter report pronounced differences in the angular distributions of the vector analyzing power of the two $l_n = 1$ transitions to ^{7}Li*(0, 0.48). See also (1972FI1E, 1973FI1C). For reaction (b) see (1966FR06). See also ^{7}Li and (1966AU1A, 1966BR25).

8. ^{6}Li(d, d)^{6}Li $\quad E_b = 22.282$

The yield of elastically scattered deuterons has been measured for $E_d = 2$ to 4.8 MeV (1964PA06), 4.0 to 6.5 MeV (1966BR1J), and 6.33 to 7.14 MeV (1969BL14): no resonances are reported. At $E_d = 12.0$ MeV, $\theta_{lab} = 95°$, the differential cross section for elastic scattering is 9.82 ± 0.20 mb/sr (1971BI11). See also ^{6}Li and (1972FI1E, 1973FI1C).

9. ^{6}Li(d, t)^{5}Li $\quad Q_{\rm m} = 0.59 \quad E_{\rm b} = 22.282$

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 $\quad Q_{\rm m} = 0.90 \quad E_{\rm b} = 22.282$

See ^{5}He.

11. (a) ^{6}Li(d, α)^{4}He $\quad Q_{\rm m} = 22.374 \quad E_{\rm b} = 22.282$
(b) ^{6}Li(d, αp)^{3}H $\quad Q_{\rm m} = 2.559$
(c) ^{6}Li(d, αn)^{3}He $\quad Q_{\rm m} = 1.795$
(d) ^{6}Li(d, 2d)^{4}He $\quad Q_{\rm m} = -1.4737$

Cross sections and angular distributions (reaction (a)) have been measured for $E_{\rm d} = 0.03$ to 12 MeV: see (1966LA04) and (1969LE22: $E_{\rm d} = 40$ to 130 keV), (1966LO18: 0.2 to 2 MeV), (1968BE1P: 0.3 to 1.0 MeV), (1965RO1E, 1969DE31, 1969HU17: 0.35 to 1.50 MeV), (1966BR25: 1.0 to 2.0 MeV), (1964AN1A: 1.0 to 2.5 MeV), (1967CL06: 3 to 12 MeV) and (1969BL14: 6.33 to 7.14 MeV). Polarization measurements are reported at $E_{\rm d} = 0.40$, 0.60, 0.80, 0.96 MeV (1971NE12, 1972SE09), 0.7 to 2.2 MeV (1967PL02), 2.1 to 10.9 MeV (1968DU07), 4.3, 6.3, 8.0, 10.1 and 11.8 MeV (1968BU13) and at $E(^{6}{\rm Li}) = 0.6$ MeV (1970HO11). See also (1967BU1B, 1972KO1P).

Maxima are observed at $E_{\rm d} = 0.8$ MeV, $\Gamma_{\rm lab} \approx 0.8$ MeV and $E_{\rm d} = 3.75$ MeV, $\Gamma_{\rm lab} \approx 1.4$ MeV (1963ME09, 1964PA06). Analysis of these and other data up to $E_{\rm d} = 12$ MeV indicate a 2^{+}, 0^{+}, (6^{+}), 2^{+}, 4^{+} sequence of states: see Table 8.10 in (1966LA04) (1965FR02, 1967CL06). See, however, reaction 4.

The assignment of $J^{\pi} = 2^{+}$ to ^{8}Be*(22.2) is consistent with the polarization information (1971NE12, 1972SE09), but the 0^{+} state may actually be virtual with respect to $^{6}{\rm Li}+{\rm d}$ (1972SE09) [^{8}Be*(20.3): see reaction 4 and (1972BA83)]. At $E_{\rm d} = 6.945$ MeV, the α-yield shows an anomaly corresponding to ^{8}Be*(27.48), the $J^{\pi} = 0^{+}$; $T = 2$ analog of the ^{8}He ground state (1969BL14). See also reaction 7 and (1969BA36; theor.).

See also (1966LE1C), (1971PL1C) and (1967TS1A, 1968CO1L, 1968KO1G, 1969CH1J, 1970FI11; theor.). For reactions (b), (c) and (d), see (1972HA34) and (1973FI04).

12. (a) ^{6}Li(t, n)^{8}Be $\quad Q_{\rm m} = 16.024$
(b) ^{6}Li(t, n)^{4}He^{4}He $\quad Q_{\rm m} = 16.116$

For reaction (b) see (1966LA02, 1967BE13, 1967BI1D). See also (1966LA04).

13. (a) ^{6}Li(^{3}He, p)^{8}Be $\quad Q_{\rm m} = 16.788$
    (b) ^{6}Li(^{3}He, p)^{4}He^{4}He $\quad Q_{\rm m} = 16.880$

Proton groups are observed to ^{8}Be*(0, 2.9, 16.63, 16.91, 17.64): see (1966LA04) and Tables 8.4 and 8.5. The excitation of ^{8}Be*(18.15, 19.0, 19.4, 19.9) is also reported by (1971Gl07). Angular distributions have been measured at $E(^{3}{\rm He}) = 1.4$ to 1.8 MeV (1969VI05; p_0, p_1) and 5, 6, 7, 9, 10, 13 and 17 MeV (1965FL03; p_0, p_1; PWBAE analysis). A gradual change is observed from a dominant back angle maximum to a dominant forward maximum (1965FL03). Measurements of the energies of all the particles emitted in this reaction and reactions 23, 38 and 42 show that the apparent width of ^{8}Be*(2.9) does not depend on the relative velocity of the spectator particle: $E_{\rm x} = 2.83 \pm 0.20$ MeV, $\Gamma = 1.75 \pm 0.30$ MeV (1969NU01). See also Table 8.4.

Reaction (b) proceeds via ^{8}Be*(16.63, 16.91): $\Gamma = 117 \pm 10$ and 85 ± 10 keV, respectively. Interference effects are observed (1969VI05). See also ^{5}Li and (1967RE03, 1968RE10, 1972TH08).

See also (1964MA57, 1968VI03, 1970GA1G, 1971TR1B), (1967HO1C) and (1967BA1E, 1968HE1F, 1969TH1D, 1970DE41, 1973ED02; theor.).

14. (a) ^{6}Li(α, d)^{8}Be $\quad Q_{\rm m} = -1.5656$
    (b) ^{6}Li(α, 2α)^{2}H $\quad Q_{\rm m} = -1.4737$

Deuteron groups have been observed to ^{8}Be*(0, 2.9, 11.3 ± 0.4) (1959ZE1A, 1962CE01). Angular distributions have been measured at $E_{\alpha} = 20$ and 24 MeV (1973GR1N), 20.5 to 24.5 MeV and at 38 MeV (1965DE1F; d_0), 43 MeV (1959ZE1A; d_0, d_1) and 48 MeV (1962CE01; d_0, d_1). At $E_{\alpha} = 12$ MeV ($\theta = 15^{\circ}$ and 20°) the deuteron spectrum does not show a "ghost" anomaly at $E_{\rm x} = 0.1 - 0.5$ MeV (1971BE52). A study of reaction (b) shows that the peak due to ^{8}Be*(2.9) is best fitted by using $\Gamma = 1.2 \pm 0.3$ MeV (1969BA18): see also Table 8.4. See also (1968LA1E) and (1971BU1K; theor.). For reaction (b) see ^{6}Li. See also (1966LA04).

15. (a) ^{6}Li(^{6}Li, α)^{8}Be $\quad Q_{\rm m} = 20.808$
    (b) ^{6}Li(^{6}Li, α)^{4}He^{4}He $\quad Q_{\rm m} = 20.900$

This reaction proceeds via ^{8}Be*(0, 2.9, 16.6, 16.9, 22.5), and there is indication also that the direct three-body break-up (reaction (b)) is possible (1971GA1N, 1971GA21, 1972GA32: $E_{\rm max}(^{6}{\rm Li}) = 13.0$ MeV). The involvement of a state at $E_{\rm x} = 19.9$ MeV ($\Gamma = 1.3$ MeV) is suggested by (1966MA40). See also (1971Gl07). Good agreement with the shapes of the peaks

Table 8.5: ^{8}Be states with $16.6 < E_x < 18.3$ MeV [a]

E_x [b] (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Reaction	Refs.
16.625 ± 10	95 ± 20	^{6}Li(^{3}He, p)	(1961ER01)
	117 ± 10	^{6}Li(^{3}He, p)	(1969VI05)
16.627 ± 5	113 ± 3	^{7}Li(^{3}He, d)	(1967MA12)
16.627 ± 15	105 ± 30	^{9}Be(^{3}He, α)	(1961ER01)
16.635 ± 15	96 ± 20	^{9}Be(^{3}He, α)	(1963DO08)
16.623 ± 10	95 ± 20	^{10}B(d, α)	(1961ER01)
	90 ± 5	^{10}B(d, α)	(1971NO04)
16.627 ± 4	107 ± 3	mean	
16.931 ± 10	85 ± 20	^{6}Li(^{3}He, p)	(1961ER01)
	85 ± 10	^{6}Li(^{3}He, p)	(1969VI05)
16.901 ± 5	77 ± 3	^{7}Li(^{3}He, d)	(1967MA12)
	103 ± 15	^{9}Be(p, d)	(1967KU10)
16.914 ± 12	88 ± 25	^{9}Be(^{3}He, α)	(1961ER01)
16.930 ± 15	80 ± 15	^{9}Be(^{3}He, α)	(1963DO08)
16.919 ± 10	85 ± 20	^{10}B(d, α)	(1961ER01)
	70 ± 5	^{10}B(d, α)	(1971NO04)
16.911 ± 4	77 ± 3	mean	
17.642 ± 10	< 20	^{6}Li(^{3}He, p)	(1961ER01)
17.642 ± 1.5	10.7 ± 0.5	^{7}Li(p, γ)	Table 8.6
17.636 ± 10	< 15	^{9}Be(^{3}He, α)	(1961ER01)
17.641 ± 10		^{9}Be(^{3}He, α)	(1963DO08)
17.642 ± 1.5	10.7 ± 0.5	best	
18.157 ± 5	147	^{7}Li(p, γ)	Table 8.6
18.150 ± 5 [c]	138 ± 6	^{10}B(d, α)	(1970CA12)
18.154 ± 4	138 ± 6	mean	

[a] See also Table 8.11 in (1966LA04).
[b] Based on listed Q_m.
[c] Based on $E_x = 17.642$ MeV.

corresponding to ^{8}Be*(16.6, 16.9) is obtained by using a simple two-level formula with interference, corrected for the effect of final state Coulomb interactions, assuming $\Gamma(16.6) = 90$ and $\Gamma(16.9) = 70$ keV: see also Table 8.5 (1971NO04). See also (1968NO03, 1969IN06). The ratio of the intensities of the groups corresponding to ^{8}Be*(16.6, 16.9) remains constant for $E(^6\text{Li}) = 4.3$ to 5.5 MeV: $I(16.6)/I(16.9) = 1.22 \pm 0.08$ (1966KI09, 1966MA40). Partial angular distributions for the α_0 group have been measured at fourteen energies for $E(^6\text{Li}) = 4$ to 24 MeV (1970FR06). For reaction (b) see also (1966BE22).

