Energy Levels of Light Nuclei
$A = 9$

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Abstract: An evaluation of $A = 5$–10 was published in *Nuclear Physics A*320 (1979), p. 1. This version of $A = 9$ 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.

(References closed 1978)

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^{9}n

(Not illustrated)

See (1977DE08).

^{9}He

(Not illustrated)

^{9}He has not been observed: see (1974AJ01). It is predicted to be particle unstable. Particle instability with respect to ^{8}He + n, ^{7}He + 2n and ^{6}He + 3n implies atomic mass excesses greater than 39.667, 42.253 and 41.808 MeV, respectively. The calculated mass excess of ^{9}He is 43.49 MeV based on the modified form of the mass equation (1975JE02). See also (1974TH01) and (1974IR04, 1975BE31, 1976IR1B; theor.).

^{9}Li

(Figs. 15 and 18)

GENERAL: (See also (1974AJ01).)

Model calculations: (1974IR04, 1976IR1B, 1977JA14).

Special reactions: (1975AB1D, 1975ZE01, 1976AL1F, 1976BE67, 1976BU16, 1977YA1B).

Pion and kaon reactions (See also reaction 3.): (1973CA1C, 1976TR1A, 1977BA1Q, 1977DO06, 1977SH1C).

Other topics: (1970KA1A, 1973TO16, 1974IR04, 1975BE56, 1976IR1B).

Ground state properties: (1975BE31).

$$\mu = 3.4359 \pm 0.0010 \text{ nm (1976COZQ; prelim.)}.$$

Mass of ^{9}Li: The atomic mass excess of ^{9}Li is determined to be 24955.4 ± 2.0 keV from the Q-values of the ^{7}Li(t, p) and ^{10}Be(d, ^{3}He) reactions. This value leads to a cubic coefficient in the IMME for $A = 9$ of $d = 5.8 \pm 1.5$ keV for the ground state; $d = 2.3 \pm 2.9$ keV for the second $T = \frac{3}{2}$ state in $A = 9$ (1975KA18).

1. ^{9}Li(β^{-})^{9}Be $\qquad Q_{\rm m} = 13.607$

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 [a]
g.s.	$\frac{3}{2}^-; \frac{3}{2}$	$\tau_{1/2} = 178.3 \pm 0.4$ msec	β^-	1, 2, 3, 4, 5, 6, 7, 8
2.691 ± 5	$(\frac{1}{2}^-)$		(γ)	2, 3, 7
4.31 ± 20		$\Gamma = 100 \pm 30$		2, 7
5.38 ± 60		600 ± 100		2
6.43 ± 15	$\geq \frac{9}{2}$	40 ± 20		2, 7

[a] See also (1974AJ01).

The half-life of ^{9}Li is 178.3 ± 0.4 msec (1976AL02). Other recent values are 175 ± 1 msec (1973AU1A), 175 ± 1 msec (1974RO31). In (1974AJ01) the adopted value was 176 ± 2 msec based on earlier measurements. ^{9}Li decays to ^{9}Be*(0, 2.43, 2.78): see ^{9}Be and Table 9.7 (1970CH07). $\log ft$ values are listed in Table 9.6: the 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$_{g.s.}$ (1970CH07). Delayed neutrons are observed due to the decay of the two excited states of ^{9}Be involved in the β^- decay: see ^{9}Be. See also (1976FI03), (1973TA30) and (1973KU1D, 1974CH46, 1974KU06, 1975KR14, 1975WI1E, 1976KU07; theor.).

2. ^{7}Li(t, p)^{9}Li $\qquad Q_m = -2.386$

Protons 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) [$\Gamma_{c.m.} = 250 \pm 30, 600 \pm 100, < 100$ keV], 4.31 ± 0.02 and 6.435 ± 0.020 MeV (1978AJ02) [$\Gamma_{c.m.} = 100 \pm 30, 40 \pm 20$ keV]. Angular distributions are reported at $E_t = 11.3$ (1964MI04: t_0), 15 MeV (1971YO04: t_0, t_2, t_4) and at 23 MeV (1978AJ02: t_0, t_1, t_2, t_4). They are consistent with $J^\pi = \frac{3}{2}^-, (\frac{1}{2}^-)$ and $\geq \frac{9}{2}$ for ^{9}Li*(0, 2.69, 6.43) (1978AJ02). See also (1974AJ01). For the mass of ^{9}Li see the "GENERAL" section here (1975KA18). See also (1976HA1M).

3. ^{9}Be(π^-, γ)^{9}Li $\qquad Q_m = 125.960$

The excitation of ^{9}Li*(0, 2.69) is observed: see (1977BA1Q).

4. ^{9}Be(n, p)^{9}Li $\qquad Q_m = -12.825$

See (1977RO01) and (1978NE1A).

5. ^{10}Be(d, ^{3}He)^{9}Li $Q_{\rm m} = -14.143$

See mass of ^{9}Li, the "GENERAL" section here (1975KA18).

6. ^{10}Be(^{11}B, ^{12}C)^{9}Li $Q_{\rm m} = -3.680$

See (1976FI03).

7. ^{11}B(^{6}Li, ^{8}B)^{9}Li $Q_{\rm m} = -25.122$

At $E(^{6}\rm{Li}) = 80$ MeV the angular distribution to ^{9}Li$_{\rm g.s.}$ has been measured. States at $E_{\rm x} = 2.59 \pm 0.10$, 4.36 ± 0.10 and 6.38 ± 0.12 MeV are also populated (1977WE03, 1977WE1B). See also (1974CE1A).

8. ^{18}O(^{7}Li, ^{16}O)^{9}Li $Q_{\rm m} = -6.093$

See (1974AJ01).

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

GENERAL: (See also (1974AJ01).)

Shell model: (1975KU27, 1975SC1K, 1977CA08, 1977JA14, 1978BO31).

α and cluster models: (1974CH19, 1974GR42, 1974PA1B, 1975AB1E, 1975CH28, 1975KR1D, 1975RO1B, 1975SC1K, 1976ZA06, 1977DE1K, 1977HO1F, 1977OK01, 1977SE1D, 1978FO1J, 1978FO1G, 1978HO1E, 1978OK01, 1978OS01).

Collective and deformed models: (1974BO25, 1976BR26, 1977CA08).

Special levels: (1974IR04, 1974KU06, 1975CH28, 1975LI20, 1975WI1E, 1976IR1B, 1976ZA06, 1977CA08, 1977JA14, 1978BO31, 1978FO1G, 1978HO1E, 1978OK01, 1978OK1B).

Electromagnetic transitions: (1974CH46, 1974HA1C, 1974KU06, 1974MU13, 1976KU07, 1977DO06, 1978KI08).

Astrophysical questions: (1973CA1B, 1973SC1C, 1973SC1D, 1973TI1A, 1973TR1B, 1973WE1D, 1974AU1A, 1974BO1J, 1974BO1K, 1974RE1A, 1974RO1G, 1975CH1F, 1975LA1E, 1975ME1E, 1975PR1B, 1976AU1B, 1976AU1C, 1976BO1E, 1976BO1H, 1976BO1J, 1976CO1B, 1976EP1A, 1976FU1B, 1976GI1C, 1976HA1F, 1976PE1A, 1976RA1C, 1976RO1J, 1976RO12, 1976SI1C, 1976SI1D, 1976VI1A, 1977AU1B, 1977BO1F, 1977DR1C, 1977DW1A, 1977GA1C, 1977HA1L, 1977MA1H, 1977PR1D, 1977SC1D, 1977WE1D, 1978AU1C, 1978BY1A, 1978DW1A).

Special reactions: (1975AR14, 1975FE1A, 1975KU01, 1975RA12, 1975RA14, 1975RA21, 1975ZE01, 1976BE1K, 1976BU16, 1976CH28, 1976FR05, 1976HI05, 1976LE1F, 1976MI13, 1976NA11, 1976OS04, 1976RA1C, 1976RO12, 1977AR06, 1977FE1B, 1977GE08, 1977GO07, 1977GR1D, 1977KU1D, 1977PR05, 1977ST34, 1977ST1G, 1977YA1B, 1978BA1J, 1978BI08, 1978DI04, 1978FA1D, 1978GE1C, 1978GR1F, 1978UN01, 1978WE1D).

Muon and neutrino capture and reactions: (1974EN10, 1975CA1H, 1975CH22, 1975FE1B, 1975KN1C, 1976SH1H, 1977CA1E, 1977DO06, 1977MU1A, 1978DE15, 1978LE04).

