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Energy Levels of Light Nuclei
$A = 10$

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Abstract: An evaluation of $A = 5$–10 was published in *Nuclear Physics A*490 (1995), p. 1. This version of $A = 10$ 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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^{10}n

(Not illustrated)

^{10}n has not been observed: see (79AJ01). See also (86AB10; theor.).

^{10}He

(Not illustrated)

^{10}He has not been observed. It has been searched for in the spontaneous fission of ^{252}Cf (82AL1C), in the fragmentation of 0.79 GeV/A ^{11}Li ions (87KO1Y) and in the fragmentation of a 30 MeV/A ^{18}O beam (88ST06). The production rate in the latter experiment is $< 3 \times 10^{-5}$ of the measured production probability of ^{8}He (88ST06). See also (84AJ01). The calculated value of the atomic mass excess of ^{10}He is 48.92 ± 0.14 MeV: ^{10}He is then unstable with respect to breakup into $^{9}\text{He} + \text{n}$ and $^{8}\text{He} + 2\text{n}$ by 0.04 and 1.18 MeV, respectively (88BRZZ). See also (84BE1C), (79AJ01, 84AJ01, 87FL1A, 87HA1R, 87PE1C, 87SE05) and (83ANZQ, 83PO1A, 84VA06, 85PO10, 85SA32, 86SA30, 87BL18, 87SA15; theor.).

^{10}Li

(Fig. 22)

At $E(^{9}\text{Be}) = 121$ MeV, ^{10}Li has been observed in the ^{9}Be(^{9}Be, ^{8}B)^{10}Li reaction with a differential cross section (c.m.) of ≈ 30 nb/sr at $\theta = 14°$ (lab): $Q_0 = -34.06 \pm 0.25$ MeV, and the atomic mass excess of ^{10}Li is 33.83 ± 0.25 MeV if the group observed ($\Gamma \approx 1.2 \pm 0.3$ MeV) corresponds to the ground state. $^{10}\text{Li}_{\text{g.s.}}$ would then be unbound with respect to breakup into $^{9}\text{Li} + \text{n}$ by 0.80 ± 0.25 MeV: see (79AJ01). See also (86GI10, 87AB1M), (84AJ01, 85AL1G, 87PE1C) and (82KA1D, 83ANZQ, 83FE07, 84VA06, 85PO10, 86AB10, 88PO1E; theor.).

^{10}Be

(Figs. 19 and 22)

GENERAL: See also (84AJ01).

Model calculations: (83MI1E, 83SH38, 84NI12, 84VA06, 85KW02).

Special states: (84NI12, 84VA06, 87AB1H, 87BL18).

Electromagnetic transitions: (84NI12).

Astrophysical questions: (84BE1F, 84EN1A, 84NE1D, 84SA1D, 85WE1A, 87EL1E, 87GR1Q, 87NA1M, 87SO1E, 88BE1B, 88FE1A, 88HA1M).

Complex reactions involving ^{10}Be: (83EN04, 83OL1A, 83WI1A, 84GR08, 84HI1A, 84ST1B, 85JA1B, 85MA13, 85PO11, 85TA18, 85TR1B, 86AN1F, 86AV1B, 86BA69, 86CS1A, 86HA1B, 86ME06, 86PO06, 86SA30, 86SI1B, 86SO10, 86WE1E, 87AR19, 87BA38, 87BA39, 87CH26, 87DE37, 87FE1A, 87GR11, 87GU04, 87JA06, 87KI05, 87NA01, 87TA1F, 87TR05, 87VI02, 87VI1B, 87WA09, 87YA16, 88BL09, 88CA06, 88KI05, 88KR11, 88RU01, 88SA19).

Applications: (83FA1B, 83KU1C, 83LI1A, 83NE1A, 83SH1G, 83TU1A, 84BE1F, 83BE1H, 84BO1E, 84DO1B, 84EL1B, 84EL1C, 84EN1A, 84HE1B, 84HE1C, 84HO1E, 84IM1A, 84KL1A, 84MA1K, 84MI1D, 84NE1C, 84NE1E, 84PO1C, 84RA1D, 84SE1B 84SE1D, 84SH1L, 84SO1A, 84SO1B, 84SP1B, 84SU1B, 84TU1A, 84TU1C, 84VA1D, 85BE1D, 85RA1A, 85YI1A, 86NI1A, 86SU1H, 86TE1A, 87BE1X, 87BR1Q, 87BR1U, 87DE1P, 87EI1A, 87EL1E, 87GO1W, 87GR1Q, 87IN1A, 87JA1G, 87KU1L, 87LA1G, 87LA1I, 87MO1F, 87NA1M, 87OE1A, 87RA1N, 87RE1H, 87SE1D, 87SE1E, 87SH1N, 87VA1S).

Muon and neutrino capture and reactions: (84KO24).

Reactions involving pions and kaons (See also reactions 3, 10, 15 and 17.): (82BE1D, 84KA1C, 85BE1K, 85TU1B, 86BE1P, 86RA16).

Hypernuclei: (82KA1D, 82WA1A, 83BA1D, 83FE07, 83MI1E, 83PO1D, 84BO1D, 84BO1G, 84CH1G, 84DZ1A, 84ER1A, 84KO1F, 84SH1J, 85AH1A, 85IK1A, 86AN1R, 86BA1W, 86BO1E, 86DA1B, 86MA1C, 86PO1H, 86WA1J, 86ZH1B, 87BO1L, 87BO1O, 87MI1A, 87PO1H, 87WU05, 88GI1B).

Other topics: (84PO11, 85AN28, 85WI1B).

Ground-state properties of ^{10}Be: (83ANZQ, 84FR13, 84NI12, 85AN28, 85SA32, 85TA18, 86WI04, 87BL18, 87HA30, 87LE1D, 87SA15, 88JO1C).

The interaction nuclear radius of ^{10}Be is 2.46 ± 0.03 fm [(85TA18), $E = 790$ MeV/A; see also for derived nuclear matter, charge and neutron matter r.m.s. radii].

$B(\mathrm{E2})\uparrow$ for ^{10}Be*(3.37) $= (5.2 \pm 0.6) \times 10^{-3}\ e^2 \cdot \mathrm{b}^2$ [$Q_0 = 0.229 \pm 0.013$ b] (87RA01).

Table 10.1
Energy levels of ^{10}Be [a])

E_x (MeV ± keV)	$J^\pi; T$	τ or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
g.s.	$0^+; 1$	$\tau_{1/2} = (1.51 \pm 0.06) \times 10^6$ y	β^-	1, 2, 4, 5, 6, 10, 11, 12, 13, 14, 15, 17, 18, 19, 20, 21, 22, 23, 24, 26
3.36803 ± 0.03	$2^+; 1$	$\tau_m = 180 \pm 17$ fs	γ	2, 3, 4, 5, 6, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 26
5.95839 ± 0.05	$2^+; 1$	$\tau_m < 80$ fs	γ	4, 6, 11, 12, 16, 18, 19, 22, 24
5.9599 ± 0.6	$1^-; 1$		γ	4, 11, 12, 18, 19, 22, 24
6.1793 ± 0.7	$0^+; 1$	$\tau_m = 1.1^{+0.4}_{-0.3}$ ps	π, γ	11, 19
6.2633 ± 5	$2^-; 1$		γ	11, 12
7.371 ± 1	$3^-; 1$	$\Gamma = 15.7 \pm 0.5$ keV	n	5, 7, 11, 12
7.542 ± 1	$2^+; 1$	6.3 ± 0.8	n	4, 5, 7, 11, 12, 24
9.27	$(4^-); 1$	150 ± 20	n	5, 7, 11, 12
9.4	$(2)^+; 1$	291 ± 20	n	5, 7, 11, 12, 18, 24
10.57 ± 30	$\geq 1; 1$		n	4, 5, 7, 11
11.76 ± 20		121 ± 10		4, 5, 11, 12, 24
17.79		110 ± 35	γ, n, t	2, 4, 5
18.55		≈ 350	n, t	2, 4, 5
(21.22)	$(2^-; 2)$	sharp	n, p, t	2
(24)				25

[a]) See also table 10.4.

1. ^{10}Be(β^-)^{10}B $\qquad Q_m = 0.5561$

The half-life of ^{10}Be is $(1.51 \pm 0.06) \times 10^6$ y (87HO1P). Log $ft = 13.397 \pm 0.017$ (M.J. Martin, private communication). For the earlier work see (74AJ01).

2. (a) ^{7}Li(t, γ)^{10}Be $\qquad Q_m = 17.2498$
   (b) ^{7}Li(t, n)^{9}Be $\qquad Q_m = 10.4378 \qquad E_b = 17.2498$
   (c) ^{7}Li(t, p)^{9}Li $\qquad Q_m = -2.386$
   (d) ^{7}Li(t, t)^{7}Li
   (e) ^{7}Li(t, α)^{6}He $\qquad Q_m = 9.839$

The yield of γ_0 and γ_1 has been studied for $E_t = 0.4$ to 1.1 MeV [^{10}Be*(17.79) is said to be involved]: see (84AJ01). The neutron yield exhibits a weak structure at $E_t = 0.24$ MeV and broad resonances at $E_t \approx 0.77$ MeV [$\Gamma = 160 \pm 50$ keV] and 1.74 MeV: see (66LA04) [^{10}Be*(17.79, 18.47)]. The total cross section for reaction (c), the yield of neutrons (reaction (b) to ^{9}Be*(14.39)), and the yield of γ-rays from ^{7}Li*(0.48)(reaction (d)) all show a sharp anomaly at $E_t = 5.685$ MeV: $J^{\pi} = 2^{-}$; $T = 2$ is suggested for a state at $E_x = 21.22$ MeV. The total cross section for α_0 (reaction (e)) and the all-neutrons yield do not show this structure: see (83AB1A), (84AJ01) and (85DE19; theor.). An additional anomaly in the proton yield is also reported at $E_t = 8.5$ MeV [^{10}Be*(23.2)][see (87AB1M)]. Differential cross sections and S-factors are reported by (83CE1A) for $E_t = 70$ to 110 keV for ^{6}He*(0, 1.80). The zero-energy S-factor for ^{6}He*(1.80) is 14 ± 2.5 MeV· b. The relevance to an Li-seeded tritium plasma is discussed by (83CE1A). See also (87AB09), (85CA41; astrophys.) and (86AB10; theor.).

3. ^{7}Li(^{3}He, π^{+})^{10}Be $\qquad Q_m = -122.337$

Cross sections have been measured to ^{10}Be*(3.37, 6.2[u], 7.4[u] [u=unresolved]) at $E(^{3}\text{He}) = 235$ MeV. The ground-state group is not seen: its intensity at $\theta_{\text{lab}} = 20°$ is ≤ 0.1 that to ^{10}Be*(3.37) (84BI08).

4. ^{7}Li(α, p)^{10}Be $\qquad Q_m = -2.5642$

See (87BI1C) and (79AJ01).

5. ^{7}Li(^{7}Li, α)^{10}Be $\qquad Q_m = 14.782$

See (74AJ01).

6. ^{9}Be(n, γ)^{10}Be $\qquad Q_m = 6.8120$

The thermal capture cross section is 8.49 ± 0.34 mb (86CO14). Reported γ-ray transitions are displayed in Table 10.2 (83KE11). Partial cross sections involving ^{10}Be*(0, 3.37, 5.96) are listed in (87LY01). See also (84SH1P, 84SH1R) and (85MU03, 86MU1B, 86RA1B, 87LY01, 88MU05; theor.).

Table 10.2
Neutron-capture γ-rays in ^{10}Be [a]

E_γ (keV) [b]	Transition	E_x (keV) [b]
6809.585 (33)	capt.$\rightarrow$ g.s.	6812.038 (29)
5955.9 (5) [a]	5.96 [c] $\rightarrow$ g.s.	5958.387 (51)
3443.374 (30)	capt. $\rightarrow$ 3.37	
3367.415 (30)	3.37 $\rightarrow$ g.s.	3368.029 (29)
2589.999 (60)	5.96 [c] $\rightarrow$ 3.37	
853.605 (60)	capt. $\rightarrow$ 5.96 [c]	

[a] See also tables 10.2 in (74AJ01, 79AJ01).
[b] (83KE11). 12 eV has been added in quadrature to the uncertainties. I am very grateful to T.J. Kennett for his comments. Some of the work displayed in table 10.2 of (84AJ01) is not shown here because it has not been published. However, those particular transitions are shown in fig. 19 since it is clear that they have been observed although the lack of published uncertainties make their inclusion in this table inadvisable.
[c] This is the 2^+ member of the doublet at $E_x = 5.96$ MeV.

7. (a) ^{9}Be(n, n)^{9}Be $\qquad E_b = 6.8120$
(b) ^{9}Be(n, 2n)^{8}Be $\qquad Q_m = -1.6654$

The scattering amplitude (bound) $a = 7.778 \pm 0.003$ fm, $\sigma_{\rm free} = 6.151 \pm 0.005$ b (81MUZQ). The difference in the spin-dependent scattering lengths, $b^+ - b^-$ is $+0.24 \pm 0.07$ (87GL06). See also (87LY01). Total cross section measurements have been reported for $E_n = 2 \times 10^{-3}$ eV to 2.6 GeV/c [see (79AJ01, 84AJ01)] and at 24 keV (83AI01), 7 to 15 MeV (83DA22; also reaction cross sections) and 10.96, 13.89 and 16.89 MeV (85TE01; for n_0 and n_2).

