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Energy Levels of Light Nuclei
$A = 9$

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Abstract: An evaluation of $A = 5$–10 was published in *Nuclear Physics A*227 (1974), p. 1. This version of $A = 9$ 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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^{9}He

(Not illustrated)

^{9}He is predicted to be particle unstable: its calculated mass excess > 40.17 MeV (1970WA1G, 1972WA07), $= 43.54$ MeV (1972TH13). Particle instability with respect to ^{8}He + n, ^{7}He + 2n and ^{6}He + 3n implies atomic mass excesses greater than 39.7, 42.25 and 41.812 MeV, respectively. See also (1968CE1A). ^{9}He has not been observed in a pion experiment [^{9}Be(π^-, π^+)^{9}He] (1965GI10) nor in the spontaneous fission of ^{252}Cf (1967CO1K).

^{9}Li

(Figs. 15 and 18)

GENERAL:

Model calculations: (1966BA26).

Special reactions: (1965DO13, 1966GA15, 1966KL1C, 1967AU1B, 1967CA1J, 1967HA10, 1968DO1C, 1972VO06, 1973KO1D, 1973MU12, 1973WI15).

Other topics: (1972CA37, 1972PN1A, 1973JU2A).

Ground state properties: (1966BA26, 1969JA1M).

Mass of ^{9}Li: From the Q-value of ^{18}O(^{7}Li, ^{16}O)^{9}Li, the atomic mass excess of ^{9}Li is 24.9654 ± 0.005 MeV (1969NE1E; prelim. results). (1971WA1E) adopt 24.966 ± 0.005 MeV. We use the latter value.

1. ^{9}Li(β^-)^{9}Be $\qquad Q_{\rm m} = 13.618$

The half-life of ^{9}Li is 172 ± 3 msec [see (1966LA04)], 176 ± 1 msec (1965DO13), 177 ± 3 msec (1970CH07, 1970CH1T). We adopt $\tau_{1/2} = 176 \pm 2$ msec. See also (1968BO32). ^{9}Li decays to ^{9}Be*(0, 2.43, 2.78): see ^{9}Be and Table 9.7 (1970CH07, 1970CH1T). See also (1963AL18, 1969MA11). Log ft values are listed in Table 9.7: the allowed nature of the transitions to ^{9}Be*(0, 2.43, 2.78) with $J^\pi = \frac{3}{2}^-$, $\frac{5}{2}^-$ and $(\frac{1}{2}^-)$ is evidence for $J^\pi = \frac{3}{2}$ for ^{9}Li(0) (1970CH07).

E_{β^-}(max) have been measured by (1963AL18, 1963NE07, 1969KL08). Delayed neutrons are observed due to the decay of the neutron unbound states ^{9}Be*(2.43, 2.78): see ^{9}Be. See also (1966BA1A, 1966BA26, 1970DA21, 1971LI1H, 1971WI18, 1972WI28, 1972WI1C, 1973HA49, 1973TO14, 1973WI11; theor.).

2. ^{7}Li(t, p)^{9}Li $\qquad Q_{\rm m} = -2.397$

$Q_0 = -2.397 \pm 0.020$ (1964MI04).

Table 9.1: Energy levels of ^{9}Li

E_x (MeV ± keV)	$J^\pi; T$	$\tau_{1/2}$ or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
g.s.	$(\frac{3}{2})^-; \frac{3}{2}$	$\tau_{1/2} = 176 \pm 2$ msec	β^-	1, 2, 3, 4, 8, 9
2.691 ± 5	$(\frac{1}{2}^-)$		(γ)	2
4.31 ± 30		$\Gamma = 250 \pm 30$		2
5.38 ± 60		600 ± 100		2
6.41 ± 20		< 100		2

Proton groups are observed to excited states at $E_x = 2.691 \pm 0.005$ MeV (1964MI04), 4.31 ± 0.03, 5.38 ± 0.06 and 6.41 ± 0.02 MeV (1971YO04) [$\Gamma_{cm} = 250 \pm 30$, 600 ± 100, < 100 keV, respectively]. Angular distributions are reported at $E_t = 11.3$ MeV (1964MI04; t_0) and 15 MeV (1971YO04; t_0, t_2, t_4). The angular distributions to ^{9}Li(0) are consistent with $J^\pi = \frac{3}{2}^-$ and the relative magnitude of the cross section to ^{9}Li*(2.69) is consistent with $J^\pi = \frac{1}{2}^-$: see (1964MI04, 1971YO04). See also (1968HO1F; theor.) and (1969MA11, 1970CH07).

3. ^{9}Be(n, p)^{9}Li $\quad Q_m = -12.836$

See (1967ME11).

4. ^{9}Be(d, 2p)^{9}Li $\quad Q_m = -15.060$

See (1951GA30).

5. ^{9}Be(t, ^{3}He)^{9}Li $\quad Q_m = -13.599$

Not reported.

6. (a) ^{11}B(γ, 2p)^{9}Li $\quad Q_m = -30.876$
(b) ^{11}B(p, 3p)^{9}Li $\quad Q_m = -30.876$

See (1966LA04).

7. $^{11}B(n, ^{3}He)^{9}Li$ $Q_m = -23.158$

Not reported.

8. $^{12}C(\gamma, 3p)^{9}Li$ $Q_m = -46.834$

See (1966LA04).

9. $^{18}O(^{7}Li, ^{16}O)^{9}Li$ $Q_m = -6.103$

See "*Mass of ^{9}Li*" in the GENERAL section here (1969NE1E). See also (1970CH07).

^{9}Be
(Figs. 16 and 18)

GENERAL: (See also (1966LA04).)

Shell model: (1961KO1A, 1965CO25, 1965GR18, 1965VO1A, 1966AD06, 1966BA26, 1966HA18, 1966MA1P, 1966WI1E, 1967CO32, 1967ST1C, 1968GO01, 1969BO1V, 1969BO19, 1969BO33, 1969GU03, 1969VA1C, 1970CO1H, 1971CO28, 1971GR02, 1971NO02, 1972LE1L, 1973HA49, 1973KU03).

Aplha and cluster models: (1965NE1B, 1966HI1A, 1967TA1C, 1968KU1B, 1969BA1J, 1969NE1C, 1970BA1Q, 1971LE1N, 1971NO02, 1972AB19, 1972CH1N, 1972HI16, 1972IK1A, 1972LE1L, 1973KU03, 1973OK1B).

Collective and deformed models: (1965VO1A, 1966EL08, 1967BO1K, 1967BO34, 1973KU13, 1973SL02).

Special levels: (1966AD06, 1966BA26, 1966EL08, 1967CO32, 1967ST1C, 1968BO19, 1968GO01, 1969BO1V, 1969BO33, 1969GU03, 1969HA1G, 1970PE18, 1970TO1E, 1971CO28, 1971GR02, 1971LI30, 1971NO02, 1972BE1E, 1972CH1N).

Electromagnetic transitions: (1965CO25, 1966BA26, 1966EL08, 1967KU1E, 1968KU1D, 1969HA1G, 1969VA1C, 1971GR02, 1972AB19, 1972NA05, 1973HA49, 1973SL02).

Astrophysical questions: (1968HA1C, 1970BA1M, 1972CL1A, 1972KO1E, 1973AU1H, 1973LA19, 1973RA37, 1973RE1G, 1974AU1A).

Special reactions: (1968HA1C, 1968YI01, 1969AR13, 1969GA18, 1969YI1A, 1971AR02, 1972VO06, 1973KO1D, 1973KU03, 1973LA19, 1973WI15).

Muon capture: (1968BA2G, 1969WU1A, 1970FA15, 1971DE2D, 1972BU29, 1973MU11).

Pion capture and reactions: (1967ME1F, 1967MI1B, 1968BA2G, 1968ER1A, 1968NO1A, 1968WI1B, 1969BU1C, 1969CA1B, 1969CH1C, 1969KO1F, 1969MO1E, 1970BA1E, 1970BE1J, 1970CA1L, 1970ER1A, 1970GO28, 1971CA01, 1971CA1J, 1971FA09, 1971GO14, 1971MA1C, 1971RE1H, 1971SE02, 1972AB1H, 1972BE34, 1972BU1P, 1972HU1A, 1972MA1H, 1972SA10, 1972SE1F, 1973BA2R, 1973BA2V, 1973DI1H, 1973GA20, 1973HS1A, 1973HS1B, 1973JA1K, 1973NY04, 1973OS01, 1973PE1E, 1973SQ01, 1973UL1D).

Kaon reactions: (1973BA1Y).

Other topics: (1965CO25, 1965VO1A, 1966CH1B, 1966DO1C, 1966HA18, 1966HE1C, 1966WI1E, 1967BA12, 1967CA17, 1967CH1H, 1967MO1H, 1968KO1H, 1968GO01, 1969GU03, 1969LE1G, 1970CO1H, 1970GR33, 1970KA1K, 1970PA1D, 1970PE18, 1970SA05, 1971DA13, 1971ER1C, 1972AN05, 1972CA37, 1972CH1P, 1972FR09, 1972HA57, 1972LE1L, 1972PN1A, 1972RA1J, 1972TA31, 1972TU1B, 1973BA1Y, 1973BE1N, 1973CL09, 1973JU2A, 1973KO1J, 1973KU03, 1973MA48, 1973RA1E).

Table 9.2: Energy levels of ^{9}Be

E_x (MeV ± keV)	$J^\pi; T$	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
g.s.	$\frac{3}{2}^-; \frac{1}{2}$		stable	2, 3, 4, 9, 10, 11, 12, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49
1.680 ± 15	$\frac{1}{2}^+; \frac{1}{2}$	210 ± 25	γ, n	4, 10, 11, 12, 15, 19, 20, 21, 23, 25, 26, 31, 36, 37, 42, 44
2.4294 ± 1.3	$\frac{5}{2}^-; \frac{1}{2}$	1.03 ± 0.18	γ, n, α	4, 10, 11, 12, 14, 15, 19, 20, 21, 23, 24, 25, 26, 31, 34, 36, 37, 41, 42, 44
2.78 ± 120	$\frac{1}{2}^-; \frac{1}{2}$	1080 ± 110	n	4, 10, 14
3.058 ± 12	$\frac{5}{2}^+; \frac{1}{2}$	292 ± 15	γ, n	4, 10, 12, 15, 19, 20, 21, 23, 25, 26, 31, 36, 37, 41, 42, 44
4.704 ± 25	$(\frac{3}{2})^+; \frac{1}{2}$	743 ± 55	γ, n	4, 10, 19, 21, 23, 25, 42
6.76 ± 60	$\frac{7}{2}^-; \frac{1}{2}$	2000 ± 200	γ, n	10, 19, 20, 21, 23, 25, 26
7.94 ± 80		≈ 1000	γ	19, 21
11.283 ± 24	$\pi = -$	575 ± 50	γ, n	10, 19, 21, 26, 37
11.81 ± 20	$T = \frac{1}{2}$	400 ± 30	γ, n	10, 12, 15, 41
13.79 ± 30	$T = \frac{1}{2}$	590 ± 60	γ	10, 12, 19, 41
14.396 ± 5 [a]	$\frac{3}{2}^-; \frac{3}{2}$	0.33 ± 0.06	γ, n, α	10, 19, 21, 25, 37, 41
14.4 ± 300		≈ 800		21, 37
15.10 ± 50			γ	12, 19, 41
15.96 ± 30	$T = \frac{1}{2}$	≈ 300	γ	19, 41
16.671 ± 8		41 ± 4	γ	10, 19, 21, 37
16.977 ± 2	$\frac{1}{2}^-; \frac{3}{2}$	< 0.47	γ, n, p, d	4, 5, 6, 19
17.300 ± 12	$(\frac{5}{2})^-$	195	γ, n, p, d, α	5, 6, 7, 19

Table 9.2: Energy levels of ^{9}Be (continued)

E_x (MeV $\pm$ keV)	$J^\pi; T$	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
17.498 ± 15	$(\frac{3}{2}, \frac{5}{2})^+$	47	γ, n, p, d, α	5, 6, 7, 19, 21
18.02 ± 50			γ, n, p, d	5, 6, 19
18.58 ± 40			γ, p, d, α	5, 6, 19
19.10 ± 30		300 ± 100	γ, n, p, d, t	1, 6, 15, 21
19.51 ± 50			γ, n, p, d	6, 19
(20.47 ± 40)			γ, p, d	6, 15
20.74 ± 30		≈ 1000	γ, p, t	1, 15, 19
(21.50 ± 50)			γ, n	15, 19
(22.4 ± 700)		broad		21
(23.9 ± 100)			γ, n	15

[a] See also Table 9.6.