Pion capture and reactions: (1973AL1A, 1973AR1B, 1973BA1G, 1973GO41, 1973WI1A, 1974AM01, 1974CL04, 1974DI20, 1974GO04, 1974HU14, 1974KA07, 1974MI06, 1974SP1A, 1974ST1G, 1974TA18, 1975BA1L, 1975BA1G, 1975BU1A, 1975ER03, 1975HU1D, 1975NI1B, 1975RO1G, 1975TA1C, 1975VO1D, 1975YA02, 1976AB1B, 1976AL1F, 1976AS1B, 1976BA1P, 1976DO1D, 1976DU1B, 1976ED1A, 1976EN02, 1976HEZU, 1976KI1E, 1976PI1B, 1976RA1F, 1976TR1A, 1977AB09, 1977AL1C, 1977AN1D, 1977AP1A, 1977AR1F, 1977AS1D, 1977BA51, 1977BA1Q, 1977BA2D, 1977BE1V, 1977DE1F, 1977DE1G, 1977DE1H, 1977DE1J, 1977DO06, 1977FY1A, 1977HO1B, 1977MA35, 1977MC1E, 1977PI1C, 1977SC1F, 1977SH1C, 1977SP1B, 1977TE1A, 1978BA1L, 1978BO01, 1978ER1C, 1978GEZX, 1978KI08, 1978MI1D, 1978MO01, 1978OL1A, 1978SE1D, 1978TH1B, 1978ZE01).

Kaon reactions and reactions involving other mesons: (1973GO41, 1975PO1C, 1976AB1B, 1976BO1K, 1976BR1G, 1976KI1E, 1977AN1D, 1977BA27, 1977BE1U, 1977PO1A, 1978AT01, 1978BR1G).

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, 9, 10, 11, 13, 14, 15, 16, 17, 18, 19, 20, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 41, 42, 43, 45, 46, 48, 49, 50, 51, 52, 53, 54, 55, 56
1.680 ± 15	$\frac{1}{2}^+$	200 ± 20	γ, n	3, 9, 10, 11, 14, 18, 19, 20, 22, 24, 25, 32, 37, 43, 45
2.4294 ± 1.3	$\frac{5}{2}^-$	0.77 ± 0.15	γ, n, α	3, 9, 10, 11, 13, 18, 19, 20, 22, 23, 24, 25, 32, 34, 36, 37, 42, 43, 45, 52, 53
2.78 ± 120	$\frac{1}{2}^-$	1080 ± 110	n	3, 9, 13, 52
3.049 ± 9	$\frac{5}{2}^+$	282 ± 11	γ, n	9, 11, 14, 18, 19, 20, 21, 22, 24, 25, 32, 37, 42, 43, 45
4.704 ± 25	$(\frac{3}{2})^+$	743 ± 55	γ, n	3, 9, 18, 20, 21, 22, 24, 35, 43, 52
6.76 ± 60	$\frac{7}{2}^-$	1540 ± 200	γ, n	9, 18, 19, 20, 22, 24, 25, 34
7.94 ± 80		≈ 1000		20
11.283 ± 24		575 ± 50	n	9, 20, 25, 34, 37
11.81 ± 20	$T = \frac{1}{2}$	400 ± 30	γ, n	9, 11, 14, 42, 52
13.79 ± 30	$T = \frac{1}{2}$	590 ± 60	γ, n	9, 11, 18, 42
14.3926 ± 1.8	$\frac{3}{2}^-; \frac{3}{2}$	0.329 ± 0.067	γ, n, α	9, 18, 24, 37, 42
14.4 ± 300		≈ 800		20, 37
15.10 ± 50			γ	11, 18, 42

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

E_x (MeV $\pm$ keV)	$J^\pi; T$	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
15.97 ± 30	$T = \frac{1}{2}$	≈ 300	γ	18, 42
16.671 ± 8		41 ± 4	γ	9, 18, 37
16.976 ± 2	$\frac{1}{2}^-; \frac{3}{2}$	< 0.47	γ, n, p, d	3, 4, 5, 14, 18
17.297 ± 10	$(\frac{5}{2})^-$	200	γ, n, p, d, α	4, 5, 18
17.490 ± 9	$\leq \frac{7}{2}^+$	47	γ, n, p, d, α	4, 5, 6, 18
18.02 ± 50			γ, n	18
18.58 ± 40			γ, n, p, d, α	4, 5, 14, 18
19.20 ± 50		310 ± 80	p, d	5
19.51 ± 50			γ, n	14, 18
(19.9 ± 200)			γ, n	14
(20.47 ± 40)			γ, p, d	5, 14
20.74 ± 30		≈ 1000	γ, n, p, t	1, 14, 18, 20
(21.4 ± 200)			γ, n	14, 18, 20
(22.4 ± 200)		broad	γ, n	14, 18, 20
(23.8 ± 200)			γ, n	14, 35
(27.0 ± 500)		broad	γ, n	14

Other topics: (1973DZ1A, 1974CH19, 1974IR04, 1974KU06, 1974MU13, 1975CH1E, 1975CH28, 1975KU27, 1975LI20, 1975SC1M, 1976BR26, 1976DA1D, 1976DA1E, 1976ES1A, 1976GA1C, 1976IR1B, 1976KU07, 1976MA04, 1977KO1K, 1977PO1A, 1978OS01).

Ground state properties: (1974DE1E, 1974EN10, 1974KU06, 1974MU13, 1974PA1B, 1974SHYR, 1975BE31, 1975CH28, 1976BR26, 1976FU06, 1977BA2E, 1977MA35, 1977OK01, 1978AN07).

$\mu = -1.1778 \pm 0.0009$ nm (1976WE17);
$Q = +53 \pm 3$ mb (1978SHZM).

The neutron spectroscopic factor of ^{9}Be is 0.42 ± 0.04 (1977LA11).

1. (a) ^{6}Li(t, n)^{8}Be $\quad Q_m = 16.0240 \quad E_b = 17.6892$
   (b) ^{6}Li(t, p)^{8}Li $\quad Q_m = 0.801$
   (c) ^{6}Li(t, d)^{7}Li $\quad Q_m = 0.993$

(d) ^{6}Li(t, α)^{5}He $Q_{\rm m} = 15.22$

(e) ^{6}Li(t, n)^{4}He^{4}He $Q_{\rm m} = 16.1159$

The $0°$ differential cross section for reaction (a) increases monotonically between $E_{\rm t} = 0.10$ and 2.4 MeV (1960SE12, 1961VA43, 1962SE1A) except for a resonance at $E_{\rm t} = 1.875$ MeV (^{9}Be* $= 18.938$). The excitation function for ^{8}Li (reaction (b)) increases monotonically for $E_{\rm t} = 0.275$ to 1.000 MeV (1972CI05, 1972CI1C). In the range $E_{\rm t} = 2.0$ to 6.8 MeV, a broad peak [$\Gamma \approx 1.3$ MeV] is observed at $E_{\rm t} = 4.57$ MeV [$E_{\rm x} = 20.73$ MeV] (1973AB10). For reaction (c), (d) and (e) see (1966LA04). See also ^{8}Li and (1977SU1A).

2. ^{6}Li(α, p)^{9}Be $Q_{\rm m} = -2.1248$

Angular distributions of $\rm p_0$ have been measured at $E_\alpha = 10.2$ to 14.7 MeV and at 30 MeV: see (1974AJ01). In a study of the inverse reaction [^{9}Be(p, α)^{6}Li] at 45 MeV, the spectroscopic factors for (^{6}Li + t) and (^{5}He + α) cluster structures in ^{9}Be are calculated to be 0.003 and 0.102, respectively (1972DE01, 1972DE02).

3. ^{7}Li(d, γ)^{9}Be $Q_{\rm m} = 16.6960$

For $E_{\rm d} = 0.1$ to 1.1 MeV, a resonance in the yield of capture γ-rays is observed at $E_{\rm d} = 362 \pm 3$ keV (1965WO01), 361 ± 2 keV (1965IM01), corresponding to ^{9}Be*(16.976) with $\Gamma_{\rm c.m.} < 0.47$ 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 / 11.8 ± 0.6 / 3.3 ± 0.7 / 13.3 ± 4.2 / $-$ / 12.9 ± 1.3 (1971SC19). The $E_{\rm x}$ 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).

4. (a) ^{7}Li(d, n)^{8}Be $Q_{\rm m} = 15.031$ $E_{\rm b} = 16.6960$

(b) ^{7}Li(d, α)^{5}He $Q_{\rm m} = 14.23$

(c) ^{7}Li(d, n)^{4}He^{4}He $Q_{\rm m} = 15.123$

The yield of neutrons has been measured for $E_{\rm d} = 0.2$ to 19 MeV [see (1974AJ01)] and for 0.4 to 3.0 MeV (1975MC02; $\sigma_{\rm t}$), 2.5 MeV (1974JO1C) and 14.8, 18 and 23 MeV (1977LO10). Resonances in the yield of neutrons are reported at $E_{\rm d} = 0.36$, 0.68, 0.98 and (1.8) MeV: see Table 9.3. Polarization measurements have been reported at $E_{\rm d} = 0.64$ MeV and at 2.5 to 3.7 MeV: see (1974AJ01). See also (1975SE07, 1977SE09).