Observed resonances are displayed in Table 10.3. Analysis of polarization and differential cross section data leads to the 3^-, 2^+ assignments for ^{10}Be*(7.37, 7.55). Below $E_n = 0.5$ MeV the scattering cross section reflects the effect of bound 1^- and 2^- states, presumably ^{10}Be*(5.960, 6.26). There is also indication of interference with s-wave background and with a broad $l = 1$, $J^\pi = 3^+$ state. The structure at $E_n = 2.73$ MeV is ascribed to two levels: a broad state at about 2.85 MeV with $J^\pi = 2^+$, and a narrow one, $\Gamma \approx 100$ keV, at $E_n = 2.73$ MeV with a probable assignment of $J^\pi = 4^-$. The 4^- assignment results from a study of the polarization of the n_0 group at $E_n = 2.60$ to 2.77 MeV. A rapid variation of the polarization over this interval is observed, and the data are consistent with 4^- ($l = 2$) for ^{10}Be*(9.27). A weak dip at $E_n \approx 4.3$ MeV is ascribed to a level with $J \geq 1$. See (74AJ01) for references. The analyzing power has been measured for $E_n = 1.6$ to 15 MeV [see (84AJ01)] and at $E_{\vec{n}} = 9$ to 17 MeV (84BY03; n_0, n_2).

The non-elastic and the (n, 2n) cross sections rise rapidly to ≈ 0.6 b (≈ 0.5 b for (n, 2n)) at $E_n \approx 3.5$ MeV and then stay approximately constant to $E_n = 15$ MeV: see (79AJ01, 84AJ01). For total γ-ray production cross sections for $E_n = 2$ to 25 MeV, see

Table 10.3
Resonances in ^{9}Be(n, n)^{9}Be [a]

E_{res} (MeV ± keV)	^{10}Be* (MeV)	$\Gamma_{c.m.}$ (keV)	J^{π}	l	θ^2 (%) [b]
0.6220 ± 0.8	7.371	15.7 ± 0.5	3^-	2	7.5
0.8118 ± 0.7	7.542	6.3 ± 0.8	2^+	1	0.28
2.73	9.27	≈ 100	(4^-)	(2)	
(2.85)	9.4	≈ 400	(2^+)	(1)	
4.3	10.7		≥ 1		

[a]) For references see table 10.3 in (79AJ01).
[b]) $R = 5.6$ fm.

(86GO1L). See also (83GO1H, 84SH1P, 84SH1R, 86MU07), (85PE06; applications) and (86DU1G, 87HA1S; theor.).

8. (a) ^{9}Be(n, p)^{9}Li $\quad Q_m = -12.824 \quad E_b = 6.8120$
(b) ^{9}Be(n, d)^{8}Li $\quad Q_m = -14.662$
(c) ^{9}Be(n, t)^{7}Li $\quad Q_m = -10.438$

Cross sections have been measured at E_n = 14.1–14.9 MeV for reaction (a), 16.3 to 18.7 MeV for (b) and 13.3 to 15.0 (t_1) and 22.5 MeV (reaction (c)): see (79AJ01). A recent measurement (reaction (c)) has been reported at E_n = 14.6 MeV (87ZA01). See (83BO1C) and (84SH1P, 84SH1R, 85BO1D).

9. ^{9}Be(n, α)^{6}He $\quad Q_m = -0.598 \quad E_b = 6.8120$

The cross section for production of ^{6}He shows a smooth rise to a broad maximum of 104±7 mb at 3.0 MeV, followed by a gradual decrease to 70 mb at 4.4 MeV. From $E_n = 3.9$ to 8.6 MeV, the cross section decreases smoothly from 100 mb to 32 mb. Excitation functions have been measured for α_0 and α_1 for E_n = 12.2 to 18.0 MeV: see (79AJ01) for references. See also (83SH1J) and (84SH1P, 84SH1R).

10. ^{9}Be(p, π^+)^{10}Be $\quad Q_m = -133.539$

Angular distributions have been studied at E_p = 185 to 800 MeV [see (84AJ01)] and at $E_{\vec{p}}$ = 650 MeV (86HO23; to ^{10}Be*(0, 3.37)). States at $E_x = 6.07 \pm 0.13$, 7.39 ± 0.13, 9.31 ± 0.24, 11.76 MeV have also been populated. A_y measurements involving ^{10}Be*(0, 3.37) are reported at $E_{\vec{p}}$ = 200 to 250 MeV [see (84AJ01)] and at 650 MeV (86HO23).

Table 10.4
Radiative transitions in ^{9}Be(d, p)^{10}Be [a]

E_x (keV)	Transition	ΔJ^{π}	Mtpl.	Branch (%)	τ_m (ps)	Γ_γ (meV)
3368.0 ± 0.2	3.37 → g.s.	$2^+ \to 0^+$	E2	100	0.189 ± 0.020	3.48 ± 0.37
					0.160 ± 0.030	4.11 ± 0.78
5958.3 ± 0.3	5.96 → 3.37	$2^+ \to 2^+$	M1	> 90	< 0.08	
	5.96 → g.s.	$2^+ \to 0^+$	E2	< 10		
5959.9 ± 0.6	5.96 → g.s.	$1^- \to 0^+$	E1	83^{+10}_{-6}		
	5.96 → 3.37	$1^- \to 2^+$	E1	17^{+6}_{-10}		
6179.3 ± 0.7	6.18 → 5.96	$0^+ \to 1^-$	E1	24 ± 2	$1.1^{+0.4}_{-0.3}$	0.14 ± 0.05
	6.18 → 3.37	$0^+ \to 2^+$	E2	76 ± 2		0.46 ± 0.28
	6.18 → g.s.	$0^+ \to 0^+$	E0			
		1^-	M1	}		
6263.3 ± 5	6.26 → 5.96	$2^- \to$		} ≤ 1		
		2^+	E1	}		
	6.26 → 3.37	$2^- \to 2^+$	E1	99^{+1}_{-2}		
	6.26 → g.s.	$2^- \to 0^+$	M2	1 ± 1		

[a]) See table 10.4 in (79AJ01) for references. However, note that there are several typographical errors in the ^{10}Be*(6.18) decay.

11. ^{9}Be(d, p)^{10}Be $\qquad Q_m = 4.5874$

Angular distributions of proton groups have been studied at many energies in the range $E_d = 0.15$ to 17.3 MeV and at 698 MeV [see (79AJ01, 84AJ01)], as well as at $E_{\vec{d}} = 2.0$ to 2.8 MeV (84DE46, 84AN1D; p_0, p_1; also VAP) and $E_d = 12.5$ MeV (87VA13; p_0, p_1). At $E_d = 15$ MeV $S = 2.1$, 0.23 ($j_n = \frac{3}{2}$) and 0.12 ($j_n = \frac{1}{2}$), ≤ 1.0, 0.065 ($j_n = \frac{5}{2}$) and 0.132 ($j_n = \frac{1}{2}$), for ^{10}Be*(0, 3.37, 5.96, 6.26). The angular distributions show $l_n = 1$ transfer for ^{10}Be*(0, 3.37, 5.958, 7.54), $l_n = 0$ transfer for ^{10}Be*(5.960, 6.26), $l_n = 2$ transfer for ^{10}Be*(7.37). ^{10}Be*(6.18, 9.27, 9.4) are also populated, as are two states at $E_x = 10.57 \pm 0.03$ and 11.76 ± 0.02 MeV. ^{10}Be*(9.27, 9.4, 11.76) have $\Gamma_{c.m.} = 150 \pm 20$, 291 ± 20 and 121 ± 10 keV. See (79AJ01) for references.

Attempts to understand the γ-decay of ^{10}Be*(5.96) and its population in ^{9}Be(n, γ)^{10}Be led to the discovery that it consisted of two states separated by 1.6 ± 0.5 keV. The lower of the two has $J^{\pi} = 2^+$ and decays primarily by a cascade transition via ^{10}Be*(3.37) [it is the state fed directly in the ^{9}Be(n, γ) decay]; the higher state has $J^{\pi} = 1^-$ and goes mainly by a crossover to ^{10}Be(g.s.). Angular correlations measured with the γ-ray detector located normal to the reaction plane ($\equiv$ angular distributions) lead to l_n values consistent with the assignments of 2^+ and 1^- for ^{10}Be*(5.9584, 5.9599) obtained from the character of the γ-decay. ^{10}Be*(6.18) decays primarily to ^{10}Be*(3.37): $E_\gamma = 219.4 \pm 0.3$ keV for the 6.18 → 5.96 transition. See Table 10.4 for a listing of the information on radiative transitions obtained in this reaction and lifetime measurements. For (p, γ) correlations through ^{10}Be*(3.37) see (87VA13) and references in (74AJ01). For polarization measurements see ^{11}B in (90AJ01).

12. ^{9}Be(α, ^{3}He)^{10}Be $Q_m = -13.7658$

Angular distributions have been studied at $E_\alpha = 65$ MeV to ^{10}Be*(0, 3.37, 5.96, 6.26, 7.37, 7.54, 9.33, 11.88). DWBA analyses of these lead to spectroscopic factors which are in poor agreement with those reported in other reactions: see (84AJ01).

13. (a) ^{9}Be(^{7}Li, ^{6}Li)^{10}Be $Q_m = -0.438$
(b) ^{9}Be(^{9}Be, ^{8}Be)^{10}Be $Q_m = 5.1466$

Angular distributions have been measured at $E(^7\text{Li}) = 34$ MeV (reaction (a)) to ^{10}Be*(0, 3.4): $S = 2.07$ and 0.42 ($p_{1/2}$), 0.38 ($p_{3/2}$). See (79AJ01). At $E(^9\text{Be}) = 20$ MeV an angular distribution involving $^8\text{Be}_{\text{g.s.}} + ^{10}\text{Be}_{\text{g.s.}}$ has been measured: transitions to excited states of ^{10}Be are very weak (85JA09).

14. (a) ^{10}Be(p, p)^{10}Be
(b) ^{10}Be(d, d)^{10}Be

Angular distributions of the p_0 and p_1 groups have been measured at $E_p = 12.0$ to 16.0 MeV. The elastically scattered deuterons have been studied at $E_d = 12.0$ and 15.0 MeV: see (74AJ01).

15. (a) ^{10}B(γ, π^+)^{10}Be $Q_m = -140.125$
(b) ^{10}B(e, $e'\pi^+$)^{10}Be $Q_m = -140.125$

Differential cross sections have been measured to ^{10}Be*(0, 3.37) at $E_\gamma = 230$ to 340 MeV [see (84AJ01)] and at $E_e = 185$ MeV (86YA07) and 200 MeV (84BL1B). See also (84AJ01).

16. ^{10}B(μ^-, ν)^{10}Be $Q_m = 105.1031$

Partial capture rates leading to the 2^+ states ^{10}Be*(3.37, 5.96) have been reported: see (84AJ01).

17. ^{10}B(π^-, γ)^{10}Be $Q_m = 139.012$

The photon spectrum from stopped pions is dominated by peaks corresponding to ^{10}Be*(0, 3.4, 6.0, 7.5, 9.4), and branching ratios have been obtained. Those to ^{10}Be*(0, 3.4) are (2.02 ± 0.17)% and (4.65 ± 0.30)%, respectively [absolute branching ratio per stopped pion] (86PE05). See (79AJ01) for the earlier work.

18. (a)^{10}B(n, p)^{10}Be $Q_m = 0.2262$
(b) ^{10}B(d, 2p)^{10}Be $Q_m = -1.9983$

Angular distributions [reaction (b)] are reported at E_d = 55 MeV to ^{10}Be*(0, 3.37, 5.96, 9.4): see (84AJ01). See also (87KW01; theor.). For reaction (a) see (74AJ01) and (87LA16) in ^{11}B (90AJ01).

19. ^{11}Li(β^-)^{11}Be→^{10}Be + n $Q_m = 20.22$

^{11}Li populates several states of ^{10}Be, via delayed neutron emission. Gamma rays have been observed for the transitions 6.18 → 5.96, 6.18 → 3.37, 5.96 (unres.)→ 3.37 and 3.37→ g.s. with I_γ = (0.95 ± 0.35), (1.65 ± 0.70), (3.5 ± 1.0) and (21 ± 6)%, respectively: see Table 11.2 in (85AJ01).

20. ^{11}B(γ, p)^{10}Be $Q_m = -11.2279$

See (84AL22) and ^{11}B in (90AJ01). See also (79AJ01).

21. ^{11}B(p, 2p)^{10}Be $Q_m = -11.2279$

Structure is observed in the summed proton spectrum corresponding to $Q = -10.9 \pm 0.35$, -14.7 ± 0.4, -21.1 ± 0.4, -35 ± 1 MeV: see (74AJ01). See also (85BE1J, 85DO1B; prelim.).

22. ^{11}B(d, ^{3}He)^{10}Be $Q_m = -5.7343$

Angular distributions have been measured at E_d = 11.8 and 22 MeV to ^{10}Be$_{g.s.}$ [see (74AJ01)] and at 52 MeV to ^{10}Be*(0, 3.37, 5.96, 9.60): S = 0.65, 2.03, 0.13, 1.19 (normalized to the theoretical value for the ground state); $\pi = +$ for ^{10}Be*(9.6): see (79AJ01).

23. $^{11}B(^{11}B, ^{12}C)^{10}Be$ $\quad\quad Q_m = 4.7293$

See (85PO02).