Ground state properties: (1965CO25, 1965GR18, 1965VO1A, 1966AD06, 1966BA26, 1966EL08, 1966MA1P, 1966WI1E, 1967SH05, 1967SH14, 1968DZ1A, 1969AF1A, 1969BO19, 1969GU03, 1969HE1N, 1969JA1M, 1969PE1D, 1969VA1C, 1971AU1G, 1972FR09, 1972LE1L, 1973MA1K).

$\mu = -1.1776$ nm (1969FU11). See also (1971SH26);

$Q = 0.065^{+0.009}_{-0.006}$ b (1973BE19). See also (1967BL09, 1969FU11, 1971SH26).

1. (a) ^{6}Li(t, n)^{8}Be — $Q_m = 16.024$ — $E_b = 17.6895$
   (b) ^{6}Li(t, p)^{8}Li — $Q_m = 0.801$
   (c) ^{6}Li(t, d)^{7}Li — $Q_m = 0.9930$
   (d) ^{6}Li(t, α)^{5}He — $Q_m = 15.22$
   (e) ^{6}Li(t, n)^{4}He^{4}He — $Q_m = 16.116$

The $0°$ differential cross section for reaction (a) increases monotonically between $E_t = 0.10$ and 2.4 MeV (1960SE12, 1961VA43, 1962SE1A) except for a resonance at $E_t = 1.875$ MeV (^{9}Be* $= 18.938$). The excitation function for ^{8}Li (reaction (b)) increases monotonically for $E_t = 0.275$ to 1.000 MeV (1972CI05). In the range $E_t = 2.0$ to 6.8 MeV, a broad peak [$\Gamma \approx 1.3$ MeV] is observed at $E_t = 4.57$ MeV [$E_x = 20.73$ MeV] (1973AB10). For reactions (c) and (d) see (1966LA04). For reaction (e) see (1966LA02, 1967BE13). See also ^{5}He, ^{7}Li and ^{8}Li.

2. ^{6}Li(α, p)^{9}Be $\quad Q_m = -2.1251$

$Q_0 = -2.1256 \pm 0.0012$ (1967BR1B).

Angular distributions of ground state protons have been measured at $E_\alpha = 10.2$, 11.5 and 13.5 MeV (1960MA15), 13.6 and 14.7 MeV (1962KO13) and 30 MeV (1960KL03). See also (1966LA04).

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

See (1964KI02).

4. ^{7}Li(d, γ)^{9}Be $\quad Q_m = 16.6965$

For $E_d = 0.1$ to 1.1 MeV, a resonance in the yield of capture γ-rays is observed at $E_d = 362 \pm 3$ keV (1965WO01), 361 ± 2 keV (1965IM01), corresponding to ^{9}Be*(16.977) with $\Gamma_{cm} < 0.47$ keV. The small width of this state and its energy correspondence with ^{9}Li*(2.69) argue for $T = \frac{3}{2}$ (1965WO01). The angular distribution of the γ-rays to ^{9}Be(0) is isotropic to within 7% (1965IM01). The branching ratios to ^{9}Be*(0, 1.7, 2.4, 2.8, 3.1, 4.7) are $100/8.5{\pm}4.3/10.6{\pm}5.3/-/\leq 4.5/9.6 \pm 4.8$ (1965IM01), $100/11.8 \pm 0.6/3.3 \pm 0.7/13.3 \pm 4.2/-/12.9 \pm 1.3$ (1971SC19). The E_x and Γ of ^{9}Be*(2.8, 4.7) are 2.82 and 1.7 MeV, and 4.64 and 0.95 MeV, respectively. The character of the decay suggests $(\frac{1}{2})^-$ for the second $T = \frac{3}{2}$ state [^{9}Be*(16.98)] and is consistent with $J^\pi = (\frac{1}{2})^-$ for ^{9}Be*(2.8) (1971SC19). See also (1968SN1A).

5. (a) ^{7}Li(d, n)^{8}Be $\quad Q_m = 15.031 \quad E_b = 16.6965$

(b) ^{7}Li(d, α)^{5}He $\quad Q_m = 14.23$

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

The yield of neutrons has been measured for $E_d = 0.2$ to 4.8 MeV (1952BA1A, 1957SL01, 1965IM01), 0.86 to 1.33 MeV by (1969NU1C), 3 to 8 MeV by (1967KE1F: yield of neutrons to ^{8}Be*(16.6, 17.6, 18.1), at one MeV intervals) and 5 to 19 MeV by (1973WE19). Polarization measurements have been reported by (1971MO1R, 1973VO07: $E_d = 0.64$ MeV; n_0) and (1970TH08: $E_d = 2.5$ to 3.7; n_0, n_1). See also (1972SE09; theor.) and (1966LA04). Resonances in the yield of neutrons are observed at $E_d = 0.36$, 0.68, 0.98 and (1.8) MeV: see Table 9.3.

Table 9.3: Resonances in ^{7}Li + d

^{7}Li(d, p)^{8}Li		^{7}Li(d, n)^{8}Be	^{7}Li(d, α)^{5}He		
E_{res} (keV)	Γ_{lab} (keV)	E_{res} (keV)	E_{res} (keV)	E_x (MeV)	J^π
360 ± 3 [a]	< 2	360 [d]		16.976	
777 ± 12 [b]	250	680 [e]	750 [f]	17.300	$(\frac{3}{2})^{-}$ [h]
1031 ± 15 [b]	60	980 [e]	1000 [f]	17.498	$(\frac{3}{2}, \frac{5}{2})^{+}$ [h]
2000 [c]		(1800) [e]		18.3	
2375 ± 50 [c,i]			2500 [g]	18.54	
3220 ± 50 [i]	400 ± 100			19.20	
≈ 4800 [i]				20.4	

[a] In ^{7}Li(d, γ)^{9}Be $E_{res} = 361 \pm 2$ keV (1965IM01, 1965WO01); $\Gamma_{n_0}/\Gamma_\gamma \approx 1.5$, $\Gamma_{\alpha_0}/\Gamma_\gamma < 20$ (1965IM01) for ^{9}Be*(16.98).

[b] (1952BA1A, 1954BA46, 1972SC1U).

[c] (1956BE1A).

[d] (1965IM01).

[e] (1952BA1A, 1957SL01).

[f] (1963PA04, 1969DE31, 1971FR04).

[g] (1963PA04): broad structure.

[h] (1972DE44). See, however, (1971FR04, 1973HE26).

[i] (1973AB10).

The yield of α-particles has been measured for $E_d = 0.2$ to 0.3 MeV by (1964MA1F), 0.6 to 2.0 MeV by (1971FR04), 0.7 to 1.6 MeV (1969DE31) and 0.7 to 3.0 MeV by (1963PA04). The excitation function for reaction (b) shows resonances at $E_d = 0.75$ and 1.00 MeV (1971FR04), 0.78 and 1.08 MeV (1969DE31), as well as a broad structure at $E_d = 2.5$ MeV (1963PA04). Also reported are α-particles from reaction (a) associated with ^{8}Be*(11.4, 16.6, 16.9); the α-particles from the decay of ^{8}Be*(11.4) seems to show resonance behavior at $E_d = 0.7$, 1.0 and 1.75 MeV. It is not clear whether the α-particles corresponding to ^{8}Be*(16.6) show resonance at $E_d = 2.5$ MeV or whether the ^{8}Be*(16.9) α-particles are appearing at this point (1963PA04).

A study of the B_L coefficients of the angular distributions of the α_0 group for $E_d = 0.45$ to 2.0 MeV and of the $\alpha - \alpha$ angular correlation coefficient, together with a re-analysis of the (d, d$_0$) data of (1964FO1B), lead to assignments of $\frac{3}{2}^-$ and $(\frac{3}{2}, \frac{5}{2})^+$ for ^{9}Be*(17.30, 17.50). The analysis also requires a $(\frac{3}{2}, \frac{5}{2})^-$ state at lower excitation energy and a $(\frac{3}{2}, \frac{5}{2})^+$ state at higher energy (1972DE44). See also (1973VO07) for an interpretation of results from reaction (a).

A kinematically complete study of reaction (c) at $E_d = 1.0$ MeV shows that the yield is dominated by sequential decay via ^{8}Be*(2.9) and ^{5}He$_{g.s.}$. There is evidence also for the involvement of ^{9}Be*(17.50) [measurement of relative yield for $E_d = 0.9$ to 1.1 MeV]: $J = \frac{3}{2}$ is suggested

(1973HE26). See also ^{5}He, ^{8}Be and (1966AS04, 1967KE1F, 1967VA11, 1968WI1E, 1973HE06). See also (1966NU1B, 1966PO1D, 1967BE13, 1967WI1C, 1968DA1H, 1971DA21, 1972BR1R, 1972SU1E, 1973DA1R).

6. ^{7}Li(d, p)^{8}Li $\quad Q_{\rm m} = -0.1919 \quad E_{\rm b} = 16.6965$

The yield of $\rm p_0$ measured for $E_{\rm d} = 0.29$ to 0.78 MeV shows a single resonance with $E_{\rm d} = 360 \pm 3$ keV, $\Gamma < 2$ keV, $\Gamma_{\rm p}/\Gamma_\gamma \approx 0.5$ (1965IM01, 1965WO01): see also reaction 4.

The yield of ^{8}Li has been measured for $E_{\rm d} = 0.4$ to 4 MeV (1952BA1A, 1954BA46, 1956BE1A, 1960KA05), for $E_{\rm d} = 0.62$ to 1.97 MeV by (1972SC1U) and for $E_{\rm d} = 2.0$ to 7.0 MeV by (1973AB10): observed resonances are displayed in Table 9.3. The yield of 0.98-MeV γ-rays [from ^{7}Li(d, p)^{8}Li*] rises monotonically from $E_{\rm d} = 1.9$ to 3.3 MeV (1962CH14).

The total cross section at the $E_{\rm d} = 0.77$ MeV resonance is 202 ± 9 mb (1972SC1U). Earlier values were 176 ± 15 mb (1960KA05) and 211 ± 15 mb (1966PA16). We adopt 205 ± 8 mb. This cross section is important since the ^{7}Be(p, γ)^{8}B data are normalized to it and the S-factor is of interest in relation to the solar neutrino problem: see (1968PA1M). See also ^{8}Li.

7. ^{7}Li(d, d)^{7}Li $\quad E_{\rm b} = 16.6965$

The upper limit for the relative partial width for elastic scattering at $E_{\rm d} = 0.36$ MeV (^{9}Be* $= 16.98$), $\Gamma_{\rm d_0}/\Gamma_\gamma$ is 400 (1965IM01).

The elastic scattering, at $E_{\rm d} = 0.4$ to 1.8 MeV, shows a marked increase in cross section for $E_{\rm d} = 0.8$ to 1.0 MeV [perhaps related to ^{9}Be*(17.30) and a conspicuous anomaly at $E_{\rm d} = 1.0$ MeV, due to p-wave deuterons [^{9}Be*(17.50)] (1964FO1B) [and discussion in (1972DE44) and in reaction 5]. The elastic scattering cross section ($\theta_{\rm cm} = 162°$) decreases monotonically for $E_{\rm d} = 10.0$ to 12.0 MeV (1971BI11). See also ^{7}Li.

