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Energy Levels of Light Nuclei
$A = 9$

F. Ajzenberg-Selove

University of Pennsylvania, Philadelphia, Pennsylvania 19104-6396

Abstract: An evaluation of A = 5–10 was published in *Nuclear Physics A*490 (1995), 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 — see introduction to references for more information.

(References closed June 1, 1988)

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^{9}n

(Not illustrated)

Not observed: see (79AJ01) and (83BE55; theor.).

^{9}He

(Fig. 18)

^{9}He has been observed in the ^{9}Be(^{14}C, ^{14}O) reaction at $E(^{14}\text{C}) = 158$ MeV (87BEYI) and in the ^{9}Be(π^-, π^+) reaction at $E_{\pi^-} = 180$ and 194 MeV (87SE05): the atomic mass excesses are 41.5 ± 1.0 MeV and 40.80 ± 0.10 MeV, respectively. We adopt the latter value. ^{9}He is then unstable with respect to decay into $^8\text{He} + \text{n}$ by 1.13 MeV. (87SE05) also report the population of excited states of ^{9}He at 1.2, 3.8 and 7.0 MeV, while (87BEYI) suggest an excited state at ~ 1.8 MeV with $\Gamma \sim 3$ MeV. Excited states are calculated at 1.64, 3.86 and 6.53 MeV, with $J^\pi = \frac{1}{2}^+, \frac{5}{2}^+$ and $\frac{3}{2}^-$ [$(0+1)\hbar\omega$ model space]. In the $(0+2)\hbar\omega$ model space the normal-parity excited states are at 6.44, 29.09 and 29.42 MeV with $J^\pi = \frac{3}{2}^-, \frac{7}{2}^-, \frac{3}{2}^-$. In both cases the ground state is $J^\pi = \frac{1}{2}^-$, as would be expected (85PO10). See also (84BE1C, 88BEYJ), (85AL1G, 85SE1B, 86FL1A, 86FL1B, 87HA1R, 87PE1C, 88SE1C) and (83ANZQ, 84VA06, 86AN07, 87GI1C, 87IK1B; theor.).

^{9}Li

(Figs. 15 and 18)

GENERAL: See also (84AJ01).

Model calculations: (83KU17, 84CH24, 84VA06).

Special states: (83KU17, 84VA06).

Electromagnetic interactions: (83KU17).

Astrophysical questions: (87MA2C).

Complex reactions involving ^{9}Li: (83OL1A, 83WI1A, 84GR08, 85JA1B, 85MA02, 85MO17, 86CS1A, 86HA1B, 86SA30, 86WE1C, 87BA39, 87CH26, 87JA06, 87KO1Z, 87SH1K, 87TA1F 87WA09, 87YA16, 88CA06, 88RU01, 88ST06, 88TA1A).

Reactions involving pions and other mesons (See also reactions 3 and 4.): (85PN01).

Hypernuclei: (82KA1D, 83FE07, 84AS1D, 85PN01, 86DA1B, 86KO1A, 86ME1F, 87MI1A, 87PO1H, 87WA1J, 88TA1B).

Other topics: (85AN28, 85PO10, 86AN07, 87BA1I).

Table 9.1
Energy Levels of ^{9}Li

E_x (MeV ± keV)	$J^\pi; T$	$\tau_{1/2}$ or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
g.s.	$\frac{3}{2}^-; \frac{3}{2}$	$\tau_{1/2} = 178.3 \pm 0.4$ ms	β^-	1, 2, 3, 4, 5, 6
2.691 ± 5	$(\frac{1}{2}^-)$		(γ)	2, 4, 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

Ground-state properties of ^{9}*Li*: (83ANZQ, 84CH24, 85AN28, 85SA32, 87HA30, 88JO1C, 88PO1E, 88VA03)

$$\mu = 3.4391 \pm 0.0006 \text{ n.m. (83CO11). See also (AR87H).}$$
$$Q = (0.88 \pm 0.18)\ Q \text{ of } {}^7\text{Li (83CO11).}$$

[A preliminary report by (88ARZU) gives $Q = (0.69 \pm 0.03) \times Q(^7\text{Li})$.]

The interaction nuclear radius of ^{9}Li is 2.41 ± 0.02 fm (85TA18). [See also for derived nuclear matter, charge and neutron matter r.m.s. radii.]

1. $^9\text{Li}(\beta^-)^9\text{Be}$ $\qquad Q_m = 13.606$

The half-life of ^{9}Li is 178.3 ± 0.4 msec: see (79AJ01). See also (86CU01, 88SA04). ^{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 $^9\text{Li}_{g.s.}$. The probability for delayed neutron decay, P_n, is (49.5 ± 5)%: see (84AJ01). See also (86RO1L), (85HA1K) and (83KU17; theor.).

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

Protons are observed to excited states at $E_x = 2.691 \pm 0.005$, 4.31 ± 0.02, 5.38 ± 0.06 and 6.430 ± 0.015 MeV. The widths of the three highest states, which are unbound, are 100 ± 30, 600 ± 100 and 40 ± 20 keV, respectively. Angular distributions have been studied at $E_t = 11.3$, 15 and 23 MeV. At the highest energy 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): see (79AJ01). See also (84AJ01) and ^{10}Be.

3. ^{9}Be(γ, π^{+})^{9}Li $\qquad Q_{\rm m} = -153.175$

The angular distribution of the π^{+} to ^{9}Li$_{\rm g.s.}$ has been measured at $E_{\rm e} = 200$ MeV (83SH19). For the earlier work see (84AJ01).

4. ^{9}Be(π^{-}, γ)^{9}Li $\qquad Q_{\rm m} = 125.962$

Capture branching ratios to ^{9}Li*(0, 2.69) are reported by (86PE05).

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

See (84GL1E: $E(^{7}$Li$) = 78$ MeV).

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

At $E(^{6}$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: see (79AJ01).

^{9}Be

(Figs. 16 and 18)

GENERAL: See also (84AJ01).

Shell model: (83VA31, 84VA06, 84ZW1A, 85AN16, 87KI1C, 88OR1C, 88WO04).

Cluster and α-particle models: (81PL1A, 82DZ1A, 83JA09, 83MI1E, 83SH38, 85HA1P, 85KW02, 86CR1B, 87VO1D).

Special states: (81PL1A, 83AU1B, 83GO28, 83MI08, 83VA31, 84BA49, 84KO40, 84VA06, 84WO09, 84ZW1A, 85GO1A, 85HA1J, 85PO19, 85SH24, 86AN07, 86WI04, 87KI1C, 87VO1D, 88KW1A).

Electromagnetic transitions and giant resonances: (83GM1A, 83MI08, 84BA49, 84MO1D, 84VA06, 85GO1A, 86ER1A, 86SC1F, 87HO1L, 87KI1C).

Astrophysical questions: (82AU1A, 82CA1A, 83SI1B, 84TR1C, 85MI1E, 85WA1K, 85WE1A, 86BO1H, 87AR1C, 87AU1A, 87DW1A, 87MA2C, 87RO1D, 88RE1B, 88SA2H).

Complex reactions involving ^{9}*Be*: (83CH23, 83EF1A, 83EN04, 83GU1A, 83HA1C, 83MA53, 83NA08, 83OL1A, 83SO08, 83ST1A, 83VA23, 83WA1F, 83WI1A, 84AI1A, 84GR08, 84HI1A, 84IS02, 84RE1A, 84SI15, 84XI1B, 85AG1A, 85BA1V, 85BH1A, 85FA02, 85MA13,