24. $^{12}C(^{6}Li, ^{8}B)^{10}Be$ $\quad\quad Q_m = -21.442$

At $E(^6Li) = 80$ MeV, $^{10}Be^*(0, 3.37, 5.96, 7.54, (9.4), 11.8)$ are populated and the angular distribution to $^{10}Be_{g.s.}$ has been measured: see (79AJ01). See also (82AL1A, 83AL1D, 85AL1G).

25. $^{13}C(p, d2p)^{10}Be$ $\quad\quad Q_m = -29.9069$

See (87GI1F) and ^{12}C in (90AJ01).

26. $^{14}C(^{14}C, ^{18}O)^{10}Be$ $\quad\quad Q_m = -5.785$

See (85KO04).

^{10}B
(Figs. 20 and 22)

GENERAL: See also (84AJ01).

Shell and deformed models: (83VA31, 84VA06, 84ZW1A, 87KI1C, 88OR1C, 88WO04).

Cluster and α-particle models: (83SH38, 84NI12, 85KW02).

Special states: (83BI1C, 83FE07, 83VA31, 84NI12, 84VA06, 84ZW1A, 85GO1A, 85HA18, 85HA1J, 86BA1X, 86XU02, 87AB1H, 87BA2J, 87KI1C, 88KW1A).

Electromagnetic transitions and giant resonances: (83GM1A, 84NI12, 85GO1A, 87BA2J, 87KI1C).

Astrophysical questions: (82AU1A, 82CA1A, 84TR1C, 85CA41, 85WA1K, 87AR1C, 87AU1A, 87RO1D, 88KR1G, 88RE1B).

Complex reactions involving ^{10}B: (83EN04, 83GU1A, 83NA08, 83OL1A, 84GR08, 84HI1A, 84HO23, 84RE1A, 84TE1A, 85KA1F, 85LI1B, 85MO08, 85WI18, 86AV1A, 86CA30, 86HA1B, 86MA19, 86ME06, 86MO34, 86SA30, 86SH1F, 86UT01, 86XU02, 86XU1B, 87AK1A, 87AR19, 87BA38, 87BA39, 87BU07, 87DE37, 87FE1A, 87GE1B, 87HE1H, 87HI05, 87JA06,

Table 10.5
Energy levels of ^{10}B [a])

E_x (MeV ± keV)	$J^\pi; T$	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
g.s.	$3^+; 0$	stable		1, 4, 5, 10, 11, 16, 17, 18, 19, 20, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 42, 43, 44, 45, 49, 50, 51, 52, 53, 54, 56, 57
0.71835 ± 0.04	$1^+; 0$	$\tau_m = 1.020 \pm 0.005$ ns $g = +0.63 \pm 0.12$	γ	1, 4, 5, 10, 11, 16, 17, 18, 19, 21, 24, 25, 26, 28, 29, 34, 40, 42, 43, 44, 45, 48, 49, 50, 51, 53, 56
1.74015 ± 0.17	$0^+; 1$	7 ± 3 fs	γ	1, 4, 10, 11, 16, 17, 18, 19, 23, 24, 25, 28, 40, 41, 42, 43, 44, 45, 49, 50, 54
2.1543 ± 0.5	$1^+; 0$	2.13 ± 0.20 ps	γ	1, 4, 11, 16, 17, 18, 19, 24, 25, 26, 28, 29, 34, 42, 43, 44, 45, 48, 49, 50, 51, 52, 53
3.5871 ± 0.5	$2^+; 0$	153 ± 12 fs	γ	1, 4, 5, 11, 16, 17, 18, 24, 25, 26, 28, 29, 41, 42, 44, 49, 50, 51, 53, 56
4.7740 ± 0.5	$3^+; 0$	$\Gamma = 8.4 \pm 1.8$ eV	γ, α	1, 4, 5, 16, 17, 18, 24, 25, 26, 29, 44, 49, 50, 51, 56
5.1103 ± 0.6	$2^-; 0$	0.98 ± 0.07 keV	γ, α	1, 11, 16, 17, 25, 29, 44, 50
5.1639 ± 0.6	$2^+; 1$	$\tau_m < 6$ fs	γ, α	1, 11, 16, 17, 23, 25, 26, 41, 44, 49
5.180 ± 10	$1^+; 0$	$\Gamma = 110 \pm 10$	γ, α	1, 3, 11, 16, 17, 26, 29, 44
5.9195 ± 0.6	$2^+; 0$	6 ± 1	γ, α	1, 3, 11, 16, 17, 18, 25, 26, 28, 29, 44, 49, 50, 51
6.0250 ± 0.6	4^+	0.05 ± 0.03	γ, α	1, 3, 16, 17, 18, 23, 24, 25, 26, 28, 29, 42, 44, 50, 51, 54, 56
6.1272 ± 0.7	3^-	2.36 ± 0.03	α	3, 16, 17, 18, 25, 26, 28, 42, 44, 50
6.560 ± 1.9	$(4)^-$	25.1 ± 1.1	α	3, 16, 17, 18, 25, 26, 28, 29, 42, 44, 49, 50
6.873 ± 5	$1^-; 0+1$	120 ± 5	γ, p, d, α	1, 11, 13, 15, 16
7.002 ± 6	$(1,2)^+; (0)$	100 ± 10	p, d, α	3, 15, 16, 18, 25, 26, 28, 44, 50, 56
7.430 ± 10	$2^{(-)}; 0+1$	100 ± 10	γ, p, d, α	1, 11, 15

Table 10.5 (continued)
Energy levels of ^{10}B

E_x (MeV ± keV)	J^π; T	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
7.467 ± 10	1^+	65 ± 10	p	13, 44
7.478 ± 2	2^+; 1	74 ± 4	γ, p	11, 13, 23, 44
7.5599 ± 0.6	0^+; 1	2.65 ± 0.18	γ, p	11, 13, 16, 44
(7.67 ± 30)	$(1^+; 0)$	250 ± 20	p, d	13, 15
7.819 ± 20	1^-	260 ± 30	p	13, 16, 18, 44
8.07	2^+	800 ± 200	γ, p, d	15, 16, 23
(8.7)	$(1^+, 2^+)$	(≈ 200)	p	13, 15, 56
8.889 ± 6	3^-; 1	84 ± 7	γ, n, p, α	12, 13, 15, 18, 23, 49
8.894 ± 2	2^+; 1	40 ± 1	γ, p, α	11, 13, 15, 18, 23, 49
(9.7)	$(T = 1)$	(≈ 700)	n, p, α	12, 15
10.84 ± 10	$(2^+, 3^+, 4^+)$	300 ± 100	γ, n, p	11, 12, 13, 23, 44
11.52 ± 35		500 ± 100	(γ)	23, 42, 44
12.56 ± 30	$(0^+, 1^+, 2^+)$	100 ± 30	γ, p	11, 13, 23, 44
13.49 ± 5	$(0^+, 1^+, 2^+)$	300 ± 50	γ, p	11, 23, 44
14.4 ± 100		800 ± 200	γ, p, α	3, 11, 42, 44
(18.2 ± 200)		(1500 ± 300)		44
18.43	2^-; 1	340	γ, ^{3}He	5, 7
18.80	2^+, 1^+	< 600	γ, ^{3}He, α	5, 9
19.29	2^-; 1	190 ± 20	γ, n, p, ^{3}He, α	5, 6, 7, 9
20.1 ± 100	1^-; 1	broad	γ, n, p, t, ^{3}He, α	5, 6, 7, 8, 9, 22
(21.1)			γ, ^{3}He	5
23.1 ± 100		broad	γ, n	22

[a]) See also tables 10.6, 10.7 and 10.11.

87KO15, 87LY04, 87MU03, 87NA01, 87PO1I, 87RO10, 87ST01, 87TR05, 87WA09, 87YA16, 88BL09, 88CA06, 88KI05, 88KR11, 88RU01, 88SA19, 88SI01, 88TS03).

Applications: (83AM1A, 83KU1C, 85KO47, 86EN1A, 86WE1E).

Muon and neutrino capture and reactions: (83GM1A, 85MI1D, 87KU23, 87SU06).

Pion and kaon capture and reactions (See also reactions 23 and 48.): (82BE1D, 83AN1F, 83BA71, 83FE07, 83GE12, 83GE13, 83GE1C, 83GM1A, 83MA1H, 83ZI1A, 84BA1U, 84CO1D, 84ER1B, 84KA1C, 84MA1F, 85IM1A, 85RO17, 85TU1B, 85ZI04, 86BE1P, 86GA1F, 86GA1H, 86MA1C, 86PE05, 86RA16, 86RO03, 87AB1E, 87LE1E, 87NA04, 87SI18, 88GIZU, 88GIZT, 88RIZZ).

Hypernuclei: (82KA1D, 83FE07, 83SH38, 83SH1E, 84BO1H, 84CH1H, 84ER1A, 84MA1F, 84MI1C, 84MI1E, 84SH1J, 84ZH1B, 85AH1A, 85DE1D, 85GU1J, 86AN1R, 86CH1P, 86DA1B, 86GA1H, 86MA1C, 86MA1W, 87BO1L, 87MI1A, 87PO1H).

Other topics: (83BI1C, 85AN28, 86IS04, 86YA1F, 87BA2J, 88AJ1B, 88KW1A, 88OR1C).

Ground-state properties of ^{10}B: (83ANZQ, 83VA31, 84BR25, 84MI1B, 84NI12, 84VA06, 85AN28, 85GO1A, 85HA18, 85ZI05, 86DO1E, 86GL1A, 86RO03, 87KI1C, 87LE1D, 88VA03, 88WO04).

$$\mu = +1.80065 \pm 0.00001 \text{ nm: see(78LEZA)}$$
$$Q = +84.72 \pm 0.56 \text{ mb: see (78LEZA).}$$

Mass of ^{10}B: (88WA18) have re-evaluated the evidence on the mass of ^{10}B: the mass excess is 12050.99 ± 0.27 keV. This readjustment includes the value obtained by (84EL05): 12937.32 ± 0.57 μu [mass spectrometer]. I am indebted to A.H. Wapstra for his comments.

Isotopic abundance: $(19.9 \pm 0.2)\%$ (84DE1A).

$$^{10}\text{B*}(0.72)\text{: } \mu = +0.63 \pm 0.12 \text{ nm: see (78LEZA).}$$
$$B(\text{E2})\!\downarrow = 4.18 \pm 0.02\ e^2 \cdot \text{fm}^4 \text{ (83VE03).}$$

1. ^{6}Li(α, γ)^{10}B $\qquad Q_{\text{m}} = 4.4596$

Observed resonances are displayed in Table 10.8. For a discussion of isovector parity mixing between ^{10}B*(5.16, 5.11) [2^+; $T = 1$ and 2^-; $T = 0$] see (84NA07). For a preliminary report involving a target of laser-polarized ^{6}Li atoms see (87MU13). See also (84YA1A, 85CA41; astrophys.).

Table 10.6
Electromagnetic transitions in ^{10}B [a]

Initial state	$J^\pi; T$	Γ_γ (total) (eV)	Branching ratios (%) to final states at:					Γ_γ/Γ
			g.s. $3^+; 0$	0.72 $1^+; 0$	1.74 $0^+; 1$	2.15 $1^+; 0$	3.59 $2^+; 0$	
0.72	$1^+; 0$	6.5×10^{-7}	100					
1.74	$0^+; 1$	0.09 ± 0.04 [b]	< 0.2	100				
2.15	$1^+; 0$	$(3.1 \pm 0.3) \times 10^{-4}$	21.1 ± 1.6	27.3 ± 0.9	51.6 ± 1.6			
3.59	$2^+; 0$	$(4.31 \pm 0.34) \times 10^{-3}$	19 ± 3	67 ± 3	< 0.3	14 ± 2		
4.77	$3^+; 0$	0.020 ± 0.004	0.5 ± 0.1	> 99				$(2.3 \pm 0.3) \times 10^{-3}$
5.11	$2^-; 0$		64 ± 7	31 ± 7	5 ± 5			
5.16	$2^+; 1$	1.5 ± 0.1 [c]	4.4 ± 0.4	22.4 ± 0.6	0.7 ± 0.2	64.8 ± 0.9	7.7 ± 0.3	0.87 ± 0.04
5.18	$1^+; 0$	0.06 ± 0.03			~ 100			
5.92	$2^+; 0$	0.15 ± 0.04	82 ± 5	18 ± 5				≤ 0.009
6.03	4^+	0.11 ± 0.02	$\simeq 100$	[d]				≤ 0.009
6.13	3^-	≤ 21						≤ 0.009
[e]								

[a] For references see table 10.6 in (79AJ01).
[b] From table 10.7.
[c] See also table 10.8 here. Branching ratios and Γ_γ/Γ from (79KE08). The mixing ratios $\delta = 0.12 \pm 0.05$, 0.03 ± 0.03, 0.02 ± 0.03 and 0.00 ± 0.02 for the transitions to ^{10}B*(0, 0.72, 2.15, 3.59), respectively (79KE08).
[d] Other branches <3%.
[e] For γ-decay of higher ^{10}B states see tables 10.8, 10.10 and 10.11. See also table 10.15.

2. (a) ^{6}Li(α, n)^{9}B $\quad Q_m = -3.977 \quad E_b = 4.4596$

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

(c) ^{6}Li(α, d)^{8}Be $\quad Q_m = -1.5669$

The excitation functions for neutrons [from threshold to $E_\alpha = 15.5$ MeV] and for deuterons [$E_\alpha = 9.5$ to 25 MeV; d_0, d_1 over most of range] do not show resonance structure: see (74AJ01, 79AJ01). See also (85GU1J; theor.).

