Energy Levels of Light Nuclei
$A = 9$

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Abstract: An evaluation of $A = 5$–10 was published in *Nuclear Physics A*413 (1984), 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. Also, Reference key numbers have been changed to the NNDC/TUNL format.

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Table of Contents for $A = 9$

Below is a list of links for items found within the PDF document. Figures from this evaluation have been scanned in and are available on this website or via the link below.

^{9}n
(Not illustrated)

Not observed: see (1977DE08).

^{9}He
(Not illustrated)

^{9}He has been observed in the ^{9}Be(π^-, π^+)^{9}He reaction at $E_{\pi^-} = 194$ MeV; the atomic mass excess is 40.81 ± 0.12 MeV. ^{9}He is then unstable with respect to decay into ^{8}He + n by 1.14 MeV (1981SE1B, 1980NA1D, 1980SE1C, 1980SE1F). See also (1979AJ01) and (1982PO1C; hypernuclei) and (1982NG01; theor.).

^{9}Li
(Figs. 15 and 18)

GENERAL: (See also (1979AJ01).)

Model calculations: (1979LA06).

Complex reactions involving ^{9}Li: (1978DU1B, 1979AL22, 1979BO22, 1979JA1C, 1980BO31, 1980WI1L, 1981BO1X, 1981MO20, 1982BO1Y).

Muon and neutrino capture and reactions: (1980MU1B).

Reactions involving pions and other mesons (See also reaction 3.): (1978FU09, 1979BO21, 1979PE1C, 1979WI1E, 1980NI03, 1980ST15, 1981YA1A).

Hypernuclei: (1978DA1A, 1978PO1A, 1980MA1Z, 1981ST1G, 1981WA1J, 1982KO11).

Other topics: (1979BE1H, 1979LA06, 1982NG01).

Ground-state properties of ^{9}Li: (1981AV02, 1982NG01).

$\mu = 3.4391 \pm 0.0006$ nm: see (1983CO1Q).

$Q = 0.88 \pm 0.18 Q$(^{7}Li): see (1983CO1Q).

1. ^{9}Li(β^-)^{9}Be $\qquad Q_{\mathrm{m}} = 13.606$

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
2.691 ± 5	$(\frac{1}{2}^-)$		(γ)	2, 6
4.31 ± 20		$\Gamma = 100 \pm 30$		2, 6
5.38 ± 60		600 ± 100		2
6.43 ± 15	$\geq \frac{9}{2}$	40 ± 20		2, 6

[a] For other reactions on which no new work is reported, see (1979AJ01).

The half-life of ^{9}Li is 178.3 ± 0.4 msec (1976AL02). See also (1979AJ01). ^{9}Li decays to a number of states in ^{9}Be: see reaction 12 in ^{9}Be and Table 9.7. The nature of the decay to ^{9}Be*(0, 2.43) with $J^\pi = \frac{3}{2}^-, \frac{5}{2}^-$ is evidence for $J^\pi = \frac{3}{2}^-$ for ^{9}Li$_{g.s.}$. The probability for delayed neutron decay, P_n, is (49.5 ± 5)% (1981LA11): see Table 9.7.

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 ± 100, < 100 keV], 4.31 ± 0.02 and 6.435 ± 0.020 MeV (1978AJ02) [$\Gamma_{c.m.} = 100 \pm 30$, 40 ± 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 (1979AB11, 1980AB16, 1983AB1A, 1983CO11) and ^{10}Be.

3. ^{9}Be(γ, π^+)^{9}Li $\qquad Q_m = -153.174$

At $E_\gamma = 175$, 187 and 200 MeV, the cross section for production of ^{9}Li$_{g.s.}$ at $\theta_\pi = 90°$ has been measured by (1982TE01). See also (1979BO21, 1980NI03).

4. ^{9}Be(n, p)^{9}Li $\qquad Q_m = -12.824$

See (1981BR1K) and (1979AJ01).

5. ^{9}Be(^{7}Li, ^{7}Be)^{9}Li $\qquad Q_m = -14.468$

See (1982AL1G: $E(^{7}\text{Li}) = 78$ MeV).

6. $^{11}\text{B}(^{6}\text{Li}, ^{8}\text{B})^{9}\text{Li}$ $\qquad Q_{\text{m}} = -25.121$

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

^{9}Be

(Figs. 16 and 18)

GENERAL: (See also (1979AJ01).)

Shell model: (1978AR1H, 1979LA06, 1981BO1Y, 1982OR03).

Cluster and α-particle models: (1978AR1H, 1978RE1A, 1979CH1D, 1979FO16, 1979LU1A, 1979OK02, 1980FU1G, 1980RE02, 1981BA2N, 1981KR1J, 1982LA11, 1982OR03, 1982PO1B).

Collective and rotaional models: (1979MA1J, 1981BA2N).

Special states: (1979CH1D, 1979KI10, 1979OK02, 1980FU1G, 1981BO1Y, 1981SE06, 1982OR03, 1983GO1R).

Electromagnetic transitions and giant resonance: (1979DO17, 1980MI1G, 1981BO1Y, 1981KO1Q, 1982AW02).

Astrophysical questions: (1978BU1B, 1978OR1A, 1979MC1A, 1980CO1R, 1980RE1B, 1980WI1M, 1981AU1D, 1981AU1G, 1981GA1C, 1981SC1M).

Applied work: (1979FO1F, 1979GR1E, 1979JU1B, 1980KI1B, 1981FA1E, 1981SA1G, 1981SC1D, 1982KL1A, 1982KU1G).

Complex reactions involving ^{9}Be: (1978BE1G, 1978BH03, 1978DU1B, 1978HE1C, 1979AL22, 1979BA10, 1979BA34, 1979BO22, 1979BU1G, 1979DY01, 1979FR12, 1979GA04, 1979GE1A, 1979JA1C, 1979LO11, 1979SA17, 1979SA27, 1979SA1E, 1979SC08, 1979SC1D, 1979VI05, 1979WE06, 1980BR1P, 1980GR10, 1980ME1F, 1980MI01, 1980MO28, 1980WI1L, 1981BH02, 1981BL1G, 1981CI03, 1981HN02, 1981LE03, 1981ME13, 1981MO20, 1981TA16, 1981TA22, 1982BO1J, 1982BO35, 1982GU1H, 1982JA1C, 1982LU01, 1982LY1A, 1982MO1N, 1982WU1B, 1983FU04, 1983SA06).

Muon and neutrino capture and reactions: (1977GR1C, 1980MU1B, 1980SC18, 1981MU1E).

Reactions involving pions (See also reaction 17): (1978AR1J, 1978ER1A, 1978FU09, 1978GE11, 1978KI13, 1978VL1B, 1978WA1B, 1979AL1J, 1979BA16, 1979BO21, 1979BO1N, 1979BU1D, 1979CO1D, 1979DE06, 1979DE1G, 1979FR1F, 1979FU1G, 1979GI1B, 1979GI1C, 1979HO1C, 1979HO13, 1979IN1A, 1979KI1G, 1979MA02, 1979MA1P, 1979NA1E, 1979OH1A, 1979PE1D, 1979PI1C, 1979SC1E, 1979ST1G, 1979TI1A, 1979WI1E, 1980BU15, 1980CR03, 1980ER01, 1980HA29, 1980JE1C, 1980LE02, 1980MA1F, 1980NA1D, 1980NA1L, 1980NI03, 1980ST15, 1980TH1C, 1980TR1A, 1981AS1H, 1981BA2M, 1981BA2R, 1981BE13, 1981BE1X, 1981BE63, 1981BO06, 1981DU1H, 1981FE2A, 1981GE03, 1981IO01, 1981IS11, 1981KU15, 1981LE14, 1981MC09, 1981NA05, 1981NI03, 1981SE1B, 1981WA1H, 1981YA1A, 1982AP1A, 1982AS01, 1982GR1F, 1982MU1C, 1983AS02).

Reactions involing kaons and other mesons: (1978AN1B, 1978DA1A, 1978SO1A, 1979GA1E, 1979LI1A, 1980AU1C, 1980BE30, 1980BE12, 1980DE11, 1980DO1E, 1980GA1C, 1980PO1A,

1981BA2N, 1981BE17, 1981BE45, 1981BO09, 1981DA1C, 1981HU1C, 1981KA1U, 1981PO1D, 1981WA1H, 1981ZH1C, 1982AB07, 1982BA17, 1982BO1U, 1982DEZQ, 1982DO1C, 1982ER1E, 1982PI1J, 1982PO1C).