Table 9.2
Energy Levels of ^{9}Be

E_x [a]) (MeV ± keV)	$J^\pi; T$	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
g.s.	$\frac{3}{2}^-; \frac{1}{2}$		stable	2, 3, 4, 9, 10, 11, 12, 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, 40, 41, 42, 43, 44, 45, 46, 48
1.684 ± 7	$\frac{1}{2}^+$	217 ± 10	γ, n	4, 9, 10, 13, 16, 18, 19, 21, 23, 24, 32, 36, 38, 40
2.4294 ± 1.3	$\frac{5}{2}^-$	0.77 ± 0.15	γ, n, α	4, 9, 10, 11, 12, 16, 17, 18, 19, 21, 22, 23, 24, 25, 26, 32, 33, 35, 36, 37, 38, 40, 44
2.78 ± 120	$\frac{1}{2}^-$	1080 ± 110	n	4, 9, 12, 38, 44
3.049 ± 9	$\frac{5}{2}^+$	282 ± 11	γ, n	4, 9, 16, 18, 19, 21, 23, 24, 32, 36, 38, 40
4.704 ± 25	$(\frac{3}{2})^+$	743 ± 55	γ, n	4, 9, 16, 21, 23, 24, 38, 44
6.76 ± 60	$\frac{7}{2}^-$	1540 ± 200	γ, n	9, 11, 16, 17, 18, 19, 21, 23, 24, 25, 35, 40
7.94 ± 80	$(\frac{1}{2}^-)$	~ 1000		12, 19
11.283 ± 24		575 ± 50	n	9, 12, 19, 24, 35, 36
11.81 ± 20	$T = \frac{1}{2}$	400 ± 30	γ, n	9, 12, 13, 37, 44
13.79 ± 30	$T = \frac{1}{2}$	590 ± 60	γ, n	9, 16, 37
14.3922 ± 1.8 [c])	$\frac{3}{2}^-; \frac{3}{2}$	0.381 ± 0.033	γ, n, α	9, 16, 19, 23, 36, 37
14.4 ± 300		~ 800		36
15.10 ± 50			γ	16, 37
15.97 ± 30	$T = \frac{1}{2}$	~ 300	γ	16, 37
16.671 ± 8	$(\frac{5}{2}^+)$	41 ± 4	γ	9, 16, 19, 36
16.9752 ± 0.8 [d])	$\frac{1}{2}^-; \frac{3}{2}$	0.49 ± 0.05	γ, n, p, d	4, 5, 6, 15, 16
17.298 ± 7	$(\frac{5}{2})^-$	200	γ, n, p, d, α	5, 6, 7, 13, 16, 19
17.493 ± 7	$(\frac{7}{2})^+$	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
(18.6 ± 100) [e])	$(T = \frac{3}{2})$	≤ 300	p	
19.20 ± 50		310 ± 80	n, p, d, t	6
19.51 ± 50			γ	13, 16
(19.9 ± 200)			γ, n	13

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

E_x [a]) (MeV ± keV)	$J^\pi; T$	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
(20.47 ± 40)			γ, p, d	13
20.74 ± 30		∼ 1000	γ, n, p, t	13, 16
(21.4 ± 200)			γ, n	13
(22.4 ± 200)		broad	γ, n	13, 19
(23.8 ± 200)			γ, n	13
(27.0 ± 500) [b])		broad	γ, n	13

[a]) See also reactions 14 and 16.
[b]) See footnote [j]) in table 9.8 of (84AJ01).
[c]) See table 9.3.
[d]) See table 9.4.
[e]) See the "General" section.

85MC03, 85MO08, 85MO17, 85PO11, 85PO19, 85RO1F, 85SH1G, 85TR1B, 85WA1F, 85WA22, 86AV1B, 86BA2D, 86BA2H, 86BA1Q, 86HA1B, 86MA19, 86MA1O, 86ME06, 86MO1C, 86PO06, 86RE13, 86SA30, 86SH1F, 86SI1B, 86SO10, 86WA1H, 86WE1C, 87AK1A, 87AR19, 87AU1C, 87BA39, 87BO23, 87DE37, 87FA09, 87FE1A, 87GO17, 87GR11, 87HE1H, 87JA06, 87KI1M, 87KO15, 87KW02, 87LY04, 87MU03, 87MU1D, 87NA01, 87PO03, 87SH23, 87SI1C, 87SO13, 87SO15, 87ST01, 87TA1F, 87TR05, 87VI1B, 87WA09, 87YA16, 87YI1A, 88BL09, 88CA06, 88CH04, 88GO1F, 88KA1L, 88KI05, 88KR11, 88PO1A, 88PO1F, 88RU01, 88SA2H, 88SA19, 88SH1E, 88TS03).

Applications: (83KU1C, 84CA1D, 84IM1A, 87IN1A, 87KU1L).

Muon and neutrino capture and reactions: (83GM1A, 83GU10, 84RO1B, 87KU23, 87SU06).

Reactions involving pions (See also reactions 2 and 17.): (83BU1D, 83GE12, 83GM1A, 83HA45, 83SH19, 83SU08, 83ZA1B, 84BO1H, 84HA1K, 84LE11, 85AR15, 85BA1V, 85LA20, 85IM1A, 85MA1G, 85MO1F, 85PN01, 86CE04, 86PE05, 86RO03, 86YA1D, 86ZO1A, 87AN1E, 87GO1Z, 87GO25, 87GR1G, 87MA1I, 87PI1B, 88BA82, 88GIZT, 88KA1N).

Reactions involving kaons and other mesons: (83BA71, 83BR1E, 83FE07, 83GE13, 83GE1C, 83PO1D, 83ZA1B, 84BO1H, 84MO09, 85MO1F, 85YA05, 86AB07, 86BA1W, 86CH1P, 86DO1B, 86FI1A, 86GA1H, 86YA1D, 86YA02, 86ZO1A, 87PI1B, 87PO1H, 87YA1I, 88BA82, 88MO1B, 88KH03, 88WA1B).

Antinucleon reactions: (87LE32, 88KA1N).

Hypernuclei: (82DZ1A, 82MO1B, 83AU1A, 83BA1M, 83BA1D, 83BR1E, 83FE07, 83KO1C, 83MA64, 83MI1E, 83MO1C, 83OR1A, 83PO1D, 83SH1E, 83ZH1B, 84BA1N,

84BO1A, 84BO1H, 84CH1G, 84CH1H, 84DA1D, 84DZ1B, 84KO1B, 84MI1C, 84MI1E, 84MO09, 84MO1H, 84SC1A, 84ZH1B, 85HA1P, 85IK1A, 85MO1F, 85YA05, 85YU1A, 86BA1W, 86BO1E, 86CH1P, 86DO1B, 86ER1A, 86GA1H, 86MA1C, 86MA1W, 86ME1F, 86PO1G, 86SH1V, 86WA1J, 86YA1D, 86YA1F, 86YA02, 86YU01, 87BA2K, 87BO1L, 87BO1O, 87IK1B, 87JI1A, 87PI1C, 87PO1H, 87WA1J, 87YA1I, 87YA1C, 87YA1M, 88BA82, 88CH48, 88HA1I, 88JI1A, 88MA1G, 88MO1B, 88KH03, 88TA1B, 88WA1B).

Other topics: (84CL11, 84DA11, 84PO11, 85AN28, 85AR1B, 85EL1A, 85KA01, 85SH24, 86BI01, 86KU11, 86IS04, 86SA02, 86SC1F, 87KU1I, 88KW1A, 88OR1C).

Ground-state properties of ^{9}*Be*: (83ANZQ, 83AU1B, 83KU06, 83VA31, 84AN1B, 84BR25, 84FR13, 84MI1B, 85AN16, 85AN28, 85BE59, 85CL1A, 85GO1A, 85HA1P, 85SA32, 86CR1B, 86DZ1A, 86GL1A, 86RO03, 86SY1A, 86WI04, 87HA30, 87KI1C, 87LE1D, 87SA15, 88JO1C, 88VA03, 88WO04).

$\mu = -1.1778 \pm 0.0009$: see (78LEZA).
$Q = +(53 \pm 3)$ mb: see (78LEZA).

The interaction nuclear radius of ^{9}Be is 2.45 ± 0.01 fm [(85TA18); $E = 790$ MeV/ A: see also for derived nuclear matter, charge and neutron matter r.m.s. radii].

The decay $^9\text{Li}_\Lambda \rightarrow \pi^- + {}^9\text{Be}^* \rightarrow \pi^- + \text{p} + {}^8\text{Li}$ appears to take place via a $T = \frac{3}{2}$ state of ^{9}Be at $E_x = 18.6 \pm 0.1$ MeV ($\Gamma \leq 300$ keV) (85PN01).

1. (a) ^{6}Li(t, n)^{8}Be	$Q_m = 16.0225$	$E_b = 17.6879$
(b) ^{6}Li(t, p)^{8}Li	$Q_m = 0.801$	
(c) ^{6}Li(t, n)2 ^{4}He	$Q_m = 16.1144$	

The 0° differential cross section for reaction (a) increases monotonically between $E_t = 0.10$ and 2.4 MeV. A resonance has been reported at $E_t = 1.875$ MeV (^{9}Be*(18.94)). The excitation function for ^{8}Li (reaction (b)) increases monotonically for $E_t = 0.275$ to 1.000 MeV. See (74AJ01) for references. In the range $E_t = 2$ to 10 MeV the total cross section for reaction (b) shows a broad structure [$\Gamma_{c.m.} = 1.5$ MeV] at $E_t = 4.2$ MeV (^{9}Be* = 20.5 MeV) (86AB04; prelim.). Yields and angular distributions for reaction (c) have been measured at $E_t = 2$ to 4.5 MeV (84LIZY; prelim.). See also (84AJ01) for other channels and (84KR1B; theor.).