For a review of the older work see (1966LA04). See also (1964MA26, 1967AL1F, 1967CH34, 1968DA20, 1971PO1D), (1966BR1G, 1967CA1D), (1966BA1T, 1966EL1A, 1966RO1E, 1966RO1F, 1966RO1H, 1972JO1D; theor.) and ^{12}C.

16. ^{7}Li(p, γ)^{8}Be $\qquad Q_\text{m} = 17.256$

Cross sections and angular distributions have been reported from $E_\text{p} = 30$ keV to 18 MeV. Gamma rays are observed to the ground (γ_0) and to the broad, 2^+, excited state at 2.9 MeV (γ_1) and to ^{8}Be*(16.6, 16.9) (γ_3, γ_4). Resonances for both γ_0 and γ_1 occur at $E_\text{p} = 0.44$ and 1.03 MeV, and for γ_1 alone at 2, 4.9, 6.0, 7.3, and possibly at 3.1 and 11.1 MeV. In addition broad resonances are reported at $E_\text{p} \approx 5$ MeV (γ_0), $\Gamma \approx 4-5$ MeV, and at $E_\text{p} \approx 7.3$ MeV (γ_1), $\Gamma \approx 8$ MeV. The $E_\text{p} \approx 5$ MeV resonance ($E_\text{x} \approx 22$ MeV) represents the giant dipole resonance based on ^{8}Be(0) while the γ_1 resonance, ≈ 2.3 MeV higher, is based on ^{8}Be*(2.9). The γ_0 and γ_1 giant resonance peaks each contain about 10% of the dipole sum strength (1966FI1B, 1968BL1E, 1970FI1B). The main trend between $E_\text{p} = 8$ and 17.5 MeV is a decreasing cross section (1970FI1B). See, however, (1967FE04). See also Table 8.6.

At the $E_\text{p} = 0.44$ MeV resonance ($E_\text{x} = 17.64$ MeV) the radiation is nearly isotropic consistent with p-wave formation, $J^\pi = 1^+$, with channel spin ratio $\sigma(J_\text{c} = 2)/\sigma(J_\text{c} = 1) = 3.2 \pm 0.5$ (1961ME10). Radiative widths for the γ_0 and γ_1 decay are displayed in Table 8.7. The E2/M1 amplitude ratio for the $17.6 \to 2.9$ transition varies over the energy of the broad final state: the average value is $\delta = 0.21 \pm 0.04$ (1967CO19). See also (1967CO29).

^{8}Be*(16.63, 16.91) are 2^+ states with mixed $T = 0$, 1 isospin [see (1965MA1G, 1966MA03, 1968PA09, 1969SW01)], with the lower state of ^{7}Li + p parentage and the higher of ^{7}Be + n parentage (1965SW03, 1968PA09). A careful study of the α-breakup of ^{8}Be*(16.63, 16.91) for $E_\text{p} = 0.44$ to 2.45 MeV shows that the non-resonant part of the cross section for production of ^{8}Be*(16.63) is accounted for by an extranuclear direct-capture process. Resonances for production of ^{8}Be*(16.63, 16.91) are observed at $E_\text{p} = 0.44$, 1.03 and 1.89 MeV [^{8}Be*(17.64, 18.15, 18.9)]. The results are consistent with the hypothesis of nearly maximal isospin mixing for ^{8}Be*(16.63, 16.91): decay to these states is not observed from the 3^+ states at $E_\text{x} = 19$ MeV, but rather from the 2^- state at 18.9 MeV excitation (1969SW01). See also reaction 17. (1968PA09) find squared $T = 1$ components of 40% and 60% in ^{8}Be*(16.6, 16.9) and of 95% and 5% in ^{8}Be*(17.6, 18.2). Gamma-α angular correlation measurements at $E_\text{p} = 0.44$ MeV show that the $17.64 \to 16.63$ γ is nearly pure M1 δ(E2/M1) $= -0.014 \pm 0.013$ (1969SW02). See also (1965SW03). Radiative widths are shown in Table 8.7.

Table 8.6: ^{8}Be levels from ^{7}Li(p, γ)^{8}Be

$E_{\rm res}$ (keV)	$\Gamma_{\rm lab}$ (keV)	^{8}Be*	$l_{\rm p}$	J^{π}	Res. [c] in	$\omega\Gamma_{\gamma}$ (eV)	Refs.
441.4 ± 0.5 [a]	12.2 ± 0.5	17.642	1	1^{+}	$\gamma_0, \gamma_1, \gamma_3, \gamma_4$	9.4	(1949FO18, 1956BU27, 1969SW01)
1030 ± 5	168	18.157	1	1^{+}	$\gamma_0, \gamma_1, \gamma_3, \gamma_4$	2	(1954KR06, 1960MA33, 1963RI09, 1970FI1B)
1890	150 ± 50	18.91		(2^{-})	γ_3, γ_4		(1969SW01)
2060 ± 20	310 ± 20	19.06		$J = 1, 2, 3$ $\pi = (-)$ [b]	γ_1		(1957NE1A, 1963PE15, 1963RI09, 1967NI1A, 1970FI1B)
(3100)		(20.0)			γ_1		(1970FI1B)
4900		21.5			γ_1		(1970FI1B)
5000	≈ 4500	21.6	(0)	(1^{-})	γ_0		(1959GE33, 1963MI08, 1963PE15, 1966FI1B, 1968BL1E, 1970FI1B)
6000		22.5			γ_1		(1963MI08, 1970FI1B)
7300		23.6			γ_1		(1970FI1B)
7500	≈ 8000	23.8	(0)	$(1^{-}, 2^{-})$	γ_1		(1963MI08, 1963PE15, 1966FI1B, 1968BL1E, 1970FI1B)
(11100)		(27.0)			γ_1		(1970FI1B)
13000	broad	28.6					(1967FE04)

[a] See (1959AJ76).
[b] (1964SC19). See however reaction 18.
[c] γ_0, γ_1, γ_3, γ_4 represent transitions to ^{8}Be*(0, 2.9, 16.6, 16.9), respectively.

Table 8.7: Electromagnetic transitions in ^{8}Be [a]

Transition	Γ_γ (eV)	$\|M\|^2$ (W.u.)	Refs.
$17.6 \rightarrow 0$	16.7	0.15	(1949FO18, 1961ME10, 1968PA09)
$17.6 \rightarrow 2.9$	8.15 ± 0.07 (M1)	0.12	(1961ME10, 1968PA09)
	0.15 ± 0.07 (E2)		(1961ME10)
$17.6 \rightarrow 16.6$	0.032 ± 0.003	1.48 ± 0.15 (M1)	(1969SW01)
	0.021 ± 0.004 [b]	1.1	(1968PA09)
$17.6 \rightarrow 16.9$	0.0013 ± 0.0003	0.15 ± 0.04 (M1)	(1969SW01)
	0.0016 ± 0.0004 [b]	0.22	(1968PA09)
$18.15 \rightarrow 0$	3.0	0.03	(1970FI1B)
$18.15 \rightarrow 2.9$	3.8	0.05	(1970FI1B)
$18.15 \rightarrow 16.6$	0.077 ± 0.019	1.04 ± 0.26 (M1)	(1969SW01)
	0.084 ± 0.018 [b]	1.2	(1968PA09)
$18.15 \rightarrow 16.9$	0.062 ± 0.007	1.51 ± 0.17 (M1)	(1969SW01)
	0.041 ± 0.011 [b]	1.1	(1968PA09)
$18.9 \rightarrow 16.6$	0.168	0.053 (E1)	(1969SW01)
$18.9 \rightarrow 16.9$	0.099	0.045 (E1)	(1969SW01)
$19.06 \rightarrow 2.9$	10.5	0.12	(1970FI1B)

[a] See also (1966LA04).

[b] Values listed by (1968PA09) multiplied by factor 0.56: see (1969SW01), p. 1019.

For a review of the earlier work, see (1959AJ76, 1966LA04). See also (1973SU1E), (1966EV1B, 1966PE1D, 1966WA1C, 1969KA1J), and (1973AS02; theor.).

17. ^{7}Li(p, n)^{7}Be $\qquad Q_\mathrm{m} = -1.64422 \qquad E_\mathrm{b} = 17.256$

Recent measurements of cross sections have been made for $E_\mathrm{p} = 1.9$ to 2.36 MeV (1967BE61; σ_t), 1.93 to 2.66 MeV (1969LE23), 2.1 to 3.8 MeV (1971BU1D), 2.4 to 6.0 MeV (1972PR03; $\mathrm{n}_1\gamma$), 2.6 to 5.4 MeV (1972EL19; n_0), 3 to 10 MeV (1966HA1J; $\mathrm{n}_1\gamma$), 3.2 to 5.4 MeV (1972EL19; n_1), 23 to 52 MeV (1967LO07; $\mathrm{n}_1\gamma$), and 30 and 50 MeV (1969CL06; n_0, n_1). See also (1973WA34). The shape of the neutron yield near threshold has been studied by (1966PA03). Polarization measurements are reported at $E_\mathrm{p} = 2.05$ to 3.00 MeV (1973RO35, 1973RO2E), 3.0 to 4.0 MeV (1971HA27; n_0, n_1), 3.0 to 5.5 MeV (1971TH07; n_0, n_1) and 30 and 50 MeV (1969RO20). For a report on the earlier yield and polarization measurements, see (1966LA04). For angular distributions, see ^{7}Be.