Table 9.2: Energy levels of ^{9}Be

E_x [a] (MeV ± keV)	$J^\pi; T$	$\Gamma_{\text{c.m.}}$ (keV)	Decay	Reactions
g.s.	$\frac{3}{2}^-; \frac{1}{2}$		stable	2, 3, 4, 9, 10, 11, 12, 13, 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
1.685 ± 15	$\frac{1}{2}^+$	≈ 150	γ, n	9, 10, 13, 16, 18, 19, 21, 23, 24, 32, 33, 36, 40, 41
2.4294 ± 1.3	$\frac{5}{2}^-$	0.77 ± 0.15	γ, n, α	9, 10, 12, 16, 17, 18, 19, 21, 22, 23, 24, 26, 32, 35, 36, 39, 40, 41, 42, 43
2.78 ± 120	$\frac{1}{2}^-$	1080 ± 110	n	9, 12, 42
3.049 ± 9	$\frac{5}{2}^+$	282 ± 11	γ, n	9, 13, 16, 18, 19, 20, 21, 23, 24, 32, 36, 39, 40, 41
4.704 ± 25	$(\frac{3}{2})^+$	743 ± 55	γ, n	9, 16, 19, 20, 21, 23, 24, 34, 40, 42
6.76 ± 60	$\frac{7}{2}^-$	1540 ± 200	γ, n	9, 16, 17, 18, 19, 20, 21, 23, 24, 35, 41
7.94 ± 80	$(\frac{1}{2}^-)$	≈ 1000		12, 19
11.283 ± 24	$(\frac{3}{2}^-)$	575 ± 50	n	9, 12, 19, 24, 35, 36
11.81 ± 20	$T = \frac{1}{2}$	400 ± 30	γ, n	9, 13, 39, 42
13.79 ± 30	$T = \frac{1}{2}$	590 ± 60	γ, n	9, 16, 39
14.3929 ± 1.8	$\frac{3}{2}^-; \frac{3}{2}$	0.381 ± 0.033	γ, n, α	9, 16, 23, 36, 39
14.4 ± 300		≈ 800		19, 36
15.10 ± 50			γ	16, 39
15.97 ± 30	$T = \frac{1}{2}$	≈ 300	γ	16, 39
16.671 ± 8		41 ± 4	γ	9, 16, 19, 36

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

E_x [a] (MeV ± keV)	$J^\pi; T$	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
16.975 ± 2	$\frac{1}{2}^-; \frac{3}{2}$	< 0.47	γ, n, p, d	4, 5, 6, 16
17.298 ± 7	$(\frac{5}{2})^-$	200	γ, n, p, d, α	5, 6, 7, 13, 16, 19
17.493 ± 7	$\leq \frac{7}{2}^+$	47	γ, n, p, d, α	5, 6, 7, 16, 19
18.02 ± 50			γ	16
18.58 ± 40			γ, n, p, d, α	6, 16
19.20 ± 50		310 ± 80	n, p, d, t	1, 6, 19
19.51 ± 50			γ	13, 16
(19.9 ± 200)			γ, n	13, 19
(20.47 ± 40)			γ, p, d	13, 19
20.74 ± 30		≈ 1000	γ, n, p, t	1, 13, 16
(21.4 ± 200)			γ, n	13, 19
(22.4 ± 200)		broad	γ, n	13, 19
(23.8 ± 200)			γ, n	13, 34
(27.0 ± 500) [b]		broad	γ, n	13

[a] See also reactions 14 and 16.
[b] See footnote [i] in Table 9.8.

Hypernuclei: (1977KO1D, 1978DA1A, 1978PO1A, 1978SO1A, 1979GA1E, 1979VE1B, 1980AU1C, 1980BE30, 1980BE12, 1980DO1E, 1980GA1P, 1980GI1C, 1980PO1A, 1980ZH1C, 1980ZO1A, 1981BA2N, 1981BE17, 1981BE45, 1981BO09, 1981DA1C, 1981DA1D, 1981PO1D, 1981PO1F, 1981RE1B, 1981ST1G, 1981SU1D, 1981WA1J, 1982BA1P, 1982BA17, 1982BO1U, 1982DA1R, 1982DEZQ, 1982DO1C, 1982DO1M, 1982ER1B, 1982ER1E, 1982GA1J, 1982IK1A, 1982JO1C, 1982KO11, 1982MO1Q, 1982PO1C, 1982SH1P, 1982ZH1F, 1983BA2K, 1983JO1E).

Other topics: (1978OS1B, 1979BE1H, 1979LA06, 1979LI1A, 1979OS02, 1980BO1N, 1980GI1C, 1981SE06, 1982AW02, 1982BA2G, 1982NG01, 1983BO1E, 1983GO1R).

Ground-state properties of ^{9}Be: (1978HE1D, 1979AL26, 1979OK02, 1979SA27, 1980BO1N, 1981AV02, 1981BO1Y, 1981HN02, 1981SE06, 1982BA2G, 1982DE35, 1982LO13, 1982NG01, 1982OR03, 1983BO1E).

$$\mu = -1.1778 \pm 0.0009 \text{ nm: see (1976WE17).}$$

$$Q = +53 \pm 3 \text{ mb: see (1978LEZA).}$$

1. (a) ^{6}Li(t, n)^{8}Be $Q_m = 16.0223$ $E_b = 17.6878$
(b) ^{6}Li(t, p)^{8}Li $Q_m = 0.801$
(c) ^{6}Li(t, d)^{7}Li $Q_m = 0.9929$
(d) ^{6}Li(t, α)^{5}He $Q_m = 15.22$
(e) ^{6}Li(t, n)^{4}He^{4}He $Q_m = 16.1141$
(f) ^{6}Li(t, 2n)^{7}Be $Q_m = -2.876$

The $0°$ differential cross section for reaction (a) increases monotonically between $E_t = 0.10$ and 2.4 MeV except for a resonance at $E_t = 1.875$ MeV (^{9}Be* $= 18.937$). The excitation function for ^{8}Li (reaction (b)) increases monotonically for $E_t = 0.275$ to 1.000 MeV. 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]: see (1974AJ01) for references. For reaction (d) see (1982CE1C). Cross sections for ^{7}Be production [reaction (f)] ($E_t = 4.4$ to 11.99 MeV) are reported by (1980GU26). For reactions (c) and (e) see (1966LA04).

2. ^{6}Li(^{3}He, π^+)^{9}Be $Q_m = -121.898$

See (1981BI1F, 1982LE1L).

3. ^{6}Li(α, p)^{9}Be $Q_m = -2.1262$

Angular distributions of p_0 have been measured at $E_\alpha = 10.2$ to 14.7 MeV and at 30 MeV: see (1974AJ01). See also (1983BE1P; theor.).

4. ^{7}Li(d, γ)^{9}Be $Q_m = 16.6950$

For $E_d = 0.1$ to 1.1 MeV, a resonance in the yield of capture γ-rays is observed at $E_d = 361 \pm 2$ keV, corresponding to ^{9}Be*(16.975) with $\Gamma_{c.m.} < 0.47$ keV. The small width of this state and its energy correspondence with ^{9}Li*(2.69) argue for $T = \frac{3}{2}$. The angular distribution of the γ-rays to ^{9}Be(0) is isotropic to within 7%: see (1974AJ01) for references.

5. (a) ^{7}Li(d, n)^{8}Be $Q_m = 15.0296$ $E_b = 16.6950$
(b) ^{7}Li(d, α)^{5}He $Q_m = 14.23$
(c) ^{7}Li(d, n)^{4}He^{4}He $Q_m = 15.1213$
(d) ^{7}Li(d, 2n)^{7}Be $Q_m = -3.869$

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

^{7}Li(d, n)	^{7}Li(d, α)	^{7}Li(d, p)		E_x (MeV)
E_{res} (keV)	E_{res} (keV)	E_{res} (keV)	Γ_{lab} (keV)	
361 ± 2 [b]		360 ± 3	< 0.5 [b]	16.975
680	750	776 ± 7 [c]	250	17.298
980	1000	1027 ± 7 [c]	60	17.493
		2000	broad	(18.5)
		2375 ± 50		18.54
		3220 ± 50	400 ± 100	19.20
		≈ 4800		20.4

[a] For references and additional information see Tables 9.3 in (1974AJ01, 1979AJ01).

[b] E_{res} from ^{7}Li(d, γ): $\Gamma_{n_0}/\Gamma_\gamma \approx 1.5$, $\Gamma_{d_0}/\Gamma_\gamma < 400$, $\Gamma_{\alpha_0}/\Gamma_\gamma < 20$.

[c] (1976SC14, 1979MI1E).

The yield of neutrons has been measured for $E_d = 0.2$ to 23 MeV: observed resonances are displayed in Table 9.3. For polarization measurements [$E_d = 0.64$ MeV and 2.5 to 3.7 MeV] see (1974AJ01). See also (1979SE04; theor.).

The yields of α-particles have been measured for $E_d = 0.25$ to 0.75 MeV (1977RO1C; α_1) and 0.2 to 3.0 MeV: see Table 9.3. For reaction (c) see (1974AJ01) and ^{5}He. The ^{7}Be production cross section (reaction (d)) has been studied for $E_d = 5.38$ to 11.94 MeV (1980GU26). See also (1978BA1F, 1979JO1B; applications).