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

^{7}Li(d, n)^{8}Be	^{7}Li(d, α)^{5}He	^{7}Li(d, p)^{8}Li		E_x	J^π
E_{res} (keV)	E_{res} (keV)	E_{res} (keV)	Γ_{lab} (keV)	(MeV)	
360 [a,b]		360 ± 3 [a]	< 2	16.976	
680 [c]	750 [d]	773 ± 10 [f]	250	17.297	$(\frac{3}{2}, \frac{5}{2})^+$ [i]
980 [c]	1000 [d]	1025 ± 10 [f]	60	17.492	$(\frac{3}{2}, \frac{5}{2}, \frac{7}{2})^-$ [i]
(1800) [c]	2500 [e]	2000 [g]		(18.5)	
		2375 ± 50 [g,h]		18.54	
		3220 ± 50 [h]	400 ± 100	19.20	
		≈ 4800 [h]		(20.4)	

[a] In ^{7}Li(d, γ), $E_{res} = 361 \pm 2$ keV (1965IM01, 1965WO01); $\Gamma_{n_0}/\Gamma_\gamma \approx 1.5$, $\Gamma_{d_0}/\Gamma_\gamma < 400$, $\Gamma_{\alpha_0}/\Gamma_\gamma < 20$ (1965IM01) for ^{9}Be*(16.98).
[b] (1965IM01).
[c] (1952BA64, 1957SL01).
[d] (1963PA04, 1969DE31, 1971FR04).
[e] (1963PA04): broad structure.
[f] (1976SC14). See also Table 9.3 in (1974AJ01).
[g] (1956BE1A).
[h] (1973AB10).
[i] (1973RO42). See, however, (1972DE44).

The yield of α-particles has been studied for $E_d = 0.2$ to 3.0 MeV [see (1974AJ01)] and at $E_d = 0.60$ to 1.25 MeV (1973RO42: α_1). Resonances are observed at $E_d = 0.75$, 1.00 and 2.5 MeV: see Table 9.3.

At $E_d = 1.0$ MeV reaction (c) 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): $J = \frac{3}{2}$ is suggested (1973HE26). See also (1975DA15, 1978SP03). See also ^{5}He, ^{8}Be, (1975FO19; astrophysics) and (1974JO1C, 1975GO38, 1977GR1F, 1977LO10, 1977SA28; applications).

5. ^{7}Li(d, p)^{8}Li $\qquad Q_m = -0.192 \qquad E_b = 16.6960$

The yield of p_0 has been measured for $E_d = 0.29$ to 0.78 MeV and the ^{8}Li yield for $E_d = 0.4$ to 7.0 MeV [see (1974AJ01)] and from threshold to 3.6 MeV (1974MCZS, 1975MC02: σ_t; also cross sections for p_0 and p_1, from 0.5 MeV). The yield of ^{8}Li has also been measured for $E_d = 0.61$ to 1.95 MeV (1976SC14): resonances are displayed in Table 9.3. The total cross section at the $E_d = 0.77$ MeV resonance is 181 ± 8 mb (1976SC14). For earlier values see (1974AJ01).

The cross section at the 0.77 MeV resonance serves as normalization for the ^{7}Be(p, γ)^{8}B data and to calculations of the S-factor, of interest in relation to the solar neutrino problem. See also (1976HA1J).

6. ^{7}Li(d, d)^{7}Li $E_{\rm b} = 16.6960$

The elastic scattering [$E_{\rm d} = 0.4$ 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)]. The elastic scattering has also been studied for $E_{\rm d} = 1.0$ to 2.6 MeV (1974LO10) and $E_{\rm d} = 10.0$ to 12.0 MeV (1971BI11). See also ^{7}Li.

7. (a) ^{7}Li(d, t)^{6}Li $Q_{\rm m} = -0.993$ $E_{\rm b} = 16.6960$
(b) ^{7}Li(d, ^{3}He)^{6}He $Q_{\rm m} = -4.482$

The cross section for reaction (a) rises steeply 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 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.

8. ^{7}Li(t, n)^{9}Be $Q_{\rm m} = 10.4387$

See (1974AJ01) and ^{10}Be.

9. (a) ^{7}Li(^{3}He, p)^{9}Be $Q_{\rm m} = 11.2025$
(b) ^{7}Li(^{3}He, np)^{8}Be $Q_{\rm m} = 9.537$

Observed proton groups are listed in Table 9.4. The parameters for the particle and γ-decay of observed states are displayed in Table 9.5, and in Table 9.6 (1976MC10). Angular distributions have been reported in the range $E(^{3}{\rm He}) = 0.9$ to 10 MeV [see (1974AJ01)], at 1.0 to 2.5 MeV (1975BO55: p_0, p_2) and at 14 MeV (1976IR02: p_0). See also ^{10}B and (1973WE15, 1975ST16; theor.).

10. ^{7}Li(α, d)^{9}Be $Q_{\rm m} = -7.1507$

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

E_x (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Refs.
1.64		(1968CO07)
2.4292 ± 1.7	< 8	(1968KR02)
2.9 ± 250	1000 ± 250 [e]	(1965LY01, 1971AD01)
3.076 ± 15 [b]	289 ± 22	(1968KR02)
4.704 ± 25 [c]	743 ± 55	(1968KR02)
6.7 ± 100	2000 ± 200	(1968CO07, 1968CO08)
11.29 ± 30	620 ± 70	(1968CO07)
11.81 ± 20	400 ± 30	(1968CO07)
13.78 ± 30	590 ± 60	(1968CO07)
14.396 ± 5 [d]	< 5 [d]	(1965LY01, 1971AD01)
16.671 ± 8	41 ± 4	(1968CO07)

[a] See also Table 9.4 in (1974AJ01).
[b] See also (1968CO07).
[c] See also (1968CO07, 1968CO08).
[d] See also Table 9.6.
[e] From γ-decay of ^{9}Be*(14.39).

At $E_\alpha = 30$ MeV d_0, d_1 and d_2 angular distributions have been measured (1972ME07). See also (1976LE1K).

11. ^{7}Li(^{6}Li, α)^{9}Be $\qquad Q_m = 15.223$

Angular distributions of the α_0 group have been measured at $E(^7\text{Li}) = 3.78$ to 5.95 MeV (1967KI03). See also (1974AJ01).

12. ^{7}Li(^{11}B, ^{8}Be)^{9}Be $\qquad Q_m = 7.286$

Not reported: see (1970LK1A; theor.).

13. ^{9}Li(β^-)^{9}Be $\qquad Q_m = 13.607$

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		2.1 ± 0.6	(1966CH20)
		6.4 ± 1.2 [c]			(1970CH07)
2.78	1	mainly		0.48 ± 0.06	(1970CH07)
3.05	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)
14.39 [b]					

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

[b] See Table 9.6.

[c] (1978CH07) report $(11 \pm 2)\%$.

^{9}Li decays by β^- emission with $\tau_{1/2} = 178.3 \pm 0.4$ msec to ^{9}Be*(0, 2.43, 2.78): see ^{9}Li, reaction 1, 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 $(6.4 \pm 1.2)\%$. ^{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 nature of the ^{9}Li decay, and the large value of $\theta_p^2[0.48 \pm 0.06]$ 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).

14. (a) ^{9}Be(γ, n)^{8}Be $\quad Q_m = -1.6652$
    (b) ^{9}Be(γ, α)^{5}He $\quad Q_m = -2.47$
    (c) ^{9}Be(γ, n)^{4}He^{4}He $\quad Q_m = -1.5733$
    (d) ^{9}Be(γ, 2n)^{7}Be $\quad Q_m = -20.565$

Table 9.6: Parameters [a] of the first $T = \frac{3}{2}$ states in ^{9}Be and ^{9}B, $J^{\pi} = \frac{3}{2}^{-}$

^{9}Be			^{9}B		
E_x (MeV)	14.3926 ± 0.0018	(1974KA15)		14.6550 ± 0.0025	(1974KA15)
Γ_{γ_0} (eV)	6.9 ± 0.5	(1973BE19)		(6.9 ± 0.5) [b]	
Γ (eV)	329 ± 67	(1971AD01, 1973BE19)		260^{+90}_{-120}	(1971AD01, 1973BE19)
				290 ± 93	(1976MC10) [c]
				275 ± 93	(1976MC10)
$\Gamma_{\gamma_1}/\Gamma_{\gamma_0}$	1.19 ± 0.16	(1971AD01)			
$\Gamma_{\gamma_2}/\Gamma_{\gamma_1}$	0.30 ± 0.04	(1971AD01)			[d]
Γ_{n_0}/Γ	0.028 ± 0.021	(1976MC10)	Γ_{p_0}/Γ	0.11 ± 0.04	(1976MC10)
Γ_{n_1}/Γ	0.50 ± 0.11	(1976MC10)	Γ_{p_1}/Γ	0.33 ± 0.09	(1976MC10)
Γ_{n_0} (eV)	9 ± 8	(1976MC10) [e]	Γ_{p_0} (eV)	30 ± 17	(1976MC10)
Γ_{n_1} (eV)	141 ± 34	(1972AD04, 1973BE19)	Γ_{p_1} (eV)	96 ± 16	(1972AD04, 1973BE19)
	156 ± 47	(1976MC10)		91 ± 38	(1976MC10)
	147 ± 28	mean		95 ± 15	mean
$\Gamma_{n_1}/\Gamma_{n_0}$	18 ± 14	(1976MC10)	$\Gamma_{p_1}/\Gamma_{p_0}$	3.2 ± 1.9	(1976MC10)
$\gamma^2_{n_1}/\gamma^2_{n_0}$	22 ± 17	(1976MC10)	$\gamma^2_{p_1}/\gamma^2_{p_0}$	3.7 ± 2.2	(1976MC10)
$\Gamma_{\alpha_0}/\Gamma_{\gamma_0}$	31.2 ± 9.8	(1972AD04, 1973BE19)			

[a] See Table 1 in (1976MC10) and Table 9.6 in (1974AJ01).
[b] Assumed identical to ^{9}Be.
[c] Calculated from $\Gamma_{p_1}/\Gamma_{\gamma_0}$, Γ_{p_1}/Γ and Γ_{γ_0}.
[d] Similar to branching ratios in ^{9}Be (1971AD01): Γ_{γ_1} is transition to ^{9}Be*(2.4) or ^{9}B*(2.4); Γ_{γ_2} is transition to ^{9}Be*(2.9) or ^{9}B*(2.8).
[e] See also (1978MC04; theor.).