8. (a) ^{7}Li(d, t)^{6}Li $\quad Q_{\rm m} = -0.993 \quad E_{\rm b} = 16.6965$
(b) ^{7}Li(d, ^{3}He)^{6}He $\quad Q_{\rm m} = -4.488$

The cross section for reaction (a) rises from threshold to 95 mb at $E_{\rm d} = 2.4$ MeV and then more slowly to ≈ 165 mb at $E_{\rm d} = 4.1$ MeV (1955MA20). The $\rm t_0$ yield curve ($\theta_{\rm lab} = 155°$) decreases monotonically for $E_{\rm d} = 10.0$ to 12.0 MeV (1971ZA07). See also ^{6}Li. For reaction (b) see ^{6}He.

9. ^{7}Li(t, n)^{9}Be $\quad Q_{\rm m} = 10.4389$

Table 9.4: Excited states of ^{9}Be from ^{7}Li(^{3}He, p)^{9}Be [a]

(1968CO07)		(1965LY01, 1971AD01)		(1968KR02)	
E_x (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	E_x (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	E_x (MeV ± keV)	$\Gamma_{c.m.}$ (keV)
1.64					
2.429 ± 12	≤ 35			2.4292 ± 1.7	< 8
		2.9 ± 250	1000 ± 250 [b]		
3.031 ± 10	274 ± 15			3.076 ± 15	289 ± 22
4.57 ± 100 [d]	800 ± 200			4.704 ± 25	743 ± 55
6.7 ± 100	1950 ± 250 [e]				
11.29 ± 30	620 ± 70				
11.81 ± 20	400 ± 30				
13.78 ± 30	590 ± 60				
		14.396 ± 5 [f]	< 5 [c]		
16.671 ± 8	41 ± 4				

[a] See also Table 9.5 in (1966LA04).
[b] From γ-decay of ^{9}Be*(14.39).
[c] See also Table 9.5.
[d] 4.65 MeV, $\Gamma = 900 \pm 250$ keV (1968CO08).
[e] 2300 ± 500 keV (1968CO08).
[f] Based on Q_m.

See (1959AJ1C, 1962SE1A) and ^{10}Be.

10. (a) ^{7}Li(^{3}He, p)^{9}Be $\quad Q_m = 11.2027$
(b) ^{7}Li(^{3}He, np)^{8}Be $\quad Q_m = 9.538$

Observed proton groups are listed in Table 9.4 (1968CO07). See also Table 9.5 in (1966LA04) for a listing of the older work. Angular distributions have been measured for the protons to ^{9}Be*(0, 1.7, 2.4, 3.1) at $E(^{3}\text{He}) = 0.90$ to 1.10 MeV (1971ST35: not to ^{9}Be*(1.7)), 2.2 to 3.2 MeV (1969SA04, 1972LI31) and at $E(^{3}\text{He}) = 10$ MeV (1970DI12, 1970DI1F), and for the group corresponding to ^{9}Be*(14.39) at $E(^{3}\text{He}) = 10$ MeV (1971AD01). The characteristics of the neutron and γ-decays of ^{9}Be states are displayed in Tables 9.5 and 9.6 (1965GR08, 1965LY01, 1966CH20, 1968CO08, 1968KR02, 1971AD01, 1972AD04, 1972MC1E). See also (1964MA57, 1970LI1Q), (1969BA1Z), (1968SA1G, 1968TA1N, 1970LK1A, 1971WE1L; theor.), ^{8}Be and ^{10}B.

Table 9.5: Neutron decay of ^{9}Be states

^{9}Be state (MeV)	l_n	Decay (in %) to ^{8}Be(0)	^{8}Be*(2.9)	θ^2 [a] (%)	Refs.
2.43	3	7.5 ± 1 [b]		2.1 ± 0.6	(1966CH20)
		6.4 ± 1.2			(1970CH07, 1970CH1T)
2.78	1	mainly		0.48 ± 0.06	(1970CH07, 1970CH1T)
3.06	2	87 ± 13		81 ± 13	(1966CH20, 1968CO08)
4.70	2	13 ± 4		6.0 ± 0.4	(1968CO08)
6.76	3	≤ 2		≤ 6	(1968CO08)
	1		55 ± 14	37 ± 10	(1968CO08)
11.28	1	≤ 2		≤ 0.1	(1968CO08)
	1		14 ± 4	0.93 ± 0.28	(1968CO08)
	3			4.0 ± 1.2	(1968CO08)
11.81	1	≤ 3		≤ 0.1	(1968CO08)
	1		12 ± 4	0.48 ± 0.16	(1968CO08)
	3			1.8 ± 0.6	(1968CO08)
14.40		< 7			(1972MC1E)
			50 ± 12		(1972MC1E)

[a] Expressed in units of $\hbar^2/mR^2 = 2.47$ MeV (1968CO08, 1970CH07).
[b] See also (1959MA34).

11. ^{7}Li(α, d)^{9}Be $Q_m = -7.1511$

At $E_\alpha = 30$ MeV angular distributions have been measured for the deuterons corresponding to ^{9}Be*(0, 1.7, 2.4) (1972ME07). See also (1971BU1K; theor.) and (1966LA04).

12. ^{7}Li(^{6}Li, α)^{9}Be $Q_m = 15.223$

At $E(^7\text{Li}) = 2.9$ MeV α-particle groups are observed corresponding to ^{9}Be*(0, 1.7, 2.4, 3.1, 11.9 ± 0.2 [$\Gamma = 0.5 \pm 0.1$ MeV]) (1964ME07). Angular distributions of the α_0 group have been measured at $E(^7\text{Li}) = 3.78$ to 5.95 MeV (1967KI03). At $E(^6\text{Li}) = 26.0$ MeV and $E(^7\text{Li}) = 30.3$ MeV the excitation of ^{9}Be*(0, 11.8, 13.8, 15.2, 17.8, 21.0) is reported (1971GL07). See also (1967CH34, 1968DA20, 1970OG1A) and (1966RO1E, 1966RO1F, 1966RO1H, 1969RO1G; theor.).

Table 9.6: Parameters of ^{9}Be*(14.40) [a]

		Refs.
E_x (MeV ± keV)	14.396 ± 5	(1965LY01)
$J^\pi; T$	$\frac{3}{2}^-; \frac{3}{2}$	
$\Gamma_{\gamma 0}$ (eV)	6.9 ± 0.5	See (1973BE19)
$\Gamma_{\gamma 0}/\Gamma$	0.021 ± 0.004	(1971AD01)
Γ (eV)	329 ± 60	(1971AD01, 1973BE19)
$\Gamma_{\gamma 2.43}/\Gamma_{\gamma 0}$	1.19 ± 0.16	(1971AD01)
$\Gamma_{\gamma 2.9}/\Gamma_{\gamma 2.43}$	0.30 ± 0.04	(1971AD01)
$\Gamma_{n_0}/\Gamma_{\gamma 0}$	6.4 ± 2.0	(1972AD04)
$\Gamma_{n_{2.9}}/\Gamma_{\gamma 0}$	20.4 ± 4.6	(1972AD04)
$\Gamma_{\alpha 0}/\Gamma_{\gamma 0}$	31.2 ± 9.8	(1972AD04)
Γ_{n_0} (eV)	44 ± 15	(1972AD04, 1973BE19)
$\Gamma_{n_{2.9}}$ (eV)	141 ± 35	(1972AD04, 1973BE19)
Γ_{α_0} (eV)	215 ± 60	(1972AD04, 1973BE19)

[a] See also Table 9.5 and reaction 4 in ^{9}B for the parameters of the analog state: ^{9}Be*(14.66). See also (1965LY01, 1965GR08).

13. ^{7}Li(^{11}B, ^{8}Be)^{9}Be $\quad Q_m = 7.286$

See (1970LK1A; theor.).

14. ^{9}Li(β^-)^{9}Be $\quad Q_m = 13.618$

^{9}Li decays by β^- emission with $\tau_{1/2} = 176 \pm 2$ msec to ^{9}Be*(0, 2.43, 2.78): see ^{9}Li and Table 9.7. ^{9}Be*(2.43, 2.78) are neutron unstable. The probability that ^{9}Li decays to these two states is 0.35. The branching ratio for the ^{9}Be*(2.43) $\rightarrow$ ^{8}Be(0) + n decay is (6.4 ± 1.2)%. ^{9}Be*(2.78) decays mainly to ^{8}Be(0) + n. The assignment $J^\pi = \frac{1}{2}^-$ to ^{9}Be*(2.78) derives from the allowed nature of the ^{9}Li decay, and the large value of θ_p^2 $[0.48 \pm 0.06]$ which is in agreement with the shell-model prediction that the $\frac{1}{2}^-$ state should decay mainly by p-wave neutron emission to ^{8}Be(0): if $J^\pi = \frac{3}{2}^-$ this decay branch should be small (1970CH07, 1970CH1T). See also (1963AL18, 1965SC17, 1973RO2F) and (1969MA11) for a general discussion of the problems in identifying the parameters of the low-lying states of ^{9}Be.

Table 9.7: Branching parameters in ^{9}Li β-decay (1970CH07, 1970CH1T) [a]

E_x in ^{9}Be (MeV)	$J^{\pi}; T$	Branching ratio (%)	$\log ft$
0	$\frac{3}{2}^-; \frac{1}{2}$	$65.0^{+2.7}_{-2.4}$	$5.12^{+0.01}_{-0.02}$
2.43	$\frac{5}{2}^-; \frac{1}{2}$	$32.0^{+2.7}_{-3.7}$ [c]	$5.00^{+0.04}_{-0.05}$
2.78 ± 0.12 [b]	$\frac{1}{2}^-; \frac{1}{2}$	$3.0^{+2.7}_{-0.3}$ [c]	$5.97^{+0.05}_{-0.28}$

[a] See also (1963AL18, 1969MA11).

[b] $\Gamma_{c.m.} = 1.10 \pm 0.12$ MeV; $\theta_p^2 = 0.48 \pm 0.06$ (1970CH07).

[c] See also (1973RO2F).

15. (a) ^{9}Be(γ, n)^{8}Be $\quad Q_m = -1.6651$
(b) ^{9}Be(γ, α)^{5}He $\quad Q_m = -2.46$
(c) ^{9}Be(γ, n)^{4}He^{4}He $\quad Q_m = -1.5732$
(d) ^{9}Be(γ, 2n)^{7}Be $\quad Q_m = -20.565$

The photoneutron cross section has been measured from threshold to 320 MeV: see Table 9.6 in (1966LA04). A sharp peak occurs 6 keV above threshold (1967BE49) [but see discussion in (1968BA1C)] with $\sigma_{max} = 1.6$ mb. The cross section then decreases slowly to 1.2 mb at $E_\gamma = 40$ keV (1967BE49). A satisfactory fit to the cross section is obtained with a one-level approximation of R-matrix theory (1968BA1C). Peaks in the cross section of (γ, xn) are reported corresponding to $E_x = 2.43 \pm 0.03$, 3.00 ± 0.03, 19.00 ± 0.03, 21.50 ± 0.05 and 23.9 ± 0.1 MeV, and there is some indication also of structure at $E_x = 9.1$, 10.8, 12.8 and 14.8 MeV (1973HU1G). See also (1966CO16, 1972TH12) and (1966LA04) for references to earlier work.

The total absorption cross section has been measured for $E_\gamma = 10$ to 155 MeV by (1972AH1B, 1973AH1A)[†] . The integrated cross section for $E_\gamma = 16$ to 29 MeV is 53 MeV · mb (1972AH1B). (1969DO09) report an integrated cross section of 156 ± 15 MeV · mb for $E_\gamma = 10$ to 29 MeV and resonant structure at $E_\gamma = 11.8$, (13.5), 14.8, (17.3), (19.5), 21.0, (23.0) and (25.0) MeV (1969DO09). Fine structure is reported at $E_\gamma = 20.47 \pm 0.04$ and 20.73 ± 0.04 MeV (1964TE04). See also (1965WY1A).