6. ^{7}Li(d, p)^{8}Li $\qquad Q_m = -0.192 \qquad E_b = 16.6950$

Excitation functions have been measured for $E_d = 0.29$ to 7 MeV [see (1974AJ01, 1979AJ01)] and 0.60 to 1.2 MeV (1982EL03, 1982FI03; σ_t) and 0.7 to 3.4 MeV (1979MI1E; σ_t): observed resonances are displayed in Table 9.3. Recent measurements of the total cross section at the $E_d = 0.78$ MeV resonance are 181 ± 8 mb (1976SC14), 174 ± 16 mb (1979MI1E), 146 ± 13 mb (1982EL03) and 148 ± 12 mb (1982FI03): we adopt 147 ± 9 mb. See also (1983FI01). For earlier values see (1974AJ01). This cross section serves as normalization for the ^{7}Be(p, γ)^{8}B data and to calculations of the S-factor. The new value predicts that the neutrino-capture rate in ^{37}Cl should be decreased by about 15%.

Polarization measurements are reported at $E_d = 4$ MeV (1982WAZS). See also (1980HU1D, 1982AB1D) and ^{8}Li.

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)
1.64	
2.4292 ± 1.7	< 8
2.9 ± 250	1000 ± 250
3.076 ± 15	289 ± 22
4.704 ± 25	743 ± 55
6.7 ± 100	2000 ± 200
11.29 ± 30	620 ± 70
11.81 ± 20	400 ± 30
13.78 ± 30	590 ± 60
14.396 ± 5 [b]	0.38 ± 0.03
16.671 ± 8	41 ± 4

[a] See also Tables 9.4 in (1974AJ01, 1979AJ01) for references.
[b] See also Table 9.6.

7. ^{7}Li(d, d)^{7}Li $\qquad E_b = 16.6950$

The elastic scattering [$E_d = 0.4$ to 1.8 MeV] shows a marked increase in cross section for $E_d = 0.8$ to 1.0 MeV (perhaps related to ^{9}Be*(17.30)) and a conspicuous anomaly at $E_d = 1.0$ MeV, due to p-wave deuterons [^{9}Be*(17.50)]. The elastic scattering has also been studied for $E_d = 1.0$ to 2.6 MeV and 10.0 to 12.0 MeV: see (1979AJ01). See also (1982AB1D) and ^{7}Li.

8. (a) ^{7}Li(d, t)^{6}Li $\qquad Q_m = -0.993 \qquad E_b = 16.6950$
(b) ^{7}Li(d, ^{3}He)^{6}He $\qquad Q_m = -4.481$

The cross section for reaction (a) rises steeply from threshold to 95 mb at $E_d = 2.4$ MeV and then more slowly to ≈ 165 mb at $E_d = 4.1$ MeV. The t_0 yield curve ($\theta_{lab} = 155°$) decreases monotonically for $E_d = 10.0$ to 12.0 MeV: see (1974AJ01). See also ^{6}Li. For reaction (b) see ^{6}He.

9. ^{7}Li(^{3}He, p)^{9}Be $\qquad Q_m = 11.2015$

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

^{9}Be state (MeV)	l_n	Decay (in %) to		θ^2 (%) [b]
		^{8}Be(0)	^{8}Be*(2.9)	
2.43	3	7.0 ± 1.0 [a]		2.1 ± 0.6
2.78	1	mainly		0.48 ± 0.06
3.05	2	87 ± 13		81 ± 13
4.70	2	13 ± 4		6.0 ± 0.4
6.76	3	≤ 2		≤ 6
	1		55 ± 14	37 ± 10
11.28	1	≤ 2		≤ 0.1
	1		14 ± 4	0.93 ± 0.28
	3			4.0 ± 1.2
11.81	1	≤ 3		≤ 0.1
	1		12 ± 4	0.48 ± 0.16
	3			1.8 ± 0.6
14.39 [c]				

[a] For references see Table 9.5 in (1979AJ01).

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

[c] See Table 9.6.

Observed proton groups are listed in Table 9.4. The parameters for the particle and γ-decay of observed states are displayed in Tables 9.5 and 9.6 Angular distributions have been reported in the range $E(^{3}\text{He}) = 0.9$ to 14 MeV: see (1974AJ01, 1979AJ01). See also (1981SL03), (1981VI1B) and ^{10}B.

The γ-decay of ^{9}Be*(14.39) $[J^\pi = \frac{3}{2}^-; T = \frac{3}{2}]$ has been measured by (1978DI08) and compared with the decay from the mirror state in ^{9}B: see Table 9.6. No evidence is found for violation of the selection rule for $\Delta T = 1$ mirror γ transitions (1978DI08).

10. ^{7}Li(α, d)^{9}Be $\qquad Q_m = -7.1517$

Angular distributions of d_0, d_1 and d_2 are reported at $E_\alpha = 30$ MeV: see (1974AJ01). See also (1980ZE05, 1983BE1P; theor.).

11. ^{7}Li(^{6}Li, α)^{9}Be $\qquad Q_m = 15.220$

Angular distributions of α_0 have been studied at $E(^7\text{Li}) = 3.78$ to 5.95 MeV: see (1974AJ01).

12. ^{9}Li(β^-)^{9}Be $\qquad Q_\text{m} = 13.606$

^{9}Li decays by β^- emission with $\tau_{1/2} = 178.3 \pm 0.4$ msec to several ^{9}Be states: see ^{9}Li, reaction 1 and Table 9.7. Measurement of $\beta - \alpha$ coincidences involving ^{9}Be*(11.28) show contributions from the direct n $+ 2\alpha$ breakup process as well as the sequntial n-emission to ^{8}Be*(2.9) [$J^\pi = 2^+$], followed by breakup into 2α (1981LA11, 1981NY1A). The branching ratio fop the ^{9}Be*(2.43) $\rightarrow$ ^{8}Be$_\text{g.s.}$ +n decay is (6.4 ± 1.2)%. ^{9}Be*(2.78) [$J^\pi = \frac{1}{2}^-$] decays mainly to ^{8}Be$_\text{g.s}$ +n presumably by p-wave neutron emission: see reaction 13 in (1979AJ01). See also (1981JOZV) and (1979DE15; theor.).

13. (a) ^{9}Be(γ, n)^{8}Be $\qquad Q_\text{m} = -1.6655$
(b) ^{9}Be(γ, α)^{5}He $\qquad Q_\text{m} = -2.46$
(c) ^{9}Be(γ, n)^{4}He^{4}He $\qquad Q_\text{m} = -1.5737$

The photoneutron cross section has been measured from threshold to 320 MeV: see Table 9.6 in (1966LA04) and (1979AJ01). A pronounced peak occurs ≈ 29 keV above threshold with $\sigma_\text{max} = 1.33 \pm 0.24$ mb. The shape of the resonance has been measured very accurately for $E_\gamma = 1675$ to 2168 keV. The FWHM of the peak is estimated to be 100 keV (1982FU11). See also (1983BA52; theor.). The cross section then decreases slowly to 1.2 mb at 40 keV above threshold. From bremsstrahlung studies, peaks in the (γ, Tn) cross section are observed corresponding to $E_\text{x} = 1.80$ and 3.03 MeV. At higher energies, using monoenergetic photons, the (γ, Tn) cross section is found to be relatively smooth from $E_\gamma = 17$ to 37 MeV with weak structures which correspond to $E_\text{x} = 17.1$, 18.8, 19.9, 21.4, 22.4, 23.8 [± 0.2] MeV and 27 ± 0.5 MeV (broad). 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 and the combined integrated cross section for (γ, n) to ^{8}Be*(16.6) and (γ, α_0) to ^{5}He$_\text{g.s.}$ is 13.1 ± 2 MeV $\cdot$ mb.

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. An integrated cross section of 156 ± 15 MeV $\cdot$ mb is reported for $E_\gamma = 10$ to 29 MeV as is resonant structure at $E_\gamma = 11.8$, (13.5), 14.8, 917.3), (19.5), 21.0, (23.0) and (25.0) MeV. Fine structure is also reported at $E_\gamma = 20.47 \pm 0.04$ and 20.73 ± 0.04 MeV. See (1979AJ01) for references. See also (1978CH1E, 1979ZI1A, 1980AH1A, 1982DE1H), (1982BA1T; applications) and (1979BA60, 1979KI1D, 1980TA1D, 1981DE18, 1981DE33, 1981IS11; theor.).