Table 9.7: Branching parameters in ^{9}Li β-decay (1970CH07)

E_x in ^{9}Be (MeV)	$J^{\pi}; T$	Branching ratio (%)	log ft [b]
0	$\frac{3}{2}^{-}; \frac{1}{2}$	$65.0^{+2.7}_{-2.4}$	$5.20^{+0.01}_{-0.02}$
2.43	$\frac{5}{2}^{-}; \frac{1}{2}$	$32.0^{+2.7}_{-3.7}$	$5.10^{+0.04}_{-0.05}$
2.78 ± 0.12 [a]	$\frac{1}{2}^{-}; \frac{1}{2}$	$3.0^{+2.7}_{-0.3}$	$6.06^{+0.05}_{-0.28}$

[a] $\Gamma_{\text{c.m.}} = 1.10 \pm 0.12$ MeV; $\theta^2_p = 0.48 \pm 0.06$ (1970CH07).
[b] M. J. Martin, Nucl. Data Project, private communication.

The photoneutron cross section has been measured from threshold to 320 MeV: see Table 9.6 in (1966LA04) and (1974KN08, 1975KN03: 17 to 37 MeV; monoenergetic γ), (1973AN29, 1975HU03, 1977BU02, 1978BU01). A sharp peak occurs 6 keV above threshold (1967BE49) [but see discussion in (1968BA1C)] with $\sigma_{\rm max} = 1.6$ mb. The cross section then decreases slowly to 1.2 mb at $E_\gamma = 40$ keV (1967BE49). From bremsstrahlung studies, peaks in the (γ, Tn) cross section are observed corresponding to $E_{\rm x} = 1.80$ and 3.03 MeV (1975HU03) [see both (1973AN29, 1975HU03) for additional structures]. At higher energies, using monoenergetic photons, (1975KN03) [who also report (γ, n) + (γ, pn) and (γ, 2n)] find the (γ, Tn) cross section to be relatively smooth from $E_\gamma = 17$ to 37 MeV with weak structures which correspond to $E_{\rm x} = 17.1$, 18.8, 19.9, 21.4, 22.4, 23.8 [± 0.2] MeV and 27 ± 0.5 MeV (broad). See also (1976BE1H).

In the range $E_\gamma = 18$ to 26 MeV the integrated (γ, n_0) cross section is < 0.1 MeV $\cdot$ mb, that for (γ, n_1) $= 2.4 \pm 0.4$ MeV $\cdot$ mb (1977BU02) and the combined integrated cross section for (γ, n) to ^{8}Be*(16.6) and (γ, α_0) to ^{5}He$_{\rm g.s.}$ is 13.1 ± 2 MeV $\cdot$ mb (1978BU01).

The total absorption cross section has been measured for $E_\gamma = 10$ to 210 MeV: it rises to ≈ 5 mb at ≈ 21 MeV, decreases to about 0 at 160 MeV and then increases to ≈ 1.5 mb at 210 MeV (1974AH03, 1975AH06). (1969DO09) report an integrated cross section of 156 ± 15 MeV $\cdot$ 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). The absorption coefficient of 6.418 MeV γ-rays is reported by (1975MO27). Double pair production by 6.6 MeV γ-rays has been observed by (1976RO1N): $\sigma_{\pi\pi}/\sigma_\pi = (1.8 \pm 0.6) \times 10^{-5}$ [average of values from interaction with several different nuclei]. See also (1973VE12, 1975SC05), (1974BU1A, 1975AB1F, 1975BR1F, 1977DA1B), (1975FO19; astrophysics) and (1976KH1C, 1978OC1B, 1978OK1B; theor.).

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

(b) ^{9}Be(γ, np)^{7}Li $\quad Q_{\rm m} = -18.921$

The yield shows structure in the energy region corresponding to the ^{9}Be levels at $17 - 19$ MeV (1962CL06) followed by the giant resonance 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 $18.2 < E_{\rm x} < 32.2$ 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 (1974AJ01) and (1974GO04). See also (1974DO07, 1975MA1K, 1978DO02) and (1975AN1H; theor.).

16. (a) ^{9}Be(γ, d)^{7}Li $\quad Q_{\rm m} = -16.6960$

(b) ^{9}Be(γ, t)^{6}Li $\quad Q_{\rm m} = -17.6892$

The integrated cross sections are reported to be 1.0 ± 0.5 MeV $\cdot$ mb ($E_\gamma = 21 \rightarrow 33$ MeV) for reaction (a) to ^{7}Li*$(0 + 0.4)$ and 0.6 ± 0.3 MeV $\cdot$ 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 $\cdot$ 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 (1974AJ01).

17. ^{9}Be(γ, γ)^{9}Be

See (1977CR1C) and (1974AJ01).

18. (a) ^{9}Be(e, e)^{9}Be

(b) ^{9}Be(e, en)^{8}Be	$Q_{\rm m} = -1.6652$
(c) ^{9}Be(e, ep)^{8}Li	$Q_{\rm m} = -16.888$
(d) ^{9}Be(e, eα)^{5}He	$Q_{\rm m} = -2.47$
(e) ^{9}Be(e, eπ^+)^{9}Li	$Q_{\rm m} = -153.174$

$\langle r^2 \rangle^{1/2} = 2.46 \pm 0.11$ 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 private communication to J.C. Bergstrom);

$\langle r^2 \rangle^{1/2}_{\rm M} = 3.2 \pm 0.3$ fm; $\Omega = 6 \pm 2$ $\mu_{\rm N} \cdot$ fm^2 [this value of the magnetic octupole moment implies a deformation of the average nuclear potential] (1975LA23; see also for calculations of (b)).

The elastic scattering of electrons has been studied for $E_{\rm e}$ up to 700 MeV: see (1974AJ01). Magnetic elastic scattering gives indications of both M1 and M3 contributions (1965GR18, 1966RA29). See also (1973FE13).

Inelastic scattering populates a number of levels: Table 9.8 displays the parameters of the states. See also (1974TI05, 1975DI05). Electron bremsstrahlung has been measured at $E_{\rm e} = 1.0$ and 2.0 MeV by (1968RE11). For reaction (b) see (1974AJ01). At $E_{\rm e} = 700$ MeV the proton separation spectra are similar to those observed in (p, 2p) except for an upward shift in the excitation (1978NA05). See also (1977BE1Q, 1977TU1C: $E_{\rm e} = 500$ MeV; observe a peak at $E_{\rm x} \approx 25$ MeV), (1973KU19: 1.184 GeV) and (1974AJ01). For reaction (d) see (1975GE12). For reaction (e) see (1977SH1C). See also (1974DE1E, 1975FA1A) and (1973GA19, 1973KE1B, 1974BE10, 1974KU06, 1975AB1E, 1976DU05, 1977KU12, 1977OK01, 1977OK1A, 1978OK01; theor.).