Table 8.8: ^{8}Be levels from ^{7}Li(p, n)^{7}Be

E_p (MeV)	Γ_{lab} (keV)	^{8}Be*	J^π	Refs.
1.88	55 ± 20	18.90	2^-	(1974AR10) [a]
2.25	220	19.22	3^+	(1957NE1A, 1961BE05)
2.6 [b]	≈ 750	19.5	1^-	(1972PR03) [a]
3.0	≈ 1250	19.9	(2^+)	(1972PR03) [a]
4.9	1100	21.5	$3^{(+)}$	(1959GI47, 1963BO06)
5.5	broad	22.1	[c]	(1972PR03)

[a] See also (1966LA04).

[b] $\gamma^2_{n_1}$ and $\gamma^2_{p_1} \approx 1\%$ of the Wigner limit (1972PR03).

[c] The broad dip in the n_1 yield at the same energy as the broad bump in the p_1 yield may be due to interference of two 2^+ states (1972PR03).

The yield of ground state neutrons (n_0) rises steeply from threshold and shows pronounced resonances at $E_p = 2.25$ and 4.9 MeV (1963BO06). The yield of n_1 also rises steeply from threshold (1964BU08) and exhibits a broad maximum near $E_p = 3.2$ MeV (1961BE05, 1972PR03) and a broad dip at $E_p \approx 5.5$ MeV, also observed in the p_1 yield (1972PR03).

Multi-channel scattering length approximation analysis of the 2^- partial wave near the n_0 threshold indicates that the 2^- state at $E_x = 18.9$ MeV is virtual relative to the threshold and that its width $\Gamma = 50 \pm 20$ keV (1974AR10). The ratio of the cross section for ^{7}Li(p, γ)^{8}Be*(18.9) $\xrightarrow{\gamma}$ ^{8}Be*($16.6 + 16.9$) [obtained by (1969SW01)] to the thermal neutron capture cross section ^{7}Be(n, γ)^{8}Be*(18.9) $\xrightarrow{\gamma}$ ^{8}Be*($16.6 + 16.9$) [obtained by (1973BA1J)], provides a rough estimate of the isospin impurity of ^{8}Be*(18.9): $\sigma_{p,\gamma}/\sigma_{n,\gamma} \approx 1.5 \times 10^{-5}$ and therefore the $T = 1$ isospin impurity is $< 4\%$ in intensity (1974AR10).

The structure at $E_p = 2.25$ MeV is ascribed to a 3^+, $T = (1)$, $l = 1$ resonance with $\Gamma_n \approx \Gamma_p$ and $\gamma^2_n/\gamma^2_p = 3$ to 10: see (1966LA04). See also (1973RO35). At higher energies the broad peak in the n_0 yield at $E_p = 4.9$ MeV can be fitted by $J^\pi = 3^{(+)}$ with $\Gamma = 1.1$ MeV, $\gamma^2_n \approx \gamma^2_p$ (1963BO06). The behavior of the n_1 cross section can be fitted by assuming a 1^- state at $E_x = 19.5$ MeV and a $J = 0, 1, 2$, positive-parity state at 19.9 MeV [presumably the 20.2 MeV state reported in reaction 4]. In addition the broad dip at $E_p \approx 5.5$ MeV may be accounted for by the interference of two 2^+ states (1972PR03). See Table 8.8.

The ratio of the cross sections of the (p, n_1) reaction to ^{7}Be*(0.43) to that for the (p, p_1) reaction to the analog state ^{7}Li*(0.48) has been measured for $E_p = 2.4$ to 6.0 MeV (1972PR03), 3 to 10 MeV (1966HA1J) and 23 to 52 MeV (1967LO07). At the lower energies it deviates markedly from unity and varies strongly with energy (1966HA1J). At the higher energies the measurements seem to indicate that the spin-flip, isospin-flip part of the effective interaction is essentially independent of energy while the pure central part appears to decrease as the energy increases (1967LO07). See also (1969CL06).

See also (1968DA1H, 1970DA26, 1971JU05, 1971SC32, 1973AR1R, 1973NE1G), (1971WA1D) and (1970HO04, 1970LU1A, 1970RA33; theor.).

18. (a) ^{7}Li(p, p)^{7}Li $E_b = 17.256$

(b) ^{7}Li(p, p$'$)^{7}Li*

Absolute differential cross sections for elastic scattering have been reported for $E_p = 0.4$ to 12 MeV (1953WA27, 1956MA12, 1965GL03), 14.5, 20.0 and 31.5 MeV (1956KI54) and more recently at 0.85 to 2.0 MeV (1966BA1Q), at 1.36 MeV (1969LE08) and at 6.868 MeV (1971BI11). The yield of inelastically scattered protons (p_1, to ^{7}Li*(0.48)) and of 0.48 MeV γ-rays have been measured in the range $E_p = 0.8$ to 12 MeV (1951BR10, 1954KR06, 1954MO04, 1955HA34, 1957NE1A, 1965GL03, 1966BA1Q, 1972PR03).

Polarization measurements are reported at $E_p = 0.67$ to 2.45 MeV (1973BR13; p_0), 2.7 to 10.6 MeV (1969KI04; p_0, p_1), 14.5 MeV (1965RO22; p_0), 49.8 MeV (1971MA13, 1971MA44; p_0, p_1), 152 MeV (1966RO1C; p_0) and 155 MeV (1968GE04; p_0, p_2). For earlier measurements see (1966LA04). For a summary of angular distribution studies see ^{7}Li.

Anomalies in the elastic scattering appear at $E_p = 0.44$, 1.03, 1.88, 2.1, 2.5, 4.2 and 5.6 MeV. Resonances at $E_p = 1.03$, 3 and 5.5 MeV and an anomaly at $E_p = 1.88$ MeV appear in the inelastic channel. A phase shift analysis and a review of the existing cross section data by (1973BR13) show that the 0.44 and 1.03 MeV resonances are due to 1^+ states which are a mixture of $^{5}P_1$ and $^{3}P_1$ with a mixing parameter of $+25°$; that the 2^- state at the neutron threshold ($E_p = 1.88$ MeV) has a width of about 50 keV [see also reaction 17]; and that the $E_p = 2.05$ MeV resonance corresponds to a 3^+ state. The anomalous behavior of the $^{5}P_3$ phase around $E_p = 2.2$ MeV appears to result from the coupling of the two 3^+ states [resonances at $E_p = 2.05$ and 2.25 MeV]. The $^{3}S_1$ phase begins to turn positive after 2.2 MeV suggesting a 1^- state at $E_p = 2.5$ MeV (1973BR13): see Table 8.9 and (1972PR03).

An attempt has been made to find the $T = 2$ analog of the ground state of ^{8}He: no resonances were observed in either the p_0 or the p_1 yield for $E_p = 11.1$ to 11.9 MeV (1968HA1H). Measurements of the intensity ratios of the reactions (p, p_1) and (p, n_1) have been made by (1966HA1J, 1967LO07, 1972PR03): see reaction 17.

See also (1967CA1G, 1972RU1C) and (1967JO01, 1967SA1C, 1969WA11; theor.).

19. ^{7}Li(p, d)^{6}Li $Q_m = -5.026$ $E_b = 17.256$

See (1969KO1P; theor.) and ^{6}Li.

20. ^{7}Li(p, t)^{5}Li $Q_m = -4.43$ $E_b = 17.256$

Table 8.9: ^{8}Be levels from ^{7}Li(p, p$_0$)^{7}Li and ^{7}Li(p, p$_1$)^{7}Li*

E_p (MeV)	Γ_{lab} (keV)	^{8}Be*	J^π	$\Gamma_{p'}$ (keV)	Refs.
0.441	12.2 [b]	17.642	1^+		(1953CH1A, 1953WA27, 1973BR13)
1.030 ± 0.005	168	18.157	1^+	≈ 6	(1954MO04, 1955LI1B, 1973BR13)
1.88 [a]	55 ± 20	18.90	2^-		(1974AR10, 1973BR13)
2.05	≈ 400	19.05	3^+	small	(1956MA12, 1957NE1A, 1973BR13)
2.25		19.22	3^+	small	(1956MA12, 1957NE1A, 1973BR13)
2.5 [c]	≈ 750	19.4	1^-	res.	(1972PR03, 1973BR13)
[d]					
4.2 ± 0.2	1800 ± 200	20.9 [e]	4^-	(res.)	(1965GL03)
5.6	broad	22.2	[f]	res.	(1965GL03, 1972PR03)

[a] (p, n) threshold: see reaction 17.
[b] $\theta_p^2 = 0.064$.
[c] See also Table 8.8, $\gamma_{n_1}^2$ and $\gamma_{p_1}^2 \approx 1\%$ of the Wigner limit (1972PR03).
[d] A 2^+ state at $E_x \approx 20$ MeV appears to be necessary to account for the cross sections: see Table 8.3 and reaction 4 (1972PR03).
[e] Reduced width is 70% of the Wigner limit (1965GL03).
[f] May be due to two 2^+ states (1972PR03). See also reaction 17.

See ^{5}Li.

21. ^{7}Li(p, α)^{4}He $\quad Q_m = 17.348 \quad E_b = 17.256$

The cross section follows the expression $E^{-1}e^{-B/\sqrt{E}}$, with $B = 91.5 \pm 4.5$ keV$^{1/2}$, in the range $E_p = 23$ to 50 keV. The cross section in that interval rises from 0.013 to 2.4 μb (1967FI05). In the range $E_p = 131$ to 561 keV, the cross section increases from 0.16 ± 0.02 to 3.7 ± 0.4 mb (1971SP05; and T.A. Tombrello, private communication). The cross section has also been measured for $E_p = 0.04$ to 0.13 MeV by (1969LE22). Taking into account ^{8}Be $J^\pi = 2^+$ levels at 16.7, 16.9 and 20.6 MeV, (1972BA41) has made an R-matrix fit to the revised data of (1971SP05) and has obtained a quadratic energy dependence for the S-factor: $S = 0.065[1 + 1.82E - 2.51E^2]$ MeV · b, over the energy range $E_p = 0$ to 600 keV.