14. (a) ^{9}Be(γ, p)^{8}Li $\qquad Q_\text{m} = -16.887$
(b) ^{9}Be(γ, np)^{7}Li $\qquad Q_\text{m} = -18.920$

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

	^{9}Be		^{9}B
E_x (keV)	14392.9 ± 1.8		14655.0 ± 2.5
Γ_{γ_0} (eV)	6.9 ± 0.5		(6.9 ± 0.5) [b]
Γ (eV)	381 ± 33 [c]		395 ± 42 [d]
Γ_{γ_0}(to $\frac{3}{2}^-$)/Γ(%)	1.81 ± 0.09 [d]		1.85 ± 0.15 [d]
Γ_{γ_1}(to $\frac{1}{2}^+$)/Γ(%)	0.03 ± 0.04 [d]		0.00 ± 0.08 [d]
Γ_{γ_2}(to $\frac{5}{2}^-$)/Γ(%)	2.05 ± 0.11 [d]		1.93 ± 0.22 [d]
Γ_{γ_3}(to $\frac{1}{2}^-$)/Γ(%)	< 0.2 [d]		} 0.31 ± 0.18 [d]
Γ_{γ_4}(to $\frac{5}{2}^+$)/Γ(%)	0.33 ± 0.07 [d]		
Γ_{γ_5}(to $\frac{3}{2}^+$)/Γ(%)	0.23 ± 0.05 [d]		
$\Gamma_{\gamma_2}/\Gamma_{\gamma_0}$	1.13 ± 0.05 [d]		1.03 ± 0.11 [d]
Γ_{n_0}/Γ	0.028 ± 0.021	Γ_{p_0}/Γ	0.11 ± 0.04
Γ_{n_1}/Γ	0.50 ± 0.11	Γ_{p_1}/Γ	0.33 ± 0.09
Γ_{n_0} (eV)	9 ± 8	Γ_{p_0} (eV)	30 ± 17
Γ_{n_1} (eV)	147 ± 28	Γ_{p_1} (eV)	95 ± 15
$\Gamma_{n_1}/\Gamma_{n_0}$	18 ± 14	$\Gamma_{p_1}/\Gamma_{p_0}$	3.2 ± 1.9
$\gamma^2_{n_1}/\Gamma^2_{n_0}$	22 ± 17	$\gamma^2_{p_1}/\gamma^2_{p_0}$	3.2 ± 2.2
$\Gamma_{\alpha_0}/\Gamma_{\gamma_0}$	31.2 ± 9.8		

[a] See Table 9.6 in (1979AJ01) for references.

[b] Assumed identical to ^{9}Be.

[c] Calculated from Γ_{γ_0}/Γ and Γ_{γ_0} (1978DI08).

[d] (1978DI08): $\Gamma(^9$B/$\Gamma(^9$Be$) = 1.04 \pm 0.10$.

Table 9.7: Branching parameters in ^{9}Li β-decay (1981LA11)

E_x in ^{9}Be (MeV)	$J^\pi; T$	Branching ratio (%)	log ft [a]
0	$\frac{3}{2}^-; \frac{1}{2}$	50.5 ± 5 [c]	5.31
2.43	$\frac{5}{2}^-; \frac{1}{2}$	34 ± 4	5.07
2.78 [b]	$\frac{1}{2}^-; \frac{1}{2}$	10 ± 2	5.54
7.94	$(\frac{1}{2}^-)$ [d]$; \frac{1}{2}$	1.5 ± 0.5	5.04
11.28	$(\frac{3}{2}^-)$ [d]$; \frac{1}{2}$	4 ± 0.5	2.87 [e]
11.81		< 0.1	> 4.0

[a] M.J. Martin, private communication.
[b] 2.78 ± 0.12 MeV, $\Gamma_{\rm c.m.} = 1.10 \pm 0.12$ MeV; $\theta_{\rm p}^2 = 0.48 \pm 0.06$: see Table 9.7 in (1979AJ01).
[c] $P_n = (50 \pm 4)$% (1981BJ01); $P_n = (49.5 \pm 5)$% (1981LA11).
[d] Suggested by (1981LA11) on the basis of the branching ratios.
[e] (1981LA11) suggest that the very low $\log ft$ value implies that ^{9}Be*(11.28) is the anti-analog to ^{9}Li$_{\rm g.s.}$.

(c) ^{9}Be(γ, d)^{7}Li $\qquad Q_{\rm m} = -16.6950$
(d) ^{9}Be(γ, t)^{6}Li $\qquad Q_{\rm m} = -17.6878$

The yield shows structure in the energy region corresponding to the ^{9}Be levels at 17–19 MeV followed by the giant resonance at $E_\gamma \approx 23$ MeV ($\sigma = 2.64 \pm 0.30$ mb). Structure attributed to eleven states of ^{9}Be with $18.2 < E_x < 32.2$ MeV has also been reported. 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). Angular and energy distributions of photoprotons in various energy intervals have been studied by many groups: see (1974AJ01) for references. See also (1976MA34). For momentum spectra using tagged photons with $E_\gamma = 180 - 420$ MeV and 360–600 MeV, see (1980HO22) and (1982BA32), respectively. See also (1981AR04, 1981TA1T, 1983ST1G).

The integrated cross sections are reported to be 1.0 ± 0.5 MeV · mb ($E_\gamma = 21 \rightarrow 33$ MeV) for reaction (c) to ^{7}Li*($0+0.4$) and 0.6 ± 0.3 MeV·mb ($E_\gamma = 25 \rightarrow 33$ MeV) for reaction (d) 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 (1974AJ01), (1980IS1E, 1982AV06, 1983HO01, 1983LI1J) and (1981IS11, 1982SU09; theor.).

15. ^{9}Be(γ, γ)^{9}Be

See (1980IS1E, 1982NO1C). See also (1979AJ01) and (1983ZH1D; theor.).

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

(b) ^{9}Be(e, en)^{8}Be $\quad Q_m = -1.6655$

(c) ^{9}Be(e, ep)^{8}Li $\quad Q_m = -16.887$

(d) ^{9}Be(e, eα)^{5}He $\quad Q_m = -2.46$

(e) ^{9}Be(e, eπ^+)^{9}Li $\quad Q_m = -153.174$

$$\langle r^2\rangle^{1/2} = 2.519 \pm 0.012 \text{ fm}, Q = 6.5^{+0.9}_{-0.6} \text{ fm}^2,$$

$$b = 1.5\pm^{+0.3}_{-0.2} \text{ fm } [b = \text{oscillator parameter}]$$

$\langle r^2\rangle^{1/2}_{\rm M} = 3.2 \pm 0.3$ fm, $\Omega = 6 \pm 2\ \mu_{\rm N} \cdot \text{fm}^2$ [this value of the magnetic octupole moment implies a deformation of the average nuclear potential].

The elastic scattering of electrons has been studied for E_e up to 700 MeV. Magnetic elastic scattering gives indications of both M1 and M3 contributions. See also (1978DE32). Inelastic scattering populates a number of levels: Table 9.8 displays the parameters of the states. See (1974AJ01, 1979AJ01) for other work and for references.

At $E_e = 134.7$ and 237 MeV (1979BU11) have determined transverse and longitudinal form factors for electrodisintegration in the region of the quasielastic scattering peak. They report the observation of E1 and E2 giant resonance peaks: see Table 9.8. The quasielastic process has been studied in the range 250–580 MeV/c by (1978KU06). For reaction (c) see ^{8}Li. For reaction (e) see (1980ST15). (1979JE04) have measured the ratio π^-/π^+ in the electroproduction of 10 MeV pions. See also (1979SC1E) and the “General” section here.

See also (1979FR1B, 1979FR1F, 1979FR1C, 1983LI1K), (1979MO1G, 1979TI1A, 1980MO1C, 1981MO1H, 1982DE1J) and (1978KE13, 1978TA1D, 1979OK02, 1980ER01, 1980FU1G, 1980SA1E, 1980ST15, 1981BO1T, 1981CH30, 1981DE1T, 1981IS11, 1981KE15, 1981LA1E, 1982BO1G, 1982KE1C, 1983BO1E, 1983OC01; theor.).

17. ^{9}Be($\pi^\pm$, $\pi^\pm$)^{9}Be (See also the “General” section here.)

The elastic scattering, and inelastic scattering to ^{9}Be*(2.43, 6.76), have been studied at $E_{\pi^\pm} = 162$ MeV (1978GE11) and 291 MeV (1981GE03). Quadrupole contributions appear to be quite important for the elastic scattering at 162 MeV (1978GE11), but are much less so at higher energy (1981GE03). The inelastic scattering suggest the importance of radial localization effects (1981GE03). For a study of the (π^+, π^0) reaction see (1981BO06). For measurements of inclusive charged pion scattering yields see (1981MC09).