See (1966LA04) for a discussion of the early evidence on ^{9}Be levels from reaction (a). See also (1966TH03, 1967GL1B, 1968AD09, 1968KA1D, 1971KA70, 1972BU1R, 1972CR1E), (1967SH1E) and (1965BO1B, 1965MA1H, 1967BO1K, 1967BO34, 1969BO1U, 1968MA1Y, 1968MA1X, 1968PA1H, 1969AU05, 1970SA17, 1972TA31, 1973SL02; theor.).

16. (a) ^{9}Be(γ, p)^{8}Li $\quad Q_m = -16.888$
(b) ^{9}Be(γ, np)^{7}Li $\quad Q_m = -18.921$

[†] We are deeply indebted to E.G. Fuller for his very helpful remarks on the ^{9}Be + γ processes.

The yield shows structure in the energy region corresponding to the ^{9}Be levels at 17–19 MeV (1962CL06) followed by the giant resonances at $E_\gamma \approx 23$ MeV (1962CL06: $\sigma = 2.64 \pm 0.30$ mb). (1966DE13) report structure attributed to eleven states of ^{9}Be with $18.2 < E_x < 32.2$ MeV. Integrated cross sections have been obtained for each of these resonances, and over different energy intervals for protons leading to ^{8}Li*($0 + 0.98$, $2.26 + 3.21$, 9.0, 17.0) (1966DE13). Angular and energy distributions of photoprotons in various energy intervals have been studied by many groups: see (1966LA04) and (1966VO06, 1968AD09). See also (1965KO1B, 1969AN1H, 1971AN04, 1973DO13), (1967SH1E, 1973CO1N) and (1968MA1X; theor.).

17. (a) ^{9}Be(γ, d)^{7}Li $\quad Q_m = -16.6965$
(b) ^{9}Be(γ, t)^{6}Li $\quad Q_m = -17.6895$

The integrated cross sections are reported to be 1.0 ± 0.5 MeV · mb ($E_\gamma = 21 \rightarrow 33$ MeV) for reaction (a) to ^{7}Li*($0 + 0.4$) and 0.6 ± 0.3 MeV · mb ($E_\gamma = 25 \rightarrow 33$ MeV) for reaction (b) to ^{6}Li(0). The total integrated cross section for [(γ, p) + (γ, pn) + (γ, d) + (γ, t)] is given as 33 ± 3 MeV · mb by (1966DE13), who also report resonances in the (γ, d) and (γ, t) cross sections corresponding to ^{9}Be*(26.0 ± 0.2) and ^{9}Be*(32.2 ± 0.3), respectively. See also (1966LA04) and (1966VO06, 1968AD09, 1969AN1H, 1971AN04, 1972AN1L) for reaction (a) and (1966VO06, 1972AN09) for reaction (b). See also (1968MA1X; theor.).

18. ^{9}Be(γ, γ)^{9}Be

See (1967LO1B, 1968SN1A, 1969MO1H).

19. (a) ^{9}Be(e, e)^{9}Be
(b) ^{9}Be(e, en)^{8}Be $\quad Q_m = -1.6651$
(c) ^{9}Be(e, ep)^{8}Li $\quad Q_m = -16.888$
(d) ^{9}Be(e, eα)^{5}He $\quad Q_m = -2.46$

$\langle r^2\rangle^{1/2} = 2.46 \pm 0.11$ fm, $Q = 6.5^{+0.9}_{-0.6}$ fm^2, $b = 1.5^{+0.3}_{-0.2}$ fm [b = oscillator parameter] (1973BE19);
$\langle r^2\rangle^{1/2} = 2.519 \pm 0.012$ fm, $Q = 6.4 \pm 2.4$ fm^2 ((1972JA10) and K. de Jager, private communication to J.C. Bergstrom);
$\langle r^2\rangle^{1/2} = 2.43 \pm 0.08$ fm, $Q = 3$ fm^2 (1969BE21).

See also (1966AF1A, 1967BE26, 1967BE1P, 1973SL02). (1973LA1T) report $b = 1.80 \pm 0.03$ fm from magnetic scattering.

Table 9.8: Levels of ^{9}Be from ^{9}Be(e, e′)^{9}Be*

E_x in ^{9}Be (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Transition	J^π	$\Gamma_{\gamma 0}$ (eV)	Refs.
1.78 ± 30 [i]	150 ± 50	E1	$\frac{1}{2}^+$	0.3 ± 0.12	(1968CL08)
				4.5 ± 0.6	(1963NG01, 1965NG1A)
2.44 ± 20 [i]	< 30	M1	$\frac{5}{2}^-$	0.13 ± 0.03	(1960BA47)
				0.12 ± 0.02	(1962ED02)
				0.13 ± 0.015	(1968VA05)
				0.089 ± 0.010	(1968CL08)
				0.12 ± 0.02	"Best"
		E2		$(1.89 \pm 0.14) \times 10^{-3}$	(1968CL08)
3.04 ± 20 [i]	450 ± 150	E1	$\pi = +$	0.45 ± 0.35 [e]	(1968CL08)
		M1	$\pi = -$	$(8.8 \pm 4.4) \times 10^{-2}$ [e]	(1968CL08)
4.7 ± 200	700 ± 300	E(1)		2.4 ± 1.2 [e]	(1968CL08)
				0.3 [e]	(1968VA05) [h]
6.4 ± 100 [i]	2000 ± 500	E2	$\frac{7}{2}^-$	0.109 ± 0.005	(1963NG01, 1965NG1A)
	1100 ± 300			0.082 ± 0.035	(1968CL08)
8.0 ± 200		M1		3.5 ± 1.0 [e]	(1968VA05)
9.1 ± 200		M1		1.9 ± 0.5 [e]	(1968VA05) [h]
10.2 ± 200		M1		1.7 ± 0.5 [e]	(1968VA05) [h]
11.2 ± 200		M1		5.6 ± 1.1 [e]	(1968VA05) [h]
13.84 ± 50 [a]					(1973BE19)
14.388 ± 15	< 70	M1	$\frac{3}{2}^-$	6.2 ± 0.6	(1973BE19)
				10.5 ± 1.5 [j]	(1966CL01)
				18 ± 9	(1962ED02)

Table 9.8: Levels of ^{9}Be from ^{9}Be(e, e′)^{9}Be* (continued)

E_x in ^{9}Be (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Transition	J^{π}	$\Gamma_{\gamma 0}$ (eV)	Refs.
				8 ± 2	(1968VA05) [h]
				6.9 ± 0.5 [f]	"Best": see (1973BE19)
15.10 ± 50 [a]					(1973BE19)
15.97 ± 30 [a]	≈ 300			3.7 ± 0.8 [e,k]	(1966CL01, 1967AR1A, 1973BE19)
16.631 ± 15 [b]	< 70	M2 [d]	$\leq \frac{7}{2}^{+}$	0.30 ± 0.08 [e,k]	(1966CL01)
				0.26 ± 0.02 [e]	(1973BE19)
		M1	$\leq \frac{5}{2}^{-}$	2.0 ± 0.5 [e]	(1973BE19)
16.961 ± 15 [b]	< 70	M1	$\frac{1}{2}^{-}$	18.8 ± 1.8 [j]	(1966CL01)
				11.5 ± 1.4	(1973BE19)
17.28		} M1	$\leq \frac{5}{2}^{-}$	7.3 ± 1.3 [e]	(1973BE19)
17.480 ± 20	≈ 100	} M2 [d]	$\leq \frac{7}{2}^{+}$	0.7 ± 0.2 [e,k]	(1966CL01)
				0.42 ± 0.10 [e]	See (1973BE19) [g]
				0.40 ± 0.03 [e]	(1973BE19)
18.02 ± 50 [a]					(1973BE19)
18.62 ± 50 [a,b]					(1973BE19)
19.51 ± 50 [a]					(1973BE19)
20.76 ± 50 [a,b]					(1973BE19)
[c]					

[a] Weak transition (1973BE19).

[b] See also (1968VA05).

[c] Higher states reached by M1 transitions are reported at 21.6 ± 0.2, 22.5 ± 0.2, 24.4 ± 0.2 and 25.7 ± 0.2 MeV (1968VA05).

[d] Or pure spin-flip E1.

[e] gΓ_{γ_0}, where g $= (2J_{\rm f} + 1)/(2J_{\rm i} + 1)$.

[f] This value is calculated by (1973BE19): it is the weighted mean of 6.2 ± 0.6 eV, 8.1 ± 0.8 eV (an unpublished correction of (1966CL01): see (1972THZF)) and 6.7 ± 1.4 eV (an unpublished value by H.S. Caplan *et al*). We are grateful to Prof. J.C. Bergstrom for his comments.

[g] Unpublished corrected value of (1966CL01)'s result: see (1973BE19).

[h] And G.J. Vanpraet, private communication. All values for the cross sections listed in Table 1 of (1968VA05) for states with $E_{\rm x} > 8$ MeV should be reduced by a factor of 3.13.

[i] See (1973SL02): $E_{\rm x} = 1.79 \pm 0.06$ for ^{9}Be*(1.7).

[j] (1972THZF) list revised values for $\Gamma_{\gamma_0} = 8.1 \pm 0.8$ and 8.6 ± 0.9 eV for ^{8}Be*(14.40, 16.96).

[k] See also (1972THZF).

The elastic scattering of electrons has been studied at E_e up to 700 MeV: see (1966LA04), the references listed above, and (1965VA1G, 1966RA29, 1969BE50). Magnetic elastic scattering at $\theta = 180°$ gives indication of both M1 and M3 contributions [(1965GR18, 1966RA29): see (1968KU1D)].

Inelastic scattering reveals a number of levels: Table 9.8 displays the parameters of these states (1960BA47, 1962ED02, 1963NG01, 1965NG1A, 1966CL01, 1967AR1A, 1968CL08, 1968VA05, 1973BE19, 1973SL02). See also (1966LA04) for a discussion of the earlier work.

Electron bremsstrahlung has been measured at $E_e = 1.0$ and 2.0 MeV by (1968RE11). See also (1966PE1E), (1968GO1J) and (1965GR1E, 1965NE1B, 1966DE1K, 1966KU1C, 1967KA1A, 1967ST1G, 1967WA1E, 1967WA1F, 1968JA1D, 1968KU1B, 1969BO1V, 1969BO19, 1969VI02, 1970BE1G, 1970TI1C, 1971GO14, 1972BL12, 1972BO01, 1972DR1B, 1973OK1B; theor.).

For reaction (b) see (1970AL1M; theor.). For reaction (c) see (1968AM1A, 1968BO46, 1970HI1F, 1970RE1E) and (1965AL1F, 1973HI03; theor.). For reaction (d) see (1973JU1E).

20. (a) ^{9}Be(n, n)^{9}Be
(b) ^{9}Be(n, 2n)^{8}Be $\qquad Q_m = -1.6651$

The neutron spectrum at $E_n = 3.7$ MeV is consistent with the excitation of ^{9}Be*(0, 1.7, 2.4, 3.1) with subsequent neutron decay of the two higher states (1957HU14, 1958WA05). About $\frac{1}{2}$ of the inelastic processes involve ^{9}Be*(2.4) for $E_n = 2.6$ to 6.0 MeV; that level decays only 12 ± 5% via ^{8}Be(0) + n (1959MA34). See Table 9.5. At $E_n = 14$ MeV ^{9}Be*(6.8) appears to be excited (1963JE05). Angular distributions have been measured at $E_n = 14$ MeV (1958AN32, 1958NA09, 1968RO1H, 1969RO1F; n_0, n_2). See also ^{10}Be, (1966LA04) and (1965BO19, 1965FR1B, 1965GO1E, 1966AM1A, 1966BO1C, 1966BO1F, 1967BO1F, 1970DR1B) and (1969WA11; theor.).