3. (a) ^{6}Li(α, α)^{6}Li $\quad E_b = 4.4596$

(b) ^{6}Li(α, 2α)^{2}H $\quad Q_m = -1.4750$

Excitation functions of α_0 and α_1 have been reported for $E_\alpha \leq 18.0$ MeV and 9.5 to 12.5 MeV, respectively: see (74AJ01). Reported anomalies are displayed in Table 10.9. Elastic scattering and VAP measurements are reported for $E(^6\vec{\text{Li}}) = 15.1$ to 22.7 MeV [see (84AJ01)] and at $E(^6\vec{\text{Li}}) = 19.8$ MeV (86CA1F; also TAP; prelim.). Small anomalies have been reported in reaction (b) corresponding to ^{10}B*(8.67, 9.65, 10.32, 11.65): see (84AJ01). See, however, Table 10.5. See also ^{6}Li, (87BU1E), (86ST1E; applications) and (86GA1F, 86YA15, 88LE06: theor.).

4. ^{6}Li(^{6}Li, d)^{10}B $\quad Q_m = 2.985$

Angular distributions of deuteron groups have been determined at $E(^6\text{Li}) = 2.4$ to 9.0 MeV (d_0, d_1, d_3) and 7.35 and 9.0 MeV (d_4, d_5). The d_2 group is also observed but its intensity is weak: see (74AJ01) and ^{12}C in (80AJ01).

5. ^{7}Li(^{3}He, γ)^{10}B $\quad Q_m = 17.7873$

Capture γ-rays have been observed for $E(^3\text{He}) = 0.8$ to 6.0 MeV. The γ_0 and γ_5 yields [to ^{10}B*(0, 4.77)] show resonances at $E(^3\text{He}) = 1.1$ and 2.2 MeV [$E_{\text{res}} = 0.92$ and 2.1 MeV], the γ_1 and γ_4 yields [to ^{10}B*(0.72, 3.59)] at 1.4 MeV and the γ_4 yield at 3.4 MeV: see Table 10.10 in (79AJ01). Both the 1.1 and 2.2 MeV resonances [^{10}B*(18.4, 19.3)] appear to result from s-wave capture; the subsequent decay is to two 3^+ states [^{10}B*(0, 4.77)]. Therefore the most likely assignment is 2^-, $T = 1$ for both [there appears to be no decay of these states via α_2 to ^{6}Li*(3.56) which has $J^\pi = 0^+$, $T = 1$: see reaction 9]. The assignment for ^{10}B*(18.8) [1.4 MeV resonance] is 1^+ or 2^+ but there appears to be α_2 decay and therefore $J^\pi = 2^+$. ^{10}B*(20.2) [3.4 MeV resonance] has an isotropic angular distribution of γ_4 and therefore $J^\pi = 0^+, 1^-, 2^-$. The γ_2 group resonates at this energy which eliminates 2^-, and 0^+ is eliminated on the basis of the strength of the transition which is too large for E2. See (74AJ01) for references.

Table 10.7
Lifetime of ^{10}B states

^{10}B* (MeV)	τ_m	Reactions	Refs.
0.72	1.020 ± 0.005 ns	^{10}B(p, p′)	(83VE03) [a]
1.74	7 ± 3 fs	^{6}Li(α, γ)	(79KE08)
2.15	2.30 ± 0.26 ps	mean	(79AJ01) [b]
	1.9 ± 0.3 ps	^{6}Li(α, γ)	(79KE08)
	2.13 ± 0.20 ps	mean	all values
3.59	153 ± 13 fs	mean	(79AJ01)
	150 ± 30 fs	^{6}Li(α, γ)	(79KE08)
	153 ± 12 fs	mean	all values
5.16	< 6 fs	^{6}Li(α, γ)	(79KE08)

[a]) See also table 10.20 of (66LA04).
[b]) Table 10.9 in (79AJ01).

6. ^{7}Li(^{3}He, n)^{9}B $Q_m = 9.351$ $E_b = 17.7873$

The excitation curve is smooth up to $E(^3\text{He}) = 1.8$ MeV and the n_0 yield shows resonance behavior at $E(^3\text{He}) = 2.2$ and 3.25 MeV, $\Gamma_{\text{lab}} = 270 \pm 30$ and 500 ± 100 keV. No other resonances are observed up to $E(^3\text{He}) = 5.5$ MeV. See Table 10.10 in (79AJ01), (86AB10; theor.) and (74AJ01).

7. ^{7}Li(^{3}He, p)^{9}Be $Q_m = 11.2016$ $E_b = 17.7873$

The yield of protons has been measured for $E(^3\text{He}) = 0.60$ to 4.8 MeV: there is some indication of weak maxima at 1.1, 2.3 and 3.3 MeV. Measurements of A_y for the ground-state group at $E(^3\vec{\text{He}}) = 14$ MeV (83LE17, 83RO22) and 33 MeV (83LE17) and of the polarization at $E(^3\text{He}) = 14$ MeV (84ME11, 84TR03) have been reported. $P = A$ in this and in the inverse reaction [see reaction 4 in ^{12}C (85AJ01) for some additional comments]. For earlier references see (84AJ01). See also (86AB10; theor.).

8. (a) ^{7}Li(^{3}He, d)^{8}Be $Q_m = 11.7606$ $E_b = 17.7873$
(b) ^{7}Li(^{3}He, t)^{7}Be $Q_m = -0.880$
(c) ^{7}Li(^{3}He, ^{3}He)^{7}Li

Yields of deuterons have been measured for $E(^3\text{He}) = 1.0$ to 2.5 MeV (d_0) and yields of tritons are reported for 2.0 to 4.2 MeV (t_0): a broad peak is reported at $E(^3\text{He}) \approx 3.5$ MeV in the t_0 yield. See (79AJ01) for references. Polarization measurements are reported at

Table 10.8
Levels of ^{10}B from $^{6}Li(\alpha, \gamma)^{10}B$ [a]

E_{res} (keV)	E_x (MeV ± keV)	$J^\pi; T$	Γ_{lab} (keV)	Decay to E_t	Branch (%)	$\omega\gamma$ (eV)	Γ_γ (eV)
500 ± 25	4.760	$3^+; 0$	$(1.4 \pm 0.3) \times 10^{-2}$	0	0.5 ± 0.1		
				0.72	> 99	$(4.1 \pm 0.4) \times 10^{-2}$ [c]	0.018 ± 0.002 [c]
1085	5.112	$2^-; 0$	1.63 ± 0.11 [b]	0	64 ± 7	0.059 ± 0.012 [d]	
				0.72	31 ± 7	0.028 ± 0.008	
				1.74	5 ± 5	0.005 ± 0.005	
1175 [e]	5.166	$2^+; 1$	$(2.8 \pm 0.3) \times 10^{-3}$	0	4.4 ± 0.4	0.018 ± 0.002	0.068 ± 0.007
				0.72	22.4 ± 0.6	0.090 ± 0.008	0.33 ± 0.03
				1.74	0.7 ± 0.2	$(2.8 \pm 0.8) \times 10^{-3}$	0.010 ± 0.003
				2.15	64.8 ± 0.9	0.259 ± 0.024	0.942 ± 0.090
				3.59	7.7 ± 0.3	0.031 ± 0.004	0.114 ± 0.015
1210 ± 35	5.186	$1^+; 0$	340 ± 50	1.74	~ 100		0.06 ± 0.03
2435 [f]	5.922	2^+	10 ± 1	0	82 ± 5	0.19 ± 0.04	0.13 ± 0.03
				0.72	18 ± 5	0.04 ± 0.01	0.02 ± 0.01
				1.74		< 0.02	
2605 [f]	6.024	4^+	0.08 ± 0.05	0	~ 100	0.34 ± 0.05	0.11 ± 0.02
				0.72		< 0.02	
4019 [g]	6.873 ± 5	$1^-; 0+1$	200 ± 10	0	6 ± 2		
				0.72	21 ± 4		
				1.74	59 ± 3		
				2.15	14 ± 4		
4964 [h]	7.440 ± 20	$2^{(-)}; 0+1$	150 ± 15	[h]			

[a] For earlier references see table 10.7 in (79AJ01).
[b] $\Gamma_\alpha = \Gamma_{c.m.} = 0.98 \pm 0.07$ keV (84NA07).
[c] (85NE05). $\Gamma_\gamma/\Gamma = (2.3 \pm 0.3) \times 10^{-3}$; $\Gamma_\alpha = 8.4 \pm 1.8$ eV (E. K. Warburton and D. E. Alburger, private communication).
[d] Absolute error only.
[e] Branching ratios of (79KE08); $\omega\gamma_{c.m.} = 0.40 \pm 0.04$ eV (79SP01). Therefore $\Gamma_\alpha\Gamma_\gamma/\Gamma_{tot} = 0.24 \pm 0.02$ eV and since $\Gamma_\gamma/\Gamma_{tot} = 0.87 \pm 0.04$, $\Gamma_\alpha = 0.28 \pm 0.03$ eV (84NA07).
[f] Values of $\omega\gamma$ (66FO05) have been multiplied by 0.6 to convert them to the c.m. system.
[g] Branching ratios calculated from 0° relative intensities; $\Gamma_\alpha/\Gamma_p = 1.25 \pm 0.12$.
[h] At 0° the branches to $^{10}B^*(0, 0.72)$ are equally strong ((50 ± 12)%).

Table 10.9
^{10}B levels from ^{6}Li(α, α)^{6}Li [a]

E_α (MeV ± keV)	E_x (MeV)	Γ_{lab} (keV)	J^π; T
1.210 ± 30	5.19	175	1^+; 0
2.440 [b]	5.92	≈ 30	2^+; 0
2.6060 ± 1.5	6.024	0.09 ± 0.04	4^+
2.7855 ± 1.5 [c]	6.132	3.93 ± 0.05	3^-
3.4985 ± 1.6 [d]	6.560	41.8 ± 1.9	4^-, 2^-
4.250 ± 15 [d]	7.011	183 ± 25	$(2)^+$; (0)
16.000	14.1	broad	

[a]) For references see tables 10.8 in (79AJ01) and 10.9 in (84AJ01).
[b]) $\Gamma_\alpha = 9.7 \pm 0.1$ keV.
[c]) $\Gamma_\alpha = 2.45 \pm 0.12$ keV and $\Gamma_d = 0.08 \pm 0.05$ keV.
[d]) There is evidence of broad structure near these states.

$E(^3\vec{\mathrm{He}}) = 33.3$ MeV for the deuteron groups to ^{8}Be*(16.63, 17.64, 18.15) and for the triton and ^{3}He groups to ^{7}Be*(0, 0.43) and ^{7}Li*(0, 0.48, 4.63): see (84AJ01).

9. ^{7}Li(^{3}He, α)^{6}Li $Q_m = 13.328$ $E_b = 17.7873$

Excitation functions have been measured for $E(^3\mathrm{He}) = 1.3$ to 18.0 MeV: see (74AJ01). The α_0 group (at 8°) shows a broad maximum at ≈2 MeV, a minimum at 3 MeV, followed by a steep rise which flattens off between $E(^3\mathrm{He}) = 4.5$ and 5.5 MeV. Integrated α_0 and α_1 yields rise monotonically to 4 MeV and then tend to decrease. Angular distributions give evidence of the resonances at $E(^3\mathrm{He}) = 1.4$ and 2.1 MeV seen in ^{7}Li(^{3}He, γ)^{10}B: $J^\pi = 2^+$ or 1^-, $T = (1)$ for both [see, however, reaction 5]: Γ_α is small. The α_2 yield [to ^{6}Li*(3.56), $J^\pi = 0^+$, $T = 1$] shows some structure at $E(^3\mathrm{He}) = 1.4$ MeV and a broad maximum at ≈3.3 MeV: see Table 10.10 in (79AJ01). Polarization measurements are reported at $E(^3\vec{\mathrm{He}}) = 33.3$ MeV to ^{6}Li*(0, 2.19, 3.56): see (84AJ01). See also (83AN1D, 84PA1E).

10. ^{7}Li(α, n)^{10}B $Q_m = -2.7905$

Angular distributions are reported at $E_\alpha = 28$ and 32 MeV for the n_0, n_1 and n_2 groups (85GU1E; prelim.). See (79AJ01, 84AJ01) for the earlier work.

Table 10.10
Resonances in ^{9}Be(p, γ)^{10}B [a]

E_p (MeV ± keV)	E_x (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	J^π; T	Γ_p/Γ	Γ_γ (eV)
0.319	6.873 ± 5	120 ± 5	1^-; $0+1$	0.30	4.8
0.938 ± 10	7.430	140 ± 30	$2^{(-)}$; $0+1$	0.7	2.4
(0.98)	(7.47)		(2^+)		
0.992 ± 2	7.478	72 ± 4	2^-; 1 [c]	≈ 0.65	25.8
1.0832 ± 0.4	7.5599	2.65 ± 0.18	0^+; 1	1.0	8.5
1.29	7.75	210 ± 60	2^-; (1)	≈ 0.65	8.5
2.567 ± 2	8.894	36 ± 2	2^+; 1		
4.72 [b]	10.83	≈ 500	$2^+, 3^+, 4^+$		
6.7 [b]	12.6	< 200	$0^+, 1^+, 2^+$		
(7.0) [b]	(12.9)	(≈ 100)	$(\pi = +)$		
7.5 [b]	13.3	≈ 300	$0^+, 1^+, 2^+$		
8.4 [b]	14.1	≈ 250	$0^+, 1^+, 2^+$		
8.9 [b]	14.6	≈ 150	$2^+, 3^+, 4^+$		
10.0 [b]	15.6	≈ 400	$2^+, 3^+, 4^+$		
14.6 [b]	19.7	≈ 500	$2^-, 3^-, 4^-$		

[a]) For references and for additional comments see table 10.11 in (79AJ01). See table 10.11 for decay schemes.
[b]) Unpublished Ph.D. thesis.
[c]) See (74AJ01). This state is assigned $J^\pi = 2^+$ on the basis of the (e, e′) work (see table 10.15). I am indebted to Dr. D. Kurath for his comments.