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	Γ_{γ_0} (eV)
1.78 ± 30	150 ± 50	E1	$\frac{1}{2}^+$	0.30 ± 0.12
2.44 ± 20	< 30	M1	$\frac{5}{2}^-$	0.089 ± 0.010
		E2		$(1.89 \pm 0.14) \times 10^{-3}$ [b]
3.04 ± 20	450 ± 150	E1 [c]	$\frac{5}{2}^+$ [c]	0.30 ± 0.25 [d]
4.7 ± 200	700 ± 300	E(1)		2.4 ± 1.2 [e]
6.4 ± 100	1000 ± 300	E2	$\frac{7}{2}^-$	0.082 ± 0.035
[f]				
13.84 ± 50 [g]				
14.388 ± 15 [h]	< 70	M1	$\frac{3}{2}^-$	6.9 ± 0.5 [f]
15.10 ± 50 [g]				
15.97 ± 30 [g]	≈ 300	M1		3.7 ± 0.8 [e]
16.631 ± 15 [h]	< 70	M2 [i]	$\leq \frac{7}{2}^+$	0.26 ± 0.02 [e]
		M1	$\leq \frac{5}{2}^-$	2.0 ± 0.5 [e]
16.961 ± 15 [h]	< 70	M1	$\frac{1}{2}^-$	11.5 ± 1.4 [f]
17.28		M1	$\leq \frac{5}{2}^-$	7.3 ± 1.3 [e]
17.480 ± 20 [h]	≈ 100	M2 [i]	$\leq \frac{7}{2}^+$	0.40 ± 0.03 [e]
18.02 ± 50 [g]				
18.62 ± 50 [g]				
19.51 ± 50 [g]				
20.76 ± 50 [g]				
[j]				

[a] For references see Table 9.8 in (1979AJ01).

[b] $B(\text{C2}, \omega) \uparrow = 45.7 \pm 3.5\ e^2 \cdot \text{fm}^4$.

[c] Assumed.

[d] The group 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.

[e] $g\Gamma_{\gamma_0}$; where $g = (2J_f + 1)/(2J_i + 1)$.

[f] See (1974AJ01) and Table 9.6 here.

[g] Weak transition.

[h] (1983LO11, 1983LOZZ) report transverse form factors for this state $(0.9 \leq q \leq 2.5\ \text{fm}^{-1})$.

[i] Or pure spin-flip E1.

[j] States belonging to the E1 and E2 giant resonances are reported at $E_x = 19.2 \pm 0.2$ $[4.0 \pm 0.6]$, 28.7 ± 0.5 $[8.9 \pm 1.7]$, 36.3 ± 0.5 $[2.8 \pm 1.3]$, 41 ± 1 $[7.2 \pm 2.0]$ and 58.0 ± 0.4 MeV $[3.1 \pm 0.5]$ MeV (1979BU11) [Γ in brackets]. See also (1974AJ01) for other reported states.

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

(b) ^{9}Be(n, 2n)^{8}Be $\qquad Q_{\rm m} = -1.6655$

The population of ^{9}Be*(0, 1.7, 2.4, 3.1, (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 measured at $E_{\rm n} = 5.9$ to 14.2 MeV [see (1974AJ01, 1979AJ01)] and at 3.5 to 7.1 MeV (1980CO1U; $\rm n_0$, $\rm n_2$), 6.97 to 14.93 MeV (1978HO23; $\rm n_0$, $\rm n_2$) and at 14.6 MeV (1982HAZK; $\rm n_0$). See also (1981DA1K, 1983ANZY), (1979BY01, 1980AK01; theor.) and ^{10}Be.

19. ^{9}Be(p, p)^{9}Be

Elastic and inelastic scattering angular distributions have been studied at many energies in the range $E_{\rm p} = 5$ to 1000 MeV [see (1974AJ01, 1979AJ01)] and at $E_{\rm p} = 2.31$ to 2.73 MeV (1980BO1L; $\rm p_0$), 35.2 MeV (1980FA07; $\rm p_0$), 72 MeV (1982AU1B; $\rm p_0$), 225 MeV (1981RO1F; $\rm p_0$) and 1 GeV (1979AL26; $\rm p_0$). The elastic distributions show pronounced diffraction maxima characteristic of the optical model. A quadrupole-deformed optical model potential is necessary to obtain a good fit to the $\rm p_0$ and $\rm p_2$ angular distributions: see (1974AJ01).

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. The population of ^{9}Be*(1.7) has been studied for $E_{\rm p} = 4.2$ to 5.5 MeV: it is consistent with a scattering length of about -20 fm between a neutron and ^{8}Be. The weighted mean of the values of $E_{\rm x}$ for ^{9}Be*(2.4) listed in (1974AJ01) is 2432 ± 3 keV. ^{9}Be*(3.1) has $E_{\rm x} = 3.03 \pm 0.03$ MeV, $\Gamma = 250 \pm 50$ keV, $J^{\pi} = \frac{3}{2}^{+}, \frac{5}{2}^{+}$. Higher states are observed at $E_{\rm x} = 4.8 \pm 0.2$, 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]. For ^{9}Be*(2.4, 6.8) $B({\rm E2}\uparrow) = 49 \pm 6$ and 24 ± 4 fm^{4} and $\Gamma({\rm E2}\downarrow) = 0.0025$ 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 (1966LA04, 1974AJ01) for references.

The elastic scattering studied at $E_{\rm p} = 25$ MeV (1974BI14) and 225 MeV (1981RO1F) shows that the depolarization parameter, D, deviates from unity and thus that a spin-spin term must be included in the optical parameter. The spin-flip probability at $E_{\rm p-bar} = 31$ MeV is ≈ 0 for the $\rm p_2$ group, which is expected in view of the collective nature of the transition (1981CO08). See also (1978AL1G) and (1979BY01, 1980KO1V, 1981BA50, 1981CO08, 1981GU1B, 1981GU1F, 1981KR17, 1982BA1X, 1982BA14, 1982GU1E; theor.).

20. (a) ^{9}Be(p, 2p)^{8}Li $\qquad Q_{\rm m} = -16.887$

(b) ^{9}Be(p, pd)^{7}Li $\qquad Q_{\rm m} = -16.6950$

(c) ^{9}Be(p, pα)^{5}He $\quad Q_{\rm m} = -2.46$

(d) ^{9}Be(p, pn)^{8}Be $\quad Q_{\rm m} = -1.6655$

(e) ^{9}Be(p, d^{3}He)^{5}He $\quad Q_{\rm m} = -20.82$

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 respctively, and a third peak of uncertain assignment (perhaps due to unresolved states) with $Q = -32.3 \pm 0.6$ MeV. See (1974AJ01). See also (1979KO21; also for (p, pX)), (1979KR1A, 1981FR24). For reaction (b) see (1974AJ01). Reactions (c) and (f) are dominated by quasifree processes at $E_{\rm p} = 101.5$ MeV: $S_\alpha(L = 0) = 0.45$, $S_\alpha(L = 2) = 0.55$ (1980NA09). See also (1982NA1N). Reaction (d) at $E_{\rm p} = 10 - 24$ MeV involves the $\frac{5}{2}^+$ state [3.01 ± 0.02 MeV]. ^{9}Be*(4.7) is also involved (1978JE01). See also (1982PE1F). For pion production see (1979BU1D). See also (1979BA28) and (1978WO1A, 1979BO27, 1979DO03, 1979KI10, 1979MA1M, 1980BO12, 1981IS11; theor.).

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

Angular distributions have been reported in the range 1.0 to 410 MeV [see (1974AJ01, 1979AJ01)] and at $E_{\rm d-bar} = 2.0$ to 2.8 MeV (1982DE1P; d$_0$) and $E_{\rm d} = 12.17$ to 14.43 MeV (1978TA12; d$_0$, d$_1$, d$_2$).

Inelastic groups have been reported to ^{9}Be*(1.7), to states with $E_{\rm x} = 2431.9 \pm 7.0$ keV and 3040 ± 15 keV ($\Gamma = 294 \pm 20$ keV), and to ^{9}B*(4.7, 6.8): see (1974AJ01). See also (1978ZE03, 1979DO03; theor.) and ^{11}B in (1985AJ01).

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

(b) ^{9}Be(t, nt)^{8}Be $\quad Q_{\rm m} = -1.6655$

Angular distributions of elastically scattered tritons have been measured at $E_{\rm t} = 2.10$ MeV [see (1974AJ01)] and at $E_{\vec{\rm t}} = 15$ and 17 MeV (1978SC02). Reaction (b) at $E_{\rm t} = 4.2$ and 4.6 MeV proceeds via ^{9}Be*(2.4): see (1974AJ01). See also (1981ME1D; theor.).

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

(b) ^{9}Be(^{3}He, 2α)^{4}He $\quad Q_{\rm m} = 19.0041$

Angular distributions have been studied for $E(^3{\rm He}) = 1.6$ to 32.6 MeV and at 217 MeV [see (1974AJ01, 1979AJ01)] and at $E(^3{\rm He}) = 46.1$ MeV (1979GO07; elastic). For optical model parameters see references in (1979AJ01). At $E(^3{\rm He}) = 39.8$ MeV, ^{9}Be*(1.7, 2.4, 3.1, 4.7, 6.8, 14.4) are populated. 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). At $E(^3{\rm He}) = 2.1$ to 2.7 MeV quasifree processes are reported by (1978AR21): see ^{8}Be. See also (1981DE1X) and (1979KA1G).

