Energy Levels of Light Nuclei
$A = 10$

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Abstract: An evaluation of $A = 5$–10 was published in *Nuclear Physics A*413 (1984), p. 1. This version of $A = 10$ 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.

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^{10}n

(Not illustrated)

^{10}n has not been observed in the interaction of 0.7 and 400 GeV protons with uranium: the cross section is $< 0.7 \times 10^{-5}$ μb (1977TU02) at 0.7 GeV and < 0.5 μb (1977TU03) at 400 GeV.

^{10}He

(Not illustrated)

^{10}He has not been observed in the bombardment of ^{232}Th by 4.8 GeV/c deuterons [the production cross section is $\lesssim 2$ μb] (1979BE60) nor in the interaction of ^{10}B, ^{11}B and ^{22}Ne [8 to 10 MeV/A] with Ti and ^{232}Th targets [the cross section is $< 5 \times 10^{-4}$ μb/sr] (1982OG02). See also (1974AJ01). The calculated value of the atomic mass excess of ^{10}He is 49.40 MeV: ^{10}He is then unstable with respect to breakup into ^{9}He + n and ^{8}He + 2n by 0.52 and 1.66 MeV, respectively (1980SEZX). See also (1979AJ01), (1980BO31, 1982BI1C) and (1979BO22, 1981AV02, 1981KI04, 1982AV1A, 1982NG01, 1982VE05; 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 the be unbound with respect to breakup into ^{9}Li + n by 0.80 ± 0.25 MeV (1975WI26). However (1979AB11, 1980AB16), on the basis of the possible location of the first $T = 2$ state in ^{10}Be (see reaction 2) with $J^{\pi} = 2^{-}$, suggest that (1975WI26) have observed an excited state of ^{10}Li, with $J^{\pi} = 1^{+}$. See also (1979AJ01) and (1979BO22, 1980MA1Z, 1981AV02, 1981WA1J, 1982NG01; theor.).

^{10}Be

(Figs. 19 and 22)

GENERAL: (See also (1979AJ01).)

Model calculations: (1980FU1G, 1981DE2G).

Special states: (1981DE2G, 1981SE06).

Electromagnetic transiitons: (1982LA26, 1982RI04).

Astrophysical questions: (1978BU1B, 1979MO04, 1979SI1D, 1980WI1M, 1981GA1B, 1981GA1C, 1981KR1C, 1981PR1B, 1981SA1G, 1982BR1N, 1982KU1J, 1982PA1F).

Applied work: (1978MU1B, 1978RA1C, 1979GO1L, 1979IN1C, 1979LI1C, 1979RA1E, 1980EL1B, 1980EL1C, 1980GO1B, 1980KI1B, 1980LA1B, 1981FA1E, 1981LI1K, 1981RA1F, 1981SA1G, 1981SC1D, 1981TH1C, 1982BO35, 1982BR1N, 1982KL1A, 1982KU1G, 1982KU1J, 1982PA1F, 1983KR1B, 1983SO1B, 1983SU1C).

Complex reactions involving ^{10}Be: (1978DU1B, 1978HE1C, 1978TU06, 1979AL22, 1979BO22, 1979JA1C, 1979SC1D, 1979VI05, 1980GR10, 1980WI1L, 1981CI03, 1981MO20, 1982BI1C, 1982BO1J, 1982GU1H, 1982LU01, 1982LY1A, 1983SA06).

Muon and neutrino capture and reactions: (1979GO1M, 1980MU1B, 1981GI08).

Reactions involving pions and kaons (See also reactions 10, 16 and 18): (1978DA1A, 1978WA1B, 1979PE1C, 1980BO1B, 1981AU1C, 1981FE2A, 1981SI09, 1981WH01, 1981YA1A, 1982AU02, 1982RO04, 1982WA1G).

Hypernuclei: (1978DA1A, 1978PO1A, 1978SO1A, 1980RO1F, 1980ZH1C, 1981WA1J, 1982IK1A, 1982KO1L, 1982KO11, 1982RA1L).

Other topics: (1981SE06, 1982DE1N, 1982NG01).

Ground-state properties of ^{10}Be: (1978SM02, 1981AV02, 1982NG01).

1. ^{10}Be(β^-)^{10}B $\qquad Q_m = 0.5568$

The half-life of ^{10}Be is $(1.6 \pm 0.2) \times 10^6$ y; log $ft = 13.42$: see (1974AJ01). See also (1979FE1E; theor.) and (1979AJ01).