11. ^{9}Be(p, γ)^{10}B $\qquad Q_m = 6.5857$

Parameters of observed resonances are listed in Tables 10.10 and 10.11. Table 10.6 summarizes the γ-transitions from this and other reactions. For references to the discussion below, see (74AJ01, 79AJ01, 84AJ01).

The $E_p = 0.32$ MeV resonance (^{10}B* = 6.87 MeV) is ascribed to s-wave protons because of its comparatively large proton width [see ^{9}Be(p, p)] and because of the isotropy of the γ-radiation. The strong transition to ^{10}B*(1.74) requires E1 and hence $J^\pi = 1^-$, $T = 0$. $T = 0$ is also indicated by the large deuteron width. On the other hand, the strength of E1 transitions to ^{10}B*(0.7, 2.1) indicates $T = 1$. The amplitudes for the $T = 0$ and $T = 1$ parts of the wave function for ^{10}B*(6.87) are 0.92 and 0.39, respectively. For the $5.16 \rightarrow 1.74$ decay see Table 10.6.

The proton capture data near $E_p = 1$ MeV appears to require at least five resonant states, at $E_p = 938$, (980), 992, 1083 and 1290 keV. The narrow $E_p = 1083$ keV level (^{10}B* = 7.56 MeV) is formed by p-wave protons, $J^\pi = 0^+$ [see ^{9}Be(p, p), ^{9}Be(p, α)]. The isotropy of the γ-rays supports this assignment. The strong M1 transitions to $J^\pi = 1^+$, $T = 0$ levels at 0.72, 2.15 and 5.18 MeV (Table 10.11) indicate $T = 1$. The width of ^{10}B*(5.18) observed in the decay is 100 ± 10 keV.

Table 10.11
Radiative transitions in $^{9}Be(p, \gamma)^{10}B$ [a]

Initial state (MeV)	$J^{\pi}; T$	Γ_{γ} (tot) (eV)	Relative intensities to final states								
			ground $3^{+}; 0$	0.72 $1^{+}; 0$	1.74 $0^{+}; 1$	2.15 $1^{+}; 0$	3.59 $2^{+}; 0$	5.11 $2^{-}; 0$	5.16 $2^{+}; 1$	5.18 $1^{+}; 0$	5.92 $2^{+}; 0$
6.87 $E_p = 0.32$	$1^{-}; 0+1$	4.8	< 0.05	0.20 ± 0.02	0.53 ± 0.02	0.13 ± 0.01	< 0.01	0.04 ± 0.01	0.03 ± 0.01	< 0.01	0.035 ± 0.01
7.43 $E_p = 0.94$	$2^{(-)}; 0+1$	[2.4]	< 2	1.3	[< 0.14]	0.62	0.5			[< 1]	
7.48 $E_p = 0.99$	$2^{+}; 1$	[25.8]	25	0.3	[< 0.14]	0.49	0			[< 1]	
7.56 $E_p = 1.08$	$0^{+}; 1$	[8.5]	< 0.2	6.7	< 0.3	0.8	< 0.2			1.0	
7.75 [b] $E_p = 1.29$	$(2^{-}; 1)$	[8.5]	6.6	0.9	< 0.08	0.3	0.3			0.4	

[a]) For references and other values see table 10.12 in (79AJ01).
[b]) See, however, table 10.12.

The excitation function for ground-state radiation shows resonance at $E_p = 992$ ($\Gamma =$ 80 keV) and 1290 keV ($\Gamma = 230$ keV). Elastic scattering studies indicate s-wave formation and $J^\pi = 2^-$ for both. For the lower level ($E_x = 7.48$ MeV) the intensity of the g.s. capture radiation, $\Gamma_\gamma = 25$ eV indicates E1 and $T = 1$. The angular distribution of γ-rays, $1+0.1 \sin^2 \theta$, is consistent with s-wave formation with some d-wave admixture or with some contribution from a nearby p-wave resonance; possibly a $J^\pi = 2^+$ level at $E_p = 980$ keV.

The angular distribution of ground-state radiation at $E_p = 1330$ keV is isotropic and $\Gamma_\gamma = 8.5$ eV, supporting E1, $T = 1$ for this level ($E_x = 7.75$ MeV).

Transitions to ^{10}B*(0.7) [γ_1] show resonance at E_p = 992, 1290 and 938 keV, $\Gamma =$ 155 keV. The latter is presumably also a resonance for (p, d) and (p, α). An assignment of $J^\pi = 2^-$, $T = 0$ is consistent with the data, although the E1 radiation then seems somewhat too strong for a $\Delta T = 0$ transition.

A resonance for capture radiation at $E_p = 2.567 \pm 0.003$ ($E_x = 8.895$ MeV) has a width of 40 ± 2 keV and decays mainly via ^{10}B*(0.7) (unpublished Ph.D. thesis). It appears from the width that this resonance corresponds to that observed in ^{9}Be(p, α), $J^\pi = 2^+$, $T = 1$ and not to the ^{9}Be(p, n) resonance at the same energy. A further resonance is reported at $E_p = 4.72 \pm 0.01$ MeV, $\Gamma \approx 0.5$ MeV.

In the range E_p = 4 to 18 MeV, the γ_0 yield at 90° shows [unpublished Ph.D. thesis] the resonance at $E_p = 4.7$ MeV ($E_x = 10.7$ MeV) and fluctuations suggest states at $E_x \approx$ 14.6, 15.6 and 19.7 MeV. ^{10}B*(19.7) possibly decays via E1 and therefore $J^\pi = 2^-$, 3^-, 4^-. The other three states presumably decay by M1 and therefore $J^\pi = 2^+$, 3^+, 4^+. These fluctuations appear on a nearly constant γ_0 yield with a 90° differential cross section ≈ 1.5 μb/sr. The average yield of γ_1 is $\approx \frac{2}{3}$ of the γ_0 yield. The broad giant resonance peak is centered at $E_x \approx 14.5$ MeV. Fluctuations in the γ_1 yield are reported at $E_x \approx$ 12.6, 13.3 and 14.1 MeV. These states presumably decay by M1 to ^{10}B*(0.7) [$J^\pi_f = 1^+$] and therefore $J^\pi_i = 0^+$, 1^+, 2^+. The weak γ_2 yield (to ^{10}B*(1.74) [J^π; $T = 0^+$; 1]) seems to exhibit a broad peak centered near $E_x = 15$ MeV (maximum 90° differential cross section ≈ 0.5 μb/sr) and possibly some structure near $E_x = 20$ MeV. The γ_3 yield (to ^{10}B*(2.15) [$J^\pi = 1^+$]) increases to ≈ 0.4 μb/sr at $E_x \approx 16$ MeV and seems to remain constant beyond that energy, with some suggestion of a fluctuation corresponding to $E_x \approx 12.9$ MeV. ^{10}B*(12.9) appears to have positive parity. Angular distributions of γ_0, γ_1, γ_2 and γ_3 are also reported [in an unpublished Ph.D. thesis].

The magnetic moment of ^{10}B*(0.72) has been studied via γ-γ correlations from ^{10}B*(7.56): $g = +0.63 \pm 0.12$. See also (85KI1B, 85NE1C; applications), (84YA1A; astrophysics) and (83GO28, 83GO1K, 86NA15; theor.).

12. ^{9}Be(p, n)^{9}B $\qquad Q_m = -1.851 \qquad E_b = 6.5857$

Resonances in the neutron yield occur at $E_p = 2562 \pm 6$, 4720 ± 10 and, possibly, at 3500 keV with $\Gamma_{c.m.} = 84 \pm 7$, ≈500 and ≈700 keV. These three resonances correspond to ^{10}B*(8.890, 10.83, 9.7): see Table 10.13 in (74AJ01). Cross section measurements for the (p, n) and (p, n_0) reactions have been obtained by (83BY01; E_p = 8.15 to 15.68 MeV) [see also for a review of earlier work]. They indicate possible structure in ^{10}B near 13–14 MeV (83BY01).

Table 10.12
Resonances in $^9Be(p, p)^9Be$ [a]

E_{res} (keV)	E_x (MeV)	$\Gamma_{c.m.}$ (keV)	J^π	Γ_p/Γ
330	6.88	145	1^-	0.30
980 ± 10	7.467	65 ± 10	1^+	1.0
980 ± 10	7.467	80 ± 8	2^- [d]	0.90 ± 0.05
1084 ± 2	7.561	2.7	0^+	1.0
(1200 ± 30)	(7.67)	250 ± 20	(1^+)	0.30 ± 0.10
1370 ± 20	7.818	265 ± 30	1^-	0.90 ± 0.05
(2070 ± 10)	(8.4)	70 ± 10	$(1^-, 2^-)$	0.43
(2300)	(8.65)	≈ 300	$(1^+, 2^+)$	
(2480)	(8.82)		$(3^-; 1)$	
2560	8.89		≥ 2; (1) [c]	large
(4600)	(10.7)			
(5100)	(11.2)			
6700 [b]	12.6	broad		

[a]) For references and for a listing of other reported resonances see table 10.13 in (79AJ01). Nine anomalies in the p_0 yield are reported by (83AL10) at $E_p = 2.07$, 2.30, 2.44, 2.55, 2.56, 2.60, 3.80, 4.20 and 4.72 MeV.
[b]) Weak resonance near $E_p = 6.5$ MeV in p_0.
[c]) Resonance shape shows $l_p = 2$ formation with a large Γ_p/Γ: the contribution from the 2^+ state appears small.
[d]) See, however, table 10.15 and footnote [a]) in table 10.13 of (79AJ01).

The $E_p = 2.56$ MeV resonance is considerably broader than that observed at the same energy in $^9Be(p, \alpha)$ and $^9Be(p, \gamma)$ and the two resonances are believed to be distinct. The shape of the resonance and the magnitude of the cross section can be accounted for with $J^\pi = 3^-$ or 3^+; the former assignment is in better accord with $^{10}Be^*(7.37)$. For $J^\pi = 3^-$, $\theta_n^2 = 0.135$, $\theta_p^2 = 0.115$ ($R = 4.47$ fm): see (74AJ01).

The analyzing power for n_0 has been measured for $E_p = 2.7$ to 17 MeV (80MA33, 83BY02, 86MU07) as has the polarization in the range $E_p = 2.7$ to 10 MeV (83BY02). See (83BY02, 86MU07) for discussions of the $\sigma(\theta)$, $A_y(\theta)$ and $P(\theta)$ measurements. Polarization measurements have also been reported at $E_{\vec{p}} = 3.9$ to 15.1 MeV and 800 MeV: [see (84AJ01)] and at 53.5, 53.9 and 71.0 MeV (88HE08) [$K_y^{y'}$, $K_z^{z'}$]. See also ^9B, (85TE1C), (85CA41; astrophys.), (86AL1J; applications) and (88ZVZZ; theor.).

13. (a) $^9Be(p, p)^9Be$ $\qquad E_b = 6.5857$
(b) $^9Be(p, pn)^8Be$ $\qquad Q_m = -1.6654$
(c) $^9Be(p, p\alpha)^5He$ $\qquad Q_m = -2.47$

The elastic scattering has been studied for $E_p = 0.2$ to 9.5 MeV [see (74AJ01, 79AJ01, 84AJ01)] and at $E_p = 2.0$ to 3.8 MeV (83AL10). Below $E_p = 0.7$ MeV only s-waves are present exhibiting resonance at $E_p = 330$ keV [^{10}B*(6.88)], $J^\pi = 1^-$. Between $E_p = 0.8$ to 1.6 MeV polarization and cross-section measurements are well fitted by a phase-shift analysis, using only the $^3S_1$, $^5S_2$, $^5P_1$ and $^5P_2$ phases. Four levels satisfy the data, 1^+ and 2^- states at $E_x = 7.48$ MeV, a sharp 0^+ state at $E_x = 7.56$ MeV, and a 1^- state at 7.82 MeV: see Table 10.12. Pronounced minima at $E_p = 2.48$ and 2.55 MeV are observed in the polarization (p_0): these are ascribed to $T = 1$ analogs of the 3^- and 2^+ states ^{10}Be*(7.37, 7.52). A strong anomaly is observed at $E_p = 6.7$ MeV: see Table 10.12.

Polarization measurements have been reported at $E_p = 0.9$ to 49.8 MeV, at 138.2 and 145 MeV, and at 990 MeV [see (74AJ01, 79AJ01)] as well as at $E_{\vec{p}} = 780$ MeV and at 1 GeV [see (84AJ01)]. Recently, A_y measurements have been reported at $E_{\vec{p}} = 200$ MeV (85GL1A; p_0; prelim.) and 220 MeV (85RO15; p_0, p_2). For inclusive proton scattering at $E_{\vec{p}} = 303$ MeV see (87MO04). See also (85SE15). For reaction (b) see (84WA21, 86ME1E, 88BO1H). Reaction (c) at $E_{\vec{p}} = 150.5$ MeV has been studied by (85WA13; A_y). For other high energy studies see (84AJ01). See also ^{9}Be, (82BA78, 85RO1C, 85TR1A, 86KO1R), (84ZU01, 85SA1G, 86BA1N, 86MU07) and (83KA37, 84SH1K, 85DY03, 86HA1K; theor.).