24. (a) ^{9}Be(α, α)^{9}Be

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

(c) ^{9}Be(α, αn)^{8}Be $\qquad Q_{\rm m} = -1.6655$

Angualr distributions have been studied at many energies in the range $E_\alpha = 5.0$ to 104 MeV [see (1974AJ01)] and at $E_\alpha = 35.5$ MeV (1982PE03; α_0, α_1, α_2, α_4, α_5 and α to ^{9}Be*(11.28)) and 65 MeV (1980HA33; α_0, α_2, α_5). See (1972DE01) 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).

At $E_\alpha = 35.5$ MeV, states belonging to the $K = \frac{3}{2}^-$ ground-state band are strongly excited [^{9}Be*(0, 2.43, 6.76, 11.28); it is suggested that the latter has $J^\pi = (\frac{9}{2}^-)$; see, however, reaction 12]. The first three states belonging to the $K = \frac{1}{2}^+$ band are also excited [^{9}Be*(1.68, 3.05, 4.70)] (1982PE03; coupled channels analysis). For reaction (b) see (1974AJ01) and (1980ZH1A; 18 MeV) and (1980WA07; 140 MeV). $S_\alpha = 0.96$ (1976WO11). For reaction (c) see (1974AJ01). See also (1978ZE03, 1981BA20, 1982BU1D; theor.).

25. (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 $E(^6{\rm Li}) = 4$, 6 and 24 MeV and at $E(^7{\rm Li}) = 24$ and 34 MeV: see (1979AJ01).

26. ^{9}Be(^{9}Be, ^{9}Be)^{9}Be

Elastic angular distributions have been obtained at $E(^9{\rm Be}) = 5$, 9, 12 and 16 MeV [see (1979AJ01)], at 14, 20 and 26 MeV (1979UN01) and at 40 to 55 MeV (1983OMZZ; also to ^{9}Be*(2.43); σ (fusion)).

27. ^{9}Be(^{10}B, ^{10}B)^{9}Be

Elastic angular distributions are reported at $E(^{10}\text{B}) = 20.1$ and 30 MeV (1980BO14).

28. (a) ^{9}Be(^{12}C, ^{12}C)^{9}Be
    (b) ^{9}Be(^{13}C, ^{13}C)^{9}Be

Elastic angular distributions have been measured for reaction (a) at $E(^{12}\text{C}) = 12$, 15, 18 and 21 MeV and $E(^9\text{Be}) = 14$, 20, 26 and 43 MeV [see (1979AJ01)] and at $E(^9\text{Be}) = 14$, 20 and 26 MeV (1979UN01), 20 MeV (1979BO1K), 20 and 26.1 MeV (1979JA04), 50 MeV (1977ST20), 69.7 and 76.6 MeV (1979MA21) and 158.4 MeV (1983FUZY). For yield and fusion cross-section measurements see (1978MA44, 1979MA21, 1981JA09, 1982DEZL, 1982HU06). Elastic angular distributions for reaction (b) are reported at $E(^9\text{Be}) = 14$, 20 and 26 MeV (1979UN01) and 19.5 and 25.0 MeV (1979JA04). See also (1978TA1B, 1982JA1E) and (1978GR22, 1980BR05, 1980OH1B, 1981GR17, 1981HU07, 1982LO13, 1983DE1U; theor.).

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

Elastic angular distributions have been measured at $E(^{14}\text{N}) = 25$ and 27.3 MeV: see (1974AJ01). For fusion studies see (1981MA1V, 1982MAZA).

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 in the range $E(^{16}\text{O}) = 15$ to 30 MeV [see (1979AJ01)] and at $E(^9\text{Be}) = 14$, 20 and 26 MeV (1979UN01) and 158.4 MeV (1983FUZY), as well as at $E(^{18}\text{O}) = 12.1$, 16 and 20 MeV [see (1974AJ01)]. See also (1981ST1P, 1982BE54), (1979HU1B, 1979MA30, 1979PA1B, 1981GR17, 1981GU1B; theor.).

31. (a) ^{9}Be(^{24}Mg, ^{24}Mg)^{9}Be
    (b) ^{9}Be(^{26}Mg, ^{26}Mg)^{9}Be
    (c) ^{9}Be(^{27}Al, ^{27}Al)^{9}Be
    (d) ^{9}Be(^{28}Si, ^{28}Si)^{9}Be
    (e) ^{9}Be(^{39}K, ^{39}K)^{9}Be
    (f) ^{9}Be(^{40}Ca, ^{40}Ca)^{9}Be
    (g) ^{9}Be(^{44}Ca, ^{44}Ca)^{9}Be

Elastic angular distributions have been measured at $E(^9\text{Be}) = 14$, 20 and 26 MeV for reactions (a), (c), (d) and at 14 and 17 MeV for reaction (d): see (1979AJ01). Recent measurements are at $E(^9\text{Be}) = 12$ to 30 MeV (1980BO11, 1981HU08; reaction (d)), 14, 20 and 26 MeV (1978UN02, 1979UN01; reactions (a) (nat. Mg), (c), (d), (f)), 20 MeV (1978JA07; reaction (d)), 27 and 40 MeV (1981GL03; reaction (d)), 40 MeV (1981HN04; reactions (e), (f), (g)), 45 and 60 MeV (1980EC01; reactions (d), (f)), 50 MeV (1977ST20; reactions (d), (f)), 158.4 MeV (1983FUZY; reactions (b), (c)) and 121 and 201.6 MeV (1980ZI02; reaction (d)). For fusion studies see (1980EC03, 1983EC01). See also (1980EC04) and (1979SA1E, 1980HU09; theor.).

32. ^{10}Be(d, t)^{9}Be $\qquad Q_\text{m} = -0.5548$

Forward angular distributions have been obtained at $E_\text{d} = 15.0$ 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) [$\approx 165 \pm 25$ 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).

33. ^{10}B(n, d)^{9}Be $\qquad Q_\text{m} = -4.3620$

Angular distributions of the d_0 and d_1 groups have been measured at $E_\text{n} = 14.4$ MeV: see (1974AJ01). See also ^{11}B in (1980AJ01).

34. ^{10}B(p, 2p)^{9}Be $\qquad Q_\text{m} = -6.5865$

The summed proton spectrum at $E_\text{p} = 460$ MeV yields $Q = -6.7 \pm 0.5, -11.9 \pm 0.5, -17.1 \pm 0.6$ (all $l \neq 0$) and $Q = -30.5 \pm 0.6$ MeV ($l = 0$): see (1974AJ01).

35. ^{10}B(d, ^{3}He)^{9}Be $\qquad Q_\text{m} = -1.0930$

Angular distributions of the ^{3}He groups corresponding to ^{9}Be*(0, 2.4) ahev been studied at $E_\text{d} = 11.8$, 28 and 52 MeV [the latter also to ^{9}Be*(6.7)], and at $E_\text{d} = 15$ MeV: $S = 0.72$ and 0.82 for ^{9}Be*(0, 2.4). At $E_{\text{d}-\text{bar}} = 52$ MeV ^{9}Be*(11.3) appears to be strongly populated: see (1979AJ01).

36. ^{10}B(t, α)^{9}Be $\qquad Q_\text{m} = 13.2275$

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 [≈ 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: see (1979AJ01). Angular distributions are also reported at $E_t = 0.9$ and 1.1 MeV to ^{9}Be*(2.4) (1980CI1B). 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: see (1974AJ01). See also (1978KR16; theor.) and ^{13}C in (1981AJ01).

37. ^{10}B(α, ^{5}Li)^{9}Be $\qquad Q_m = -8.551$

See ^{5}Li.

38. ^{11}B(n, t)^{9}Be $\qquad Q_m = -9.5589$

The angular distribution of t_0 has been measured at $E_n = 14.4$ MeV: see (1974AJ01).

39. ^{11}B(p, ^{3}He)^{9}Be $\qquad Q_m = -10.3227$

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 $J = \frac{3}{2}^-, T = \frac{1}{2}$ analogs to ^{9}B*(12.06, 14.01, 16.02). Angular distributions are also reported at $E_p = 40$ MeV. The intensity of the group to ^{9}Be*(3.1) is ≈ 1% of the ground-state group at that energy: see (1974AJ01). The excitation energy of the first $T = \frac{3}{2}$ state is $E_x = 14392.9 \pm 1.8$ keV (1974KA15), using Q_m. See also (1981CO2D) and ^{12}C in (1985AJ01).