2. ^{6}Li(^{3}He, π^+)^{9}Be $\qquad Q_m = -121.899$

The energy dependence of the π^+ to $^9\text{Be}_{g.s.}$ has been measured at $E(^3\text{He}) = 235$ to 283 MeV (84WI06).

3. ^{6}Li(α, p)^{9}Be $\quad Q_m = -2.1261$

Angular distributions of p_0 have been measured at $E_\alpha = 10.2$ to 14.7 MeV and at 30 MeV: see (74AJ01). See also (87BI1C) and (83BE1H; theor.).

4. ^{7}Li(d, γ)^{9}Be $\quad Q_m = 16.6951$

For $E_d = 0.1$ to 1.1 MeV, a resonance in the yield of capture γ-rays is observed at $E_d = 360.8 \pm 0.3$ keV (87ZI01), 360.7 ± 1.8 keV (86BE33), corresponding to the excitation of ^{9}Be*(16.97), the second $T = \frac{3}{2}$ state $[J^\pi = \frac{1}{2}^-]$: see table 9.4 (87ZI01). The reduced width for the isospin "forbidden" deuteron breakup is 5.4×10^{-4} relative to the Wigner limit (87ZI01). See also (84AJ01).

5. (a) ^{7}Li(d, n)^{8}Be $\quad Q_m = 15.0297 \quad E_b = 16.6951$
   (b) ^{7}Li(d, α)^{5}He $\quad Q_m = 14.23$
   (c) ^{7}Li(d, n)2 ^{4}He $\quad Q_m = 15.1216$

The yield of neutrons has been measured for $E_d = 0.2$ to 23 MeV [see (79AJ01)] and at $E_d = 0.19$ to 0.55 MeV (87DA25). See also (83SZ1A). Polarization measurements have been carried out at $E_d = 0.64$ MeV and 2.5 to 3.7 MeV [see (74AJ01)] and at 0.40 and 0.46 MeV (84GA07; n_0). Resonances are reported at 0.36, 0.68 and 0.98 MeV: see table 9.3 in (74AJ01). See also (85CA41; astrophys.).

The yields of α-particles have been measured for $E_d = 0.25$ to 3.0 MeV: see (74AJ01, 79AJ01). Resonances are reported at $E_d = 0.75$, 1.00 and 2.5 MeV; the latter is broad: see table 9.3 in (79AJ01). See also (83SZ1A), (86DI1B, 87LE1F; applied) and (84KR1B; theor.).

6. ^{7}Li(d, p)^{8}Li $\quad Q_m = -0.192 \quad E_b = 16.6951$

Excitation functions and cross sections have been measured for $E_d = 0.29$ to 7 MeV [see (74AJ01, 79AJ01, 84AJ01)] and 0.60 to 0.95 MeV (83FI13). See also (83SZ1A, 86AB04). Resonances are reported at $E_d = 0.360(3)$ [< 0.5], 0.776(7) [250], 1.027(7) [60], 2.0 [broad], 2.375(50), 3.220(50) [400 ± 100] and $\sim$4.8 MeV [Γ_{lab} in keV] corresponding to ^{9}Be*(16.975 [see also table 9.4], 17.298, 17.493, (18.5), 18.54, 19.20, 20.4): for references see tables 9.3 in (79AJ01, 84AJ01). The total cross section at the $E_d = 0.78$ MeV resonance is important because it serves as normalization for the ^{7}Be (p, γ) ^{8}B reaction: the "best" value suggested by (83FI13) is 157 ± 10 mb. See also (86BA38) and (74AJ01, 84AJ01) for the earlier values. At $E(^7\text{Li}) = 12.2 \pm 1.3$ MeV [corresponding to $E_d = 3.5$ MeV] the cross section is reported to be 155 ± 20 mb (85HA40).

Table 9.3
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 (keV)	14392.2 ± 1.8		14655.0 ± 2.5
Γ_{γ_0} (eV)	6.9 ± 0.5		(6.9 ± 0.5) [b])
Γ (eV)	381 ± 33		395 ± 42
Γ_{γ_0} (to $\frac{3}{2}^-$)/Γ (%)	1.81 ± 0.09		1.85 ± 0.15
Γ_{γ_1}(to $\frac{1}{2}^+$)/Γ(%)	0.03 ± 0.04		0.00 ± 0.08
Γ_{γ_2} (to $\frac{5}{2}^-$)/Γ (%)	2.05 ± 0.11		1.93 ± 0.22
Γ_{γ_3} (to $\frac{1}{2}^-$)/Γ(%)	< 0.2		} 0.31 ± 0.18
Γ_{γ_4} (to $\frac{5}{2}^+$)/Γ(%)	0.33 ± 0.07		
Γ_{γ_5} (to $\frac{3}{2}^+$)/Γ (%)	0.23 ± 0.05		
$\Gamma_{\gamma_2}/\Gamma_{\gamma_0}$	1.13 ± 0.05		1.03 ± 0.11
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	$\gamma^2_{p_1}/\gamma^2_{p_0}$	3.7 ± 2.2
$\Gamma_{\alpha_0}/\Gamma_{\gamma_0}$	31.2 ± 9.8		

[a]) See tables 9.6 in (79AJ01, 84AJ01) for references.
[b]) Assumed identical to ^{9}Be.

7. ^{7}Li(d, d)^{7}Li $\qquad E_b = 16.6951$

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 (79AJ01).

8. ^{7}Li(d, t)^{6}Li $\qquad Q_m = -0.993 \qquad E_b = 16.6951$

The cross section 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 (74AJ01).

Table 9.4
Parameters [a]) of the second $T = \frac{3}{2}$ state in ^{9}Be, $J^\pi = \frac{1}{2}^-$

E_x (keV)	16975.2 ± 0.8
$\Gamma_{c.m.}$ (eV)	490 ± 50
Γ_γ (eV) [b])	23.4 ± 1.7
Γ_{γ_0} (eV)	16.6 ± 1.2 [c])
Γ_{γ_1} (eV) [b])	2.0 ± 0.2
Γ_{γ_2} (eV) [b])	0.55 ± 0.12
Γ_{γ_3} (eV) [b])	2.2 ± 0.7
Γ_{γ_4} (eV) [b])	< 0.8
Γ_{γ_5} (eV) [b])	2.2 ± 0.3
Γ_n (eV) [b])	< 380 [d])
Γ_{n_0} (eV) [b])	~ 35
Γ_p (eV) [b])	~ 12
Γ_d (eV)	86 ± 18
Γ_α (eV) [b])	< 350 [d])

[a]) (87ZI01) and C. van der Leun, private communication. See also (86BE33).
[b]) Deduced from present results and older work: see table 3 in (87ZI01).
[c]) See also table 9.8.
[d]) $\Gamma_\alpha + \Gamma_n = 380 \pm 50$ eV.

9. ^{7}Li(^{3}He, p)^{9}Be $\qquad Q_m = 11.2016$

Observed proton groups are displayed in table 9.5. The parameters for the particle and γ-decay of observed states are displayed in tables 9.6 and 9.3. Angular distributions have been reported in the range $E(^3\text{He}) = 0.9$ to 14 MeV [see (74AJ01, 79AJ01)] and at $E(^3\vec{\text{He}}) = 14$ and 33 MeV (83LE17, 83RO22; p_0). See also ^{10}B, (84ME11) and (86SC1G; applications).

10. ^{7}Li(α, d)^{9}Be $\qquad Q_m = -7.1516$

Angular distributions of d_0, d_1 and d_2 have been reported at $E_\alpha = 30$ MeV: see (74AJ01). See also (83BE1H; theor.).

Table 9.5
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 (74AJ01, 79AJ01) for references.
[b]) See also table 9.3.

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

Angular distributions of the α-groups to ^{9}Be*(0, 2.43, 6.76) have been measured at $E(^{7}\text{Li}) = 78$ MeV (GL86C: prelim.). For the excitation of ^{4}He* see (87GLZY; prelim.; $E(^{6}\text{Li}) = 93$ MeV). For the earlier work see (74AJ01).

12. ^{9}Li(β^-)^{9}Be $\quad Q_m = 13.606$

^{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. Measurements of β-α coincidences involving ^{9}Be*(11.28) show contributions from the direct n + 2α breakup process as well as the sequential n-emission to ^{8}Be*(3.0)[$J^\pi = 2^+$], followed by breakup into 2α. The branching ratio for the ^{9}Be*(2.43)→^{8}Be$_{g.s.}$ + n decay is $(6.4 \pm 1.2)\%$. ^{9}Be*(2.78) [$J^\pi = \frac{1}{2}^-$] decays mainly to ^{8}Be$_{g.s.}$ + n, presumably by p-wave neutron emission: see (79AJ01, 84AJ01) for references, and (88MI03) for a discussion of the evidence.