19. (a) ^{9}Be(n, n)^{9}Be

Table 9.8: Levels of ^{9}Be from ^{9}Be(e, e$'$)^{9}Be* [a]

E_x in ^{9}Be (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Transition	J^π	$\Gamma_{\gamma 0}$ (eV)	Refs.
1.78 ± 30 [b]	150 ± 50	E1	$\frac{1}{2}^+$	0.30 ± 0.12	(1968CL08)
2.44 ± 20 [c]	< 30	M1	$\frac{5}{2}^-$	0.089 ± 0.010	(1968CL08)
		E2		$(1.89 \pm 0.14) \times 10^{-3}$ [d]	(1968CL08)
3.04 ± 20	450 ± 150	E1 [e]	$\frac{5}{2}^+$ [e]	0.30 ± 0.25 [n]	(1968CL08, 1975FA1A)
4.7 ± 200	700 ± 300	E(1)		2.4 ± 1.2 [f]	(1968CL08)
6.4 ± 100	2000 ± 500	E2	$\frac{7}{2}^-$	0.109 ± 0.005	(1963NG01, 1965NG1A)
	1100 ± 300			0.082 ± 0.035	(1968CL08)
[g]					
13.84 ± 50 [h]					(1973BE19)
14.388 ± 15	< 70	M1 [i]	$\frac{3}{2}^-$	6.9 ± 0.5 [j]	(1973BE19)
15.10 ± 50 [h]					(1973BE19)
15.97 ± 30 [h]	≈ 300	M1		3.7 ± 0.8 [f]	(1973BE19)
16.631 ± 15	< 70	M2 [k]	$\leq \frac{7}{2}^+$	0.26 ± 0.02 [f]	(1973BE19)
		M1	$\leq \frac{5}{2}^-$	2.0 ± 0.5 [f]	(1973BE19)
16.961 ± 15	< 70	M1	$\frac{1}{2}^-$	11.5 ± 1.4 [l]	(1973BE19)
17.28		M1	$\leq \frac{5}{2}^-$	7.3 ± 1.3 [f]	(1973BE19)
17.480 ± 20	≈ 100	M2 [i,k]	$\leq \frac{7}{2}^+$	0.40 ± 0.03 [f]	(1973BE19)
18.02 ± 50 [h]					(1973BE19)
18.62 ± 50 [h]					(1973BE19)
19.51 ± 50 [h]					(1973BE19)
20.76 ± 50 [h]					(1973BE19)
[m]					

[a] See also Table 9.8 in (1974AJ01).
[b] $E_x = 1.79 \pm 0.06$ (1973SL02).
[c] See also (1975FA1A).
[d] $B(\text{C2}, \omega)\uparrow = 45.7 \pm 3.5\ e^2 \cdot \text{fm}^4$. Form factor measured for $E_e = 60.7$ to 120.0 MeV (1974EN01).
[e] Assumed.
[f] $g\Gamma_{\gamma 0}$, where $g = (2J_f + 1)/(2J_i + 1)$.
[g] For additional states reported by (1968VA05) see Table 9.8 in (1974AJ01) and footnote [h] in that table.
[h] Weak transition.
[i] See also (1974NA25).
[j] Best value, calculated by (1973BE19): see footnote [f] in Table 9.8 in (1974AJ01).
[k] Or pure spin-flip E1.
[l] See also footnote [j] in (1974AJ01) and (1975FA1A).
[m] 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).
[n] The group reported by (1968CL08) may consist of two unresolved states, the second one reached by an M1 transition [$J^\pi = (\frac{1}{2})^-$] with $\Gamma_{\gamma_0} = 0.18 \pm 0.09$ eV. I am indebted to Dr. L.W. Fagg for his help in understanding this point.

(b) ^{9}Be(n, 2n)^{8}Be $\qquad Q_m = -1.6652$

(c) ^{9}Be(n, nd)^{7}Li $\qquad Q_m = -16.6960$

Population of ^{9}Be*(0, 1.7, 2.4, 3.1) and possibly ^{9}Be*(6.8) has been reported in this reaction: see (1974AJ01). For the neutron decay of these states see Table 9.5. Angular distributions have been reported at $E_n = 14$ MeV [see (1974AJ01)], at 5.9, 10.1 and 14.2 MeV (1977DR09: n_0, $n_{1+2+3+4}$), and 14.1 MeV (1974HY01: n_0, n_2). See also (1974HO1E, 1975HO1F, 1976BI1B). For reactions (a) and (b) see also ^{10}Be. For reaction (c) see (1978RI02). See also (1976MC1E) and (1978BY1B, 1978BY1C; theor.).

20. ^{9}Be(p, p)^{9}Be

Elastic and inelastic scattering angular distributions have been studied at many energies for $E_p = 5$ to 1000 MeV [see (1974AJ01)] and (1974YA1C: p_0(5.0, 6.0 MeV), p_1(5.2, 6.0 MeV), p_2(4.2 $\rightarrow$ 6.0 MeV)), (1977CO1G: p_0(35.2 MeV) and (1976AL1G: p_0; 1 GeV). The elastic angular distributions show pronounced diffraction maxima characteristic of the optical model. See (1973MO01) for a discussion of optical model parameters. (1973VO02), in a coupled channels analysis, find that a quadrupole-deformed optical model potential with a deformation parameter $\beta = 1.1$ provides an improved description of the elastic data and a good fit to the p_2 data.

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). The population of ^{9}Be*(1.7) has been studied for $E_p = 4.2$ to 5.5 MeV: it is consistent with a scattering length of about -20 fm between a neutron and ^{8}Be. An anomaly at $E_p = 5.1$ MeV is attributed to FSI between n, p and ^{8}Be (1974YA05).

The weighted mean of the values of E_x listed in (1974AJ01) is 2432 ± 3 keV. ^{9}Be*(3.1) has a width 250 ± 50 keV (1960SP08), $J^\pi = \frac{3}{2}^+, \frac{5}{2}^+$, $E_x = 3.03 \pm 0.03$ MeV (1956BO18), 3.04 ± 0.05 MeV (1960SP08). 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] (1965HA17). (1965JA1A) reports for ^{9}Be*(2.4, 6.8) $B(\text{E2}\uparrow) = 49 \pm 6$ and 24 ± 4 fm^4 and $\Gamma(\text{E2}\downarrow) = 0.0025$ and 0.10 eV, respectively. The strong population of ^{9}Be*(2.4, 6.8) is consistent 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 also (1966LA04).

(1974BI14) have studied the elastic scattering at $E_p = 25$ MeV: a non-zero D (depolarization) is reported; its existence constitutes evidence of a nucleon-nucleus spin-spin interaction. On the other hand (1976MOZF: $E_{\bar{p}} = 32$ MeV) find no evidence for a non-zero value of D in the transition to ^{9}Be*(2.4). See also (1977KI04, 1978FR1D), (1974LO1B), (1973WE15, 1974GU13, 1974GU1D, 1974JA1F, 1978BY1B, 1978BY1C, 1978WO13; theor.) and ^{10}B.

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

(b) ^{9}Be(p, pd)^{7}Li $Q_m = -16.6960$

(c) ^{9}Be(p, pα)^{5}He $Q_m = -2.47$

(d) ^{9}Be(p, pn)^{8}Be $Q_m = -1.6652$

(e) ^{9}Be(p, p^{3}He)^{6}He $Q_m = -21.177$

(f) ^{9}Be(p, d^{3}He)^{5}He $Q_m = -20.82$

The summed proton spectrum (reaction (a)) shows two peaks with $Q = -16.4 \pm 0.3$ and -25.4 ± 0.5 MeV, corresponding to removal of a p-proton and an s-proton respectively, and a third peak of uncertain assignment (perhaps due to unresolved states) with $Q = -32.3 \pm 0.6$ MeV (1966TY01: $E_p = 460$ MeV). See also ^{8}Li and (1973MA67; theor.). For reaction (b) see (1974AJ01). Quasi-free scattering of the incident protons by zero-momentum α-particle clusters is consistent with the data obtained at $E_p = 26.0$, 35.0, 46.8 and 57 MeV (1968RO19, 1972QU01). At $E_p = 100$ MeV (1977CO07, 1977RO02) find $\langle S_\alpha \rangle = 0.45 \pm 0.02$ using DWIA analysis: this value is consistent with that predicted by a simple LS coupling shell model calculation. See also (1975RO1B, 1978CH1H) and (1975SA01; theor.).

At $E_p = 12.7$ MeV, ^{9}Be*(3.05) is strongly populated and ^{9}Be*(4.70) is also observed in reaction (d) (1977JE01). See also Table 9.5 (1978CH07), ^{8}Be (1977WA05; $E_p = 45$ and 47 MeV), (1974MI05, 1974YA05) and (1974AV02; theor.). See also (1974AJ01). In reaction (f), at $E_p = 100$ MeV, (1977CO07) find $\langle S_\alpha \rangle = 0.47 \pm 0.04$.

22. ^{9}Be(d, d)^{9}Be

Elastic angular distributions have been studied in the range 1.1 to 410 MeV [see (1974AJ01)] and at $E_d = 1.0$ to 2.2 MeV (1972LO05), $E_{\vec{d}} = 15$ MeV (1976DA15; also d_2, d_4) and $E_d = 27.98$ MeV (1977OO01). Angular distributions to ^{9}Be*(2.4) have also been reported at $E_d = 11.8$, 14.35 and 15.8 MeV: see (1974AJ01).

Inelastic groups have been reported to ^{9}Be*(1.7, 2.4, 3.1, 4.7, 6.8): see (1966LA04). (1968KR02) report $E_x = 2431.9 \pm 7.0$ keV and 3040 ± 15 keV ($\Gamma = 294 \pm 20$ keV). See also (1978LO1C), (1977TE1A) and (1974BO39, 1974CH58, 1974GU1D, 1977DM1A; theor.).