14. (a) ^{9}Be(p, t)^{7}Be	$Q_m = -12.082$	$E_b = 6.5857$
(b) ^{9}Be(p, ^{3}He)^{7}Li	$Q_m = -11.2016$	

Polarization measurements (reaction (b)) are reported at $E_{\vec{p}} = 23.06$ MeV: see (84AJ01). For a study at $E_p = 190$ and 300 MeV see (87GR11). See also (85SE15).

15. (a) ^{9}Be(p, d)^{8}Be	$Q_m = 0.5592$	$E_b = 6.5857$
(b) ^{9}Be(p, α)^{6}Li	$Q_m = 2.126$	

Knowledge of the cross sections of these two reactions at low energies is of importance for power generation and astrophysical considerations. Absolute cross sections for the d_0 and α_0 groups have been measured for $E_p = 28$ to 697 keV with ±5–6% uncertainty. The value of $S_{c.m.}$ ($E = 0$) for the combined cross sections is estimated to be 35^{+45}_{-15} MeV·b. At the 0.33 MeV resonance ($J^\pi = 1^-$), $\sigma_{\alpha_0} = 360 \pm 20$ mb and $\sigma_{d_0} = 470 \pm 30$ mb. The data (including angular distributions), analyzed by an R-matrix compound nucleus model, were fitted by assuming three states at E_p(c.m.) $= -20$ keV ($J^\pi = 2^+$; 3^+ possible) [$E_x = 6.57$ MeV] [see, however, Table 10.8], 310 keV (1^-) and 410 keV (1^+; 2^+ or 3^+ possible): see (79AJ01). See also (88ABZW).

Measurements of excitation functions for deuterons and α-particles have been reported at a number of energies to $E_p = 15$ MeV: see (74AJ01, 79AJ01). Observed resonances are displayed in Table 10.13.

Polarization measurements have been made in the range $E_p = 0.30$ to 15 MeV and at 185 MeV [see (74AJ01, 79AJ01)] and at $E_{\vec{p}} = 60$ MeV (87KA25; A_y; inclusive deuteron spectra). For a fragmentation study at $E_p = 190$ and 300 MeV see (87GR11). See also (83AN1D, 84BA1L, 85SE15, 86ER1B), (84YA1A, 85CA41; astrophysics), (84PA1E) and (82BR1A; theor.).

Table 10.13
Resonances in ^{9}Be(p, d)^{8}Be and ^{9}Be(p, α)^{6}Li [a]

E_p (MeV)	E_x (MeV)	$\Gamma_{c.m.}$ (keV)	J^π; T	Γ_p/Γ
0.34	6.89		1^-; 0	0.30
0.46	7.00		1^+ (2^+, 3^+) [d]	
(0.68)	(7.20)			
0.94	7.43	140	(2^-; 0)	0.7
1.15	7.62	225 ± 50	(1^+; 0)	≈ 0.4
1.65	8.07	800 ± 200	(2^-; 0)	≈ 0.07
(2.3)	(8.7)	(≈ 220)		
2.56 [b]	8.89	36 ± 2	2^+; 1	
3.5 [c]	9.7		$T = 1$	
4.49 [c]	10.62		$T = 1$	

[a] For references and for a listing of other reported resonances and additional information see table 10.14 in (79AJ01).
[b] (77KI04) have analyzed the ($\alpha_2\gamma$) and p_0 yields with an R-matrix formalism and find the following parameters

$$\left.\begin{array}{ll} 2.566 \pm 0.001 & 2^+ \\ 2.561^{+10}_{-2} & 3^- \end{array}\right\} \qquad \Gamma_{c.m.} = \left\{\begin{array}{l} 40 \pm 1 \text{ keV}, \\ 100 \pm 20 \text{ keV}. \end{array}\right.$$

[c] Resonance for α_2 to ^{6}Li*(3.56), $J^\pi = 0^+$, $T = 1$.
[d] See, however, table 10.8.

16. ^{9}Be(d, n)^{10}B $\qquad Q_m = 4.3612$

Neutron groups are observed corresponding to the ^{10}B states listed in Table 10.14. Angular distributions have been measured for $E_d = 0.5$ to 16 MeV [see (74AJ01, 79AJ01)], at 8 MeV (86BA40; $n_0 \rightarrow n_5$, n_{6+7+8}; also at 4 MeV to the latter) and at 18 MeV (87KAZL; n_0, n_1). Observed γ-transitions are listed in Table 10.16 of (79AJ01). See Tables 10.6 and 10.7 here for the parameters of radiative transitions and for τ_m.

From all the various experiments the following picture emerges: the first five states of ^{10}B have even parity [from l_p]. The ground state is known to have $J = 3$, by direct measurement, and ^{10}B*(1.74) has $J^\pi = 0^+$ and is the $T = 1$ analog of the ^{10}C$_{g.s.}$ [from the β^+ decay of ^{10}C]. Then looking at the branching ratios and lifetimes of the other states, the sequence for ^{10}B*(0, 0.72, 1.74, 2.15, 3.59) is $J^\pi = 3^+, 1^+, 0^+, 1^+, 2^+$ [see discussion in (66LA04, 66WA10)].

See also ^{11}B in (85AJ01), (83TA1B, 85SM08) and (86OV1A; applications).

17. ^{9}Be(^{3}He, d)^{10}B $\qquad Q_m = 1.0922$

Deuteron groups have been observed to a number of states of ^{10}B: see Table 10.14. Angular distributions have been reported at $E(^{3}\mathrm{He}) = 10$ to 33.3 MeV [see (74AJ01, 79AJ01, 84AJ01)]. Spectroscopic factors obtained in the (d, n) and (^{3}He, d) reactions are not in good agreement: see the discussions in (74KE06, 80BL02). See also (86AV1C; theor.).

18. ^{9}Be(α, t)^{10}B $\qquad Q_m = -13.2282$

Angular distributions have been studied at $E_\alpha = 27$, 28.3 and 43 MeV [see (79AJ01)], at 30.2 MeV (84VA07; t_0, t_1, t_3, t_4) and at 65 MeV (80HA33). In the latter experiment DWBA analyses have been made of the distributions to ^{10}B*(0, 0.72, 1.74, 2.15, 3.59, 5.2, 5.92, 6.13, 6.56, 7.00, 7.5, 7.82, 8.9) and spectroscopic factors were derived. The distributions to ^{10}B*(4.77, 6.03) could not be fitted by either DWBA or coupled channel analyses. In general coupled-channels calculations give a better fit to the 65 MeV data than does DWBA (80HA33; see also for a comparison with the (d, n) and (^{3}He, d) results).

19. ^{9}Be(^{7}Li, ^{6}He)^{10}B $\qquad Q_m = -3.389$

At $E(^{7}\mathrm{Li}) = 34$ MeV angular distributions have been obtained for the ^{6}He ions to the first four states of ^{10}B. Absolute values of the spectroscopic factors are $S = 0.88$, 1.38 ($p_{1/2}$ or $p_{3/2}$), 1.40 and 0.46 ($p_{1/2}$), 0.54 ($p_{3/2}$) for ^{10}B*(0, 0.74, 1.74, 2.15) (FRDWBA analysis): see (79AJ01). See also (88AL1G).

20. ^{10}Be(β^-)^{10}B $\qquad Q_m = 0.5561$

See ^{10}Be.

21. ^{10}Be(p, n)^{10}B $\qquad Q_m = -0.2261$

The yield of the n_1 group has been studied for $E_p = 0.9$ to 2.0 MeV: see ^{11}B in (90AJ01) (86TE1A).

22. (a) ^{10}B(γ, n)^{9}B $\qquad Q_m = -8.436$
(b) ^{10}B(γ, p)^{9}Be $\qquad Q_m = -6.5857$
(c) ^{10}B(γ, pn)^{8}Be $\qquad Q_m = -8.2511$
(d) ^{10}B(γ, π^+)^{10}Be $\qquad Q_m = -140.125$

Table 10.14
Levels of ^{10}B from ^{9}Be(d, n) and ^{9}Be(^{3}He, d) [a]

E_x (MeV) [a]	^{9}Be(d, n) [b]		^{9}Be(^{3}He, d) [c]		$J^{\pi}; T$ [a]
	l_p	S_{rel}	l_p	$(2J+1)C^2S$	
0	1	1.0	1	3.30	$3^+; 0$
0.72	1	1.97	1	2.76	$1^+; 0$
1.74	1	1.36	1	1.20	$0^+; 1$
2.15	1	0.41	1	0.82	$1^+; 0$
3.59	1	0.10	1	0.29	$2^+; 0$
4.77	(≥ 2)		$1 + (3)$ [e]	0.10	$3^+; 0$
				≤ 0.82	
5.11	0	0.14	$0 + 2$	0.34, 0.14	$2^-; 0$
5.16 } 5.18 }	1	0.43	1	0.86	$2^+; 1$ $1^+; 0$
5.92	1	0.49	1	2.05	$2^+; 0$
6.03			(3) [e]	≤ 0.20	4^+
6.13	(2)		(2) [f]	3.04	3^-
6.56	(3)		(2) [f]	2.01	$(4)^-$
6.89 ± 15	(1)				$1^-; 0 + 1$
7.00 ± 15	(1)				$(1, 2)^+; (0)$
7.48 ± 15	[d]				[g]
7.56 ± 25	[d]				$0^+; 1$
(7.85 ± 50)	[d]				1^-
(8.07 ± 50)	[d]				$(2^-; 0)$
(8.12 ± 50)	[d]				

[a]) Values without uncertainties are from table 10.5; others are from table 10.15 in (79AJ01). See that table for additional information and for references. See also (84AJ01).
[b]) S_{rel} from experiment at $E_d = 12.0$–16.0 MeV.
[c] $E(^{3}\text{He}) = 18$ MeV; DWBA analysis; values shown are those obtained with one of the two optical-model potentials used in the analysis. For earlier (^{3}He, d) results see table 10.17 in (79AJ01).
[d]) State observed in (d, n) reaction; l_p not determined.
[e]) Angular distribution poorly fitted by DWBA.
[f]) See (80BL02) for a discussion of these two states, including a comparison with the (d, n) data: $l_p = 2$ is slightly preferred to $l_p = 1$ on the basis of the observed strengths. Neither $l_p = 2$ nor 1 gives a good DWBA fit.
[g]) Group shown corresponds to unresolved states in ^{10}B.

Table 10.15
Radiative widths for ^{10}Be(e, e′) [a]

E_x in ^{10}B (MeV)	$J^\pi; T$	Mult.	Γ_{γ_0} (eV)
1.74	$0^+; 1$	M3	$(1.05 \pm 0.25) \times 10^{-7}$
5.16 ± 0.04 [b]	$2^+; 1$	M1	0.05 ± 0.05
		M3	$(1.1 \pm 0.1) \times 10^{-6}$
6.03	4^+	C2	0.106 ± 0.005
		C4	$(3.3 \pm 0.8) \times 10^{-7}$
7.48	$2^+; 1$	M1	11.75 ± 0.75
8.07	2^+ [c]	C2	0.19 ± 0.02
8.9	$2^+; 1$	M1	0.3 ± 0.1
		M3	$(1.0 \pm 0.1) \times 10^{-5}$
	$3^-; 1$	M2	$(1.2 \pm 0.1) \times 10^{-3}$
10.79		M1 or C2	
11.56		(M1)	11.4 ± 2.3 [c]
12.6			
13.3			

[a]) See table 10.16 in (84AJ01) for references. See also table 10.18 in (79AJ01).
[b]) Assumed to correspond to 2^+ state at 5.16 MeV. $\Gamma_{\gamma_0} = (3.5 \pm 0.3) \times 10^{-4}$ eV for M2 if the transition were to the 2^- state at 5.11 MeV: see also footnote [g]) in table 10.18 (79AJ01).
[c]) $\Gamma \approx 760$ keV.

Absolute measurements have been made of the ^{10}B(γ, Tn) cross section from threshold to 35 MeV with quasimonoenergetic photons; the integrated cross section is 0.54 in units of the classical dipole sum (60 NZ/A MeV·mb). The (γ, 2n) + (γ, 2np) cross section is zero, within statistics, for E_γ = 16 to 35 MeV: see (79AJ01) and (88DI02). The giant resonance is broad with the major structure contained in two peaks at $E_x = 20.1 \pm 0.1$ and 23.1 ± 0.1 MeV ($\sigma_{max} \approx 5.5$ mb for each of the two maxima): see (79AJ01). (87AH02) [and H. H. Thies, private communication] [using bs] report two broad [$\Gamma \approx 2$ MeV] maxima at 20.2 and 23.0 MeV [± 0.05 MeV] (σ = 5.0 and 6.0 mb, respectively; $\pm 10\%$) and a minor structure at E_x = 17.0 MeV. For reactions (b) and (c) see (88SU14). For reaction (d) see ^{10}Be. See also (74AJ01) and (83GO28, 83GO1K, 85GO1A, 87KI1C; theor.).