Table 9.6
Neutron decay of ^{9}Be states [a]

^{9}Be state (MeV)	l_n	Decay (in %) to		θ^2 (%) [b]
		^{8}Be(0)	^{8}Be*(3.0)	
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 (79AJ01).
[b]) Expressed in units of $\hbar^2/mR^2 = 2.47$ MeV.
[c]) See table 9.3.

13. (a) ^{9}Be(γ, n)^{8}Be $\quad Q_m = -1.6654$
(b) ^{9}Be(γ, α)^{5}He $\quad Q_m = -2.47$
(c) ^{9}Be(γ, n)2 ^{4}He $\quad Q_m = -1.5735$

The photoneutron cross section has been measured from threshold to 320 MeV: see table 9.6 in (66LA04), (79AJ01) and (88DI02). A pronounced peak occurs ~29 keV above threshold with $\sigma_{max} = 1.33 \pm 0.24$ 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 (82FU11). See also (83BA52; theor.) and (87KU05). 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 $E_x = 1.80$ 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 $E_x = 17.1$, 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$_{g.s.}$ 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

Table 9.7
Branching parameters in ^{9}Li β-decay [a]

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

[a]) See table 9.7 in (84AJ01) for references.
[b]) M. J. Martin, private communication.
[c]) 2.78 ± 0.12 MeV, $\Gamma_{\text{c.m.}} = 1.10 \pm 0.12$ MeV; $\theta_p^2 = 0.48 \pm 0.06$: see table 9.7 in (79AJ01).
[d]) $P_n = (49.5 \pm 5)$ %.
[e]) Suggested on the basis of the branching ratios. These should be remeasured [see the ^{9}C(β^+) work of (88MI03): reaction 9, in ^{9}B]. F.C. Barker (private communication) suggests, on the basis of analog evidence, $J^\pi = (\frac{9}{2}, \frac{7}{2})^-$ for ^{9}Be*(11.28).

$E_\gamma = 10$ to 29 MeV as is resonant structure at $E_\gamma = 11.8$, (13.5), 14.8, (17.3), (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 (79AJ01) for references. At $E_\gamma = 1.58$ MeV, the cross section for reaction (c) is 0.40 ± 0.18 μb (83FU13). For the electroproduction and photoproduction of helium nuclei for $E_e = 100$ to 225 MeV see (86LI22). For hadron production at high energies see (83AR1C). See also (87GO1Q), (82DR08; applications), (83FR1B, 84GE1A, 85AH06, 85HA1H) and (83BE45, 83BO1B, 83CA22, 84KO33, 85GO1A, 85SH24, 86DZ1A, 87TE1E; theor.).

14. (a) ^{9}Be(γ, p)^{8}Li $\qquad Q_m = -16.8869$
(b) ^{9}Be(γ, np)^{7}Li $\qquad Q_m = -18.9197$
(c) ^{9}Be(γ, d)^{7}Li $\qquad Q_m = -16.6951$
(d) ^{9}Be(γ, t)^{6}Li $\qquad Q_m = -17.6879$

The yield shows structure in the energy region corresponding to the ^{9}Be levels at 17–19 MeV followed by the giant resonance at $E_\gamma \simeq 23$ 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 (74AJ01) for references. For momentum spectra of protons using tagged photons with $E_\gamma = 360 - 600$ MeV, see (84BA09). See also (84AJ01) and (84HO24).

The integrated cross sections are reported to be 1.0 ± 0.5 MeV · mb ($E_\gamma = 21 - 33$ MeV) for reaction (c) to ^{7}Li*($0 + 0.4$) and 0.6 ± 0.3 MeV · mb ($E_\gamma = 25 - 33$ MeV) for reaction (d) to ^{6}Li(0). The total integrated cross section for [(γ, p) + (γ, pn) + (γ, d) + (γ, t)] is 33 ± 3 MeV · mb. 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, have been reported: see (74AJ01). For momentum spectra of deuterons and tritons at $E_\gamma = 360 - 600$ MeV see (86BA07). Cross sections have been measured in the region of the Δ(1232) resonance by (HO84C) [(γ, pn), (γ, 2p)], (KA87E) [(γ, p), (γ, pn), (γ, 2p)] and (AR86B) [(γ, π^0)]. For a high energy study of hadron production see (83AR1C). See also (86MC1G), (85HO27, 85MA1G) and (83TR04, 86HO11, 87LU1B; theor.).

15. ^{9}Be(γ, γ)^{9}Be

The second $T = \frac{3}{2}$ state of ^{9}Be at $E_x = 16.98$ MeV has been studied in this reaction: see table 9.4 and reaction 4 (87ZI01). See also (86ZI01). With $E_{bs} = 31$ MeV eight resonances in (γ, γ') are reported for $17.4 < E_x < 29.4$ MeV (84AL22).

16. (a) ^{9}Be(e, e)^{9}Be
    (b) ^{9}Be(e, en)^{8}Be $\qquad Q_m = -1.6654$
    (c) ^{9}Be(e, ep)^{8}Li $\qquad Q_m = -16.8869$
    (d) ^{9}Be(e, eα)^{5}Li $\qquad Q_m = -2.47$

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

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

$\langle r^2 \rangle^{1/2}_M = 3.2 \pm 0.3$ fm; $\Omega = 6 \pm 2$ $\mu_N \cdot$ 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. Inelastic scattering populates a number of levels: see table 9.8. At $E_e = 45$ and 49 MeV ^{9}Be*(1.68) has a strongly asymmetric line shape, as expected from its closeness to the ^{8}Be + n threshold. The form factor is dominated by a $0p_{3/2} \rightarrow 1s_{1/2}$ particle-hole transition. ^{9}Be*(2.43) is strongly excited (87KU05). Form factors have also been measured for ^{9}Be*(0, 14.39, 16.67, 16.98, 17.49) by (83LO11; $E_e = 100.0$ to 270.2 MeV). See also (86MA48, 87HY01, 85HY1A). (84WO09) suggest that the $T = \frac{1}{2}$ states [^{9}Be*(16.67, 17.49)] have $J^\pi = \frac{5}{2}^+$ and $\frac{7}{2}^+$, respectively, and that they have large parentage amplitudes with ^{8}Be*($16.6 + 16.9$) [$J^\pi = 2^+$], rather than with ^{8}Be$_{g.s.}$. See (74AJ01, 79AJ01, 84AJ01) for other work and earlier references.

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)
1.684 ± 7 [b])	217 ± 10 [b])	C1	$\frac{1}{2}^+$	0.30 ± 0.12
2.44 ± 20	< 30	M1	$\frac{5}{2}^-$	0.089 ± 0.010
		C2		$(1.89 \pm 0.14) \times 10^{-3}$ [c])
3.04 ± 20	450 ± 150	C1 [d])	$\frac{5}{2}^+$ [d])	0.30 ± 0.25 [e])
4.7 ± 200	700 ± 300	C(1)		2.4 ± 1.2 [f])
6.4 ± 100	1000 ± 300	C2	$\frac{7}{2}^-$	0.082 ± 0.035
13.84 ± 50 [g])				
14.388 ± 15 [h])	< 70	M1	$\frac{3}{2}^-$	6.9 ± 0.5
15.10 ± 50 [g])				
15.97 ± 30 [g])	~ 300	M1		3.7 ± 0.8 [f])
16.631 ± 15 [h])	< 70	M2 [i])	$\leq \frac{7}{2}^+$	0.26 ± 0.02 [f])
		M1	$\leq \frac{5}{2}^-$	2.0 ± 0.5 [f])
16.961 ± 15 [h])	< 70	M1	$\frac{1}{2}^-$	11.5 ± 1.4
17.28		M1	$\leq \frac{5}{2}^-$	7.3 ± 1.3 [f])
17.480 ± 20 [h])	~ 100	M2 [i])	$\leq \frac{7}{2}^+$	0.40 ± 0.03 [f])
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 (79AJ01). See also (84AJ01).
[b]) $B(\text{C1})\uparrow = 0.027 \pm 0.002\ e^2 \cdot \text{fm}^2$ and $B(\text{M2})\uparrow = 8.8 \pm 1.5\ \mu_N^2 \cdot \text{fm}^2$ (87KU05).
[c]) $B(\text{C2}, \omega)\uparrow = 45.7 \pm 3.5\ e^2 \cdot \text{fm}^4$.
[d]) Assumed.
[e]) 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.
[f]) $g\Gamma_{\gamma_0}$; where $g = (2J_f + 1)/(2J_i + 1)$.
[g]) Weak transition.
[h]) (83LO11).
[i]) Or pure spin-flip E1. (84WO09) assign $J^\pi = \frac{5}{2}^+$ and $\frac{7}{2}^+$, respectively, for ^{9}Be*(16.67, 17.49).
[j]) See (74AJ01, 84AJ01) for states reported at higher excitation energies.