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

(b) ^{9}Be(t, nt)^{8}Be $Q_m = -1.6652$

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

24. (a) ^{9}Be(^{3}He, ^{3}He)^{9}Be

(b) ^{9}Be(^{3}He, 2α)^{4}He $\qquad Q_{\rm m} = 19.0045$

Angular distributions of elastically scattered ^{3}He particles have been obtained at $E(^3\text{He}) = 4$ to 32.3 MeV [see (1974AJ01)], at $E(^3\text{He}) = 1.6$ to 2.4 MeV (1974BO38) and 32.6 MeV (1975BU11; polarized ^{3}He). See also (1975DA1A). At $E(^3\text{He}) = 217$ MeV (1973WI07, 1976WI05) angular distributions have been studied to ^{9}Be*(0, 2.4). For optical model parameters see discussions in (1972BU30, 1973WI07, 1976WI05). At $E(^3\text{He}) = 39.8$ MeV inelastic ^{3}He groups are observed to ^{9}Be*(1.7, 2.4, 3.1, 4.7, 6.8, 14.4) (1969BA06). See also (1976RO1L). In a study of reaction (b) the (^{5}He + α) system is found to be mainly in an S-state: the probability of finding such a cluster in ^{9}Be is $N_{\rm eff} = 0.05$ (1975KA05). See also ^{8}Be.

25. (a) ^{9}Be(α, α)^{9}Be

(b) ^{9}Be(α, 2α)^{5}He $\qquad Q_{\rm m} = -2.47$

(c) ^{9}Be(α, αn)^{8}Be $\qquad Q_{\rm m} = -1.6652$

Elastic scattering has been studied at many energies for $E_\alpha = 8.76$ to 104 MeV [see (1974AJ01)] and at 5.00 to 5.50 MeV (1973GO15). See (1972DE01, 1972DE02) for a discussion of optical model parameters. The structure (^{5}He + α) for ^{9}Be is found to be much more probable than (^{6}Li + t): the ratio of 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 α_1 group 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, 1967FU08). Analysis based on the rotational model leads to a deformation coefficient $\beta_2 = 0.34 \pm 0.01$ (1964GR39).

The summed α-spectra from reaction (b) show a peak corresponding to quasi-elastic scattering leaving ^{5}He in its ground state. The angular distribution peaks at the angle corresponding to zero-momentum α-cluster. The probability of formation of such clusters is $(7^{+13}_{-5})\%$ (1969PI11). See also (1977WA1M). (1976WO11) find $S_\alpha = 0.96$.

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, 3.1) (1972OB01). See also (1974AJ01, 1975RO1B) and (1974CH58, 1974KU15, 1974LO09, 1974PI11, 1976AV05, 1977DE1K, 1977DM1A, 1977MO11; theor.).

26. (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 $E(^6\text{Li}) = 4$ and 6 MeV (1974VO06) and 24 MeV (1968DA20) and at $E(^7\text{Li}) = 24$ MeV (1972WE08) and 34 MeV (1977KE09).

27. ^{9}Be(^{9}Be, ^{9}Be)^{9}Be

Elastic angular distributions have been obtained at $E = 5$, 9, 12 and 16 MeV (1977YO02).

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

Elastic angular distributions are reported at $E(^{12}\text{C}) = 12$, 15, 18 and 21 MeV (1970BA49) and $E(^{9}\text{Be}) = 14$, 20 and 26 MeV (1978LA1G) and 43 MeV (1977MA1L). The neutron spectroscopic factor for ^{9}Be is 0.84 (1970BA49). For spallation studies see (1977IG1D, 1978CH02). See also (1976ECZZ, 1977PE1B, 1978MA1L), (1978EN06) and (1978PA1B; theor.).

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

Elastic angular distributions have been measured at $E(^{14}\text{N}) = 25$ (1966OE1A) and 27.3 MeV (1959HA28).

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), 25.7 to 29.5 MeV (1975FU05) and 30 MeV (1969KR03), and at $E(^{18}\text{O}) = 12.1$, 16 and 20 MeV (1971KN05). See also (1974TA1C, 1978CH02), (1978EN06) and (1978PA1B; theor.).

31. (a) ^{9}Be(^{24}Mg, ^{24}Mg)^{9}Be
(b) ^{9}Be(^{27}Al, ^{27}Al)^{9}Be
(c) ^{9}Be(^{28}Si, ^{28}Si)^{9}Be

Elastic angular distributions have been measured at $E(^{9}\text{Be}) = 14$, 20 and 26 MeV for reactions (a), (b) and (c) (1977BA71) and at 14 and 17 MeV for reaction (c) (1977EC04). See also (1978DE1M) and (1978EN06).

32. ^{10}Be(d, t)^{9}Be $\qquad Q_{\rm m} = -0.5545$

Forward angular distributions have been obtained at $E_{\rm d} = 15.0$ MeV for the tritons 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 $E_{\rm x} = 5.5$ MeV (1970AU02).

33. (a) ^{10}B(γ, p)^{9}Be $\quad Q_{\rm m} = -6.5853$

(b) ^{10}B(e, ep)^{9}Be $\quad Q_{\rm m} = -6.5853$

See ^{10}B.

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

A good fit to the angular distributions of the deuterons to ^{9}Be*(0, 2.4) has been obtained at $E_{\rm n} = 14.4$ MeV, using DWBA. The spectroscopic factors are in close agreement with shell model predictions (1965VA05). See also ^{11}B in (1980AJ01).

35. ^{10}B(p, 2p)^{9}Be $\quad Q_{\rm m} = -6.5863$

The summed proton spectrum at $E_{\rm p} = 460$ 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 ^{10}B.

36. ^{10}B(d, ^{3}He)^{9}Be $\quad Q_{\rm m} = -1.0918$

Angular distributions of the ^{3}He groups corresponding to ^{9}Be*(0, 2.4) have previously been measured at $E_{\rm d} = 11.8$ and 28 MeV: see (1974AJ01). Recent angular distribution measurements at $E_{\vec{\rm d}} = 15$ MeV (1974LU06; to ^{9}Be*(0, 2.4)) and at $E_{\rm d} = 52$ MeV (1975SC41; to ^{9}Be*(0, 2.4, 6.7)) lead to $S = 0.72$ and 0.82 (1974LU06) and relative $S = 1.00$, 0.98 and 0.58 (1975SC41). In the latter experiment ^{9}Be*(11.3) appears also to be strongly populated. The data for ^{9}Be*(0, 2.4) are very similar, as predicted, to those obtained in the mirror reaction: see reaction 12 in ^{9}B. See also (1974DA1D; theor.) and ^{12}C in (1980AJ01).

37. ^{10}B(t, α)^{9}Be $\quad Q_{\rm m} = 13.2287$

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). See also (1977CI1A) and ^{13}C in (1981AJ01).

38. ^{10}B(^{7}Li, ^{8}Be)^{9}Be $\qquad Q_m = 10.670$

See (1977KO27).

39. ^{10}B(^{14}N, ^{15}O)^{9}Be $\qquad Q_m = 0.712$

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

40. ^{10}B(^{16}O, ^{17}F)^{9}Be $\qquad Q_m = -5.985$

See (1968OK06).

41. ^{11}B(n, t)^{9}Be $\qquad Q_m = -9.5586$

The angular distribution of t_0 has been measured at $E_n = 14.4$ MeV (1970MI14).

42. (a) ^{11}B(p, ^{3}He)^{9}Be $\qquad Q_m = -10.3224$
(b) ^{11}B(p, pd)^{9}Be $\qquad Q_m = -15.8159$

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). The excitation energy of the first $T = \frac{3}{2}$ state is $E_x = 14392.6 \pm 1.8$ keV (1974KA15) using the (1977WA08) mass for ^{9}Be$_{\text{g.s.}}$. For reaction (b) see (1964BA1C).

43. (a) ^{11}B(d, α)^{9}Be $\quad Q_{\rm m} = 8.0308$

(b) ^{11}B(d, nα)^{4}He^{4}He $\quad Q_{\rm m} = 6.4575$

Alpha groups are reported corresponding to ^{9}Be*(0, 1.7, 2.4, 3.1). The width of ^{9}Be*(1.7) [$E_{\rm x} = 1.70 \pm 0.01$ MeV (1975FO13)] is $\Gamma_{\rm c.m.} = 224 \pm 25$ (1958KA31, 1966PU02), 200 ± 10 keV (1975FO13). The weighted mean of the values of $E_{\rm x}$ of ^{9}Be*(2.4), reported in (1974AJ01), is 2425 ± 3 keV. The $\frac{5}{2}^{+}$ state is at $E_{\rm x} = 3.02 \pm 0.03$ MeV (1955LE36), 3.05 ± 0.03 MeV (1956BO18): $\Gamma_{\rm c.m.} = 257 \pm 25$ keV (1958KA31, 1966PU02). The ratio Γ_γ/Γ of ^{9}Be*(1.7) $\leq 2.4 \times 10^{-5}$, that for ^{9}Be*(2.4) is $(1.16 \pm 0.14) \times 10^{-4}$ (1966PU02). Since Γ_γ is known from (e, e$'$) [see Table 9.8: 0.089 ± 0.010 eV], $\Gamma = 0.77 \pm 0.15$ keV.