2. (a) ^{7}Li(t, γ)^{10}Be	$Q_m = 17.2498$	
(b) ^{7}Li(t, n)^{9}Be	$Q_m = 10.4377$	$E_b = 17.2498$
(c) ^{7}Li(t, p)^{9}Li	$Q_m = -2.386$	
(d) ^{7}Li(t, d)^{8}Li	$Q_m = -4.225$	
(e) ^{7}Li(t, t)^{7}Li		
(f) ^{7}Li(t, α)^{6}He	$Q_m = 9.839$	

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.	$0^+; 1$	$\tau_{1/2} = (1.6 \pm 0.2) \times 10^6$ y	β^-	1, 2, 3, 4, 5, 10, 11, 12, 13, 14, 15, 16, 17, 18, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29
3.3680 ± 0.2	$2^+; 1$	$\tau_m = 180 \pm 17$ fsec	γ	2, 3, 4, 5, 10, 11, 12, 13, 14, 15, 16, 17, 18, 20, 21, 22, 24, 25, 26, 29
5.9583 ± 0.3	$2^+; 1$	$\tau_m < 80$ fsec	γ	5, 10, 11, 13, 16, 17, 18, 20, 21, 25, 29
5.9599 ± 0.6	$1^-; 1$		γ	5, 10, 11, 13, 21, 25, 29
6.1793 ± 0.7	$0^+; 1$	$\tau_m = 1.1^{+0.4}_{-0.3}$ psec	π, γ	5, 10, 11, 21
6.2633 ± 5	$2^-; 1$		γ	5, 11, 13
7.371 ± 1	$3^-; 1$	$\Gamma = 15.7 \pm 0.5$ keV	n	4, 6, 10, 11, 13
7.542 ± 1	$2^+; 1$	6.3 ± 0.8	n	3, 4, 6, 11, 13, 29
9.27	$(4^-); 1$	150 ± 20	n	4, 6, 10, 11, 13
9.4	$(2)^+; 1$	291 ± 20	n	4, 6, 10, 11, 13, 20, 25, 29
10.57 ± 30	$\geq 1; 1$		n	3, 4, 6, 11
11.76 ± 20		121 ± 10		3, 4, 10, 11, 13, 29
17.79		110 ± 35	γ, n, t	2, 3, 4
18.55		≈ 350	n, t	2, 3, 4
(21.22)	$(2^-; 2)$	sharp	n, p, t	2
(24)				24

[a] See also Table 10.4.

The yield of γ_0 and γ_1 has been studied for $E_t = 0.4$ to 1.1 MeV (1978SU02) [^{10}Be*(17.79) is said to be involved]. See also (1974AJ01). 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 (1966LA04) [^{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 (e)) 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 (1979AB11, 1980AB16, 1982AB1D, 1983ABZW). Differential cross sections and S-factors are reported by (1983CE01) 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 (1983CE01). See also (1974AJ01, 1979AJ01).

3. ^{7}Li(α, p)^{10}Be $\qquad Q_m = -2.5642$

Angular distributions have been measured at $E_\alpha = 30$ and 50 MeV: see (1979AJ01).

4. ^{7}Li(^{7}Li, α)^{10}Be $\qquad Q_m = 14.782$

Angular distributions have been reported for $E(^7\mathrm{Li}) = 2.1$ to 5.75 MeV and at 30.3 MeV: see (1974AJ01).

5. ^{9}Be(n, γ)^{10}Be $\qquad Q_m = 6.8121$

$Q_0 = 6812.1 \pm 0.2$ keV: see (1980IS02).

$Q_0 = 6912.08 \pm 0.10$ keV: see (1981KE02).

The thermal capture cross section is 7.6±0.8 mb (1981MUZQ). Reported γ-ray transitions are displayed in Table 10.2.

6. ^{9}Be(n, n)^{9}Be $\qquad E_b = 6.8121$

The scattering amplitude (bound) $a = 7.778 \pm 0.003$ fm, $\sigma_{\mathrm{free}} = 6.151 \pm 0.005$ b (1981MUZQ). Earlier cross-section measurements are listed in (1979AJ01, 1981MUZQ). Recent σ_t measurements have been reported for $E_n = 0.002$ to 0.005 eV (1979ADZW), 23.5 keV (1975BL07; 5.903 ± 0.011 b), 1.0 to 13.5 MeV (1979AU07), 6.97 to 14.94 MeV (1978HO23; total elastic) and 200 to 590 MeV (1980FR1K). See also (1980AD1A).