Peaks are observed for the quasifree reaction and for the Δ-resonance at 72 ± 3 and 315 ± 20 MeV at $E_e = 537$ MeV, and at 115 ± 5 and 375 ± 10 MeV at $E_e = 730$ MeV. The FWHM widths for the quasifree reaction peaks are 80 ± 5 and 115 ± 5 MeV at $E_e = 537$ and 730 MeV (84OC01, 0C87). For the deep inelastic cross sections at very high energies see (84AR02). A parity-violation study using polarized 300 MeV electrons is reported by (87OT1C; prelim.). See also (84LI07, 85LI15, 86AC1A, 86BA1T, 86LI1G), (84DO1A, 85BE1K, 85KI1A, 87DE1A, 87FR1B, 87HO1D, 87HO1F) and (83AL1B, 84CH20, 84LI1E, 86AZ1A, 86BE1L; theor.).

17. ^{9}Be($\pi^\pm$, $\pi^\pm$)^{9}Be

The elastic scattering and inelastic scattering to ^{9}Be*(2.43, 6.76) have been studied at $E_{\pi^\pm} = 162$ and 291 MeV. Quadrupole contributions appear to be quite important for the elastic scattering at 162 MeV, but are much less so at the higher energy: see (84AJ01) and the “General” section.

18. (a) ^{9}Be(n, n)^{9}Be
(b) ^{9}Be(n, 2n)^{8}Be $\qquad Q_m = -1.6654$

The population of ^{9}Be*(0, 1.7, 2.4, 3.1, (6.8)) has been reported in this reaction: see (74AJ01). For the neutron decay of these states see table 9.6. Angular distributions have been measured at $E_n = 3.5$ to 14.93 MeV [see (74AJ01, 79AJ01, 84AJ01)], at $E_n = 7$ to 15 MeV (83DA22; n_0), 11 to 17 MeV (85TE01; n_0, n_2), 14.6 MeV (85HA02, 86HA1U; n_0) and 14.7 MeV (84SH01; n_0, n_2) as well as at $E_n = 9$ to 17 MeV (84BY03; n_0, n_2; see also for transition to ^{9}Be*(6.76)). See also ^{10}Be, (86MU07), (86RO1H) and (85BE59, 85DI1B, 85GU1D, 87HA1S; theor.).

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

Elastic and inelastic angular distributions have been studied at many energies in the range $E_p = 2.3$ to 1000 MeV [see (74AJ01, 79AJ01, 84AJ01)], at $E_p = 2.31$ to 2.73 MeV (83AL10; p_0), 11 to 17 MeV (MU86A; p_0) and 1 GeV (85AL1F; p_0) as well as at $E_{\vec{p}} =$ 200 MeV (85GL1A; p_0; prelim.) and 220 MeV (85RO15; p_0, p_2). The elastic distributions show pronounced diffraction maxima. A quadrupole-deformed optical-model potential is necessary to obtain a good fit to the p_0 and p_2 angular distributions: see (74AJ01). The spin-flip probability at $E_{\vec{p}} = 31$ MeV is ≈ 0 for the p_2 group, which is expected in view of the collective nature of the transition (81CO08).

The structure corresponding to ^{9}Be*(1.7) is asymmetric, as expected: see reaction 16 and table 9.8 for its parameters. [At $E_p = 13$ MeV the spectra are dominated by ^{9}Be*(2.43) (87KU05)]. The weighted mean of the values of E_x for ^{9}Be*(2.4) listed in (74AJ01) is

2432 ± 3 keV. ^{9}Be*(3.1) has $E_x = 3.03 \pm 0.03$ MeV, $\Gamma = 250 \pm 50$ keV, $J^{\pi} = \frac{3}{2}^{+}, \frac{5}{2}^{+}$. Higher states are observed at $E_x = 4.8 \pm 0.2$, 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 ($\Gamma \sim 1$ MeV), 11.3 ± 0.2 MeV ($\Gamma \sim 1$ MeV), 14.4 ± 0.3 ($\Gamma \sim 1$ 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) $B(\text{E2}\uparrow) = 49 \pm 6$ 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 (66LA04, 74AJ01) for references. For K^{+} production see (AB86B).See also ^{10}B, (82BE1E), (86MU07, 86RO1H) and (84SH1K, 85GU1D, 86BE1L, 86NA15, 87CU01, 87HA01; theor.).

20. (a) ^{9}Be(p, 2p)^{8}Li $\quad Q_m = -16.8869$

(b) ^{9}Be(p, pd)^{7}Li $\quad Q_m = -16.6951$

(c) ^{9}Be(p, pn)^{8}Be $\quad Q_m = -1.6654$

(d) ^{9}Be(p, pt)^{6}Li $\quad Q_m = -17.6879$

(e) ^{9}Be(p, p^{3}He)^{6}He $\quad Q_m = -21.176$

(f) ^{9}Be(p, pα)^{5}He $\quad Q_m = -2.47$

The reactions (p, 2p)X and (p, pd)X have been studied at $E_p = 300$ MeV (83GR21, 84HE03). For reactions (a) and (c) see also ^{8}Li, ^{8}Be (85BE1J, 85DO1B; 1 GeV) and (84AJ01). Reaction (c) at $E_p = 10$–24 MeV involves ^{9}Be*(3.0, 4.7): see (84AJ01). See also (84WA21). For reactions (b) and (d) at $E_p = 58$ MeV see ^{7}Li, ^{6}Li and (85DE17, 84DE1F). For reactions (e) and (f) see (85PA1C; $E_{\vec{p}} = 70$ MeV). The (p, pα) process (reaction (f)) has been studied at $E_p = 150.5$ MeV (85WA13; see for S_{α}). For inclusive proton spectra yields see (85SE15). See also (83AN18, 87BO1N), (86CH1J) and (83KA1A, 84KO1E, 85BO1A, 85GA1A, 85VD03, 86ER1A, 86OS08, 87HA01; theor.).

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

Angular distributions have been measured in the range 1.0 to 410 MeV [see (74AJ01, 79AJ01, 84AJ01)] and at $E_d = 2.0$ to 2.8 MeV (83DE50, 84AN1D). See also ^{11}B in (90AJ01).

Inelastic groups have been reported to ^{9}Be*(1.7, 4.7, 6.8) and to states with $E_x = 2431.9 \pm 7.0$ keV and 3040 ± 15 keV ($\Gamma = 294 \pm 20$ keV): see (74AJ01).

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

(b) ^{9}Be(t, nt)^{8}Be $\qquad Q_m = -1.6654$

Angular distributions of elastically scattered tritons have been measured at E_t = 2.10 MeV and at $E_{\vec{t}}$ = 15 and 17 MeV: see (74AJ01, 84AJ01). Reaction (b) at 4.2 and 4.6 MeV proceeds via ^{9}Be*(2.4): see (74AJ01).

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

(b) ^{9}Be(^{3}He, 2α)^{4}He $\qquad Q_m = 19.0043$

Angular distributions have been studied for $E(^3$He) = 1.6 to 46.1 MeV and at 217 MeV [see (74AJ01, 79AJ01, 84AJ01)]. At $E(^3$He) = 39.8 MeV, ^{9}Be*(1.7, 2.4, 3.1, 4.7, 6.8, 14.4) are populated.

Reaction (b) has been studied in a kinematically complete experiment for $E(^3$He) = 3 to 12 MeV (86LA26) and 11.9 to 24.0 MeV (87WA25). For the earlier work see (84AJ01). See also (87TR01; theor.).

24. (a) ^{9}Be(α, α)^{9}Be

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

Angular distributions have been studied at many energies in the range E_α = 5.0 to 104 MeV [see (74AJ01, 84AJ01)] and E_α = 23.1 MeV (84HU1D, 85HU1B; α_0, α_2). At E_α = 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)] (82PE03; coupled channels analysis). For reaction (b) see (83ZH09; 18 MeV); S_α = 0.96 [see (84AJ01)] and (87WA25; $E(^3$He) = 12 to 24 MeV). See also ^{8}Be, (87BU1E, 87KO1K) and (84LI1D, 85SR01; 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 $E(^6$Li) = 4, 6 and 24 MeV and at $E(^7$Li) = 24 and 34 MeV [see (79AJ01)] as well as at $E(^6$Li) = 32 MeV (85CO09; also to ^{9}Be*(2.43)) and 50 MeV (88TRZY; prelim.) and $E(^7$Li) = 78 MeV (86GL1C, 86GL1D; also to ^{9}Be*(2.43, 6.76). For the interaction cross section at E(Li) = 790 MeV/A see (85TA18).