Angular distributions for α_0 and α_2 are reported at $E_{\rm d} = 0.39$ to 2.5 MeV and at 12 MeV [see (1974AJ01)] and at 3.0 to 3.9 MeV (1974CA34, 1975CA1J, 1975CA1K). Reaction (b), at $E_{\rm d} = 10.4$ 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 ^{8}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 (1978GR07) and ^{13}C in (1981AJ01).

44. ^{11}B(^{16}O, ^{18}F)^{9}Be $\quad Q_{\rm m} = -8.290$

See (1968OK06).

45. (a) ^{12}C(n, α)^{9}Be $\quad Q_{\rm m} = -5.7015$

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

Angular distributions of the α_0 group have been measured at $E_{\rm n} = 13.9$ to 18.8 MeV; ^{9}Be*(1.7, 2.4, 3.1) are also populated: see (1974AJ01). Reaction (b) at $E_{\rm n} = 13$ to 18 MeV involves ^{9}Be*(2.4) (1966MO05). See also (1975AN01, 1976AN16), (1973PE19; theor.) and ^{12}C and ^{13}C in (1980AJ01, 1981AJ01).

46. ^{12}C(α, ^{7}Be)^{9}Be $\quad Q_{\rm m} = -24.693$

Angular distributions have been obtained for the transition to ^{7}Be*(0, 0.43)+^{9}Be$_{\rm g.s.}$ (1972RU03: 42 MeV).

47. ^{12}C(^{10}B, ^{13}N)^{9}Be $\quad Q_{\rm m} = -4.642$

See (1975RA13; theor.).

48. ^{12}C(^{18}O, ^{21}Ne)^{9}Be $\qquad Q_{\rm m} = -6.398$

See (1974BA15).

49. ^{13}C(γ, α)^{9}Be $\qquad Q_{\rm m} = -10.6479$

See ^{13}C in (1981AJ01).

50. ^{13}C(p, pα)^{9}Be $\qquad Q_{\rm m} = -10.6479$

See (1975OB01) and ^{14}N in (1981AJ01).

51. ^{13}C(d, ^{6}Li)^{9}Be $\qquad Q_{\rm m} = -9.174$

See (1966DE09).

52. ^{13}C(^{3}He, ^{7}Be)^{9}Be $\qquad Q_{\rm m} = -9.062$

Angular distributions have been obtained at $E(^{3}\text{He}) = 70$ MeV for the transitions to ^{9}Be*(0, 2.4) and ^{7}Be*(0, 0.43). Broad states at 2.9, 4.8 ± 0.2, 7.3 ± 0.2 and 11.9 ± 0.4 MeV are also populated (1976ST11).

53. ^{13}C(α, ^{8}Be)^{9}Be $\qquad Q_{\rm m} = -10.740$

At $E_{\alpha} = 65$ MeV angular distributions have been measured for the transitions to ^{9}Be*(0, 2.4) (1976WO11).

54. (a) ^{13}C(^{17}O, ^{21}Ne)^{9}Be $\qquad Q_{\rm m} = -3.300$

(b) ^{13}C(^{18}O, ^{22}Ne)^{9}Be $\qquad Q_{\rm m} = -0.980$

See (1974CH1Q) and (1978EN06).

55. ^{14}C(^{18}O, ^{23}Ne)^{9}Be $\qquad Q_{\rm m} = -3.956$

See (1974BA15) and (1978EN06).

56. ^{16}O(α, ^{11}C)^{9}Be $\qquad Q_{\rm m} = -24.310$

See (1972RU03).

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

GENERAL: (See also (1974AJ01).)

Model calculations: (1977HO1F, 1977OK01, 1978HO1E).

Special levels: (1974IR04, 1975WI1E, 1976IR1B, 1978HO1E).

Astrophysical questions: (1977SI1D).

Pion reactions: (1974KA07).

Other topics: (1974HA1C, 1974IR04, 1976IR1B).

Ground state properties: (1975BE31, 1977OK01).

1. (a) ^{6}Li(^{3}He, n)^{8}B	$Q_m = -1.975$	$E_b = 16.603$
(b) ^{6}Li(^{3}He, p)^{8}Be	$Q_m = 16.7878$	
(c) ^{6}Li(^{3}He, d)^{7}Be	$Q_m = 0.113$	
(d) ^{6}Li(^{3}He, t)^{6}Be	$Q_m = -4.306$	
(e) ^{6}Li(^{3}He, ^{3}He)^{6}Li		
(f) ^{6}Li(^{3}He, p)^{4}He^{4}He	$Q_m = 16.8797$	

The total cross section for reaction (a) increases monotonically from threshold to $\approx$ 7 mb at 3.8 MeV. It then decreases monotonically from $\approx$ 20 mb at $E(^3\text{He}) = 5.5$ MeV to 7.6 MeV (1974MCZS, 1975MC02) and the decrease continues in the range $E(^3\text{He}) = 8.9$ to 26.5 MeV (1973MA24). See also ^{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)): see (1974AJ01). Resonances are reported at $E(^3\text{He}) = 1.6$ MeV [$J^\pi = \frac{3}{2}^-$ or $\frac{5}{2}^-$ (1969VI05), $\Gamma = 0.25$ MeV] and 3.0 MeV ($\Gamma = 1.5$ MeV) (1956SC01). Total cross sections have been measured for the p_1 and p_2 groups for $E(^3\text{He}) = 3 - 6$ MeV (1976GO1F). Polarization measurements are reported at $E(^3\text{He}) = 14$ MeV (1977AS04, 1977IR01: p_0, p_1). See also ^{8}Be.

The yields of 0.43 and 0.48 MeV γ-rays (reaction (c)) 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 and (1976KA1D).

Excitation functions for t_0 (reaction (d)) have been measured for $E(^3\text{He}) = 10$ to 16 and 23.3 to 25.4 MeV: see (1974AJ01). See also ^{6}Be. For reaction (e) see (1972GI07). See also ^{6}Li. The total cross section for reaction (f) has been measured for $E(^3\text{He}) = 3$ to 6 MeV (1976GO1F). The yield of α-α coincidences [to $^5\text{Li}_{\text{g.s.}}$] has been measured for $E(^3\text{He}) = 1.4$ to 1.8 MeV: a resonance is observed at 1.57 ± 0.02 MeV [^{9}B*(17.63)], $\Gamma = 70 \pm 20$ keV (1978GU15).

Table 9.9: Energy levels of ^{9}B

E_x (MeV ± 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)	$\frac{5}{2}^-; \frac{1}{2}$	≈ 700	(p, α)	13
2.361 ± 5		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
11.70 ± 70	$(\frac{7}{2})^-; \frac{1}{2}$	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
14.6550 ± 2.5	$\frac{3}{2}^-; \frac{3}{2}$	0.275 ± 0.093	γ, p	4, 7, 15
14.7 ± 180	$(\frac{5}{2})^-; \frac{1}{2}$	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
17.076 ± 4	$T = \frac{3}{2}$	22 ± 5		15
17.190 ± 25		120 ± 40	p, d, ^{3}He	1, 4, 5, 15
17.637 ± 10		71 ± 8	p, d, ^{3}He, α	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}B*(0, 2.4): the upper limit of the cross section to a state at ≈ 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 $\qquad Q_{\rm m} = 9.352$

(b) ^{7}Li(^{3}He, np)^{8}Be $\qquad Q_{\rm m} = 9.537$

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 (1965DI03) [widths in brackets].

^{9}B*(14.66) is the first $T = \frac{3}{2}$ state in ^{9}B. Its decay properties are displayed in Table 9.6 and compared with those of ^{9}Be*(14.40) (1971AD01, 1972AD04, 1976MC10).

The n_0 angular distribution has been measured at $E(^{3}\text{He}) = 3.1$ MeV. A state at $E_{\rm x} = 4.8 \pm 0.1$ MeV, $\Gamma = 1.0 \pm 0.2$ MeV is also reported (1970GU08). See also (1976RA1G, 1976SL1A) and ^{10}B.

5. ^{7}Be(d, p)^{8}Be $\qquad Q_{\rm m} = 16.675 \qquad E_{\rm b} = 16.490$

For $E_{\rm d} = 0.75$ to 1.70 MeV, resonances in the yields of protons are observed at $E_{\rm d} = 0.900 \pm 0.025$ MeV (p_0, p_1) and 1.475 ± 0.010 MeV (p_1 only) with $\Gamma_{\rm c.m.} = 120 \pm 40$ and 71 ± 8 keV, respectively [^{9}B* $= 17.19$ and 17.64 MeV] (1960KA17).

6. (a) ^{9}Be(p, n)^{9}B $\qquad Q_{\rm m} = -1.850$

(b) ^{9}Be(p, pn)^{8}Be $\qquad Q_{\rm m} = -1.6652$

At $E_{\rm p} = 20$ MeV, ^{9}B*(0, 2.4) are populated. The results are 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 $E_{\rm x} < 7.1$ MeV (1970AN07). Additional states have been reported by a number of groups: see (1974AJ01) and (1978CH07). The width of the ground state is 540 ± 210 eV (1964TE01).