21. ^{9}Be(p, p)^{9}Be

The elastic scattering has been studied at many energies for $E_p = 5$ to 725 MeV: see (1966LA04). More recent angular distribution measurements have been carried out at $E_p = 2.009$ to 2.099 MeV (1971SI1K; p_0), 6.36 and 6.48 MeV (1971VA34; p_1), 13.0, 14.0, 15.0, 21.35 and 30.3 MeV (1973VO02; p_0, p_2), 17.0, 21.0, 25.0, 29.1 (1973MO01; p_0, p_2 and p to ^{9}Be*(3.1)), 33.6 MeV (1970KU1D; p_0), 46 MeV (1967SA13, 1967VE01; p_0, p_2 and p to ^{9}Be*(11.3, 14.4, 16.7, 17.5)), 49.75 MeV (1971MA13, 1971MA44; p_0, p_2 and p to ^{9}Be*(6.4)), and 100 MeV (1966MA38, 1968LI1C; p_0, p_2 and p to ^{9}Be*(4.7, 6.8)). The elastic angular distributions show pronounced diffraction maxima characteristic of the optical model. See (1973MO01) for a discussion of optical model parameters. (1973VO02), in coupled channels analysis, find that a quadrupole-deformed optical model potential with a deformation parameter $\beta = 1.1$ [see also (1967SA13)] provides an improved description of the elastic data and a good fit to the p_2 data [to ^{9}Be*(2.4)].

The structure corresponding to ^{9}Be*(1.7) is asymmetric: the line shape peaks 25^{+15}_{-11} keV above the threshold for ^{8}Be + n (1970TU06): see also the discussions in (1960SP08, 1971JE03) and in (1966LA04). The energy of ^{9}Be*(2.4) is given as 2433 ± 5 (1951BR72), 2434 ± 5 (1956BO18), 2432 ± 4 (1955GO48), 2430 ± 5 keV (1960SP08). ^{9}Be*(3.1) has a width of 250 ± 5 keV (1960SP08): $E_x = 3.03 \pm 0.03$ MeV (1956BO18), 3.04 ± 0.05 MeV (1960SP08), $J^\pi = \frac{3}{2}^+, \frac{5}{2}^+$. Higher states are observed at $E_x = 4.8 \pm 0.2$, 6.76 ± 0.06 [$J^\pi = \frac{1}{2}^+, \frac{5}{2}^+, \frac{7}{2}^+$ (but see below), $\Gamma = 1.2 \pm 0.2$ MeV], 7.94 ± 0.08 ($\Gamma \approx 1$ MeV), 11.3 ± 0.2 MeV ($\Gamma \approx 1$ MeV), 14.4 ± 0.3 ($\Gamma \approx 1$ MeV), 16.7 ± 0.3, 17.4 ± 0.3, 19.0 ± 0.4, 21.1 ± 0.5 and 22.4 ± 0.7 MeV [the five highest states are all broad] (1956BE14, 1965HA17). See also Table 9.8 in (1966LA04). (1965JA1A) reports for ^{9}Be*(2.4, 6.8) B(E2↑) $= 49 \pm 6$ and 24 ± 4 fm^4 and Γ(E2↓) $= 0.0025$ and 0.10 eV, respectively. The strong population of ^{9}Be*(2.4, 6.8) in this reaction is consitent with the assumption that they have $J^\pi = \frac{5}{2}^-$ and $\frac{7}{2}^-$, respectively, and are members of the ground state $K = \frac{3}{2}^-$ band: see discussion in (1966LA04). See also (1966MA38).

See also (1965HU10, 1971HU1A, 1971SC1N) and (1968GL1A, 1968NE1A, 1968NE1B, 1968SE1B, 1969NE1A, 1969NE08, 1969WA11, 1970MA04, 1970MA38, 1971BA87, 1971IN05, 1971RA36, 1972SO03, 1973GU08, 1973HU05; theor.).

22. (a) ^{9}Be(p, 2p)^{8}Li $Q_m = -16.888$

(b) ^{9}Be(p, pd)^{7}Li $Q_m = -16.6965$

(c) ^{9}Be(p, pα)^{5}He $Q_m = -2.46$

(d) ^{9}Be(p, pn)^{8}Be $Q_m = -1.6651$

(e) ^{9}Be(p, p^{3}He)^{6}He $Q_m = -21.181$

The summed proton spectrum (reaction (a)) shows two peaks with $Q = -16.4 \pm 0.3$ and $Q = -25.4 \pm 0.5$ MeV, corresponding to removal of a p-proton and an s-proton respectively, and a third peak of uncertain assignment with $Q = -32.3 \pm 0.6$ MeV (probably due to unresolved states) (1966TY01: $E_p = 460$ MeV). See also (1966LA04), (1966WA12, 1968PE1A), (1965BE1E, 1966JA09, 1966JA1A, 1967BE1Q, 1967JA1E, KO67Q, 1968JA1G, 1969KO1J; theor.) and ^{8}Li. For reaction (b) see (1966LA04) and (1973KO1M). Reaction (c) is characterized by a sequential mechanism at low energies and by a quasi elastic scattering mechanism at higher energies. At $E_p = 26.0$, 35.0, 46.8 and 57 MeV the data are consistent with quasi free scattering of the incident protons by zero-momentum α-particle clusters in ^{9}Be: the probability of finding such clusters at these four energies is determined to be 0.166, 0.099, 0.124 and 0.09, respectively (1968RO19, 1970QU1C, 1972QU01). See also (1967TA1C, 1969YA1B, 1970GO12, 1973WO1E), (1969HO1K, 1971GA1J) and (1973HO30; theor.).

For reaction (d), see (1969WI1F, 1970TH1F, 1971HU1A, 1973MI1J) and (1967BE1Q; theor.). For reaction (e) see (1969KO1G). See also (1968KO1E, 1969ED01).

23. ^{9}Be(d, d)^{9}Be

Elastic scattering has been studied at many energies in the range $E_{\mathrm{d}} = 7.8$ to 27.7 MeV: see (1966LA04). Elastic angular distributions are also reported for $E_{\mathrm{d}} = 1.1$ to 2.5 MeV (1968MA1H), 4.5 to 6.0 MeV (1970PO03), 5.00 to 7.00 MeV (1971DJ02), 11.8 MeV (1967FI07; also d_2), 12.8 MeV (1973VA08; d_1), 13.6 MeV (1968VE11, 1968VE1C, 1970VE06, 1972MA47), 14.35 MeV (1966NG1A; also d_2), 15.0 MeV (1969AR1B), 15.8 MeV (1966CO24; also d_2) and 410 MeV (1960BU25; forward angles). For optical model parameters see discussions in (1966CO24, 1967FI07).

Inelastic deuteron groups have been observed to ^{9}Be*(1.7, 2.4, 3.1, 4.7, 6.8): see (1966LA04). (1968KR02) report $E_{\mathrm{x}} = 2431.9 \pm 7.0$ keV and 3040 ± 15 keV [$\Gamma = 294 \pm 20$ keV]. See also (1963ST1A, 1969VE09, 1970EL16, 1973ZW1A; theor.) and ^{11}B.

24. (a) ^{9}Be(t, t)^{9}Be

(b) ^{9}Be(t, nt)^{8}Be $\quad Q_{\mathrm{m}} = -1.6651$

The angular distribution of elastically scattered tritons has been measured at $E_{\mathrm{t}} = 2.10$ MeV (1969HE08, 1970CO04). Reaction (b) at $E_{\mathrm{t}} = 4.2$ and 4.6 MeV proceeds via ^{9}Be*(2.4) (1967SE11).

25. ^{9}Be(^{3}He, ^{3}He)^{9}Be

Angular distributions of elastically scattered ^{3}He particles have been obtained at $E(^{3}\mathrm{He}) = 4$, 6, 8, 10, 15 and 18 MeV (1969PA11), 6.0 and 8.0 MeV (1967EA01), 13.2, 20.4, 22.2 and 27.0 MeV (1972BU30), 22.7 and 32.3 MeV (1965AR1E), and 217 MeV (1973WI07). See also (1970BA1P). For optical model parameters see discussions in (1972BU30, 1973WI07). At $E(^{3}\mathrm{He}) = 39.8$ MeV inelastic ^{3}He groups are observed to ^{9}Be*(1.7, 2.4, 3.1, 4.7, 6.8, 14.4) (1968BA1E, 1969BA06). See also (1968HO1C, 1968PA1P, 1969HO27; theor.), (1966LA04) and reaction 28 in ^{6}Li.

26. (a) ^{9}Be(α, α)^{9}Be

(b) ^{9}Be(α, 2α)^{5}He $\quad Q_{\mathrm{m}} = -2.46$

(c) ^{9}Be(α, αn)^{8}Be $\quad Q_{\mathrm{m}} = -1.6651$

Elastic scattering has been studied at many energies for $E_{\alpha} = 9.5$ to 48 MeV: see (1966LA04). Recent measurements of the angular distributions of α_0 are reported at $E_{\alpha} = 8.76$, 9.27 and 10.13 MeV (1967BR1F), 28.5 MeV (1967FU08; also α_2, and partial angular distributions for α_1 and α_3) and 104 MeV (1969HA14, 1970HA1G, 1972DE01, 1972DE02). See (1972DE01, 1972DE02) for a discussion of optical model parameters. The structure ($^{5}\mathrm{He}+\alpha$) for ^{9}Be is found to be much more probable than ($^{6}\mathrm{Li} + \mathrm{t}$): the ratio of the spectroscopic factors is about 30 (1972DE01, 1972DE02).

Inelastic groups have been observed to ^{9}Be*(1.7, 2.4, 3.1, 6.8, 11.3): see (1966LA04). The angular distribution of the group corresponding to ^{9}Be*(1.7) is consistent with $J^\pi = \frac{1}{2}^+$ (1964LU02: $E_\alpha = 18.4$ MeV). The angular distributions for α_2 are consistent with $l = 2$ ($J^\pi = (\frac{1}{2}, \frac{5}{2}, \frac{7}{2})^-$ (1958SU14: $E_\alpha = 48$ MeV) and (1967FU08: $E_\alpha = 28.5$ MeV). Analysis based on the rotational model leads to a deformation coefficient $\beta_2 = 0.46$ (1959BL31), 0.34 ± 0.01 (1964GR39). See also (1966GR1E, 1966GR1F, 1968LI1E, 1970WO1B, 1972DM01, 1972RA34).

The summed α-spectra from reaction (b) show a peak corresponding to quasi-elastic scattering leaving ^{5}He in the ground state. The angular distribution peaks at the angle corresponding to a zero-momentum α-cluster. The probability of formation of such clusters is 7^{+13}_{-5}% (1969PI11, 1970PI1D: $E_\alpha = 55$ MeV). See also (1965YA02, 1968YA02, 1969DO02, 1969DO03) and ^{5}He. The reaction cross section has been measured at $E_\alpha = 42.8$ and 49.2 MeV by (1971GU15).

See also (1965HI1B, 1965KU1B, 1966HI1A, 1967ME1C, 1968BA1H, 1968TA1K, 1969BA1J, 1970MI12, 1972AV04, 1972HI16; theor.) and (1971GA1J).

A study of continuum neutrons at $E_\alpha = 4.9$ to 6.4 MeV (reaction (c)) indicates that sequential decay takes place via ^{9}Be*(1.7, 2.4, 3.0) (1972OB01). See also (1971GE09, 1973GE1J, 1973WE03).