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 $E_n = 2.73$

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

E_γ (keV) [b]	Transition	Intensities [c]	E_x (keV) [b]
6809.4 ± 0.4	capt. $\rightarrow$ g.s.	64.6	
5955.9 ± 0.5	5.96 [d] $\rightarrow$ g.s.	1.5	5958.3 ± 0.3
3443.3 ± 0.3	capt. $\rightarrow$ 3.37	11.3	
3367.4 ± 0.2	3.37 $\rightarrow$ g.s.	33.0	3368.0 ± 0.2
2896.4 [e]	6.26 $\rightarrow$ 3.37	0.15	
2811.8 [e]	6.18 $\rightarrow$ 3.37	0.13	
2589.9 ± 0.25	5.96 [d] $\rightarrow$ 3.37	22.4	
853.5 ± 0.3	capt. $\rightarrow$ 5.96 [d]	26.4	
631.8 [e]	capt. $\rightarrow$ 6.18	0.24	
547.4 [e]	capt. $\rightarrow$ 6.26	0.16	
219.3 [e]	6.18 $\rightarrow$ 5.96 [f]	0.05	

[a] See also Tables 10.2 in (1974AJ01, 1979AJ01).
[b] (1966GR18).
[c] Gamma rays per 100 captures (1979JUZU).
[d] This is the 2^+ member of the doublet at $E_x = 5.96$ MeV.
[e] (1979JUZU).
[f] This is the 1^- member of the doublet.

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 (1974AJ01) for references. The analyzing power has been measured for $E_n = 1.6$ to 4.8 MeV (1975HO01) and $E_{\vec{n}} = 9$ to 15 MeV (1981FL1A, 1981FL04; n_0, n_2). See also (1981WA1G, 1983ANZY) and (1979BY01, 1983BY01; theor.).

7. (a) ^{9}Be(n, n′)^{9}Be* $\qquad E_b = 6.8121$

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

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 (1979AJ01). Recent measurmeents include those of (1978HO23; $E_n = 6.97$ to 14.94 MeV; inelastic cross sections to unresolved states at $E_x = 1.7$–3.1 MeV). A_y measurements are reported for the n_2 group [to ^{9}Be*(2.4)] at $E_n = 9$ to 15 MeV (1981FL1A). For reaction (b) see also (1980BA2L; applied work) and (1978HE1F; theor.).

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

$E_{\rm res}$ (MeV $\pm$ keV)	^{10}Be* (MeV)	$\Gamma_{\rm c.m.}$ (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 (1979AJ01).

[b] $R = 5.6$ fm.

8. (a) ^{9}Be(n, p)^{9}Li $\qquad Q_{\rm m} = -12.824 \qquad E_{\rm b} = 6.8121$

(b) ^{9}Be(n, d)^{8}Li $\qquad Q_{\rm m} = -14.662$

(c) ^{9}Be(n, t)^{7}Li $\qquad Q_{\rm m} = -10.438$

Cross sections have been meaasured at $E_{\rm n} = 14.1$–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 (1979AJ01). See also (1981HAZJ, 1982HA1A).

9. ^{9}Be(n, α)^{6}He $\qquad Q_{\rm m} = -0.598$

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 $E_{\rm n} = 3.9$ 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 $E_{\rm n} = 12.2$ to 18.0 MeV: see (1979AJ01) for references. See also (1981HAZJ, 1982HA1A).

10. ^{9}Be(p, π^+)^{10}Be $\qquad Q_{\rm m} = -133.538$

Angular distributions have been studied at $E_{\rm p} = 185$ MeV (1973DA09: to ^{10}Be*(0, 3.37, 6.07 ± 0.13, 7.39 ± 0.13, 9.31 ± 0.24, 11.76)), 200 MeV (1978AU07: to ^{10}Be*(0, 3.37)), 410 and 605 MeV (1980DI02: to ^{10}Be*(0, 3.37, 6.1)) and 800 MeV (1979HO13: to ^{10}Be*(0, 3.37, 11.8)); the latter may be unresolved). (1982AU02) have studied $A_{\rm y}(\theta)$ for the π^+ to ^{10}Be*(0, 3.37) for $E_{\vec{\rm p}} = 200$ and 250 MeV: little variation with E is observed. The cross section for π^+ production near threshold has been studied by (1979MA38). See also the "General" section here, and (1981NI1B, 1982HO1C, 1982NA1K).