23. (a) ^{10}Be(e, e)^{10}B
    (b) ^{10}B(e, en)^{9}B $\quad Q_m = -8.436$
    (c) ^{10}B(e, ep)^{9}Be $\quad Q_m = -6.5857$
    (d) ^{10}B(e, eπ^+)^{10}Be $\quad Q_m = -140.125$

$$\langle r^2\rangle^{1/2} = 2.49 \pm 0.09 \text{ fm (86DO1E; prelim.)}.$$

Inelastic electron groups are displayed in Table 10.15. (86FR1D; prelim.) have measured the form factors for ^{10}B*(0, 1.74, 5.16). For reactions (b) and (c) see (84AJ01). For reaction (d) see ^{10}Be. See also (84DO1A, 86PE05, 87DE1A, 87HI1F) and (86HA1M; theor.).

24. ^{10}B(n, n)^{10}B

Angular distributions have been studied for $E_{\rm n}$ = 1.5 to 14.1 MeV [see (74AJ01, 79AJ01)] and at 3.02 to 12.01 MeV (86SA1U, 87SA1H; prelim; $n_1 \rightarrow n_5$), 8 to 14 MeV (83DA22; n_0) and 9.96 to 16.94 MeV (86MU1D; prelim.; n_0). See also ^{11}B in (85AJ01, 90AJ01), (84TU02) and (83KO1F; theor.).

25. (a) ^{10}B(p, p)^{10}B
(b) ^{10}B(p, 2p)^{9}Be $Q_{\rm m} = -6.5857$

Angular distributions have been measured for a number of energies between $E_{\rm p}$ = 3.0 and 800 MeV [see (74AJ01, 79AJ01, 84AJ01)] and at 10 to 17 MeV (86MU1D; p_0; prelim.). Table 10.16 displays the states observed in this reaction. The γ-ray results are shown in Table 10.6. See also (79AJ01). For $\tau_{\rm m}$ see Table 10.7 (83VE03).

Axions may cause e^+e^- pairs in competition with γ-ray emission in an isoscalar M1 transition: a search for axions was undertaken in the case of the 3.59 → g.s. $[2^+ \rightarrow 3^+]$ transition. It was negative (86DE25). A beam dump experiment and other attempts to observe axions are discussed in (87HA1O). For reaction (b) at $E_{\rm p}$ = 1 GeV see (85BE1J, 85DO1B; prelim.) and (74AJ01). See also (88KRZY), (85KI1B, 88KOZL; applied) and ^{11}C in (85AJ01, 90AJ01).

26. ^{10}B(d, d)^{10}B

Angular distributions have been reported at $E_{\rm d}$ = 4 to 28 MeV: see (74AJ01, 79AJ01). Observed deuteron groups are displayed in Table 10.16. The very low intensity of the group to ^{10}B*(1.74) and the absence of the group to ^{10}B*(5.16) is good evidence of their $T = 1$ character: see (74AJ01).

27. ^{10}B(t, t)^{10}B

Angular distributions of elastically scattered tritons have been measured at $E_{\rm t}$ = 1.5 to 3.3 MeV: see (74AJ01).

Table 10.16
^{10}B levels from ^{10}B(p, p), ^{10}B(d, d) and ^{10}B(^{3}He, ^{3}He) [a]

E_x (MeV ± keV) [b]	$\Gamma_{c.m.}$ (keV)	L	β_L [b,c]
0 [d]			
0.7183 ± 0.4 [d,e,f]		2	0.67 ± 0.05
$\equiv 1.7402$ [f,g]		(3)	
2.1541 ± 0.5 [d]		2	0.49 ± 0.04
3.5870 ± 0.5 [d]		2	0.45 ± 0.04
4.7740 ± 0.5 [h]			
5.1103 ± 0.6		3	0.45 ± 0.04
5.1639 ± 0.6			
5.18 ± 10 [h,i]	110 ± 10		
5.9195 ± 0.6 [d]	< 5		0.28 ± 0.03
6.0250 ± 0.6 [d]	< 5	2	0.95 ± 0.04
6.1272 ± 0.7 [d]	< 5	3	0.58 ± 0.03
6.55 ± 10 [d]	25 ± 5	3	0.46 ± 0.04 [j]
7.00 ± 10 [d]	95 ± 10		
7.48 ± 10	90 ± 15		

[a]) For references and a more complete presentation see table 10.19 in (79AJ01).
[b]) From (p, p).
[c]) See results obtained from (^{3}He, ^{3}He) in table 10.19 of (79AJ01).
[d]) Also observed in (d, d) and (^{3}He, ^{3}He).
[e]) $E_x = 718.35 \pm 0.04$ (from E_γ).
[f]) $E_x = 718.5 \pm 0.2$ and 1740.0 ± 0.6 keV (from E_γ).
[g]) Also observed in (^{3}He, ^{3}He).
[h]) Also observed in (d, d).
[i]) Not reported in (p, p) at $E_p = 10$ MeV.
[j]) If $J^\pi = 4^-$; $\beta_L = 0.59 \pm 0.03$ if $J^\pi = 2^-$.

28. $^{10}B(^3He, ^3He)^{10}B$

Angular distributions have been measured at $E(^3He) = 4$ to 46.1 MeV [see (74AJ01, 79AJ01, 84AJ01)] and at 2.10 and 2.98 MeV (87BA34; elastic). $L = 2$ gives a good fit of the distributions of ^{3}He ions to ^{10}B*(0.72, 2.15, 3.59, 6.03): derived β_L are shown in Table 10.19 of (79AJ01). See also Table 10.16 here, ^{13}N in (86AJ01) and (87RA36; theor.).

29. (a) $^{10}B(\alpha, \alpha)^{10}B$
(b) $^{10}B(\alpha, 2\alpha)^6Li$ $\quad Q_m = -4.4596$

Angular distributions have been measured for $E_\alpha = 5$ to 56 MeV [see (74AJ01, 79AJ01, 84AJ01)] and at 91.8 MeV (85JA12; α_0). Reaction (b) has been studied at $E_\alpha = 24$ and 700 MeV: see (79AJ01, 84AJ01). See also (83GO27, 85SH1D; theor.).

30. (a) $^{10}B(^6Li, ^6Li)^{10}B$
(b) $^{10}B(^7Li, ^7Li)^{10}B$

Elastic-scattering angular distributions have been studied at $E(^6Li) = 5.8$ and 30 MeV and at $E(^7Li) = 24$ MeV: see (79AJ01).

31. $^{10}B(^9Be, ^9Be)^{10}B$

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

32. (a) $^{10}B(^{10}B, ^{10}B)^{10}B$
(b) $^{10}B(^{11}B, ^{11}B)^{10}B$

Elastic angular distributions (reaction (a)) have been studied at $E(^{10}B) = 8$, 13 and 21 MeV. For yields and reaction (b) see (79AJ01). See also (85BE1A, 85CU1A) and (84HA43, 86RO12; theor.).

33. (a) $^{10}B(^{12}C, ^{12}C)^{10}B$
(b) $^{10}B(^{13}C, ^{13}C)^{10}B$

Elastic angular distributions have been measured at $E(^{10}B) = 18$ and 100 MeV for reaction (a) [see (79AJ01)] and at 18–46 MeV [see (84AJ01)] and 42.5, 62.3 and 80.9 MeV for reaction (b) (85MA10). For yield, cross section and fusion experiments see (83DA20, 83MA53, 85MA10, 88MA07) and (84AJ01). See also (84DE1J, 84HAZK, 87SA1I), (82BA1D, 85BA1T; astrophysics), (83BI1A, 83DU13, 84FR1A, 84HA53, 85BE1A, 85CU1A, 86MA19) and (83HA1E, 84HA43, 84IN03, 84MA1J, 85KO1J, 86RO12; theor.).

34. $^{10}B(^{14}N, ^{14}N)^{10}B$

Angular distributions have been reported at $E(^{10}B) = 100$ MeV and $E(^{14}N) = 73.9$ and 93.6 MeV: see (79AJ01, 84AJ01). For fusion cross section studies see (79AJ01, 84AJ01) and (83DE26). See also (83BI1A, 83DA10, 84FR1A, 84HA53, 85BE1A, 85CU1A) and (83GO1A, 84HA43, 84IN03, 85KO1J, 86RO12; theor.).

35. (a) $^{10}B(^{16}O, ^{16}O)^{10}B$
(b) $^{10}B(^{17}O, ^{17}O)^{10}B$
(c) $^{10}B(^{18}O, ^{18}O)^{10}B$

Elastic angular distributions (reaction (a)) have been studied at $E(^{16}O) = 15.0$ to 32.5 MeV and at $E(^{10}B) = 33.7$ to 100 MeV: see (79AJ01, 84AJ01). The elastic scattering for reaction (c) has been studied at $E(^{18}O) = 20$, 24 and 30.5 MeV: see (74AJ01). For yield and fusion cross section measurements see (84AJ01) and (84GO1C). See also (83BI1A, 84FR1A, 84HA53) and (83GO1A, 85HU04; theor.).

36. (a) $^{10}B(^{19}F, ^{19}F)^{10}B$
(b) $^{10}B(^{20}Ne, ^{20}Ne)^{10}B$

The elastic scattering has been investigated for $E(^{19}F) = 20$ and 24 MeV for reaction (a) and $E(^{10}B) = 65.9$ MeV for reaction (b): see (74AJ01, 84AJ01).

37. (a) $^{10}B(^{24}Mg, ^{24}Mg)^{10}B$
(b) $^{10}B(^{25}Mg, ^{25}Mg)^{10}B$

The elastic scattering for both reactions has been studied at $E(^{10}B) = 87.4$ MeV: see (84AJ01). The elastic scattering for reaction (b) has been measured at $E(^{10}B) = 34$ MeV by (85WI18).

38. (a) ^{10}B(^{27}Al, ^{27}Al)^{10}B
(b) ^{10}B(^{28}Si, ^{28}Si)^{10}B
(c) ^{10}B(^{30}Si, ^{30}Si)^{10}B

The elastic scattering for all three reactions has been studied at $E(^{10}\text{B}) = 41.6$ and ≈ 50 MeV [and also at 33.7 MeV for reaction (b)]: see (84AJ01). See also (84TE1A).

39. (a) ^{10}B(^{39}K, ^{39}K)^{10}B
(b) ^{10}B(^{40}Ca, ^{40}Ca)^{10}B

The elastic scattering has been studied at $E(^{10}\text{B}) = 44$ MeV for reaction (a) (85WI18) and at 46.6 MeV for reaction (b): see (84AJ01).

40. ^{10}C(β^+)^{10}B $\qquad Q_\text{m} = 3.6481$

The half-life of ^{10}C is 19.255 ± 0.53 s [see (74AJ01, 79AJ01)]: the decay is to ^{10}B*(0.72, 1.74) with branching ratios of (98.53 ± 0.02)% and (1.465 ± 0.014)% and $\log ft = 3.047$ for the transition to ^{10}B*(0.72) and 3.492 ± 0.005 for that to the analog state, ^{10}B*(1.74): see Table 10.20 in (79AJ01). The excitation energies of the two states are 718.32 ± 0.09 and 1740.16 ± 0.17 keV [$E_\gamma = 718.29 \pm 0.09$ and 1021.78 ± 0.14 keV]. See (79AJ01) for a further discussion of the decay. See also (88GI02, 88KRZY).

41. ^{11}B(γ, n)^{10}B $\qquad Q_\text{m} = -11.4542$

The intensities of the transitions to ^{10}B*(3.59, 5.16) [$T = 0$ and 1, respectively] depend on the region of the giant dipole resonance in ^{11}B from which the decay takes place: it is suggested that the lower-energy region consists mainly of $T = \frac{1}{2}$ states and the higher-energy region of $T = \frac{3}{2}$ states: see ^{11}B in (80AJ01). See also ^{11}B in (85AJ01, 90AJ01) and (84AL22).

42. (a) ^{11}B(p, d)^{10}B $\qquad Q_\text{m} = -9.2296$
(b) ^{11}B(p, pn)^{10}B $\qquad Q_\text{m} = -11.4542$

Angular distributions of deuteron groups have been measured at several energies in the range $E_\text{p} = 17.7$ to 154.8 MeV [see (79AJ01)] and at 18.6 MeV (85BE13; d_0, d_1). The population of the first five states of ^{10}B and of ^{10}B*(5.2, 6.0, 6.56, 7.5, 11.4 ± 0.2, 14.1 ± 0.2) is reported. For reaction (b) see (85BE1J, 85DO1B; 1 GeV; prelim.). See also (88GU1D) and (88BE1I; theor.).

Table 10.17
^{10}B levels from ^{11}B(^{3}He, α)^{10}B [a])

E_x (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	l	S_{rel}
0		1	1.0
0.718 ± 7		1	0.22
1.744 ± 7		1	0.73
2.157 ± 6		1	0.44
3.587 ± 6		1	0.09
4.777 ± 5		1	0.09
5.114 ± 5			
5.166 ± 5		1	1.81
5.923 ± 5			
6.028 ± 5			
6.131 ± 5			
6.570 ± 7	30 ± 10		
7.002 ± 10	95 ± 10		
7.475 ± 10			
7.567 ± 10			
7.87 ± 40	240 ± 50		
10.85 ± 100	300 ± 100		
11.52 ± 35	500 ± 100		
12.56 ± 30	100 ± 30		
13.49 ± 50	300 ± 50		
14.4 ± 100	800 ± 200		
(18.2 ± 200)	(1500 ± 300)		

[a]) See table 10.21 in (79AJ01) for references.

43. ^{11}B(d, t)^{10}B $\quad Q_m = -5.1969$

Angular distributions have been measured at $E_d = 11.8$ MeV ($t_0 \rightarrow t_3$; $l = 1$) [see (74AJ01)] and at 18 MeV (87GU1F, 88GU1D; prelim.).