Angular distributions have been reported at many energies in the range $E_{\rm p} = 3.5$ to 49.3 MeV [see (1974AJ01)] and at 22.8 MeV (1975CA18: quasi elastic). See also (1978WA1D). A study of reaction (b) at $E_{\rm p} = 5.5$ MeV is said to suggest a $(19 \pm 5)\%$ decay of ^{9}B*(2.4) to ^{8}Be$_{\rm g.s.}$ (1978CH07): see, however, reaction 13. See also (1974BO1H, 1976ANZQ, 1976CA17, 1977JE01, 1977LO10, 1978BY1B, 1978BY1C, 1978GO1G, 1978LO1C) and ^{10}B.

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

Angular distributions have been measured in the range $E(^{3}\text{He}) = 3.0$ to 25 MeV [see (1974AJ01)] and at 217 MeV (1976WI05: t_0, t_1). At $E(^{3}\text{He}) = 39.8$ MeV, ^{9}B$_{\rm g.s.}$ is strongly populated 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 (1976UE01), (1974LO1B) and ^{12}C in (1975AJ02, 1980AJ01).

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 ^{8}Be(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).
[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.

8. ^{9}Be(^{6}Li, ^{6}He)^{9}B $\qquad Q_m = -4.575$

At $E(^6\text{Li}) = 30.8$ 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 $\rightarrow$ ^{8}Be + p $\qquad Q_m = 16.681$
$\rightarrow$ ^{5}Li + α $\qquad Q_m = 14.81$

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 via ^{5}Li + α: see (1972ES05).

10. ^{10}B(γ, n)^{9}B $\qquad Q_m = -8.436$

See ^{10}B.

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

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

E_x [a] (MeV ± keV)	$\Gamma_{c.m.}$ [a] (MeV)	l_n [b]	J^π [c]
0		1	$\frac{3}{2}^-$
2.35 ± 20		1	$\frac{5}{2}^-$
(2.8) [d]			
7.1 ± 140	2.15 ± 0.15	1	$\frac{7}{2}^-$
11.70 ± 70 [b,e]	0.80 ± 0.05	1	$(\frac{7}{2})^-$
14.7 ± 180	1.35 ± 0.2	1	$(\frac{5}{2})^-$
(18.4) [f]			

[a] (1968KU04): $E_p = 33.6$ MeV.
[b] (1968KU04) and (1969BA05: $E_p = 155.6$ MeV).
[c] J from best fit to theoretical spectroscopic factor (1968KU04).
[d] Weak group.
[e] (1970SQ01: $E_p = 49.5$ MeV).
[f] (1969BA05).

Observed groups are displayed in Table 9.11 (1968KU04, 1969BA05, 1970SQ01). See also (1977GU14; α to ^{9}B*(0, 2.36); $E_p = 16.7$ and 17.7 MeV).

12. ^{10}B(d, t)^{9}B $\qquad Q_m = -2.179$

Angular distributions have been measured at $E_d = 11.8$, 13.5 and 28 MeV [see (1974AJ01)], at 13.6 MeV (1973ZA06: t_0) and at $E_{\bar{d}} = 15$ MeV (1974LU06: t_0, t_1). S for ^{9}B*(0, 2.4) are 0.66 and 0.58, respectively (1974LU06). See also (1975ZA06), (1974DA1D; theor.) and ^{12}C in (1975AJ02, 1980AJ01).

13. (a) ^{10}B(^{3}He, α)^{9}B $\qquad Q_m = 12.142$
(b) ^{10}B(^{3}He, αp)^{8}Be $\qquad Q_m = 12.3273$

Alpha-particle spectra show the excitation of ^{9}B*(0, 2.4, 2.8, 11.8): see (1966LA04). Measurements by (1968KR02) determine $E_x = 2.361 \pm 0.005$ 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 $E_x \approx 1.6$ MeV, $\Gamma \approx 0.7$ MeV, but it is not conclusive, in agreement with the older work. No evidence is found for any narrow levels in ^{9}B with $\Gamma \leq 100$ keV and

$4 < E_x < 7$ 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 $E(^3\text{He}) = 5.5$ 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) [$\theta_f^2 < 5.1 \times 10^{-3}$] [it decays to ^{5}Li(0) by α-emission] while the second state, $E_x = 2.71 \pm 0.03$ MeV [$\Gamma = 0.71 \pm 0.06$ MeV] decays almost 100% by that channel [$\theta_d^2 = 0.74$] (1966WI08). No other excited states of ^{9}B with $3.5 < E_x < 9.5$ MeV decay by proton emission to ^{8}Be(0) (1968KR02). A number of additional states of ^{9}B are reported by (1974FO08). See also (1974LO1B) and (1974AJ01).

14. ^{10}B(^{16}O, ^{17}O)^{9}B $\qquad Q_m = -4.292$

See (1968OK06).

15. ^{11}B(p, t)^{9}B $\qquad Q_m = -11.409$

At $E_p = 45$ 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, 17.64). $T = \frac{1}{2}$ states are reported at $E_x = 15.29 \pm 0.04$ and 15.58 ± 0.04 MeV (1971HA10). The first two $T = \frac{3}{2}$ states have been observed at $E_x = 14.6550 \pm 0.0025$ (1974KA15) and 17.076 ± 0.004 MeV [$\Gamma = 22 \pm 5$ keV] (1974BE66). See also (1975BE56) and reaction 42 in ^{9}Be.

16. (a) ^{12}C(p, α)^{9}B $\qquad Q_m = -7.552$
(b) ^{12}C(p, p)^{4}He^{4}He^{4}He $\qquad Q_m = -7.2748$

Angular distributions have been measured for the α_0 group at $E_p = 14.0$ to 54.1 MeV. Alpha groups are also observed to ^{9}B*(2.3, 2.9 ± 0.2, 6.97 ± 0.06): see (1974AJ01). The angular distribution to ^{9}B*(6.97) is consistent with $J^\pi = \frac{7}{2}^-$, $\Gamma \approx 2$ MeV (1972MA21: $E_p = 54.1$ MeV). Angular distributions involving the α_0 and α* groups [to ^{4}He*(20.1), 0^+] to $^9\text{B}_{\text{g.s.}}$ have been studied at $E_p = 45.2$ MeV (1978DA1C). For reaction (b) see (1974AJ01). See also ^{12}C in (1975AJ02, 1980AJ01), ^{13}N in (1976AJ04) and (1978HA04; theor.).

17. ^{12}C(^{3}He, ^{6}Li)^{9}B $\qquad Q_m = -11.572$

Angular distributions of ^{6}Li ions have been obtained at $E(^{3}\text{He}) = 30.0$ and 40.7 MeV (1972OH01). See also (1974AJ01).

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

GENERAL: (See also (1974AJ01).)

Model calculations: (1974IR04, 1976IR1B).

Pion reactions: (1974KA07, 1976HEZU, 1978SE1D).

Other topics: (1974IR04, 1975BE56, 1976IR1B, 1977CE05).

Ground state properties: (1975BE31).

Mass of ^{9}*C:* The atomic mass excess of ^{9}C is 28912 ± 3 keV (1975KA18) based on the Q-value of the ^{12}C(^{3}He, ^{6}He)^{9}C reaction (1971TR03) and the threshold energy of the ^{7}Be(^{3}He, n)^{9}C reaction (1971MO01).

1. ^{9}C(β^{+})^{9}B $\rightarrow$ ^{8}Be + p $\quad Q_{\text{m}} = 16.681$
   $\rightarrow$ ^{5}Li + α $\quad Q_{\text{m}} = 14.81$

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 (1974KU06, 1975WI1E; theor.).

2. ^{7}Be(^{3}He, n)^{9}C $\quad Q_{\text{m}} = -6.282$

$E_{\text{thresh.}} = 8980 \pm 5$ keV (1971MO01).

3. ^{12}C(^{3}He, ^{6}He)^{9}C $\quad Q_{\text{m}} = -31.575$
   $Q_{0} = -31.578 \pm 0.008$ (1971TR03).

At $E(^{3}\text{He}) = 74.1$ MeV a ^{6}He group is observed to the first excited state whose atomic mass excess is measured to be 31.131 ± 0.011 MeV, $\Gamma = 100 \pm 20$ keV. Based on the adopted AME for the ground state of ^{9}C of 28.912 ± 0.003 MeV, $E_{\text{x}} = 2.219 \pm 0.011$ MeV (1974BE66).

Table 9.12: Energy levels of ^{9}C

E_x (MeV ± keV)	$J^\pi; T$	$\tau_{1/2}$ or Γ	Decay	Reactions
g.s.	$(\frac{3}{2}^-); \frac{3}{2}$	126.5 ± 0.9 msec	β^+	1, 2, 3, 4 [a]
2.219 ± 11		$\Gamma = 100 \pm 20$ keV		3

[a] See also (1974AJ01).

4. ^{14}N(^{3}He, ^{8}Li)^{9}C $\qquad Q_m = -32.064$

See ^{8}Li (1976RO04).

^{9}N

(Not illustrated)

Not observed: see (1974IR04, 1975BE31, 1976IR1B; theor.).

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(Closed 1978)

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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