Excitation functions and angular distributions have been measured at many energies up to 18.6 MeV: see (1966LA04) for earlier references. Recently, differential cross-section measurements are reported by (1966MA03, 1969SW01: $E_p = 0.4$ to 2.45 MeV), (1969LE08: $E_p = 1.36$ MeV) and (1967CR05: $E_p = 41.3$ and 45.2 MeV). Polarization measurements have been carried out for $E_p = 0.8$ to 3 MeV (1968PE03), 2.7 to 10.6 MeV (1969KI04), 3.00 to 10.04 MeV (1968PL01), 5.5 to 6.7 MeV (1966BO09), and 7.4 to 10.4 MeV (1968AR04). See also (1966LA04) for a listing of the earlier references and (1966DA1B, 1971PL1C). In the range $E_p = 3$ to 10 MeV the asymmetry has one broad peak in the angular distribution at all energies except near 5 MeV; the peak value is 0.98 ± 0.04 at 6 MeV and is essentially 1.0 for $E_p = 8.5$ to 10 MeV (1968PL01, 1969KI04) [see Fig. 12 in (1969KI04) and Fig. 6 (1968PL01) for contour maps of the asymmetry].

Broad resonances are reported to occur at $E_p = 3.0$ MeV, $\Gamma \approx 1$ MeV (1948HE1A) and at $E_p = 5.6$ MeV, $\Gamma \approx 1$ MeV (1961HA27, 1962TE04, 1964MA51). Some structure is also reported near $E_p = 6.0$ to 6.5 MeV, and at $E_p = 9.0$ MeV (1964MA51). The latter is also reflected in the behavior of the A_2 coefficient (1968PL01). The experimental data on yields and on polarization have been analyzed by (1970KU1H, 1971KU10): the data appear to require including two 0^+ states [at $E_x \approx 19.7$ and 21.8 MeV] with very small α-particle widths, and four 2^+ states [at $E_x \approx 15.9$, 20.1, 22.2 and 25 MeV]. See, however, reaction 4 and (1972BA83). A 4^+ state near 20 MeV was also introduced in the calculation but its contribution was negligible. The observed discrepancies are said to be probably due to the assumption of pure $T = 0$ for these states (1971KU10).

See also (1968CO1L, 1968CO1M, 1970CO1M), (1969AU1C, 1972BA2M, 1973TR1E; astrophys. considerations), (1967BO38, 1969DA1G, 1970PE1D).

At $E_p = 9.1$ MeV, α-particle spectra are discussed in terms of the first excited state of ^{4}He (1970LI06): see (1973FI04).

22. (a) ^{7}Li(d, n)^{8}Be $\qquad Q_m = 15.031$

(b) ^{7}Li(d, n)^{4}He^{4}He $\qquad Q_m = 15.1233$

At $E_d = 2$ MeV, recoil proton spectra show only the ground state and ^{8}Be*(2.9). No other groups with $E_x < 9$ MeV appear with intensity > 10% of n_0. The spectrum yields $E_x = 3.1 \pm 0.1$, $\Gamma = 1.75 \pm 0.1$ MeV (1964JO04) [(1971RO05) report $E_x = 3.10 \pm 0.09$, $\Gamma = 1.74 \pm 0.08$ MeV]. See Table 8.4. At higher deuteron energies the population of ^{8}Be*(16.6, 16.9, 17.6, 18.2, 18.9, 19.1, 19.2) is reported and $l_p = 1$ is obtained for the transitions to ^{8}Be*(16.6, 17.6, 18.2): see (1960DI02, 1966DI1B, 1967KE1A, 1967KE1F). Angular distributions of the n_0 and n_1 groups to ^{8}Be*(0, 2.9) are reported by (1966JU1A: $E_d = 0.7$ and 0.8 MeV), (1969NU1C: $E_d = 0.90$ to 1.09 MeV), (1966MI09: $E_d = 1$ MeV), and by (1970OSZY: $E_d = 1.62$ to 2.97 MeV). See also (1966LA04) for earlier references, (1966MA1J, 1966NU1B, 1966PO1D, 1968SA14, 1970SA20, 1970SA25, 1970SA29, 1973JO1L, 1973WE19) and the important theoretical paper by (1969BA43).

Reaction (b) appears to proceed primarily by sequential decay via ^{8}Be*(2.9, 16.6, 16.9) and ^{5}He(0): see (1967VA11). See also (1966AS04, 1966MI09, 1967JE01, 1972DE44, 1973HE26, 1973MC13). However, (1969HO11) deduce the involvement of a state with $E_x = 11.4 \pm 0.05$ MeV, $\Gamma_{c.m.} = 2.8 \pm 0.2$ MeV. See also (1973KA32). Attempts to observe n-α rescattering ("proximity scattering") proceeding via ^{8}Be*(16.6, 16.9) have been unsuccessful: see (1968VA12, 1971SW10, 1972BR08). See also (1969TH02, 1971TH08) and the discussion in ^{5}He.

For polarization measurements see ^{9}Be. See also (1965LE12, 1967BE13, 1967BI1D, 1967FL12, 1967WI1C, 1969CO1F, 1971HU1H).

23. (a) ^{7}Li(^{3}He, d)^{8}Be $\qquad Q_m = 11.762$

(b) ^{7}Li(^{3}He, pn)^{8}Be $\qquad Q_m = 9.538$

Deuteron groups are observed to ^{8}Be*(0, 2.9, 16.6, 16.9, 17.6). The group to ^{8}Be*(2.9) is well fitted by $E_x = 2.82$ MeV, $\Gamma = 1.27$ MeV (1971PI06). See also reaction 13 (1969NU01). The $J^\pi = 1^+$ mixed isospin state have $E_x = 16.627 \pm 0.005$ and 16.901 ± 0.005 MeV and $\Gamma = 113 \pm 3$ and 77 ± 3 keV (1967MA12): see also Table 8.5 and (1971PI06). Angular distributions have been measured at $E(^3\text{He}) = 0.90$ and 1.10 MeV (1971ST35; d_0), 3 MeV (1972LI31; d_0, d_1), and at 10 MeV by (1970DI12, 1970DI1F; d_0, d_1) and by (1968CO07; d to ^{8}Be*(16.6, 16.9)). Spin-dependent effects in the angular distributions of d_0 and d_1 obtained by (1963WE1B) at 24.3 MeV are discussed by (1967SI1A). The angular distribution to ^{8}Be*(16.6) is forward peaked, that for ^{8}Be*(16.9) is roughly isotropic (1968CO07). See also (1964MA57).

The decay of various ^{9}Be states to ^{8}Be*(0, 2.9) has been studied by (1966CH20, 1968CO08, 1972MC1E): see ^{9}Be and Table 9.5. See also (1968LI1D, 1970LI1Q) and (1967CO1L; theor.).

24. (a) ^{7}Li(α, t)^{8}Be $\qquad Q_m = -2.559$

(b) ^{7}Li(α, αt)^{4}He $\qquad Q_m = -2.4668$

The angular distributions of the t_0 group have been measured at many energies up to 48 MeV: see (1966LA04). Recently, measurements have been carried out at $E_\alpha = 23.2$ and 25.0 MeV (1973VA1A; t_0, t_1), 30 MeV (1972ME07; t_0, t_1; PWBAE and DWBA analysis) and at 50 MeV (1970LA14; t_0). The ground state of ^{8}Be does decay isotropically in the c.m. system and therefore $J^\pi = 0^+$ (1970LA14). Spin-dependent effects in the angular distributions for t_0 and t_1 obtained by (1963WE1B: $E_\alpha = 28$ MeV) are discussed by (1967SI1A). At $E_\alpha = 10$ MeV an anomaly ("ghost") is observed in the ^{8}Be excitation spectrum at $E_x \approx 0.5$ MeV. It may be due to interference of the 0^+ states ^{8}Be*(0, 6.) [see reaction 4] or to thresholds of particle channels (1971BE52).

In reaction (b), sequential decay is observed at $E_\alpha = 50$ MeV, via ^{8}Be*(0, 2.9, 11.4, 16.6, 16.9, 19.9) (1970LA14). See also (1968BE1Q, 1968MA25).

25. ^{7}Li(^{7}Li, ^{6}He)^{8}Be $\qquad Q_m = 7.278$

At $E(^7\text{Li}) = 1.4$, 1.7 and 1.8 MeV, the angular distributions of ^{6}He ions leaving ^{8}Be in its ground and 2.9 MeV states are essentially isotropic (1968ST12). See also (1966LA04).

26. (a) ^{7}Be(n, p)^{7}Li $\quad Q_m = 1.64422 \quad E_b = 18.900$

(b) ^{7}Be(n, α)^{4}He $\quad Q_m = 18.992$

(c) ^{7}Be(n, $\gamma\alpha$)^{4}He $\quad Q_m = 18.992$

At thermal energies, the (n, p) cross section is $(4.8 \pm 0.9) \times 10^4$ b (1955HA34, 1973MU14), the (n, α) cross section is ≤ 0.1 mb (1962BA1B, 1963BA34) and the (n, $\gamma\alpha$) cross section is 155 mb (1963BA34). These values, and comparison of the (p, n) cross section with that of reaction (a), support the $J^\pi = \frac{3}{2}^-$ assignment for ^{7}Be(0) (1957NE1A, 1963BA34). The role of these reactions in astrophysical phenomena is discussed by (1968FO1A, 1969BA1N). See also (1959AJ76) and reaction 17.

27. ^{7}Be(d, p)^{8}Be $\quad Q_m = 16.676$

For $E_d = 0.8$ to 1.7 MeV, proton groups are observing corresponding to the ground state and ^{8}Be*(2.9): derived parameters for the latter are shown in Table 8.4 (1959SP1A, 1960KA17). See also (1969BA43; theor.).

28. ^{8}Li(β^-)^{8}Be $\quad Q_m = 16.006$

^{8}Li decays mainly to the broad 2.9 MeV, 2^+ level of ^{8}Be, which decays into two α-particles. Both the β-spectrum and the resulting α-spectrum have been extensively studied. There appears to be an increasing excess of α-particles with E_α which may reflect transitions into the tail of the $J^\pi = 2^+$ level at $E_x = 16.67$ MeV. See (1959AJ76, 1966LA04) for earlier references. See also (1969KL08) and ^{8}B(β^+).