27. (a) ^{9}Be(^{6}Li, ^{6}Li)^{9}Be
(b) ^{9}Be(^{7}Li, ^{7}Li)^{9}Be

Elastic angular distributions have been measured at $E(^6\text{Li}) = 24$ MeV (1968DA20) and $E(^7\text{Li}) = 24$ MeV (1972WE08). See also (1970LK1A; theor.) for reaction (b).

28. ^{9}Be(^{12}C, ^{12}C)^{9}Be

Elastic scattering angular distributions have been obtained at $E(^{12}\text{C}) = 12$, 15, 18 and 21 MeV. The neutron spectroscopic factor for ^{9}Be is 0.84 (1970BA49).

29. ^{9}Be(^{14}N, ^{14}N)^{9}Be

Elastic angular distributions have been measured at $E(^{14}\text{N}) = 25$ MeV (1966OE1A) and 27.3 MeV (1959HA28). See also (1966LA04), (1969BR1D) and (1965BO37).

30. (a) ^{9}Be(^{16}O, ^{16}O)^{9}Be
(b) ^{9}Be(^{18}O, ^{18}O)^{9}Be

Elastic angular distributions have been reported at $E(^{16}\text{O}) = 15$, 18, 21.5 and 25 MeV (1970BA49) and 30 MeV (1969KR03), and at $E(^{18}\text{O}) = 12.1$, 16 and 20 MeV (1971KN05).

31. ^{10}Be(d, t)^{9}Be $\qquad Q_\text{m} = -0.5544$

Forward angular distributions have been obtained at $E_\text{d} = 15.0$ MeV for the tritions to ^{9}Be*(0, 1.7, 2.4, 3.1). The ground state transition is well fitted by $l = 1$. The transition to ^{9}Be*(1.7) [$\Gamma \approx 165 \pm 25$ keV] is consistent with $J^\pi = \frac{1}{2}^+$, that to ^{9}Be*(2.4) is quite well fitted with $l = 3$ [$J^\pi = \frac{5}{2}^-$], and that to ^{9}Be*(3.1) [$\Gamma = 280 \pm 25$ keV] is consistent with $l = 2$. No other narrow states are seen up to $E_\text{x} = 5.5$ MeV (1970AU02).

32. ^{10}B(γ, p)^{9}Be $\qquad Q_\text{m} = -6.5853$

See ^{10}B.

33. ^{10}B(e, ep)^{9}Be $\qquad Q_\text{m} = -6.5853$

See (1969BA1F; theor.) and ^{10}B.

34. ^{10}B(n, d)^{9}Be $\qquad Q_\text{m} = -4.3607$

A good fit to the angular distributions of the deuterons to ^{9}Be*(0, 2.4) has been obtained at $E_\text{n} = 14.4$ MeV, using DWBA. The spectroscopic factors are in close agreement with shell-model predictions (1965VA05). See also (1966GO1D), (1966WE1B, 1971MI12), (1966LA04) and ^{11}B in (1975AJ02).

35. ^{10}B(p, 2p)^{9}Be $\qquad Q_\text{m} = -6.5853$

The summed proton spectrum at $E_\text{p} = 460$ MeV yields $Q = -6.7 \pm 0.5$, -11.9 ± 0.5, -17.1 ± 0.6 (all $l \neq 0$) and $Q = -30.5 \pm 0.6$ MeV ($l = 0$) (1966TY01). See also (1965BE1E, 1966JA09, 1966JA1A, 1967JA1E, 1967KO1B, 1968JA1G; theor.), ^{10}B and (1966LA04).

36. ^{10}B(d, ^{3}He)^{9}Be $\qquad Q_\text{m} = -1.0916$

Angular distributions of the ^{3}He groups corresponding to ^{9}Be*(0, 2.4) have been measured at $E_d = 11.8$ MeV (1966BA21, 1967FI07: $S_{exp} = 0.76$ and 0.66, respectively) and at 28 MeV [(1971IN1C); (1968GA13: ground state only)]. The data are very similar, as predicted, to those obtained in the mirror reaction: see reaction 12 in ^{9}B. See also (1965SY02, 1971WA1K, 1972WA1M).

37. ^{10}B(t, α)^{9}Be $\quad Q_m = 13.229$

At $E_t = 12.9$ MeV α groups are observed to the ground state of ^{9}Be and to excited states at $E_x = 1.75 \pm 0.03$, 2.43, 3.02 ± 0.04 [$\Gamma = 320 \pm 60$ keV], 11.27 ± 0.04 [$\Gamma = 530 \pm 70$ keV], (14.4) [$\Gamma \approx 800$ keV], 14.39 and 16.67 MeV. The $T = \frac{3}{2}$ state ^{9}Be*(14.39) is very weakly populated [$\approx$ 5% of intensity of α_2]. The angular distribution of the α_2 group shows sharp forward and backward peaking. The α_0 group is not peaked in the backward direction (1968AJ01). A study at $E_t = 1.0$ to 3.2 MeV finds $E_x = 1.750 \pm 0.025$ MeV, $\Gamma = 220 \pm 8$ keV. The angular distribution of the corresponding α-group has been determined at $E_t = 2.5$ MeV (1971GE09).

38. ^{10}B(^{14}N, ^{15}O)^{9}Be $\quad Q_m = 0.707$

The ground state angular distribution has been measured at $E(^{14}\text{N}) = 27.5$ MeV (1962NE01).

39. ^{10}B(^{16}O, ^{17}F)^{9}Be $\quad Q_m = -5.985$

See (1968OK06).

40. ^{11}B(n, t)^{9}Be $\quad Q_m = -9.5591$

The angular distribution of the ground state group has been measured at $E_n = 14.4$ MeV (1970MI14).

41. (a) ^{11}B(p, ^{3}He)^{9}Be $\quad Q_m = -10.3229$
(b) ^{11}B(p, pd)^{9}Be $\quad Q_m = -15.8167$

At $E_p = 45$ MeV angular distributions are reported for the ^{3}He ions corresponding to ^{9}Be*(0, 2.4, 11.8, 13.8, 14.39 $[T = \frac{3}{2}]$, 15.96 ± 0.04 $[T = \frac{1}{2}]$). In addition one or more states may be located at ^{9}Be*(15.13). It is suggested that ^{9}Be*(11.8, 13.8, 15.96) are the $J^\pi = \frac{3}{2}^-$; $T = \frac{1}{2}$ analogs to ^{9}B*(12.06, 14.01, 16.02) (1971HA10). Angular distributions are also reported at $E_p = 40$ MeV (1971KA21; α_0, α_2). The intensity of the group to ^{9}Be*(3.1) is $\approx 1\%$ of the ground state group (1971KA21). For reaction (b) see (1964BA1C).

42. (a) ^{11}B(d, α)^{9}Be $\quad Q_m = 8.0309$
(b) ^{11}B(d, nα)^{4}He^{4}He $\quad Q_m = 6.4577$
$Q_0 = 8.0297 \pm 0.0028$ (1967OD01). See also (1964MA57, 1967SP09).

Alpha groups are reported corresponding to ^{9}Be*(0, 1.7, 2.4, 3.1). The width of ^{9}Be*(1.7): $\Gamma_{cm} = 224 \pm 25$ keV (1958KA31, 1966PU02). The energy of ^{9}Be*(2.4) is 2422 ± 5 keV (1951VA08), 2431 ± 6 keV (1954EL10), 2424 ± 5 keV (1956BO18). The $\frac{5}{2}^+$ state is at $E_x = 3.02 \pm 0.03$ MeV (1955LE36), 3.05 ± 0.03 MeV (1956BO18): $\Gamma_{cm} = 257 \pm 25$ keV (1958KA31, 1966PU02).

Angular distributions are reported at $E_d = 0.39$ to 0.7 MeV (1965SA15; α_0, α_2), 0.8 to 2.5 MeV (1968CO31; α_0, α_2) and at 12.6 MeV (1966DR04; α_0, α_2). See also (1966ME1E; theor.).

The ratio of the γ-decay width to the total width, Γ_γ/Γ, of ^{9}Be*(2.4) is $(1.16 \pm 0.14) \times 10^{-4}$. Since Γ_γ is known from (e, e′) [see Table 9.8], $\Gamma = 1.03 \pm 0.18$ keV. For ^{9}Be*(1.7), $\Gamma_\gamma/\Gamma \leq 2.4 \times 10^{-5}$ (1966PU02).

Reaction (b), at $E_d = 10.4$ and 12.0 MeV, proceeds via ^{9}Be*(2.4) and to some extent via ^{9}Be*(3.1, 4.7) and possibly some higher excited states. The dominant decay of ^{9}Be*(2.4) is to ^{5}He(0) + α while ^{9}Be*(3.1, 4.7) decay to ^{9}Be(0) + n (1971RE19). It should be noted, however, that the peaks corresponding to ^{9}Be*(3.1) have a FWHM of ≈ 1 MeV, which may imply that ^{9}Be*(2.8) is involved (1971RE19). See also ^{8}Be, ^{13}C in (1976AJ04) and (1966LA04).

43. ^{11}B(^{16}O, ^{18}F)^{9}Be $\quad Q_m = -8.290$

See (1968OK06).

44. (a) ^{12}C(n, α)^{9}Be $\quad Q_m = -5.7016$
(b) ^{12}C(n, nα)^{4}He^{4}He $\quad Q_m = -7.2748$

Angular distributions of the α_0 group have been measured at $E_n = 14.1$ MeV (1969HS02, 1969KI02), 13.9 and 15.6 MeV (1968BR21), and 14.8 to 18.8 MeV (1971SA31). (1968BR21, 1969HS02) also report the population of ^{9}Be*(1.7, 2.4, 3.1). Reaction (b) at $E_{\rm n} = 13$ to 18 MeV involves ^{9}Be*(2.4) (1966MO05). See also (1965MO09, 1966MI1D, 1968BE1J, 1969KA1D, 1969LO1D, 1971DO1K, 1971FA04), (1966CI1A, 1966LA04), (1967EL1D, 1968CH1J; theor.), ^{12}C in (1975AJ02), and ^{13}C in (1976AJ04).

45. ^{12}C(α, ^{7}Be)^{9}Be $\qquad Q_{\rm m} = -24.694$

Angular distributions have been obtained for the transitions to ^{7}Be*(0, 0.43)+^{9}Be(0) (1972RU03; 42 MeV). See also (1971LE33).

46. ^{13}C(γ, α)^{9}Be $\qquad Q_{\rm m} = -10.6480$

See ^{13}C in (1976AJ04).

47. ^{13}C(p, pα)^{9}Be $\qquad Q_{\rm m} = -10.6480$

See (1971BR07).

48. ^{13}C(d, ^{6}Li)^{9}Be $\qquad Q_{\rm m} = -9.174$

A partial angular distribution involving the transition to ^{6}Li(0) + ^{9}Be(0) has been measured at $E_{\rm d} = 14.6$ MeV (1966DE09).

49. ^{16}O(α, ^{11}C)^{9}Be $\qquad Q_{\rm m} = -15.387$

The angular distribution involving the transition to ^{11}C(0) + ^{9}Be(0) has been measured at $E_\alpha = 42$ MeV (1972RU03).

^{9}B

(Figs. 17 and 18)

GENERAL: (See also (1966LA04).)

Model calculations: (1966BA26, 1966EL08, 1967ST1C, 1971CO28, 1972LE1L, 1973HA49).

Special levels: (1966BA26, 1966EL08, 1967BA59, 1967ST1C, 1969HA1G, 1970TO1E, 1971CO28, 1971LI30, 1972BE1E).

Astrophysical questions: (1970BA1M).

Other topics: (1967CA17, 1967CH1H, 1970SA05, 1972AN05, 1972HA57, 1972CA37, 1972LE1L, 1972PN1A, 1973JU2A).

Ground state properties: (1966BA26, 1966EL08, 1969HE1N, 1969JA1M, 1969LE1D, 1969PE1D, 1971AU1G, 1972LE1L).