40. (a) ^{11}B(d, α)^{9}Be $\qquad Q_m = 8.031$
(b) ^{11}B(d, nα)^{4}He^{4}He $\qquad Q_m = 6.457$

Alpha groups reported corresponding to ^{9}Be*(0, 1.7, 2.4, 3.1). The width of ^{9}Be*(1.7) [$E_x = 1.70 \pm 0.01$ MeV] is $\Gamma_{c.m.} = 220 \pm 20$ keV. The weighted mean of the values of E_x of ^{9}Be*(2.4), reported in (1974AJ01), is 2425 ± 3 keV. The $\frac{5}{2}^+$ state is at $E_x = 3.035 \pm 0.025$ MeV: $\Gamma_{c.m.} = 257 \pm 25$ keV. The ratio Γ_γ/Γ of ^{9}Be*(1.7) $\leq 2.4 \times 10^{-5}$, that for ^{9}Be*(2.4) is reported to be $(1.16 \pm 0.14) \times 10^{-4}$. Since Γ_γ is known from (e, e′) [see Table 9.8: 0.089 ± 0.010 eV], $\Gamma = 0.77 \pm 0.15$ keV. See (1974AJ01, 1979AJ01) for references.

Angular distributions for α_0 and α_2 are reported at $E_d = 0.39$ to 3.9 MeV and at 12 MeV [see (1974AJ01, 1979AJ01)]. 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 ^{8}Be(0) + n. 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.

41. (a) ^{12}C(n, α)^{9}Be $\quad Q_m = -5.7010$
    (b) ^{12}C(n, nα)^{4}He^{4}He $\quad Q_m = -7.2747$

Angular distributions of the α_0 group have been measured at $E_n = 13.9$ to 18.8 MeV [see (1974AJ01)] and at 14 MeV (1981HA1K). ^{9}Be*(1.7, 2.4, 3.1) are also populated. At $E_n = 14.7$ MeV (1981GU12) report the involvement of ^{9}Be*(6.76) which subsequently decays by n-emission. Reaction (b) at $E_n = 13$ to 18 MeV populates ^{9}Be*(2.4). See also (1979SU1C) and ^{12}C, ^{13}C in (1980AJ01, 1981AJ01).

42. ^{13}C(^{3}He, ^{7}Be)^{9}Be $\quad Q_m = -9.060$

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).

43. ^{13}C(α, ^{8}Be)^{9}Be $\quad Q_m = -10.7392$

At $E_\alpha = 65$ MeV angular distributions have been measured for the transitions to ^{9}Be*(0, 2.4) (1976WO11). See also (1979BE1J).

44. ^{19}F(d, ^{12}C)^{9}Be $\quad Q_m = 0.3009$

See (1981GO16) in ^{12}C (1985AJ01).

45. ^{23}Na(d, ^{16}O)^{9}Be $\quad Q_m = -3.0059$

See (1981RU09; $E_d = 13.6$ MeV).

^{9}B

(Figs. 17 and 18)

GENERAL: (See also (1979AJ01).)

Model calculations: (1978AR1H, 1979LA06, 1979MA1J, 1981KO1Q).

Special states: (1981KO1Q).

Reactions involving pions: (1978WA1B, 1979AL1J, 1982EL07, 1982HI02, 1983HU02).

Hypernuclei: (1978PO1A, 1978SO1A, 1979MA1L, 1981WA1J, 1982KO11).

Other topics: (1979BE1H, 1979LA06, 1982NG01).

Ground state of ^{9}*B:* (1982NG01).

1. (a) ^{6}Li(^{3}He, γ)^{9}B	$Q_m = 16.601$	
(b) ^{6}Li(^{3}He, n)^{8}B	$Q_m = -1.975$	$E_b = 16.601$
(c) ^{6}Li(^{3}He, p)^{8}Be	$Q_m = 16.7861$	
(d) ^{6}Li(^{3}He, d)^{7}Be	$Q_m = 0.112$	
(e) ^{6}Li(^{3}He, t)^{6}Be	$Q_m = -4.307$	
(f) ^{6}Li(^{3}He, ^{3}He)^{6}Li		
(g) ^{6}Li(^{3}He, α)^{5}Li	$Q_m = 14.91$	
(h) ^{6}Li(^{3}He, p)^{4}He^{4}He	$Q_m = 16.8779$	

The 90° yields of γ_0 and of γ to ^{9}Be*(2.36) (reaction (a)) has been measured for $E(^3\text{He}) = 0.6$ to 1.2 MeV [as have the 2 α-particles from the decay of ^{8}Be*(16.6) (reaction (c)]: they are reported to show a resonance at $E(^3\text{He}) = 765 \pm 5$ keV [^{9}B*(17.111)], attributed to ^{9}B*(17.076) [$T = \frac{3}{2}$] (1978AL37). The total cross section for reaction (b) increases monotonically from threshold to ≈ 7 mb at 3.8 MeV. It then decreases monotonically from ≈ 20 mb at $E(^3\text{He}) = 5.5$ to 7.6 MeV and also from 8.9 to 26.5 MeV: see (1979AJ01), and ^{8}B.

Absolute cross sections for protons (reaction (c)) to ^{8}Be*(0, 2.9, 16.6, 16.9) as well as for the continuum protons (reaction (h)) have been measured for $E(^3\text{He}) = 0.5$ to 1.85 MeV. Reaction rate parameters, $\langle\sigma\nu\rangle$, have been calculated for $kT = 0.01$ to 10.0 MeV (1980EL02). Excitation functions for p_0 and p_1 have been measured for $E(^3\text{He}) = 0.9$ to 17 MeV, and polarization measurements are reported at $E(^3\text{He}) = 14$ MeV. Resonances are reported at $E(^3\text{He}) = 1.6$ and 3.0 MeV [$\Gamma = 0.25$ and 1.5 MeV]: see (1974AJ01, 1979AJ01), and ^{8}Be. See also (1979SL01). Polarization measurements are also reported at $E(^6\vec{\text{Li}}) = 21$ MeV (1983KO04; VAP; p_0). A resonance in the excitation function for deuterons (reaction (d)) is observed corresponding to ^{9}B*(17.6) (1979BU1E) [$E(^3\text{He}) = 0.7$ to 2.0 MeV]. Polarization measurements at $E(^3\vec{\text{He}}) = 33.3$ MeV for

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	1, 2, 3, 4, 6, 7, 8, 10, 11, 12, 13, 14, 16, 17, 18, 19
(1.6)		≈ 700	(p, α)	4, 13
2.361 ± 5	$\frac{5}{2}^-; \frac{1}{2}$	81 ± 5	α	1, 2, 4, 6, 7, 8, 11, 12, 13, 14, 16, 18
2.788 ± 30	$(\frac{3}{2}, \frac{5}{2})^+; \frac{1}{2}$	550 ± 40	p	4, 6, 11, 13, 16, 18
(4.8 ± 100)		1000 ± 200		4, 9
6.97 ± 60	$\frac{7}{2}^-; \frac{1}{2}$	2000 ± 200	p	4, 6, 9, 11, 14, 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, 14
14.01 ± 70	$; \frac{1}{2}$	390 ± 110		4, 14
14.6550 ± 2.5	$\frac{3}{2}^-; \frac{3}{2}$	0.395 ± 0.042	γ, p	4, 7, 14
14.7 ± 180	$(\frac{5}{2})^-; \frac{1}{2}$	1350 ± 200		11
15.29 ± 40	$; \frac{1}{2}$			14
15.58 ± 40	$; \frac{1}{2}$			14
16.024 ± 25	$; (\frac{1}{2})$	180 ± 16		4, 14
17.076 ± 4	$T = \frac{3}{2}$	22 ± 5	(γ, ^{3}He)	1, 14
17.190 ± 25		120 ± 40	p, d, ^{3}He	4, 5, 14
17.637 ± 10		71 ± 8	p, d, ^{3}He, α	1, 4, 5, 14
(18.6)		1000	p, ^{3}He	1, 11

the d_0 and d_1 groups are reported by (1981BA38). See also (1979AJ01), and ^{7}Be. Excitation functions for t_0 (reaction (e)) have been measured for $E(^3\text{He}) = 10$ to 16 and 23.3 to 25.4 MeV: see (1974AJ01). Polarization measurements are reported at $E(^3\vec{\text{He}}) = 33.3$ MeV for the t_0 group as well as for the ^{3}He ions to ^{6}Li*(0, 2.19) (1981BA37) (reaction (f)). The elastic scattering has also been studied for $E(^3\text{He}) = 0.7$ to 2.0 MeV (1979BU1E). See also ^{6}Li and ^{6}Be.

The $\alpha - \alpha$ coincidences from the $^5\text{Li}_{g.s.}$ decay (reaction (g)) have 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). Polarization measurements of the α-particles to ^{5}Li*(0, 16.7) are reported at $E(^3\vec{\text{He}}) = 33.3$ MeV (1981BA38). For reaction (h) see also (1979AJ01). See also (1982LA20), (1979KA1G, 1981HO1E) and (1980LE06, 1982HI02, 1982LE10; theor.).