Studies of the distribution of recoil momenta and neutrino recoil correlation indicate that the decay is overwhelmingly GT, axial vector [see reaction 1 in ^{8}Li] and that the ground state of ^{8}Li has $J^\pi = 2^+$: see (1966LA04).

Angular correlations 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 values of the coefficients are displayed in Table 8.10. See also (1973TR1J, 1973TR1K, 1973TR1L). The experimental value of δ [$\delta \equiv$ B(^{8}Li) − B(^{8}B)] is $(5.4 \pm 0.4)\ W_\beta$, consistent with CVC theory (1966EI02).

A recent asymmetry measurement is reported by (1971VA19). See also (1971VA1E, 1973NE10). Measurements of the excitation spectra in the decays of ^{8}Li and ^{8}B show no evidence for second class currents: $|g_{IT}| < 7 \times 10^{-4}$ (1971WI05). See also (1966JA1C) and (1960KU05, 1960WE1A, 1966BA26, 1966LI1C, 1968KR10, 1969BA43, 1970DA21, 1971LI1H, 1971WI18, 1971WI1C, 1972EM02, 1972HO23, 1972MI1M, 1972WI28, 1972WI1C, 1973EM1B, 1973HA49, 1973TO14, 1973WI11, 1974WI1L; theor.).

Table 8.10: α-β angular correlation coefficients in ^{8}Li, ^{8}B [a]

Nuclide	A/W_β	B/W_β	W_β (MeV)	δ/W_β [b]	Refs.
^{8}Li		$(5.7^{+2.9}_{-1.9}) \times 10^{-3}$	7.0		(1960KR03)
^{8}Li	$(-8.7 \pm 0.7) \times 10^{-3}$	$(+3.2 \pm 0.6) \times 10^{-3}$	11	$(7.0 \pm 1.2) \times 10^{-3}$	(1962NO02)
^{8}Li	$(-8.3 \pm 1.1) \times 10^{-3}$	$(+3.7 \pm 1.0) \times 10^{-3}$	7.5		(1963GR11)
^{8}Li	$(-9.7 \pm 0.7) \times 10^{-3}$	$(+3.1 \pm 0.3) \times 10^{-3}$	6.6	$(5.4 \pm 0.4) \times 10^{-3}$	(1966EI02)
^{8}B	$(-8.7 \pm 0.9) \times 10^{-3}$	$(-3.9 \pm 1.0) \times 10^{-3}$	11		(1962NO02)
^{8}B	$(-11.1 \pm 1.3) \times 10^{-3}$	$(-2.3 \pm 0.3) \times 10^{-3}$	7.0		(1966EI02)

[a] $W(\theta) = 1 + A\cos\theta + B\cos^2\theta$.
[b] $\delta \equiv B(^8\text{Li}) - B(^8\text{B})$.

29. ^{8}B(β^+)^{8}Be $\qquad Q_m = 17.981$

The decay proceeds mainly to ^{8}Be*(2.9) [see Table 8.4 for its parameters]. 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*(16.63), for which parameters $E_x = 16.67$ MeV, $\Gamma = 150$ to 190 keV or $E_x = 16.62$ MeV, $\Gamma = 95$ keV are derived. Using $\tau_{1/2} = 769 \pm 4$ msec, $\log ft = 2.9$. The low ft value supports the identification $J^\pi = 2^+$; $T = 1$ for ^{8}Be*(16.63) (1964MA35). See, however, (1965MA1G). The energy distribution of α-particles has also been measured by (1969CL10). Analysis of this data and of data from α-α scattering in a three level R-matrix formalism indicate a 2^+ state of ^{8}Be at $E_x = 12.0^{-3.0}_{+3.5}$ MeV and of $\Gamma = 14^{-3}_{+4}$ MeV ($a_2 = 6.0 \pm 0.5$ fm) (1969CL10). See also (1969BA43; theor.).

For angular correlation measurements see reaction 28 (1966EI02) and Table 8.10. See also (1973TR1J, 1973TR1K, 1973TR1L).

30. (a) ^{9}Be(γ, n)^{8}Be $\qquad Q_m = -1.6651$
(b) ^{9}Be(n, 2n)^{8}Be $\qquad Q_m = -1.6651$
(c) ^{9}Be(p, pn)^{8}Be $\qquad Q_m = -1.6651$
(d) ^{9}Be(t, tn)^{8}Be $\qquad Q_m = -1.6651$
(e) ^{9}Be(α, αn)^{8}Be $\qquad Q_m = -1.6651$

For reaction (a) see (1966DE07, 1968AD09, 1969GA1M) and (1965BO1B, 1969AU05; theor.). See also ^{9}Be.

Reaction (b) appears to proceed largely via excited states of ^{9}Be, with subsequent decay to ^{8}Be, mainly ^{8}Be*(2.9): see (1966LA04), ^{9}Be and ^{10}Be. At $E_n = 14$ MeV the cross section at

$20°$ for production of dineutrons is < 2 mb/sr (1966RO1G). See also (1965GO1C, 1965GO1E, 1966BO1C, 1966BO1F, 1966FE1C, 1967BO1F, 1970PR1E).

For reaction (c) see (1966NO1A; theor.) and ^{9}Be. For reaction (d) see (1967SE11). For reaction (e) see (1971GU15, 1973GE1J) and ^{9}Be.

31. (a) ^{9}Be(p, d)^{8}Be $\quad Q_{\rm m} = 0.5595$

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

$Q_0 = 559.0 \pm 1.1$ keV (1966RE02, 1967ST30);

$Q_0 = 559.6 \pm 0.6$ keV (1967OD01); see also (1967SP09).

Angular distributions of deuteron groups have been reported at $E_{\rm p} = 0.11$ to 0.55 MeV (1973SI27; d$_0$), 0.30 to 0.90 MeV (1968BE1N; d$_0$), 5 to 11 MeV (1972HU03; d$_0$) [analysis by DWBA and BHMM (1967BU23); derived spectroscopic factors], 13.0, 14.0, 15.0 and 21.35 MeV (1972VO1H; d$_0$), 17.0, 21.0, 25.0, 29.1 MeV (1973MO01; d$_0$, d$_1$), 33.6 MeV (1967KU10, 1970KU1D: deuterons to ^{8}Be*(0, 2.9, 16.95, 17.62, 18.18, 19.21); also derived spectroscopic factors) [also saw ^{8}Be*(11.4); determined $\Gamma_{\rm c.m.}(16.95) = 103 \pm 15$ keV, $\Gamma_{\rm c.m.}(19.21) = 208 \pm 30$ keV], 40.8 MeV (1966MA22: deuterons to ^{8}Be*(16.63, 16.91)), 46 MeV (1967VE01: deuterons to ^{8}Be*(0, 2.9, 16.9, 17.6, 18.2, 19.1) [also report ^{8}Be*(24.5)], 100 MeV (1968LE01: deuterons to ^{8}Be*(0, 2.9, 16.9, 18.9)) [also saw ^{8}Be*(11.0, 23.0, 26.0)], 155 MeV (1969BA05, 1969TO1A: deuterons to ^{8}Be*(0, 2.9) [$\Gamma = 2.0 \pm 0.1$ MeV], 11.5 [$\Gamma = 8 \pm 1$ MeV], 16.8 ± 0.2, 18.9 ± 0.3) [also saw ^{8}Be*(17.6 ± 0.4, 21.5 ± 0.3)] and 185 MeV (1969SU02: deuterons to ^{8}Be*(0, 2.94 ± 0.08, 11.3 ± 0.3, 16.87 ± 0.06, 17.58 ± 0.08, 18.10 ± 0.10, 19.16 ± 0.07, 22.0 ± 0.15, 22.9 ± 0.15)) [also report ^{8}Be*(20.0 ± 0.2 (?)); $\Gamma_{\rm c.m.}(2.9) = 1.5 \pm 0.1$ MeV; $\Gamma_{\rm c.m.}$(22.0, 22.9) ≥ 1 MeV (the angular distributions for these two states are not clear cut)]. (1971SC26) have analyzed the angular distributions obtained by (1967VE01, 1968LE01) using DWBA with a local-energy approximation and have derived spectroscopic factors. With the exception of ^{8}Be*(11.4, 22.0, 22.9) the angular distributions are consistent with $l = 1$. The yield of the deuterons corresponding to ^{8}Be*(16.63) is very low: [$\approx$ 5% compared to ^{8}Be*(16.91)] as expected by predictions of the cluster model (1966MA22: $E_{\rm p} = 40.8$ MeV). See also (1967KU10) and reaction 21 in ^{9}Be in (1966LA04).

Anomalies in the deuteron spectrum between the d$_0$ and the d$_1$ groups have been reported at various energies [see (1966LA04) and (1967FI1D, 1967HA1K, 1971BE52, 1971MI1C)]. The shape of the deuteron spectrum near ^{8}Be*(2.9) requires $a_2 \approx 7.1$ fm (1969BA43). See also reaction 4 and (1968BA2D). At $E_{\rm p} = 17$ MeV, for the transitions to ^{8}Be*(0, 2.9) the ratios of σ(p, d)/σ(p, d) $= 11.8$ and 14.1, respectively (1967CO09, 1969CO06). See also (1968NA1A; theor.).

Reaction (b) at $E_{\rm p} = 9$ MeV is dominated by strong final state interactions 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 (1967FI1D). See also ^{10}B and (1966CA1E, 1966LA20, 1967OG1A, 1967RO07, 1968TI1A, 1972QU01) and (1967BA1M, 1967JO1D, 1968BO1P, 1970BO1K; theor.).

32. (a) ^{9}Be(d, t)^{8}Be $Q_m = 4.5925$
(b) ^{9}Be(d, t)^{4}He^{4}He $Q_m = 4.684$
$Q_0 = 4591.7 \pm 3.1$ keV (1967OD01: see also (1967SP09)).