1. (a) ^{6}Li(^{3}He, n)^{8}B	$Q_{\rm m} = -1.975$	$E_{\rm b} = 16.604$
(b) ^{6}Li(^{3}He, p)^{8}Be	$Q_{\rm m} = 16.788$	
(c) ^{6}Li(^{3}He, d)^{7}Be	$Q_{\rm m} = 0.1126$	
(d) ^{6}Li(^{3}He, t)^{6}Be	$Q_{\rm m} = -4.306$	
(e) ^{6}Li(^{3}He, ^{3}He)^{6}Li		

The total cross section for reaction (a) has been measured from threshold to $E(^{3}\text{He}) = 3.5$ MeV: it increases monotonically reaching the value 4.3 mb at 3.5 MeV (1973MCZW). No structure is observed in the n_0 excitation curve for $E(^{3}\text{He}) = 4.0$ to 5.7 MeV (1967VA24). The yield of ^{8}B has also been measured for $E(^{3}\text{He}) = 8.9$ to 26.5 MeV (1973MA24). See also (1966FA1A) and ^{8}B.

The excitation functions for protons leading to ^{8}Be*(0, 2.9) [p_0, p_1] have been measured for $E(^{3}\text{He}) = 0.9$ to 17 MeV (reaction (b)). Resonances are reported at $E(^{3}\text{He}) = 1.6$ MeV ($\Gamma = 0.25$ MeV) [1.68 MeV: (1969VI05). $J^{\pi} = \frac{3}{2}^{-}$ or $\frac{5}{2}^{-}$] and 3.0 MeV ($\Gamma = 1.5$ MeV) (1956SC01). Above 5 MeV, the p_0 yield at $0°$ increases monotonically with energy to $E(^{3}\text{He}) = 17$ MeV (1965FL03). Polarization measurements are reported at $E(^{3}\text{He}) = 1.4$ to 2.0 MeV (1966SI1C, 1971SI1J; p_0, p_1). See also (1970GA1G) and ^{8}Be.

The yields of 0.43 and 0.48 MeV γ-rays (reaction (c)), measured for $E(^{3}\text{He}) = 0.5$ to 1.3 MeV, are reported to show the excitation of ^{9}B*(17.20 ± 0.02) with $\Gamma = 110 \pm 30$ keV, $J^{\pi} = \frac{1}{2}^{+}, \frac{3}{2}^{+}$; $T = \frac{1}{2}$ (1970AL25). See also ^{7}Be.

Excitation functions for ground state tritons (reaction (d)) have been measured for $E(^{3}\text{He}) = 10$ to 16 MeV (1969NU1A) and 23.3 to 25.4 MeV (1972GI07). See also ^{6}Be. Differential cross sections have been measured at several angles for the ^{3}He groups to ^{6}Li*(0, 2.19) (reaction (e)) for $E(^{3}\text{He}) = 23.3$ to 25.4 MeV (1972GI07). See also ^{6}Li.

Table 9.9: Energy levels of ^{9}B

E_x (MeV $\pm$ keV)	$J^\pi; T$	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
g.s.	$\frac{3}{2}^-; \frac{1}{2}$	0.54 ± 0.21	p, α	2, 3, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17
(1.6)		≈ 700	(p, α)	13
2.361 ± 5	$\frac{5}{2}^-; \frac{1}{2}$	81 ± 5	α	2, 4, 6, 7, 8, 11, 12, 13, 15, 16
2.788 ± 30	$(\frac{3}{2}, \frac{5}{2})^+; \frac{1}{2}$	550 ± 40	p	4, 6, 11, 13, 16
(4.8 ± 100)		1000 ± 200		4, 9
6.97 ± 60	$\frac{7}{2}^-; \frac{1}{2}$	2000 ± 200	p	4, 6, 9, 11, 15, 16
11.75 ± 100	$(\frac{7}{2})^-; \frac{1}{2}$	800 ± 50	p	9, 11, 13
12.06 ± 60	$; \frac{1}{2}$	800 ± 200	p	4, 9, 15
14.01 ± 70	$; \frac{1}{2}$	390 ± 110		4, 15
14.659 ± 5	$\frac{3}{2}^-; \frac{3}{2}$	$0.26^{+0.09}_{-0.12}$	γ, p	4, 7, 15
14.7 ± 200	$(\frac{5}{2})^-; \frac{1}{2}$	1350 ± 200		11
15.29 ± 40	$; \frac{1}{2}$			15
15.58 ± 40	$; \frac{1}{2}$			15
16.024 ± 25	$; (\frac{1}{2})$	180 ± 16		4, 15
17.190 ± 25		120 ± 40	p, d, ^{3}He	1, 4, 5, 15
17.637 ± 10		71 ± 8	p, d, ^{3}He	1, 4, 5, 15
(18.6)		1000	p, ^{3}He	1, 11

2. ^{6}Li(α, n)^{9}B $\qquad Q_m = -3.975$

Angular distributions at $E_\alpha = 8.0$, 10.0, 12.0 and 14.0 MeV all display strong forward peaking (1963ME08). At $E_\alpha = 14.4$ MeV, neutron groups are observed to ^{9}Be*(0, 2.4): the upper limit of the cross section to a state at $\approx$ 1.7 MeV is 100 μb/sr or < 0.1 of the ground state group (1964BA29). See also ^{10}B.

3. ^{6}Li(^{6}Li, t)^{9}B $\qquad Q_m = 0.809$

Angular distributions of the t_0 group have been measured for $E(^{6}\text{Li}) = 4.0$ to 5.5 MeV and at 7.35 and 9.0 MeV. No evidence was observed for a group corresponding to ^{9}B*(1.6) (1966KI09).

4. (a) ^{7}Li(^{3}He, n)^{9}B $\quad Q_m = 9.353$

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

For $E(^3\text{He})$ to 12.5 MeV this reaction populates ^{9}B*(0, 2.4, 2.8, (7.0)) (1963DU12) and levels at 12.06 ± 0.06 [0.8 ± 0.2], 14.01 ± 0.07 [0.39 ± 0.11], 14.670 ± 0.016 [< 0.045], 16.024 ± 0.025 [0.180 ± 0.016], 17.19 and 17.63 MeV [widths in brackets] (1964DI1A, 1965DI03). (1967BA59) report $Q = (-5306 \pm 5)$ keV and therefore $E_x = 14.659 \pm 0.005$ MeV (based on Q_m).

^{9}B*(14.66) is the first $T = \frac{3}{2}$ state in ^{9}B (1965DI03). It γ-decays to ^{9}B*(0, 2.4, 2.8) with branching ratios which appear to be similar to those for the analog state in ^{9}Be: see Table 9.6. Assuming that the Γ_γ for both $T = \frac{3}{2}$ states in ^{9}Be, ^{9}B are the same, the total Γ for ^{9}B*(14.66) is then $\approx$ 80% of that for ^{9}Be*(14.40): 260^{+90}_{-120} eV (1971AD01) [corrected for revised value of Γ of ^{9}Be*(14.40)]. The ratio $\Gamma_{p_0}/\Gamma_{\gamma_0} < 1.5$, $\Gamma_{p_1}/\Gamma_{\gamma_0} = 13.9 \pm 2.1$ [Γ_{p_0} is the width for decay of ^{9}B*(14.66) to the ground state of ^{8}Be; Γ_{p_1} is that for decay to ^{8}Be*(2.9)]. Assuming Γ_{γ_0} for ^{9}B*(14.66) $= 6.9 \pm 0.5$ eV [the value for the analog state in ^{9}Be: see Table 9.6], $\Gamma_{p_0} < 10$ eV, $\Gamma_{p_1} = 96 \pm 20$ eV (1972AD04). See also (1971AD1C).

Angular distributions have been reported for $E(^3\text{He}) = 1.56$ to 5.27 MeV (1966DI04; n_0) and 3.1 MeV (1970GU08; n_0). (1970GU08) find that a structure in the neutron spectrum which might correspond to ^{9}B*(1.5) is really due to sequential decay of ^{9}Be*(11.8) to ^{8}Be(0). They also report a ^{9}B state with $E_x = 4.8 \pm 0.1$ MeV, $\Gamma = 1.0 \pm 0.2$ MeV. See also (1970LI1Q), (1969BA1Z) and ^{10}B.

5. ^{7}Be(d, p)^{8}Be $\quad Q_m = 16.676 \quad E_b = 16.491$

For $E_d = 0.75$ to 1.70 MeV, resonances in the yields of protons are observed at $E_d = 0.900 \pm 0.025$ MeV (p_0, $p_{2.4}$) and 1.475 ± 0.010 MeV ($p_{2.4}$ only) with $\Gamma_{cm} = 120 \pm 40$ and 71 ± 8 keV, respectively [^{9}B* $=$ 17.19 and 17.64 MeV] (1960KA17). See (1972PA1C) for astrophysical considerations.

6. ^{9}Be(p, n)^{9}B $\quad Q_m = -1.8498$

A high resolution experiment at $E_p = 20$ MeV shows the population of ^{9}B*(0, 2.4) and is consistent with the excitation of ^{9}B*(2.8) [$\Gamma \approx 0.3$ MeV] and ^{9}B*(7.0) [$\Gamma > 1$ MeV]. No other states are excited for $E_x < 7.1$ MeV (1970AN07). (1972AR22) report $E_x = 3.09 \pm 0.10$ MeV. Additional states have been reported by a number of groups: see (1966LA04) for earlier references and (1967SL04, 1970CL01). The width of the ground state is 540 ± 210 eV (1964TE01).

Angular distributions have been measured at $E_p = 3.5$ to 10.9 MeV (1965WA04), 6.8 MeV (1967DR08), 8 to 14 MeV (1960SA03), 18.5 MeV (1964AN1B) and 30.3 and 49.3 MeV (1970CL01). See also (1967BO1D, 1969JU1A, 1969VE02, 1970WI1B, 1971BE46, 1971CA1F, 1972CA1Q, 1973WA28), (1966LA04) and (1966PA1H, 1968TH1H; theor.).

7. ^{9}Be(^{3}He, t)^{9}B $\qquad Q_{\mathrm{m}} = -1.0860$

Angular distributions have been reported at $E(^{3}\mathrm{He}) = 3.0$ to 3.8 MeV (1969OR01; t_0), 5.0 to 9.0 MeV (1967EA01; t_0), 5.7 MeV (1959HI69; t_0), 10 MeV (1967CR04; t_0, $t_{2.4}$), 20 to 27.8 MeV (1969OP1A, 1970OP1B; t_0, $t_{2.4}$) and 25 MeV (1960WE04; t_0, $t_{2.4}$). At $E(^{3}\mathrm{He}) = 39.8$ MeV ^{9}Be(0) is very stongly excited and ^{9}B*(2.4, 14.7) are also observed. There is some indication that other known ^{9}B states are also populated (1969BA06). See also ^{12}C in (1975AJ02) and (1970CA28).

8. ^{9}Be(^{6}Li, ^{6}He)^{9}B $\qquad Q_{\mathrm{m}} = -4.577$

At $E(^{6}\mathrm{Li}) = 30.8$ and 31.8 MeV the ground state of ^{9}B is strongly excited. ^{9}B*(2.4) is also observed (1970CH19, 1971CH1B). A partial angular distribution for the ground state transition is reported at the higher energy by (1971CH1B).

9. ^{9}C(β^{+})^{9}B* $\rightarrow$ ^{9}Be + p $\qquad Q_{\mathrm{m}} = 16.677$

$\rightarrow$ ^{5}Li + α $\qquad Q_{\mathrm{m}} = 14.80$

Several groups of delayed protons are observed indicating the involvement of a number of ^{9}B states: see Table 9.10 (1972ES05). It is not possible to determine ft values since some of the ^{9}B states involved in the ^{9}C decay may decay via $^{5}\mathrm{Li} + \alpha$: see (1972ES05).