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

Elastic angular distributions have been obtained at $E(^9\text{Be}) = 5$ to 26 MeV [see (79AJ01, 84AJ01)] and at 35 to 50 MeV (84OM02; also to ^{9}Be*(2.43)). See also (85JA09). For yields and cross sections see (84OM03, 86CU02). For the interaction cross section at $E(^9\text{Be}) = 790$ MeV/A see (85TA18).

27. (a) ^{9}Be(^{10}B, ^{10}B)^{9}Be
(b) ^{9}Be(^{11}B, ^{11}B)^{9}Be

Elastic angular distributions have been reported at $E(^{10}\text{B}) = 20.1$ and 30.0 MeV (83SR01). For yields and cross section measurements see (83SR01, 84DA17, 86CU02). See also (83DU13) and (84IN03, 86RO12; theor.).

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 $E(^9\text{Be}) = 14$ to 76.6 MeV [see (79AJ01, 84AJ01)] and 158.3 MeV (84FU10) as well as at $E(^{12}\text{C}) = 65$ MeV (85GO1H; prelim.; various ^{12}C states). For yield and fusion cross-section measurements see (83JA09, 85DE22) and (84AJ01). Elastic angular distributions for reaction (b) are reported at $E(^9\text{Be}) = 14$ to 26 MeV: see (84AJ01). For yield measurements see (84DA17, 86CU02). See also (83DU13, 84FR1A, 84HA53, 85BE1A, 85CU1A) and (82GU1B, 83KA17, 83OH04, 83SA20, 84HA43, 86BA69, 86HA13, 86KA22, 86MI24; 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 (74AJ01). For a fusion study see (84MA28).

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 (79AJ01)], at $E(^9\text{Be}) = 14$, 20 and 26 MeV [see (84AJ01)], 43 MeV (85WI18) and 157.7 MeV (84FU10), as well as at $E(^{18}\text{O}) = 12.1$, 16 and 20 MeV [see (74AJ01)]. See also (83BI1A, 83DA10, 85BE1A, 85CU1A) and (82GU1B, 83GR18, 83SA20, 84HA43, 88PO1D; theor.).

31. (a) ^{9}Be(^{20}Ne, ^{20}Ne)^{9}Be
(b) ^{9}Be(^{24}Mg, ^{24}Mg)^{9}Be
(c) ^{9}Be(^{26}Mg, ^{26}Mg)^{9}Be
(d) ^{9}Be(^{27}Al, ^{27}Al)^{9}Be
(e) ^{9}Be(^{28}Si, ^{28}Si)^{9}Be
(f) ^{9}Be(^{39}K, ^{39}K)^{9}Be
(g) ^{9}Be(^{40}Ca, ^{40}Ca)^{9}Be
(h) ^{9}Be(^{44}Ca, ^{44}Ca)^{9}Be

Elastic angular distributions have been measured for many of these reactions: see (79AJ01, 84AJ01). Recently they have been studied on ^{26}Mg and ^{40}Ca at $E(^9\text{Be}) = 43$ and 45 MeV, respectively (85WI18) and on ^{26}Mg, ^{27}Al and ^{40}Ca at $E(^9\text{Be}) = 158.1$–158.3 MeV (84FU10). For pion production in reaction (a) see (85FR1C). The interaction cross section for 790 MeV/A ^{9}Be on ^{27}Al has been measured by (85TA18). Breakup measurements involving ^{40}Ca are reported by (84GR20). See also (83BI1A, 84FR1A, 84HA53) and (84GU09, 85AN16, 85BL18; theor.).

32. ^{10}Be(d, t)^{9}Be $\qquad Q_m = -0.5547$

Forward angular distributions have been obtained at $E_d = 15.0$ 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) [$\sim 165 \pm 25$ 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 $E_x = 5.5$ MeV: see (74AJ01).

33. ^{10}B(n, d)^{9}Be $\qquad Q_m = -4.3612$

See (74AJ01) and ^{11}B in (80AJ01).

34. ^{10}B(p, 2p)^{9}Be $\qquad Q_m = -6.5857$

See (74AJ01) and (85BE1J, 85DO1B).

35. ^{10}B(d, ^{3}He)^{9}Be $\qquad Q_m = -1.0922$

Angular distributions of the ^{3}He groups corresponding to ^{9}Be*(0, 2.4) have been studied at $E_d = 11.8$, 28 and 52 MeV [the latter also to ^{9}Be*(6.7)], and at $E_d = 15$ MeV: $S = 0.72$ and 0.82 for ^{9}Be*(0, 2.4). At $E_d = 52$ MeV ^{9}Be*(11.3) appears to be strongly populated: see (79AJ01).

36. ^{10}B(t, α)^{9}Be $\qquad Q_m = 13.2283$

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) [$\Gamma \sim 800$ keV], 14.39 and 16.67 MeV. The $T = \frac{3}{2}$ state ^{9}Be*(14.39) is very weakly populated [$\sim 5\%$ 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 (79AJ01). See also (84AJ01) and (82CI1A; theor.).

37. ^{11}B(p, ^{3}He)^{9}Be $\qquad Q_m = -10.3218$

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}Be*(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 $\sim$1% of the ground-state group at that energy: see (74AJ01). The excitation energy of the first $T = \frac{3}{2}$ state is $E_x = 14392.2 \pm 1.8$ keV (74KA15), using Q_m.

38. (a) ^{11}B(d, α)^{9}Be $\qquad Q_m = 8.0314$
(b) ^{11}B(d, nα)2 ^{4}He $\qquad Q_m = 6.4579$

Alpha groups are 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 (74AJ01), 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 (74AJ01, 79AJ01) 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 (74AJ01, 79AJ01)]. 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*(3.0) have a FWHM of $\simeq$1 MeV, which may imply that ^{9}Be*(2.8) is involved.

39. ^{12}C(γ, pd)^{9}Be $\qquad Q_{\rm m} = -31.7726$

See (86BU1F, 87BU1A, 87VO08).

40. (a) ^{12}C(n, α)^{9}Be $\qquad Q_{\rm m} = -5.7012$
(b) ^{12}C(n, nα)2 ^{4}He $\qquad Q_{\rm m} = -7.2747$

Angular distributions of the α_0 group have been measured at $E_{\rm n}$ = 13.9 to 18.8 MeV [see (74AJ01)] and at 14.1 MeV (84HA48). ^{9}Be*(1.7, 2.4, 3.1, 6.8) are also populated. Reaction (b) at $E_{\rm n}$ = 13 to 18 MeV involves ^{9}Be*(2.4). See (84HA48) for differential cross sections at 14.1 MeV and for partial and total cross sections.

41. ^{12}C(p, p^{3}He)^{9}Be $\qquad Q_{\rm m} = -26.2790$

See (85DE17; $E_{\rm p}$ = 58 MeV).

42. ^{12}C(α, ^{7}Be)^{9}Be $\qquad Q_{\rm m} = -24.692$

See ^{7}Be.

43. (a) ^{12}C(^{7}Li, ^{10}B)^{9}Be $\qquad Q_{\rm m} = -8.492$
(b) ^{12}C(^{13}C, ^{16}O)^{9}Be $\qquad Q_{\rm m} = -3.4856$
(c) ^{12}C(^{14}N, ^{17}F)^{9}Be $\qquad Q_{\rm m} = -10.4360$

For reaction (a) see ^{10}B. For reaction (b) see (88KR11) and (85OS06; theor.). For reaction (c) see (86GO1B; $E(^{14}$N) = 150 MeV).

44. ^{13}C(^{3}He, ^{7}Be)^{9}Be $\qquad Q_{\rm m} = -9.060$

Angular distributions have been obtained at $E(^{3}$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: see (79AJ01).

45. ^{13}C(α, ^{8}Be)^{9}Be $\qquad Q_m = -10.7395$

See ^{8}Be here and ^{9}Be in (79AJ01).

46. ^{14}N(^{7}Li, ^{12}C)^{9}Be $\qquad Q_m = 6.423$

See (86GO1B; $E(^{14}N) = 150$ MeV).

47. ^{16}O(α, ^{11}C)^{9}Be $\qquad Q_m = -24.310$

See (87KW01, 87KW03; theor.).

48. ^{16}O(^{13}C, ^{20}Ne)^{9}Be $\qquad Q_m = -5.912$

See ^{20}Ne in (87AJ02). See also (85KA1J).

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

GENERAL: See also (84AJ01).

Model calculations: (83SH38, 87VO1D).

Special states: (83AU1B, 83FE07, 83GO28, 84KO40, 85PO18, 85PO19, 85SH24, 86AN07, 87BA54, 87VO1D).

Complex reactions involving ^{9}B: (85PO18, 85PO19, 87AR19, 87PO03).

Reactions involving pions: (85PN01).