2. ^{6}Li(α, n)^{9}B $\qquad Q_{\rm m} = -3.977$

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 n$_0$ group: see (1974AJ01). See also ^{10}B.

3. ^{6}Li(^{6}Li, t)^{9}B $\qquad Q_{\rm m} = 0.805$

Angular distributions of the t$_0$ group have been measured for $E(^6{\rm Li}) = 4.0$ 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): see (1974AJ01).

4. (a) ^{7}Li(^{3}He, n)^{9}B $\qquad Q_{\rm m} = 9.351$

(b) ^{7}Li(^{3}He, np)^{8}Be $\qquad Q_{\rm m} = 9.5360$

For $E(^3{\rm He})$ to 12.5 MeV this reaction populates ^{9}B*(0, (1.6), 2.4, 2.8, (7.0)), and states at $E_{\rm x} = 4.8 \pm 0.1$ MeV [1.0 ± 0.2 MeV], 12.06 ± 0.06 [0.8 ± 0.2], 14.01 ± 0.07 [0.39 ± 0.11], 14.657 ± 0.005 (based on $Q_{\rm m}$) [< 0.045], 16.024 ± 0.025 [0.180 ± 0.016], 17.19 and 17.63 MeV [Γ in brackets]: see (1974AJ01). ^{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): see reaction 9 in ^{9}Be and (1974AJ01). Angular distributions have been measured at $E(^3{\rm He}) = 1.56$ to 5.27 MeV: see (1974AJ01).

5. ^{7}Be(d, p)^{8}Be $\qquad Q_{\rm m} = 16.6738 \qquad E_{\rm b} = 16.489$

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 $\qquad Q_{\rm m} = -1.851$

(b) ^{9}Be(p, pn)^{8}Be $\qquad Q_{\rm m} = -1.6655$

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: see (1979AJ01) and the comments in (1978JE01). See also (1983BY01). The width of the ground state is 540 ± 210 eV (1964TE01).

Angular distributions have been reported at many energies in the range $E_p = 3.5$ to 49.3 MeV [see (1979AJ01)] and at 8.15 to 16.98 MeV (1983BY01; n_0). At $E_p = 10$ to 24 MeV reaction (b) does not appear to involve states of ^{9}B (1978JE01) [see ^{9}Be]: see, however, (1979AJ01). For polarization and yield measurements see ^{10}B. See also (1978BA1F, 1979WA1E, 1979WA1F; applications) and (1979BY01, 1980BA2H, 1983GU1G; theor.).

7. ^{9}Be(^{3}He, t)^{9}B $\qquad Q_m = -1.087$

Angular distributions have been measured for $E(^3\text{He}) = 3.0$ to 25 MeV and at 217 MeV: see (1974AJ01, 1979AJ01). At $E(^3\text{He}) = 39.8$ MeV, $^9\text{B}_{\text{g.s.}}$ is strongly populated and ^{9}B*(2.4, 14.7) are also observed (1969BA06). See also ^{12}C in (1980AJ01).

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

At $E(^6\text{Li}) \approx 31$ MeV $^9\text{B}_{\text{g.s.}}$ is strongly excited. ^{9}B*(2.4) is also populated: see (1974AJ01).

9. $^9\text{C}(\beta^+)^9\text{B} \rightarrow {}^8\text{Be} + \text{p}$ $\qquad Q_m = 16.682$
$\rightarrow {}^5\text{Li} + \alpha$ $\qquad Q_m = 14.81$

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 decay via $^5\text{Li} + \alpha$: (1972ES05).

10. ^{10}B(γ, n)^{9}B $\qquad Q_m = -8.437$

See ^{10}B.

11. ^{10}B(p, d)^{9}B $\qquad Q_m = -6.212$

See Table 9.11. See also (1979AJ01).

12. ^{10}B(d, t)^{9}B $\qquad Q_m = -2.180$

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.

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

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

[a] For references see Table 9.11 in (1974AJ01).

[b] J from best fit to theoretical specroscopic factor (1968KU04).

[c] Weak group.

Angular distributions have been measured at $E_{\rm d} = 11.8$ to 28 MeV. S for ^{9}B*(0, 2.4) are 0.66 and 0.58, respectively. See (1974AJ01, 1979AJ01).

13. (a) ^{10}B(^{3}He, α)^{9}B $\qquad Q_{\rm m} = 12.141$
(b) ^{10}B(^{3}He, αp)^{8}Be $\qquad Q_{\rm m} = 12.3258$

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. 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. 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 $E(^3{\rm He}) = 5.5$ and 33.7 MeV.

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). 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 (1974AJ01).

14. ^{11}B(p, t)^{9}B $\qquad Q_{\rm m} = -11.409$

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, 17.64). $T = \frac{1}{2}$ states are reported at $E_{\rm x} = 15.29 \pm 0.04$ and 15.58 ± 0.04 MeV (1971HA10). The first two $T = \frac{3}{2}$ states have been observed at $E_{\rm x} = 14.6550 \pm 0.0025$ (1974KA15) and 17.076 ± 0.004 MeV [$\Gamma = 22 \pm 5$ keV] (1974BE66).

15. ^{12}C(π^+, π^+t)^{9}B $\qquad Q_{\rm m} = -27.366$

See (1979EL12).

16. (a) ^{12}C(p, α)^{9}B $\qquad Q_{\rm m} = -7.552$
(b) ^{12}C(p, p)^{4}He^{4}He^{4}He $\qquad Q_{\rm m} = -7.2747$

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). The angular distribution to ^{9}B*(6.97) at $E_p = 54.1$ MeV is consistent with $J^\pi = \frac{7}{2}^-$, $\Gamma \approx 2$ MeV: see (1974AJ01). Angular distributions involving the α_0 and α* groups [to ^{4}He*(20.1), 0^+] to ^{9}B$_{\rm g.s.}$ have been studied at $E_p = 45.2$ MeV (1980DA07). At $E_p = 72.4$ MeV, a study of the inclusive (p, dX) reaction shows a structure which, if attributed to ^{9}B, would correspond to $E_x \approx 20.7$ MeV (1981KO28). See also ^{13}N (1981AJ01) and (1978GO14, 1981KA04; theor.).

17. ^{12}C(^{3}He, ^{6}Li)^{9}B $\qquad Q_m = -11.570$

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

18. ^{12}C(α, ^{7}Li)^{9}B $\qquad Q_m = -24.898$

At $E_\alpha = 65$ MeV, ^{9}B$_{\rm g.s.}$ and possibly ^{9}B*(2.36, 2.79) are populated (1978SA26).

19. ^{12}C(^{16}O, ^{19}F)^{9}B $\qquad Q_m = -15.665$

See (1982LE1N).

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

GENERAL: (See also (1979AJ01) for other references in this category and for some reactions on which no new work has been done.)

Model calculations: (1979LA06).

Complex reactions involving ^{9}C: (1981MO20).

Reactions involing pions: (1979AS01, 1979NA1E, 1980BU15, 1983HU02).

Other topics: (1979BE1H, 1979LA06, 1982NG01).

Mass of ^{9}C: Tthe recent Q_0 value for the ^{12}C(^{3}He, ^{6}He)^{9}C reaction (see reaction 3) has not been published. We therefore adopt the Wapstra mass excess: 28913.1 ± 2.5 keV.

1. ^{9}C(β^+)^{9}B $\rightarrow$ ^{8}Be + p $\qquad Q_m = 16.682$

$\rightarrow$ ^{5}Li + α $\qquad Q_m = 14.81$

The half-life of ^{9}C is 126.5 ± 0.9 msec: see (1974AJ01). Several groups of delayed protons are observed indicating the involvement of a number of ^{9}B states: see Table 9.10 (1972ES05). See also (1978RA2A).

Table 9.12: Energy levels of ^{9}C

E_x (MeV ± keV)	$J^\pi; T$	$\tau_{1/2}$ or Γ	Decay	Reactions
g.s.	$(\frac{3}{2}^-); \frac{3}{2}$	$\tau_{1/2} = 126.5 \pm 0.9$ msec	β^+	1, 2, 3 [a]
2.218 ± 11		$\Gamma = 100 \pm 20$ keV		3

[a] See also (1974AJ01, 1979AJ01).

2. ^{9}Be(π^+, π^-)^{9}C $\qquad Q_m = -3.959$

^{9}C$_{\text{g.s.}}$ has been observed at $E_{\pi^+} = 180$ MeV (1980BU15). See also (1979NA1E).

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

$Q_0 = -31.5762 \pm 0.0032$: see (1980KA1J).

At $E(^{3}\text{He}) = 74.1$ MeV a ^{6}He group is observed to the first excited state of ^{9}C (1974BE66). Based on Q_m, $E_x = 2218 \pm 11$ keV and $\Gamma = 100 \pm 20$ keV.

^{9}N

(Not illustrated)

Not observed: see (1979AJ01). See also (1982NG01; theor.).

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(Closed 1 June 1983)

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