10. ^{10}B(γ, n)^{9}B $\qquad Q_{\mathrm{m}} = -8.435$

See ^{10}B.

11. ^{10}B(p, d)^{9}B $\qquad Q_{\mathrm{m}} = -6.211$

At $E_{\mathrm{p}} = 33.6$ MeV (1968KU04, 1970KU1D) and 155.6 MeV (1969BA05) deuteron groups are observed to ^{9}B*(0, 2.4, 7.0, 11.7, 14.7). All have angular distributions characteristic of $l_{\mathrm{n}} = 1$ and therefore odd parity and $J = (\frac{3}{2}, \frac{5}{2}, \frac{7}{2}, \frac{9}{2})$: see Table 9.11. There is some evidence also for the population of ^{9}B*(2.8, 18.4) (1968KU04, 1969BA05). Angular distributions have also been reported at $E_{\mathrm{p}} = 49.5$ MeV (1970SQ01; d_0, $d_{2.4}$, $d_{11.7}$). See also (1968KR02), (1966LA04) and (1969TO1A; theor.).

Table 9.10: Delayed protons following the β^+ decay of ^{9}C [a]

E_p (c.m.) (MeV)	$\Gamma_{c.m.}$ (keV)	Corresponding state in ^{9}B (MeV)	
		if decay is to $^8Be_{g.s.}$	if decay is to ^{8}Be*(2.9)
3.45 ± 0.25	200 ± 100	3.26 ± 0.25 [d]	[c]
(4.2 ± 0.3)	1000 ± 200	4.0 ± 0.3	6.9 ± 0.3
(5.0 ± 0.2)	400 ± 200	4.8 ± 0.2	[c]
6.10 ± 0.10	400 ± 100	5.91 ± 0.10	[c]
9.28 ± 0.24 [b]	1800 ± 200	9.09 ± 0.24	11.99 ± 0.24
12.30 ± 0.10 [b]	450 ± 100	12.11 ± 0.10	[c]

[a] (1972ES05). See also (1965HA09).

[b] Ratio of the intensities $I_{9.28}/I_{12.30} = 1.2 \pm 0.2$.

[c] The relatively narrow width of the proton group does not permit this option.

[d] By analogy with the ^{9}Li decay, this decay may involve a $J^\pi = \frac{1}{2}^-$ analog of ^{9}Be*(2.78). Such a state in ^{9}B has not been reported in any other reaction.

Table 9.11: Levels of ^{9}B from ^{10}B(p, d)^{9}B

(1969BA05) [a]			(1968KU04) [b]			
E_x (MeV)	l_n	F^2_{exp} [c]	E_x (MeV)	Γ_{cm} (MeV)	l_n	J^π [d]
0	1	0.44	0		1	$\frac{3}{2}^-$
2.4 ± 0.1	1	0.60	2.35 ± 0.02		1	$\frac{5}{2}^-$
			(2.8) [g]			
7.1 ± 0.2 [e]	1	0.52	7.1 ± 0.2	1.95 ± 0.2	1	$\frac{7}{2}^-$
11.5 ± 0.2	1	1.12	11.75 ± 0.1 [h]	0.80 ± 0.05	1	$(\frac{7}{2})^-$
14.9 ± 0.3 [f]	1	0.32	14.6 ± 0.2 [g]	1.35 ± 0.2	(1)	$(\frac{5}{2})^-$
(18.4)						

[a] (1969BA05): $E_p = 155.6$ MeV.

[b] (1968KU04, 1970KU1D): $E_p = 33.6$ MeV.

[c] Spectroscopic factor.

[d] J from best fit to theoretical spectroscopic factor.

[e] $\Gamma = 2.4 \pm 0.2$ MeV.

[f] $T = \frac{1}{2}$.

[g] Weak group.

[h] 11.66 ± 0.10 MeV (1970SQ01).

12. ^{10}B(d, t)^{9}B $Q_{\rm m} = -2.178$

$Q_0 = -2.189 \pm 0.010$ (1967SP09).

Angular distributions have been measured at $E_{\rm d} = 11.8$ MeV (1966BA21, 1967FI07; t_0, $t_{2.4}$) [S for ^{9}B*(0, 2.4) $= 0.80$ and 0.64, respectively], 13.5 MeV (1964FU15; t_0) and 28 MeV [(1968GA13; t_0); (1971IN1C; t_0, $t_{2.4}$ (partial)]. See also (1971WA1K, 1972WA1M) and (1966BA1X, 1971BO50; theor.).

13. (a) ^{10}B(^{3}He, α)^{9}B $Q_{\rm m} = 12.143$

(b) ^{10}B(^{3}He, αp)^{8}Be $Q_{\rm m} = 12.328$

Alpha particle spectra show the excitation of ^{9}B*(0, 2.4, 2.8, 11.8): see (1966LA04). Measurements by (1968KR02) determine $E_{\rm x} = 2.361 \pm 0.005$ and 2.788 ± 0.030 MeV, $\Gamma = 81 \pm 5$ and 548 ± 40 keV, respectively [see Table 9.11 in (1966LA04) for other values]. There is some evidence for a state with $E_{\rm x} \approx 1.6$ MeV, $\Gamma \approx 0.7$ MeV, but it is not conclusive, in agreement with the older work [see (1960SP08, 1962BA1C)]. No evidence is found for any narrow levels in ^{9}B with $\Gamma \leq 100$ keV and $4 < E_{\rm x} < 7$ MeV: the upper limit to the intensity of the corresponding α-group is 1% of the intensity of the group to ^{9}B*(2.4) (1968KR02). Angular distributions have been determined at $E(^{3}{\rm He}) = 5.5$ MeV (1966CA02; α_0) and 33.7 MeV (1971SQ03; α_0, $\alpha_{2.4}$, $\alpha_{11.8}$). DWBA does not seem to give a good description of the transition to ^{9}B*(11.8) (1971SQ03).

In reaction (b) study of the decays of ^{9}B*(2.4, 2.8) shows that ^{9}B*(2.4) decays $< 0.5\%$ by proton emission to ^{8}Be(0) [$\theta^2_{\rm f} < 5.1 \times 10^{-3}$] [it decays to ^{5}Li(0) by α-emission] while the second state, $E_{\rm x} = 2.71 \pm 0.03$ MeV [$\Gamma = 0.71 \pm 0.06$ MeV] decays almost 100% by that channel [$\theta^2_{\rm d} = 0.74$] (1966WI08). (1966WA16) find $\Gamma = 1.1 \pm 0.2$ MeV for ^{9}B*(2.8) and suggest $J = \frac{1}{2}$ for this state [see, however, (1960SP08)]. No other excited states of ^{9}B with $3.5 < E_{\rm x} < 9.5$ MeV decay by proton emission to ^{8}Be(0) (1968KR02). See also (1970BE1F, 1971FO1E) and (1968TA1M; theor.). See also ^{8}Be, and ^{13}N in (1976AJ04).

14. ^{10}B(^{16}O, ^{17}O)^{9}B $Q_{\rm m} = -4.293$

See (1968OK06).

15. ^{11}B(p, t)^{9}B $Q_{\rm m} = -11.409$

At $E_{\rm p} = 45$ MeV angular distributions have been obtained for the triton groups to ^{9}B*(0, 2.36, 12.06, 14.01, 14.66, 16.02). In addition the spectra show some indication of the groups corresponding to ^{9}B*(7.0, 17.19, 17.63). New $T = \frac{1}{2}$ states are reported at $E_{\rm x} = 15.29 \pm 0.04$ and 15.58 ± 0.04 MeV (1971HA10). See also (1971KA04; theor.) and reaction 41 in ^{9}Be.

16. (a) ^{12}C(p, α)^{9}B $\quad Q_{\rm m} = -7.551$

(b) ^{12}C(p, p)^{4}He^{4}He^{4}He $\quad Q_{\rm m} = -7.2748$

Angular distributions of ground state α-particles have been measured at $E_{\rm p} = 14.0$ to 17.2 MeV (1969KO1D), 19.1 to 44 MeV (1967AC01, 1969GA03, 1970GU06, 1971GU23), 38.5, 41.6 and 44.5 MeV [also partial back-angle measurements at $E_{\rm p} = 30.5$, 32.0, 33.0, 34.5 and 39.5 MeV] (1966CR05, 1967CR05, 1968LI1E) and at $E_{\rm p} = 54.1$ MeV (1972MA21). Alpha groups are also observed to ^{9}B*(2.3, 2.9 ± 0.2, 6.97 ± 0.06): see (1955RE16, 1962MA40, 1964BA29, 1972MA21). See also (1966LA04). The angular distribution to ^{9}B*(6.97) is consistent with $J^{\pi} = \frac{7}{2}^{-}$; $\Gamma \approx 2$ MeV (1972MA21: $E_{\rm p} = 54.1$ MeV). For reaction (b) see (1972MA62) and (1966LA04). See also ^{12}C in (1975AJ02) and ^{13}N in (1976AJ04).

17. ^{12}C(^{3}He, ^{6}Li)^{9}B $\quad Q_{\rm m} = -11.571$

Angular distributions of ^{6}Li ions have been obtained at $E(^{3}{\rm He}) = 28$ MeV (1971KL1E), 30.0 and 40.7 MeV (1972OH01) and 35.7 MeV (1969ZE1A, 1970FO1D).

^{9}C
(Figs. 17 and 18)

GENERAL: (See also (1966LA04).)

Model calculations: (1966BA26).

Other topics: (1966BA26, 1966MC1C, 1972AN05, 1972CA37, 1973LA19).

Ground state properties, including theoretical mass predictions: (1965GO1D, 1966BA26, 1966GO1B, 1966KE16, 1969GA1P, 1969JA1M, 1972CE1A, 1973HA77).

Mass of ^{9}C: From the threshold energy of ^{7}Be(^{3}He, n)^{9}C (1971MO01) the atomic mass excess of ^{9}C is 28.908 ± 0.004 MeV. This value is in good agreement with that obtained from the Q-value of ^{12}C(^{3}He, ^{6}He)^{9}C [28.912 ± 0.009 MeV]. See also (1967BA59).

1. ^{9}C(β^{+})^{9}B $\rightarrow$ ^{8}Be + p $\quad Q_{\rm m} = 16.677$
   $\rightarrow$ ^{5}Li + α $\quad Q_{\rm m} = 14.80$

The half-life of ^{9}C is 126.5 ± 1.0 msec (1971HA05, 1972ES05), 126.5 ± 2 msec (1971MO01). Several groups of delayed protons are observed indicating the involvement of a number of ^{9}B states: see Table 9.10 (1972ES05). See also (1965HA09). See also (1966BA26, 1971WI18, 1972WI28, 1972WI1C, 1973TO14; theor.).

2. ^{7}Be(^{3}He, n)^{9}C $\quad Q_{\rm m} = -6.278$

$E_{\rm thresh.} = 8980 \pm 5$ keV (1971MO01). See also (1967BA59).

3. ^{10}B(p, 2n)^{9}C $\quad Q_{\rm m} = -25.710$

See (1965RO1G).

4. ^{11}B(p, 3n)^{9}C $\quad Q_{\rm m} = -37.166$

See (1965HA09).

5. ^{12}C(p, d2n)^{9}C $\quad Q_{\rm m} = -50.898$

Table 9.12: Energy levels of ^{9}C

E_x (MeV)	$J^\pi; T$	$\tau_{1/2}$ (msec)	Decay	Reactions
g.s.	$(\frac{3}{2}^-); \frac{3}{2}$	126.5 ± 0.9	β^+	1, 2, 3, 4, 5, 6

See (1965HA09).

6. ^{12}C(^{3}He, ^{6}He)^{9}C $\quad Q_m = -31.574$

$Q_0 = -31.578 \pm 0.008$ MeV (1970TR05, 1970TR1F, 1971TR03). See also (1964CE04).

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(Closed December 31, 1973)

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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