44. (a) ^{11}B(^{3}He, α)^{10}B $\quad Q_m = 9.1236$
(b) ^{11}B(^{3}He, 2α)^{6}Li $\quad Q_m = 4.6640$

Reported levels are displayed in Table 10.17. Angular distributions have been measured at a number of energies between $E(^{3}\text{He}) = 1.0$ and 33 MeV [see (74AJ01)] and at 23.4 MeV (87VA1I; α_0, α_1; prelim.). For the decay of observed states see Table 10.6.

The α-α angular correlations (reaction (b)) have been measured for the transitions via ^{10}B*(5.92, 6.03, 6.13, 6.56, 7.00). The results are consistent with $J^\pi = 2^+$ and 4^+

for ^{10}B*(5.92, 6.03) and require $J^\pi = 3^-$ for ^{10}B*(6.13). There is substantial interference between levels of opposite parity for the α-particles due to ^{10}B*(6.56, 7.00): the data are fitted by $J^\pi = 3^+$ for ^{10}B*(7.00) and $(3, 4)^-$ for ^{10}B*(6.56) [the ^{6}Li(α, α) results then require $J^\pi = 4^-$]. See, however, reaction 15, and see (74AJ01) for the references. See also (88GO1E; theor.).

45. ^{11}B(^{7}Li, ^{8}Li)^{10}B $\qquad Q_m = -9.421$

Angular distributions have been measured at $E(^{7}\text{Li}) = 34$ MeV involving ^{10}B*(0, 0.72, 1.74, 2.15) and $^{8}\text{Li}_{\text{g.s.}}$ (as well as ^{8}Li*(0.98) in the case of the $^{10}\text{B}_{\text{g.s.}}$ transition) (87CO16).

46. (a) ^{12}C(γ, d)^{10}B $\qquad Q_m = -25.1868$
(b) ^{12}C(γ, pn)^{10}B $\qquad Q_m = -27.4114$

For reaction (a) see (86SH1M) and ^{12}C in (90AJ01). For reaction (b) see ^{12}C in (85AJ01). See also (84DO1C) and (84CH1A, 86GU1G; theor.).

47. ^{12}C(n, t)^{10}B $\qquad Q_m = -18.9295$

See (85FR07, 87FR16; $E_n = 319$ to 545 MeV). See also (86DO12).

48. ^{12}C($\pi^\pm$, $\pi^\pm$d)^{10}B $\qquad Q_m = -25.1868$

At $E_{\pi^+} = 180$ MeV and $E_{\pi^-} = 220$ MeV, ^{10}B*(0.72, 2.15) are populated: see (84AJ01). At $E_{\pi^+} = 150$ MeV momentum distributions of pions to unresolved states of ^{10}B are reported by (87HU13).

49. (a) ^{12}C(p, ^{3}He)^{10}B $\qquad Q_m = -19.6933$
(b) ^{12}C(p, pd)^{10}B $\qquad Q_m = -25.1868$

Angular distributions of ^{3}He ions have been measured for $E_p = 39.8$, 51.9 and 185 MeV: see (79AJ01). ^{10}B*(0, 0.72, 1.74, 2.15, 3.59, 4.77, 5.16, 5.92, 6.56, 7.50, 8.90) are populated. For reaction (b) see (85DE17; $E_p = 58$ MeV; ^{10}B*(0.72, 1.74)) and (84AJ01). See also (86VD1C) and (86GO28, 86ZH03, 87GA08, 87KW01; theor.).

50. ^{12}C(d, α)^{10}B $\qquad Q_m = -1.3401$

Alpha groups have been observed to most of the known states of ^{10}B below E_x = 7.1 MeV: see Table 10.23 in (74AJ01). Angular distributions have been measured for E_d = 5.0 to 40 MeV: see (79AJ01). Single-particle S-values are 1.5, 0.5, 0.1, 0.1 and 0.3 for ^{10}B*(0, 0.72, 2.15, 3.59, 4.77). A study of the $m_s = 0$ yield at E_d = 14.5 MeV ($\theta = 0°$) leads to assignments of 3^+, 2^- and (3^+, 4^-) for ^{10}B*(4.77, 5.11, 6.56). The population of the isospin-forbidden group to ^{10}B*(1.74) [α_2] has been studied with E_d up to 30 MeV: see ^{14}N in (86AJ01). See also (84LO1A).

51. ^{12}C(α, ^{6}Li)^{10}B $\qquad Q_m = -23.7118$

Angular distributions have been reported at E_α = 42 and 46 MeV: see (79AJ01). At E_α = 65 MeV, an investigation of the ^{6}Li breakup shows that ^{10}B*(0, 0.72, 2.16, 3.57, 4.77, 5.2, 5.9, 6.0) are involved: see (84AJ01). See also (87GA20).

52. ^{12}C(^{7}Li, ^{9}Be)^{10}B $\qquad Q_m = -8.492$

At $E(^7$Li) = 78 MeV angular distributions have been measured to ^{10}B*(0, 2.15) (86GL1C; prelim.).

53. (a) ^{12}C(^{12}C, ^{14}N)^{10}B $\qquad Q_m = -14.9144$
(b) ^{12}C(^{14}N, ^{16}O)^{10}B $\qquad Q_m = -4.4505$

Angular distributions (reaction (a)) involving ^{10}B*(0, 0.7) have been studied at $E(^{12}$C) = 49.0 to 75.5 and 93.8 MeV. Angular distributions (reaction (b)) involving ^{10}B*(0, 0.72, 2.15, 3.59) have been measured at $E(^{14}$N) = 53 MeV and 78.8 MeV (not to ^{10}B*(3.59)): see (79AJ01, 84AJ01) for references. See also (86AR04, 86CR1A, 86MO1D).

54. ^{13}C(p, α)^{10}B $\qquad Q_m = -4.0618$

Angular distributions have been measured at E_p = 5.8 to 18 MeV and 43.7 and 50.5 MeV: see (79AJ01). See also ^{14}N in (86AJ01) and (85MA1F; theor.).

55. ^{14}N(p, pα)^{10}B $\qquad Q_m = -11.6125$

See (86VD1C; $E_p = 50$ MeV; prelim.). See also (86GO28; theor.).

56. ^{14}N(d, ^{6}Li)^{10}B $\qquad Q_m = -10.137$

At E_d = 80 MeV angular distributions are reported to ^{10}B*(0, 0.72, 2.15, 3.59, 4.8, 6.04, 7.05, 8.68): see (84AJ01).

57. ^{16}O(^{9}Be, ^{15}N)^{10}B $\qquad Q_m = -5.542$

See (85WI18).

^{10}C

(Figs. 21 and 22)

GENERAL: See also (84AJ01).

Model calculations: (84SA37, 87BL18).

Special states: (86AB10).

Astrophysical questions: (87RA1D).

Complex reactions involving ^{10}C: (83FR1A, 83OL1A, 86HA1B, 87AR19, 87BEYI, 87RI03, 87SN1A, 87TA1F, 88BEYJ, 88CA06, 88KI05, 88SA19).

Reactions involving pions and other mesons (See also reactions 2 and 4.): (85LI1E, 87SI18).

Other topics: (82KA1D, 85AN28, 86YA1F).

Ground-state properties of ^{10}C: (83ANZQ, 85AN28, 87BL18, 87SA15).

Mass of ^{10}C: The threshold energy for the ^{10}B(p, n)^{10}C reaction is 4876.90 ± 0.37 keV: then $Q_0 = -4430.17 \pm 0.34$ keV (84BA12). Using the (88WA18) masses for ^{10}B, p and n, the atomic mass excess of ^{10}C is then 15698.8 ± 0.5 keV. This value does not include a contribution from unpublished work on ^{12}C(p, t)^{10}C quoted in (84AJ01). However, we adopt the (88WA18) value: 15699.1 ± 0.3 keV.

$$B(\text{E2})\uparrow \text{ for } ^{10}\text{C}^*(3.35) = (6.2 \pm 1.0) \times 10^{-3}\ e^2 \cdot \text{b}^2,$$

$$[Q_0 = 0.25 \pm 0.02 \text{ b}] \text{ (87RA01)}.$$

Table 10.18
Energy levels of ^{10}C

E_x (MeV ± keV)	$J^\pi; T$	τ or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
g.s.	$0^+; 1$	$\tau_{1/2} = 19.255 \pm 0.053$ s	β^+	1, 4, 5, 6, 7, 8
3.3536 ± 0.7	2^+	$\tau_m = 155 \pm 25$ fs	γ	2, 4, 5, 6, 7, 8
5.22 ± 40	[a])	$\Gamma = 225 \pm 45$ keV		4, 5, 6, 7
5.38 ± 70	[a])	300 ± 60		4, 5, 6, 7
6.580 ± 20	(2^+)	200 ± 40		4, 6, 7

[a]) One of these two states is presumably a 2^+ state.

1. ^{10}C(β^+)^{10}B $\qquad Q_m = 3.6481$

^{10}C decays with a half-life of 19.255 ± 0.053 s to ^{10}B*(0.7, 1.7): the branching ratios are (98.53 ± 0.02)% and (1.465 ± 0.014)%, respectively: see (74AJ01). See also reaction 40 in ^{10}B and (86CA1L).

2. ^{7}Li(^{3}He, π^-)^{10}C $\qquad Q_m = -125.429$

At $E(^3\text{He}) = 235$ MeV ^{10}C*(3.35) is populated (84BI08). π^- production in this reaction has also been studied by (84BR22) At $E(^3\text{He}) = 910$ MeV.

3. ^{7}Li(^{7}Li, 4n)^{10}C $\qquad Q_m = -18.171$

Tetraneutron (n^4) production has been studied in this and in other reactions involving ^{10}C at $E(^7\text{Li}) = 82$ MeV (87ALZG; prelim.): it is not observed.

4. ^{9}Be(p, π^-)^{10}C $\qquad Q_m = -136.631$

Angular distributions of π^- groups have been measured at $E_p = 185$ MeV (to ^{10}C*(0, 3.35, 5.28, 6.63)), at 200 MeV (g.s.), at 800 MeV (to ^{10}C*(0, 3.35, 5.3, 6.6)) [see (84AJ01)] and at $E_{\vec{p}} = 650$ MeV (86HO23; ^{10}C*(0, 3.35); also A_y). A_y measurements have also been reported at $E_{\vec{p}} = 200$ to 250 MeV: see (84AJ01).

5. ^{10}B(p, n)^{10}C $\qquad Q_m = -4.4305$

$Q_0 = -4430.17 \pm 0.34$ keV (84BA12)

The E_x of ^{10}C*(3.35) = 3352.7 ± 1.5 keV, $\tau_m = 155 \pm 25$ fsec, $\Gamma_\gamma = 4.25 \pm 0.69$ meV. Angular distributions have been measured for the n_0 and n_1 groups and for the neutrons to ^{10}C*(5.2 ± 0.3) at E_p = 30 and 50 MeV [see (74AJ01, 79AJ01)] and for the n_0 and n_1 groups at E_p = 14.0, 14.3 and 14.6 MeV (85SC08) and 15.8 and 18.6 MeV (85GU1C; prelim.). See also (84BA1R, 88KA2E).

6. ^{10}B(^{3}He, t)^{10}C $\qquad Q_m = -3.6667$

Angular distributions have been measured at $E(^3\text{He})$ = 14 MeV and 217 MeV: see (79AJ01). The latter [to ^{10}C*(0, 3.35, 5.6)] have been compared with microscopic calculations using a central + tensor interaction [$J^\pi = 0^+, 2^+, 2^+$]. Structures have been reported at $E_x = 5.22 \pm 0.04$ [$\Gamma = 225 \pm 45$ keV], 5.38 ± 0.07 [300 ± 60 keV] and 6.580 ± 0.020 MeV [190 ± 35 keV].

7. ^{12}C(p, t)^{10}C $\qquad Q_m = -23.3600$

Angular distributions have been reported at E_p = 30.0 to 54.1 MeV and at 80 MeV [see (74AJ01, 79AJ01, 84AJ01)]. L = 0, 2 and 2 to ^{10}C*(0, 3.35, 5.28) thus leading to 0^+, 2^+ and 2^+ for these states [but note that the "5.28 MeV" state is certainly unresolved]: see reaction 6 and table 10.18. ^{10}C*(6.6) is also populated. Two measurements of the excitation energy of ^{10}C*(3.4) are 3353.5 ± 1.0 keV, 3354.3 ± 1.1 keV: see (84AJ01) [based on Q_m]. See also (87KW01; theor.).

8. ^{13}C(^{3}He, ^{6}He)^{10}C $\qquad Q_m = -15.235$

At $E(^3\text{He})$ = 70.3 MeV the angular distributions of the ^{6}He ions corresponding to the population of ^{10}C*(0, 3.35) have been measured. The group to ^{10}C*(3.35) is much more intense than the ground-state group: see (79AJ01).

^{10}N, ^{10}O, ^{10}F, ^{10}Ne
(Not illustrated)

Not observed: see (79AJ01). (85WA02) suggest 39.7 ± 0.4 MeV for the atomic mass excess of ^{10}N. See also (82KA1D, 83ANZQ, 87BL18, 87SA15; theor.).

References

(Closed 1 June 1988)

References are arranged and designated by the year of publication followed by the first two letters of the first-mentioned author's name and then by two additional characters. Most of the references appear in National Nuclear Data Center files (Nuclear Science References database) and have NNDC key numbers. Otherwise, TUNL key numbers were assigned with the last two characters of the form 1A, 1B, etc.

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