At $E_d = 11.8$ MeV, angular distributions have been obtained for the tritons to ^{8}Be*(0, 2.9) (1967FI07): $S = 0.51$ and 0.75, respectively (DWBA analysis). At $E_d = 38$ MeV, angular distributions of the tritons to ^{8}Be*(16.91, 17.64, 19.0) have been compared with those of the ^{3}He to the analog states in ^{8}Li. The cross-section ratios $\sigma_{17.64}/\sigma_{0.98(^8\text{Li})} = 0.45 \pm 0.04$ and $\sigma_{16.91}/\sigma_{0(^8\text{Li})} = 0.75 \pm 0.04$, consistent with the pure $T = 1$ nature of ^{8}Be*(17.64) and the mixed T nature of ^{8}Be*(16.91) [and ^{8}Be*(16.63)] (1966GA21; abstract). Angular distributions have also been measured at $E_d = 0.3$ to 1.0 MeV (1968BE1E; t_0), 0.9 to 3.1 MeV (1973SA1Q; t_0), 15.0 MeV (1969AR1B; t_0) and at many other energies up to $E_d = 20$ MeV: see (1966LA04). The ghost anomaly which is seen near the t_0 group has been studied at $E_d = 2.5$ MeV: it is interpreted as being due to an extreme threshold effect (1971BE52). See also (1967DE1J) and (1970BO1K, 1973HE1J; theor.). A kinematically complete study of reaction (b) at $E_d = 26.3$ MeV indicates the involvement of ^{8}Be*(0, 2.9, 11.4, 16.9, $19.9 + 20.1$). Parameters obtained for ^{8}Be*(2.9, 11.4) are $E_x = 3.20 \pm 0.03$ and 11.70 ± 0.07 MeV, $\Gamma = 1.72 \pm 0.09$ and 4.41 ± 0.5 MeV (1973SO08).

33. (a) ^{9}Be(^{3}He, α)^{8}Be $Q_m = 18.9134$
(b) ^{9}Be(^{3}He, α)^{4}He^{4}He $Q_m = 19.005$
(c) ^{9}Be(^{3}He, αp)^{7}Li $Q_m = 1.657$

Angular distributions have been measured at $E(^3\text{He}) = 3.0$ MeV (1968MO05; $\alpha_{16.91}$), 3.0 and 4.0 MeV (1963DO08; α_0, $\alpha_{2.9}$, $\alpha_{16.6}$, $\alpha_{16.9}$, $\alpha_{17.6}$), 18.0, 22.7, 26.7, 32.3 MeV (1965AR07; α_0, α_1) and 26.7 MeV (1968AR12; $\alpha_{16.9}$, $\alpha_{17.6}$, $\alpha_{18.1}$, $\alpha_{19.2}$). See also (1959AJ76) and (1967SI1A). The parameters of the observed states are shown in Tables 8.4 and 8.5 (1961ER01, 1963DO08).

Reaction (b) has been studied at $E(^3\text{He}) = 1.6$ MeV (1970EH1A), 3.0 MeV (1966SU04, 1968MO05) and 3.0 and 4.0 MeV (1972TA04). See also (1966LA04) and (1967ST1E). The reaction proceeds by sequential decay via ^{8}Be*(0, 2.9, 11.4, 16.6, 16.9, 19.9, 22.5) (1972TA04). The angular correlation via ^{8}Be*(16.91) is consistent with $J^\pi = 2^+$ for that state (1968MO05). $J^\pi = 2^+$ is also indicated for ^{8}Be*(16.63) (1966SU04). See also (1968TH1G). For reaction (c) see (1967ST1D). See also (1964MA57, 1966CA08, 1966DI1C, 1967OG1A, 1970CA28, 1971TR1B, 1972RO1N), (1967HO1C) and (1970BO1K, 1971OS05, 1972TH04, 1973RO28; theor.).

34. (a) ^{9}Be(^{6}Li, ^{7}Li)^{8}Be $Q_m = 5.586$
(b) ^{9}Be(^{7}Li, ^{8}Li)^{8}Be $Q_m = 0.368$
(c) ^{9}Be(^{12}C, ^{13}C)^{8}Be $Q_m = 3.281$
(d) ^{9}Be(^{16}O, ^{17}O)^{8}Be $Q_m = 2.477$

(e) ^{9}Be(^{18}O, ^{19}O)^{8}Be $\quad Q_m = 2.292$

(f) ^{9}Be(^{19}F, ^{20}F)^{8}Be $\quad Q_m = 4.936$

At $E(^{6}\text{Li}) = 3.5$ MeV the population of ^{8}Be*(2.9) is very small but $^{8}\text{Be}_{\text{g.s.}}$ is involved (1968JA08). See also (1966LA04). For reaction (b) see (1966LE10) and (1968TO1C; theor.). For reaction (c) see (1970BA1J, 1970BA1Y). For reaction (d) see (1968KN1A, 1970BA1J, 1970BA1Y). Reaction (e) has been studied at $E(^{18}\text{O}) = 16$ and 20 MeV (1971KN05). See also (1968FA04). For reaction (f) see (1968FA04).

35. ^{10}B(γ, d)^{8}Be $\quad Q_m = -6.0258$

See ^{10}B and (1959AJ76).

36. (a) ^{10}B(n, t)^{8}Be $\quad Q_m = 0.2318$

(b) ^{10}B(n, t)^{4}He^{4}He $\quad Q_m = 0.3237$

Angular distributions have been measured at $E_n = 14.4$ MeV (1964VA14; t_0, t_1). Reaction (b) has been studied at the same energy by (1967VA12). See also (1971MI1H) and (1967BA1E; theor.). See also ^{11}B in (1975AJ02).

37. (a) ^{10}B(p, ^{3}He)^{8}Be $\quad Q_m = -0.5320$

(b) ^{10}B(p, pd)^{8}Be $\quad Q_m = -6.0258$

At $E_p = 49.5$ MeV angular distribution measurements have been carried out for the ^{3}He groups to ^{8}Be*(0, 2.9, 16.6, 16.9): the ratio d$\sigma(16.63)$/d$\sigma(16.91)$ has a mean value of 0.65 ± 0.05 for $\theta = 15°$ to $30°$, suggesting possibly a preferential excitation of the $T = 1$ components of these two states. The ratio of the differential cross sections dσ(p, t) [to $^{8}\text{B}_{\text{g.s.}}$] to d$\sigma$(p, ^{3}He) [to ^{8}Be*(16.63, 16.91)] ($15°$ to $30°$) seems to also suggest this (1971SQ01).

38. (a) ^{10}B(d, α)^{8}Be $\quad Q_m = 17.822$

(b) ^{10}B(d, α)^{4}He^{4}He $\quad Q_m = 17.9138$

$Q_0 = 17.8186 \pm 0.0041$ (1967OD01).

Angular distributions have been reported at $E_{\rm d} = 0.5$ to 1.0 MeV (1968FR07; α_0, α_1), 0.8 to 2.5 MeV (1968CO31; α_0, α_1), 3.0 to 7.2 MeV (1967LE1C; α_0) and 7.5 MeV (1966BR08; α to ^{8}Be*(16.63, 16.91, 17.64, 18.15)). At $E_{\rm d} = 7.5$ MeV the total cross section for formation of ^{8}Be*(16.63), $\sigma_{\rm t}$(16.63), is about 1.15 $\sigma_{\rm t}(16.91)$, consistent with the mixed isospin character of these two states. $\sigma_{\rm t}(18.15)$ is $\approx$ 0.85 $\sigma_{\rm t}(16.91)$, but the other nearby 1^+ state ^{8}Be*(17.64) has $\sigma_{\rm t}(17.64) \approx 0.07\ \sigma_{\rm t}(16.91)$, consistent with the nearly pure $T = 1$ nature of ^{8}Be*(17.64) (1966BR08). These four states [^{8}Be*(16.63, 16.91, 17.64, 18.15)] have been studied for $E_{\rm d} = 4.0$ to 12.0 MeV. Interference between the 2^+ states [^{8}Be*(16.63, 16.91)] varies as a function of energy. The cross section ratios for formation of ^{8}Be*(17.64, 18.15) vary in a way consistent with a change in the population of the $T = 1$ part of the wave function over the energy range: at the higher energies, there is very little isospin violation. At higher $E_{\rm x}$ only the 3^+ state at $E_{\rm x} = 19.2$ MeV is observed, the neighboring 3^+ state at $E_{\rm x} = 19.06$ MeV is not seen. The $J^\pi = 1^+; T = 0$ state is found to have $E_{\rm x} = 18.146 \pm 0.005$ MeV (based on 17.638 for the $J^\pi = 1^+; T = 1$ state) and $\Gamma = 138 \pm 6$ keV (1970CA12). There is some question as to whether a two-level fit can be made for the α groups to ^{8}Be*(16.63, 16.91). ((1970CA12) and W.D. Callender, private communication) are dubious about this, feeling that other 2^+ states have to be brought into the calculation. Based on a two-level fit they find the following average values: $\Gamma_{16.6} = 113$ keV, $\Gamma_{16.9} = 80$ keV, $\Delta Q = 302$ keV. However, (1971NO04) state that the two-level fit is appropriate if the spectra are properly corrected for effects of final state Coulomb interactions: $\Gamma_{16.6} = 90 \pm 5$ keV, $\Gamma_{16.9} = 70 \pm 5$ keV, $\Delta Q = 290 \pm 7$ keV. See also (1966BR22) and (1970KI1D; theor.). For a listing of the parameters of observed states see Tables 8.4 and 8.5 (1961ER01, 1969NU01, 1970CA12).

Angular correlation studies [$E_{\rm d} \leq 3$ MeV] indicate that reaction (b) takes place mainly by a sequential process involving ^{8}Be*(0, 2.9, 11.4, 16.6, 16.9): see (1968LO01, 1970ST02, 1971LA14) and (1967CA13, 1968AS01). (1968LO01) report $E_{\rm x} = 2.7 \pm 0.2$ MeV, $\Gamma = 1.0 \pm 0.1$ MeV, and $\Gamma = 3.0 \pm 0.5$ MeV for ^{8}Be*(11.4). See also (1967CA13, 1970ST02). For a study of rescattering effects see (1972VA1L).