Hypernuclei: (82KA1D, 83KO1D, 83SH38, 83SH1E, 84ZH1B, 85AH1A, 85PN01, 86DA1B, 86KO1A, 87BO1L, 87MI1A, 87PO1H).

Other topics: (85AN28, 85SH24).

Ground state of ^{9}B: (83ANZQ, 83AU1B, 85AN28).

Table 9.9
Energy levels of ^{9}B

E_x [a]) (MeV ± keV)	J^π; 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, 9, 10, 11, 12, 13, 14, 15, 16
(1.6) [b])		$\simeq 700$	(p, α)	4, 7, 12
2.361 ± 5	$\frac{5}{2}^-$; $\frac{1}{2}$	81 ± 5	α	1, 2, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16
2.788 ± 30 [c])	$(\frac{3}{2}, \frac{5}{2})^+$; $\frac{1}{2}$	550 ± 40	p	4, 6, 9, 10, 12, 14
4.8 ± 100		1200 ± 200	α	4, 7, 12
6.97 ± 60	$\frac{7}{2}^-$; $\frac{1}{2}$	2000 ± 200	p	4, 6, 10, 13, 14
11.70 ± 70	$(\frac{7}{2})^-$; $\frac{1}{2}$	800 ± 50	p	10, 12
12.06 ± 60	$T = \frac{1}{2}$	800 ± 200	p	4, 9, 13
14.01 ± 70	$T = \frac{1}{2}$	390 ± 110		4, 13
14.6550 ± 2.5	$\frac{3}{2}^-$; $\frac{3}{2}$	0.395 ± 0.042	γ, p	4, 7, 13
14.7 ± 180	$(\frac{5}{2})^-$; $\frac{1}{2}$	1350 ± 200		10
15.29 ± 40	$T = \frac{1}{2}$			13
15.58 ± 40	$T = \frac{1}{2}$			13
16.024 ± 25	$T = (\frac{1}{2})$	180 ± 16		4, 13
17.076 ± 4	$T = \frac{3}{2}$	22 ± 5	(γ, ^{3}He)	1, 13
17.190 ± 25		120 ± 40	p, d, ^{3}He	4, 5, 13
17.637 ± 10		71 ± 8	p, d, ^{3}He, α	1, 4, 5, 13
(18.6)		1000	p, ^{3}He	1, 7, 10

[a]) See reactions 6 and 7 for additional states and other values.
[b]) See the discussion in (87BA54; theor.). See also reaction 7.
[c]) See also reactions 6 and 9 for the possible existence of a $\frac{1}{2}^-$ state at $E_x \sim 2.8$ MeV [the analog to ^{9}Be*(2.78)], and see (88MI03).

1. (a) ^{6}Li(^{3}He, γ)^{9}B $\quad Q_{\rm m} = 16.601$

   (b) ^{6}Li(^{3}He, n)^{8}B $\quad Q_{\rm m} = -1.975 \quad E_{\rm b} = 16.601$

   (c) ^{6}Li(^{3}He, p)^{8}Be $\quad Q_{\rm m} = 16.7863$

   (d) ^{6}Li(^{3}He, d)^{7}Be $\quad Q_{\rm m} = 0.112$

   (e) ^{6}Li(^{3}He, t)^{6}Be $\quad Q_{\rm m} = -4.307$

   (f) ^{6}Li(^{3}He, ^{3}He)^{6}Li

   (g) ^{6}Li(^{3}He, α)^{5}Li $\quad Q_{\rm m} = 14.91$

The 90° yields of γ_0 and of γ to ^{9}B*(2.36) (reaction (a)) have been measured for $E(^{3}\text{He}) = 0.6$ to 1.2 MeV [as have the 2α-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) [$T = \frac{3}{2}$]. The total cross section for reaction (b) increases monotonically from threshold to ∼7 mb at 3.8 MeV. It then decreases monotonically from $E(^{3}\text{He}) = 5.5$ to 7.6 MeV and also from 8.9 to 26.5 MeV: see (79AJ01, 84AJ01), 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 have been measured for $E(^{3}\text{He}) = 0.5$ to 1.85 MeV. Reaction rate parameters, $\langle \sigma v \rangle$, have been calculated for $kT = 0.01$ to 10.0 MeV. 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 observed at $E(^{3}\text{He}) = 1.6$ and 3.0 MeV [$\Gamma = 0.25$ and 1.5 MeV]: see (74AJ01, 79AJ01), and ^{8}Be. Polarization measurements are also reported at $E(^{6}\vec{\text{Li}}) = 21$ MeV (VAP; p_0). In the range $E(^{3}\text{He}) = 0.7$ to 2.0 MeV, a resonance in the excitation function for deuterons (reaction (d)) is reported corresponding to ^{9}B*(17.6). Polarization measurements at $E(^{3}\vec{\text{He}}) = 33.3$ MeV for the d_0 and d_1 groups are reported. 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 (74AJ01). 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) (reaction (f)). The elastic scattering has also been studied for $E(^{3}\text{He}) = 0.7$ to 2.0 MeV. The α-α coincidences ($^{5}\text{Li}_{\rm g.s.}$ 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. Polarization measurements of the α-particles to ^{5}Li*(0, 16.7) are reported at $E(^{3}\vec{\text{He}}) = 33.3$ MeV. For a study of the (^{3}He, pα)^{4}He reaction at 3.5, 4.4 and 5.5 MeV see (87ZA07). See (79AJ01, 84AJ01) for references.

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

At $E_\alpha = 28$ and 32 MeV angular distributions have been measured to ^{9}B*(0, 2.36) (85GU1E; prelim.). See also (74AJ01).

3. ^{6}Li(^{6}Li, t)^{9}B $\qquad Q_m = 0.806$

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): see (74AJ01).

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

For $E(^{3}\text{He})$ to 12.5 MeV this reaction populates ^{9}B*(0, (1.6), 2.4, 2.8, (7.0)), and states at $E_x = 4.8 \pm 0.1$ 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_m) [< 0.045], 16.024 ± 0.025 [0.180 ± 0.016], 17.19 and 17.63 MeV [Γ in brackets]: see (74AJ01). ^{9}B*(14.66) is the first $T = \frac{3}{2}$ state in ^{9}B. Its decay properties are displayed in table 9.3 and compared with those of ^{9}Be*(14.40): see reaction 9 in ^{9}Be and (74AJ01). Angular distributions have been measured at $E(^{3}\text{He}) = 1.56$ to 5.27 MeV: see (74AJ01).

5. (a) ^{7}Be(d, n)^{8}B $\qquad Q_m = -2.087 \qquad E_b = 16.489$
   (b) ^{7}Be(d, p)^{8}Be $\qquad Q_m = 16.6740$

The cross section for reaction (a) for $E(^{7}\text{Be}) = 16.9$ MeV is 58 ± 11 mb (83HA17, 85HA40). For $E_d = 0.75$ to 1.70 MeV, resonances in the yields of protons are observed at $E_d = 0.900 \pm 0.025$ MeV (p_0, p_1) and 1.475 ± 0.010 MeV (p_1 only) with $\Gamma_{c.m.} = 120 \pm 40$ and 71 ± 8 keV, respectively [^{9}B* = 17.19 and 17.64 MeV]: see (74AJ01). See also (85CA41; astrophys.).

6. (a) ^{9}Be(p, n)^{9}B $\qquad Q_m = -1.851$
   (b) ^{9}Be(p, pn)^{8}Be $\qquad Q_m = -1.6654$

Angular distributions have been reported at many energies in the range $E_p = 3.5$ to 49.3 MeV [see (79AJ01, 84AJ01)] and at 16.44 and 17.57 MeV (86MU07; n_0).

The width of the ground state is 0.54 ± 0.21 keV: see (74AJ01). At $E_p = 135$ MeV, neutron groups are reported to states at 0, 2.36, 2.71 ± 0.1 [$\Gamma = 0.7 \pm 0.1$ MeV], 2.75 ± 0.3 [3.1 ± 0.2], 4.3 ± 0.2 [1.6 ± 0.2], 12.23 ± 0.1 [0.5 ± 0.1], 13.96 ± 0.1 [not broad] and 14.60 ± 0.1 [0.6 ± 0.1] MeV ((PU85A); Ph.D. thesis quoted and discussed in (88MI03)) [Γ in MeV]. For the earlier work see (79AJ01, 84AJ01). Reaction (b) does not seem to involve states of ^{9}B. See also (84BA1R, 88BO1H, 88HE08), (84AL1C, 87VO1F; applications), (83BY02, 87RA32) and (82GU1A; theor.). For yield and polarization measurements see ^{10}B.