See also ^{12}C and (1964MA57, 1965PA1E, 1966AS10, 1966DI1C, 1967AS1A, 1967NA11, 1967PE1B, 1968TH1G, 1969NA17, 1972RO1N), (1966BR1G) and (1967BA1M, 1968NA1B, 1970KO01, 1970NA06, 1973RO28; theor.).

39. ^{10}B(^{3}He, pα)^{8}Be $Q_{\rm m} = 12.328$

At $E(^3{\rm He}) = 2.45$ and 6.00 MeV this reaction proceeds primarily by sequential decay via ^{8}Be*(0, 2.9) and via ^{5}Li, ^{9}B and ^{12}C states [see also the latter nuclei] (1966WA16). See also (1966WI08, 1968KR02, 1970BE1F), (1966LA04, 1967HO1C) and (1967PR1B; theor.).

40. ^{10}B(α, ^{6}Li)^{8}Be $Q_{\rm m} = -4.552$

At $E_\alpha = 46$ MeV angular distributions obtained for the transitions to ^{8}Be*(0, 2.9) are consistent with a direct interaction mechanism (1970ZE03).

41. (a) ^{11}B(γ, t)^{8}Be $Q_{\rm m} = -11.2242$
(b) ^{11}B(γ, t)^{4}He^{4}He $Q_{\rm m} = -11.1323$

See ^{11}B in (1975AJ02).

42. (a) ^{11}B(p, α)^{8}Be $Q_{\rm m} = 8.591$
(b) ^{11}B(p, α)^{4}He^{4}He $Q_{\rm m} = 8.6824$
$Q_0 = 8.575 \pm 0.011$ (1967SP09).

Angular distributions have been measured at $E_{\rm p} = 0.78$ to 12.00 MeV (1963SY01, 1968WA1G; α_0), 1.4, 2.0 and 2.6 MeV (1972GE19; α_0, α_1 (not at 2.0)), 12, 20, 24 and 30 MeV (1971CA16; α_0), 26.7 and 38 MeV (1969GA03, 1970GU06; α_0), 40 MeV (1971KA21; α_0, α_1 and α to ^{8}Be*(12.5) [$\Gamma = 4.0 \pm 0.5$ MeV] and to ^{8}Be*($16.6 + 16.9$, 17.6, 18.1, 19.0)) and at $E_{\rm p} = 45$ MeV (1971DE2B, 1972DE01, 1972DE02; α_0, α_1). At $E_{\rm p} = 45$ MeV the angular distributions are typical of a direct reaction mechanism, with a rise in the backward direction indicative of heavy particle stripping (1972DE01, 1972DE02). Observed parameters for ^{8}Be*(2.9) are shown in Table 8.4 (1969NU01, 1971KA21). At $E_{\rm p} = 40$ MeV, $\theta = 20°$, d$\sigma_{16.6}$/d$\sigma_{16.9} = 2.3 \pm 0.4$ (1971KA21).

Reaction (b) has been studied for $E_{\rm p} = 0.15$ to 9.5 MeV. The reaction proceeds predominantly by sequential two-body decay via ^{8}Be*(0, 2.9): see, e.g., (1965BR18, 1968CH01, 1972HU04). See also (1967KA09, 1967MA11, 1968GI03, 1969QU01, 1970CO03, 1971KO22, 1972MI1J). Some papers report very narrow widths in this reaction for ^{8}Be*(2.9). However, (1972HU04) find a good fit to the data with $E_{\rm x} = 2.99$ MeV, $\Gamma = 1.45$ MeV when an interference term is included. The interference effect is attributable to the identity of the three α-particles and to the ambiguity in their order of emission (1965BR18).

See also ^{12}C in (1968AJ02, 1975AJ02), (1966LA04), (1966LO1G, 1967CO29, 1967EN1A, 1967FL12, 1967TR1B, 1968LA1C, 1969LA1B, 1969TR1D, 1972DZ10, 1973PR1C), (1969PH1B) and (1969GO13, 1970GO1J, 1970GO33, 1970GO49, 1970KO1K, 1970MC25, 1970MC1T, 1970SC01, 1972TH1M, 1973DU1D, 1973GO35; theor.).

43. ^{11}B(d, nα)^{8}Be $Q_{\rm m} = 6.3658$

See (1971RE19) and ^{9}Be.

44. ^{11}B(^{3}He, ^{6}Li)^{8}Be $Q_{\rm m} = 4.570$

This reaction has been studied for $E(^3{\rm He}) = 1.4$ to 5.8 MeV. Angular distributions have been measured at $E(^3{\rm He}) = 5.2$ MeV involving $^8{\rm Be}_{\rm g.s.} + {}^6{\rm Li}_{\rm g.s.}$, $^8{\rm Be}_{\rm g.s.} + {}^6{\rm Li}^*_{3.56}$, and $^8{\rm Be}^*_{2.9} + {}^6{\rm Li}_{\rm g.s.}$ (1967YO02, 1967YO1C, 1968ME13).

45. (a) ^{11}B(α, ^{7}Li)^{8}Be $Q_m = -8.758$

(b) ^{11}B(α, ^{7}Li)^{4}He^{4}He $Q_m = -8.666$

Angular distributions have been reported at $E_\alpha = 28.4$ and 29.0 MeV for ^{8}Be$_{g.s.}$ + ^{7}Li$_{g.s.}$, ^{8}Be$_{g.s.}$ + ^{7}Li$^*_{0.48}$ and ^{8}Be$^*_{2.9}$ + ^{7}Li (29 MeV only) by (1968KA24) and at 42 MeV for ^{8}Be$_{g.s.}$ + ^{7}Li$_{g.s.}$ and ^{8}Be$_{g.s.}$ + ^{7}Li$^*_{0.48}$ by (1968MI05). At $E_\alpha = 65$ MeV ^{8}Be*($16.6 + 16.9$, 20.0) are apparently also excited (1973WO06). See also (1966GE12) and ^{7}Li. For reaction (b) see (1969FU09).

46. (a) ^{12}C(γ, α)^{8}Be $Q_m = -7.367$

(b) ^{12}C(e, eα)^{8}Be $Q_m = -7.367$

For reaction (a) see (1966LA04), (1973CL1E) and (1965DZ1A; theor.). For reaction (b) see (1970EN1A).

47. ^{12}C(n, nα)^{8}Be $Q_m = -7.367$

This reaction proceeds via ^{8}Be*(0, 2.9) at $E_n = 13$ to 18 MeV, and via states in ^{5}He, ^{9}Be and ^{12}C (1966MO05). See also (1966LA04) and (1971DO1K).

48. ^{12}C(p, pα)^{8}Be $Q_m = -7.367$

This reaction has been studied for $13 \le E_p \le 160$ MeV. At low energies it involves ^{8}Be(0); at higher energies ^{8}Be*(0, 2.9) (1966RO1D, 1967GA01, 1969LU1B, 1970GO12, 1970KE1B, 1972MA62). It is not clear whether higher states are also involved: see (1970KE1B). See also (1966LA04) and (1966JA1B, 1968YA1C, 1972YA1B).

49. ^{12}C(d, ^{6}Li)^{8}Be $Q_m = -5.893$

Angular distributions have been determined at $E_d = 19.5$ MeV (1971GU07), 28 MeV (1972BE1T, 1972BE29: ^{8}Be(0)) and 51.8 MeV (1970EI05: both ^{8}Be*(0, 2.9)). At $E_d = 28$ MeV a structure is observed which is attributed to the process ^{12}C(d, α)^{10}B $\rightarrow$ α + ^{6}Li (1972CO23). At $E_d = 55$ MeV the population of ^{8}Be*(11.4, $16.6 + 16.9$) is also reported (1971MC04). See also (1966DA1C, 1970AN1E), (1967OG1A, 1972GA1E) and (1968RO1D, 1970EL1F, 1971DR02, 1973HE1J; theor.). See also ^{12}C and (1966LA04).

50. ^{12}C(^{3}He, ^{7}Be)^{8}Be $\qquad Q_{\rm m} = -5.780$

Angular distributions have been measured for the transitions to $^{7}{\rm Be}_{\rm g.s.} + {}^{8}{\rm Be}_{\rm g.s.}$ and $^{7}{\rm Be}^{*}_{0.43} + {}^{8}{\rm Be}_{\rm g.s.}$ at $E(^{3}{\rm He}) = 25.5$ to 29 MeV (1972PI1A, 1973PI1B, 1973PI1D), 28 MeV (1970DE12, 1973KL1B) and at 35.7 MeV (1969ZE1A, 1970FO1D). The transitions to $^{7}{\rm Be}_{\rm g.s.+0.43} + {}^{8}{\rm Be}^{*}_{2.9}$ have also been studied by (1970DE12). See also (1967ZA1B, 1973ST1N) and (1969NE1D; theor.).

51. (a) ^{12}C(α, 2α)^{8}Be $\qquad Q_{\rm m} = -7.367$

(b) ^{12}C(α, ^{8}Be)^{8}Be $\qquad Q_{\rm m} = -7.4587$

This reaction has been studied up to $E_{\alpha} = 104$ MeV. At $E_{\alpha} = 25$ MeV it involves ^{8}Be(0) (1966BO28); at $E_{\alpha} = 28.0$, 37.4, 70, 90 and 104 MeV, the reaction goes via ^{8}Be*(0, 2.9) (1965YA02, 1967TA1C, 1968YA02, 1971BR1G, 1972SH1J) and at 90 MeV it may, in addition, involve the broad 4^{+} state at 11.4 MeV (1970JA06). See also (1966LA04) and (1965KU1B, 1967ME1C; theor.).

Reaction (b) has been studied for $11.9 \leq E_{\alpha} \leq 19.4$ MeV and angular distributions are reported for $E_{\alpha} = 12.70$ to 16.25 MeV (1967CH21) and 65 MeV (1973WO06: ^{8}Be*(0, 2.9)). See ^{16}O in (1971AJ02).

52. ^{12}C(^{12}C, ^{16}O)^{8}Be $\qquad Q_{\rm m} = -0.2051$

Angular distributions have been measured for $E(^{12}{\rm C}) = 11.6$ to 13.4 MeV (1972CO1H). At $E(^{12}{\rm C}) = 50$ to 65 MeV the population of ^{8}Be*(0, 2.9) is reported by (1972FL1C). See also (1968JA1F, 1970JA1B, 1972GR1T, 1973CR1A, 1973SC1J).

53. ^{12}C(^{14}N, ^{18}F)^{8}Be $\qquad Q_{\rm m} = -2.951$

See (1965WI1A).

54. ^{12}C(^{16}O, ^{20}Ne)^{8}Be $\qquad Q_{\rm m} = -2.637$

See (1972GR1Q).

55. ^{13}C(p, ^{6}Li)^{8}Be $\qquad Q_{\rm m} = -8.615$

Angular distributions have been measured at $E_{\rm p} = 45$ MeV for the transitions to ^{8}Be*(0, 2.9) (1971BR07).

56. ^{13}C(d, ^{7}Li)^{8}Be $\qquad Q_{\rm m} = -3.589$

Angular distributions are reported at $E_{\rm d} = 14.6$ MeV for the transitions to $^8{\rm Be}_{\rm g.s.} + {^7{\rm Li}_{\rm g.s.}}$ and $^8{\rm Be}_{\rm g.s.} + {^7{\rm Li}^*_{0.48}}$ (1967DE03).

57. ^{13}C(^{3}He, ^{8}Be)^{8}Be $\qquad Q_{\rm m} = 8.173$

Angular distributions have been obtained at $E(^3{\rm He}) = 3.3$, 5.0 and 5.8 MeV for the transition to $^8{\rm Be}_{\rm g.s.} + {^8{\rm Be}_{\rm g.s.}}$ (1968JA07, 1969JA1L). See also ^{16}O in (1971AJ02) and (1967SA1E).

58. (a) ^{14}N(n, ^{7}Li)^{4}He^{4}He $\qquad Q_{\rm m} = -8.823$
(b) ^{14}N(n, t)^{4}He^{4}He^{4}He $\qquad Q_{\rm m} = -11.290$

See (1967MO21, 1971SC16) and ^{7}Li.

59. ^{14}N(^{10}B, 6α) $\qquad Q_{\rm m} = 0.366$

See (1965SH11, 1966SH1E).

60. ^{16}O(γ, 2α)^{8}Be $\qquad Q_{\rm m} = -14.528$

See (1966LA04) and ^{12}C in (1968AJ02).

61. ^{16}O(p, p)^{4}He^{4}He^{4}He^{4}He $\qquad Q_{\rm m} = -14.436$

See (1961KO02, 1962VA1A) and ^{16}O in (1971AJ02).

62. ^{16}O(α, ^{12}C)^{8}Be $\qquad Q_{\rm m} = -7.2535$

Angular distributions have been measured at $E_\alpha = 65$ MeV involving ^{8}Be$_{\rm g.s.}$ and ^{12}C*(0, 4.4) (1973WO06). See also (1968PA12) and ^{16}O in (1971AJ02) and ^{20}Ne in (1972AJ02).

63. ^{16}O(^{10}B, 6α) $Q_{\rm m} = -7.234$

See (1965SH11).

64. ^{19}F(p, ^{12}C)^{8}Be $Q_{\rm m} = 0.861$

See (1969GO1B, 1971GO1U) and ^{20}Ne in (1972AJ02).

65. ^{20}Ne(α, ^{16}O)^{8}Be $Q_{\rm m} = -4.822$

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

^{8}B

(Figs. 13 and 14)

GENERAL: (See also (1966LA04).)

Shell model: (1966BA26, 1973HA49).

Special levels: (1966BA26).

Electromagnetic transitions: (1966BA26, 1973HA49).

Special reactions: (1968BA1M, 1968BH1A, 1969BA1L, 1970BA44, 1972AG01).

Astrophysical questions: (1967BA1J, 1967SH1F, 1968BA2E, 1968BA2F, 1969FO1D, 1970BA1M, 1972PA1C).

Other topics: (1966KE16, 1966TO04, 1967DI1B, 1969GA1G, 1972AN05, 1973RO1R).

Ground-state properties: (1966BA26, 1972VA36, 1973HA77, 1973MA1K, 1973SU1B).

$$\mu = 1.0355 \pm 0.003 \text{ nm (1973MIYZ).}$$

1. ^{8}B(β^{+})^{8}Be $\qquad Q_{\rm m} = 17.981$

The β^{+} decay leads mainly to ^{8}Be*(2.9). The half-life is 774 ± 5 msec (1964MA35), 762 ± 5 msec (1971WI05), 772 ± 4 msec (1973MCZW): the mean is 770 ± 3 msec. See also Table 8.19 in (1966LA04): $\log ft = 5.64$ (1966BA1A) ‡ . There is also a branch to a ^{8}Be state at ≈ 16.6 MeV; $\log ft = 2.9$ (1964MA35). See, however, (1969BA43): $\log ft = 3.33$. Measurements of the excitation spectra in the decays of ^{8}Li and ^{8}B show no evidence for second-class currents: $|g_{\rm IT}| < 7 \times 10^{-4}$ (1971WI05). See also (1964FO1A, 1969BA1X, 1969BA1M, 1972BA2M, 1972KO1A, 1973BA2C) for astrophysical applications, (1967BA1M, 1970DA21, 1971LI1H, 1971WI1C, 1971WI18, 1972EM02, 1972HO23, 1972WI28, 1972WI1C, 1973EM1B, 1973HA49, 1973TO14, 1974WI1L; theor.).

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

At $E(^{3}\text{He}) = 3.5$ to 5.7 MeV, time-of-flight spectra locate the first excited state at 0.767 ± 0.012 (1965FA03, 1966FA1A), 0.783 ± 0.010 MeV (1965MC06: $\Gamma = 40 \pm 10$ keV). Angular distributions for the n_0 group have been reported at $E(^{3}\text{He}) = 4.8$ to 5.7 MeV. The appearance of a forward peak indicates an $L = 0$ transfer and hence a knockout mechanism ($L = 0$ is forbidden for simple diproton stripping) (1967VA24). See also (1963DI02). A state at $E_{\rm x} = 2.17 \pm 0.05$ MeV is reported by (1963DI02; abstract). For threshold measurements see (1966LA04). See also ^{9}B.

‡ and B. Zimmerman, private communication.

Table 8.11: Energy levels of ^{8}B

E_x (MeV ± keV)	$J^\pi; T$	$\tau_{1/2}$ or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
g.s.	$2^+; 1$	$\tau_{1/2} = 769 \pm 4$ msec	β^+	1, 2, 3, 4, 5, 6, 7
0.778 ± 7		$\Gamma = 40 \pm 10$	γ, p	2, 3, 4, 5
2.32 ± 30	$3^+; 1$	350 ± 40		2, 4, 5

3. ^{7}Be(p, γ)^{8}B $\quad Q_m = 0.137$

Absolute cross sections have been measured for $E_p = 0.165$ to 10.0 MeV (1969KA1K, 1972KA1B), 0.48 to 1.93 MeV (1966PA16) and 0.95 to 3.28 MeV (1970VA26). In the data of (1966PA16, 1972KA1B) a resonance at $E_p = 724$ keV reflects ^{8}B*(0.77) with $\Gamma_{lab} \approx 46$ keV: the peak cross section is 2.20 ± 0.22 μb, $\Gamma_\gamma = 50 \pm 25$ meV. See also (1969KA1K).

The low-energy cross-section factor, evaluated at the Gamow peak ($E_p \approx 20$ keV), $S(0.02) = 0.031$ keV · b (1973RO08). Other values are $S(0) = 0.0335 \pm 0.003$ keV · b, dS/d$E = -3 \times 10^{-5}$ b (1972KA1B), 0.035 ± 0.004 keV · b, dS/d$E = -3 \times 10^{-5}$ b (1968PA1M) and $0.0430 \leq S(0) \leq 0.0453$ keV · b (1970AU1B). See also (1969KA1K, 1970VA26). The relevance of this reaction to astrophysics is discussed by (1965TO02, 1966PA16, 1967FO1B, 1967TO1B, 1968BA1W, 1968BA2E, 1968PA1M, 1969BA1U, 1969BA1M, 1970AU1B, 1970VA26, 1971BA2X, 1972BA2M, 1972KA1B, 1972PA1C, 1972TO1D, 1973BA2C, 1973RO08, 1973TR1E).

4. ^{10}B(p, t)^{8}B $\quad Q_m = -18.531$

At $E_p = 49.5$ MeV angular distributions have been measured for the tritons to ^{8}B*(0, 2.32) (1970SQ01): $L = 2$ and $L = 0 + 2$, leading to $J^\pi = 2^+$ and 3^+, respectively. See also ^{10}B(p, ^{3}He)^{8}Be. The energy of the excited state is 2.29 ± 0.05 MeV (1970SQ01), 2.34 ± 0.04 MeV (1968BR23): $\Gamma_{lab} = 390 \pm 40$ keV (1967MC14). ^{8}B*(0.78) is also observed. See also (1971KA04; theor.).

5. ^{11}B(^{3}He, ^{6}He)^{8}B $\quad Q_m = -16.920$

At E(^{3}He) $= 50$ MeV, ^{6}He groups are observed to the first three states of ^{8}B (1967MC14).

6. ^{12}C(^{3}He, ^{7}Li)^{8}B $\quad Q_m = -22.899$

This reaction has been studied at E(^{3}He) $= 40.7$ MeV (1971DE37).

7. ^{12}C(α, ^{8}Li)^{8}B $\qquad Q_m = -41.445$

See (1968MC02).

^{8}C
(Not illustrated)

^{8}C has been observed in the ^{12}C(α, ^{8}He)^{8}C reaction at $E_\alpha = 156$ MeV: $M - A = 35.30 \pm 0.20$ MeV, $\Gamma_{\rm c.m.} = 220^{+80}_{-140}$ keV [the differential cross section at 2° (lab) is ≈ 20 nb/sr] (R.G.H. Robertson, S. Martin, W.R. Falk, D. Ingham and A. Djaloeis, private communication). ^{8}C is then unstable with respect to ^{7}B + p ($Q = 0.1$), ^{6}Be + 2p ($Q = 2.3$), ^{5}Li + 3p ($Q = 1.8$), ^{4}He + 4p ($Q = 3.7$). See also (1960GO1B, 1966KE16, 1970WA1G).

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(Closed December 31, 1973)

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