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

Angular distributions have been measured for $E(^{3}{\rm He}) = 3.0$ to 25 MeV and at 217 MeV: see (74AJ01, 79AJ01). At $E(^{3}{\rm He}) = 39.8$ MeV, $^{9}{\rm B}_{\rm g.s.}$ is strongly populated and ^{9}B*(2.4, 14.7) are also observed: see (74AJ01). At $E(^{3}{\rm He}) = 90$ MeV triton groups are reported to states at $E_{\rm x} = 1.16 \pm 0.05$ [1.3 ± 0.05], 4.8 ± 0.03 [1.5 ± 0.3], 16.7 ± 0.1 [< 0.1], 18.6 ± 0.3 and 20.7 ± 0.5 [1.6 ± 0.3] MeV [Γ in MeV], in addition to ^{9}B*(2.36, 2.79, 7.0) and unresolved states at higher $E_{\rm x}$ (87KA36). See also (83DJ1A).

8. (a) ^{9}Be(^{6}Li, ^{6}He)^{9}B $\qquad Q_{\rm m} = -4.575$
(b) ^{9}Be(^{7}Li, ^{7}Be)^{9}B $\qquad Q_{\rm m} = -1.930$

At $E(^{6}{\rm Li}) = 32$ MeV angular distributions are reported to ^{9}B*(0, 2.36) (85CO09). A weak group between these two may have been populated (87BU1F; prelim.). See also (84GL1E; $E(^{6}{\rm Li}) = 93$ MeV, $E(^{7}{\rm Li}) = 78$ MeV).

9. ^{9}C(β^{+})^{9}B $\qquad Q_{\rm m} = 16.498$

The β^{+} decay is observed to ^{9}B*(0, 2.36, 2.8) [$J^{\pi} = \frac{3}{2}^{-}, \frac{5}{2}^{-}, \frac{1}{2}^{-}$] with branching ratios of (60 ± 10), (17 ± 6) and (11 ± 5)%. A state at $E_{\rm x} = 12.1 \pm 0.6$ MeV, $\Gamma = 0.4 \pm 0.1$ MeV is also observed. The remaining strength goes to it (88MI03; and D. Mikolas, priv. comm.). See also (88MI1G). For an earlier study on delayed protons observed in the decay of ^{9}C see reaction 9 and table 9.10 in (74AJ01).

10. (a) ^{10}B(p, d)^{9}B $\qquad Q_{\rm m} = -6.212$
(b) ^{10}B(p, pn)^{9}B $\qquad Q_{\rm m} = -8.436$

Angular distributions are reported at $E_{\rm p} = 18.6$ MeV involving ^{9}B*(0, 2.36) (85BE13). For other observed groups see table 9.10. For reaction (b) see (85BE1J, 85DO1B; $E_{\rm p} =$ 1 GeV; prelim.). See also (88GU1D).

11. ^{10}B(d, t)^{9}B $\qquad Q_{\rm m} = -2.179$

Angular distributions have been measured at $E_{\rm d} = 11.8$ to 28 MeV [see (74AJ01, 79AJ01)] and 18 MeV (88GO02; to ^{9}B*(0, 2.36)). See also (83DJ1A), (88GU1D) and (84SH1E; theor.).

Table 9.10
Levels of ^{9}B from ^{10}B(p, d)^{9}B ^{a})

E_x (MeV ± keV)	$\Gamma_{c.m.}$ (MeV)	l_n	J^π ^{b})
0		1	$\frac{3}{2}^-$
2.35 ± 20		1	$\frac{5}{2}^-$
(2.9) ^{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 (74AJ01).
^{b}) J from best fit to theoretical spectroscopic factor.
^{c}) Weak group.

12. (a) ^{10}B(^{3}He, α)^{9}B $\quad Q_m = 12.141$
(b) ^{10}B(^{3}He, αp)^{8}Be $\quad Q_m = 12.3267$
(c) ^{10}B(^{3}He, 2α)^{5}Li $\quad Q_m = 10.45$

Alpha-particle spectra show the excitation of ^{9}B*(0, 2.4, 2.8, 11.8): see (66LA04). $E_x = 2.361 \pm 0.005$ and 2.788 ± 0.030 MeV, $\Gamma = 81 \pm 5$ and 548 ± 40 keV, respectively. There is some evidence for a state with $E_x \simeq 1.6$ MeV, $\Gamma \sim 0.7$ MeV, but it is not conclusive. 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). Angular distributions have been determined at $E(^3\text{He}) = 5.5$ and 33.7 MeV [see (74AJ01)] and at $E(^3\text{He}) = 22.7$ MeV (87VA1I; to ^{9}B*(0, 2.36); prelim.).

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) [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 [$\theta^2 = 0.74$]. No other excited states of ^{9}B with $3.5 < E_x < 9.5$ MeV decay by proton emission to ^{8}Be(0): see (74AJ01). In a kinematically complete experiment (reaction(c)) at $E(^3\text{He}) = 2.3$ and 5.0 MeV, the E_x of ^{9}B*(4.8) is estimated to be 4.9 ± 0.2 MeV, and its width to be 1.5 ± 0.3 MeV (86AR14). A preliminary report of a study of reactions (b) and (c) at $E(^3\text{He}) = 2.3$ and 5 MeV suggests $E_x = 1.8 \pm 0.3$ MeV, $\Gamma = 0.9 \pm 0.3$ MeV (88AR05). See also (83DJ1A) and (88GO1E; theor.).

13. ^{11}B(p, t)^{9}B $\quad Q_m = -11.409$

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. The first two $T = \frac{3}{2}$ states have been observed at $E_x = 14.6550 \pm 0.0025$ and 17.076 ± 0.004 MeV [$\Gamma = 22 \pm 5$ keV]: see (74AJ01, 79AJ01). See also (87KW01; theor.).

14. (a) ^{12}C(p, α)^{9}B $\qquad Q_m = -7.552$
    (b) ^{12}C(p, p)3 ^{4}He $\qquad Q_m = -7.27473$
    (c) ^{12}C(p, pt)^{9}B $\qquad Q_m = -27.366$

Angular distributions have been measured at $E_p = 14.0$ to 54.1 MeV [see (74AJ01)] and at $E_p = 42.8$ MeV (83PE07; to ^{9}B*(0, 2.36, 6.98)). The transitions to these three states involve $L = 1$, 3 and 3, respectively (83PE07). Earlier work is consistent with $J^\pi = \frac{7}{2}^-$, $\Gamma = 2$ MeV, $E_x = 6.97 \pm 0.06$ MeV. A state at 2.9 ± 0.2 MeV has also been reported: see (74AJ01). Angular distributions involving the α_0 and α^* groups [to ^{4}He*(20.1), 0^+] to ^{9}B$_{g.s.}$ have been studied at $E_p = 42$ MeV: see (84AJ01). For reaction (c) see (85DE17; $E_p = 58$ MeV). See also (84AJ01) and (85MA1F, 86GO28, 87GA08; theor.).

15. ^{12}C(^{3}He, ^{6}Li)^{9}B $\qquad Q_m = -11.570$

Angular distributions have been studied at $E(^3\text{He}) = 30.0$ and 40.7 MeV [see (74AJ01)] and at $E(^3\vec{\text{He}}) = 33.4$ MeV (86CL1B; to ^{9}B*(0, 2.36); also A_y; prelim.).

16. ^{12}C(α, ^{7}Li)^{9}B $\qquad Q_m = -24.898$

Angular distributions have been measured at $E_\alpha = 49.0$ and 80.1 MeV (84GO03). See also (84AJ01).

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

GENERAL: See also (84AJ01).

Model calculations: (83AU1B).

Complex reactions involving ^9C: (83FR1A, 83OL1A, 86HA1B, 87SN1A).

Reactions involving pions: (83AS1B, 84BR22, 85PN01).

Other topics: (82KA1D, 85AN28, 86AN07).

Ground state of ^9C: (83ANZQ, 83AU1B, 85AN28, 87SA15).

Table 9.11
Energy levels of ^{9}C

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

[a] See also (74AJ01, 79AJ01).

1. ^{9}C(β^+)^{9}B $\qquad Q_m = 16.498$

The half-life of ^{9}C is 126.5 ± 0.9 ms: see (74AJ01). The decay is complex: see reaction 9 in ^{9}B.

2. ^{9}Be(π^+, π^-)^{9}C $\qquad Q_m = -17.566$

See (84AJ01). See also (86SE04).

3. ^{12}C(^{3}He, ^{6}He)^{9}C $\qquad Q_m = -31.575$

At $E(^3\text{He}) = 74.1$ MeV a ^{6}He group is observed to the ground state and to a state at $E_x = 2218 \pm 11$ keV, $\Gamma = 100 \pm 20$ keV: see (84AJ01).

^{9}N
(Not illustrated)

Not observed: see (84AJ01) and (83ANZQ, 86AN1J; theor.).

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(Closed 1 June 1988)

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