11. ^{9}Be(d, p)^{10}Be $\qquad Q_{\rm m} = 4.5875$

Angular distributions of proton groups have been studied at many energies in the range $E_d = 0.15$ to 17.13 MeV [see (1979AJ01)], at $E_d = 2.0$ to 2.8 MeV (1983DE1P; p_0, p_1) and at 698 MeV (1981BO03; p to ^{10}Be*(0, 3.37, 6.1, 7.37 + 7.54, 9.27 + 9.4, 11.8). At $E_d = 15$ MeV (1976DA15) find $S = 2.1$, 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, 6.62) (1976DA15). 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 (1974AN27). ^{10}Be*(9.27, 9.4, 11.76) have $\Gamma_{c.m.} = 150 \pm 20$, 291 ± 20 and 121 ± 10 keV (1974AN27).

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 ther 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*(5.9658, 5.9660) obtained from the character of the γ-decay (1969RO12). ^{10}Be*(6.18) decays primarily to ^{10}Be*(3.37): $E_\gamma = 219.4 \pm 0.3$ keV for the $6.18 \rightarrow 5.96$ transition (1969AL17). 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 (1974AJ01). For polarization measurements see ^{11}B in (1980AJ01). See also (1981CE04), (1974FI1D) and (1982GO05; theor.).

12. ^{9}Be(^{3}He, 2p)^{10}Be $\qquad Q_m = -0.9061$

See (1980CO12; $E(^3$He$) = 13$ MeV) and ^{12}C in (1985AJ01).

13. ^{9}Be(α, ^{3}He)^{10}Be $\qquad Q_m = -13.7657$

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 (1980HA33).

14. ^{9}Be(^{7}Li, ^{6}Li)^{9}Be $\qquad Q_m = -0.438$

Angular distributions have been measured at $E(^7$Li$) = 34$ MeV to ^{10}Be*(0, 3.4): $S = 2.07$ and 0.42($p_{1/2}$), 0.38($p_{3/2}$) (1977KE09).

15. (a) ^{10}Be(p, p)^{10}Be

(b) ^{10}Be(d, d)^{10}Be

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

E_x (keV)	Transition	ΔJ^π	Mult.	Branch (%)	τ_m (psec)	Γ_γ (meV)
3368.0 ± 0.2	$3.37 \to$ 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	$5.96 \to 3.37$	$2^+ \to 2^+$	M1	> 90	< 0.08	
	$5.96 \to$ g.s.	$2^+ \to 0^+$	E2	< 10		
5959.9 ± 0.6	$5.96 \to$ g.s.	$1^- \to 0^+$	E1	83^{+10}_{-6}		
	$5.96 \to 3.37$	$1^- \to 2^+$	E1	17^{+6}_{-10}		
6179.3 ± 0.7	$6.18 \to 5.96$	$0^+ \to 1^-$	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
	$6.18 \to$ g.s.	$0^+ \to 0^+$	E0	[b]		
6263.3 ± 5	$6.26 \to 5.96$	$2^- \to 1^-$ 2^+	M1 E1	≤ 1		
	$6.26 \to 3.37$	$2^- \to 2^+$	E1	99^{+1}_{-2}		
	$6.26 \to$ g.s.	$2^- \to 0^+$	M2	1 ± 1		

[a] See Table 10.4 in (1979AJ01) for references. However, note that there are several typographical errors in the ^{10}Be*(6.18) decay.

[b] (1975WA06).

Angular distrinbutions 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 (1974AJ01).

16. (a) ^{10}Be(γ, π^+)^{10}Be $\qquad Q_m = -140.124$
    (b) ^{10}B(e, e$'\pi^+$)^{10}Be $\qquad Q_m = -140.124$

Differential cross sections have been measured for reaction (a) to ^{10}Be*(0, 3.37) for $E_\gamma \approx 230$ to 340 MeV (1980BO24). Measurements are also reported at $E_{\pi^+} = 17$, 29 and 48 MeV to ^{10}Be$_{\text{g.s.}}$ and at the two higher energies for the transitions to ^{10}Be*(3.37) (1982RO04). See also (1981YA1A; $E_\gamma \approx 183$ MeV; g.s.). At $E_e = 158.5$ to 165.0 MeV the angular distributions of 12.3 ± 0.7 MeV pions are reported by (1982ZU03). The (e, π^+) angular distributions to ^{10}Be*(0, 3.37) are in good agreement with the M3 form factors. It is suggested that ^{10}Be*(5.96) is also populated through an M1 transition. (1982ZU03) also present a review of the data for the 90° photopion cross section leading to ^{10}Be$_{\text{g.s.}}$ as a function of E_{π^+}. See also (1982DE14; theor.).

17. ^{10}B(μ^-, ν)^{10}Be $\qquad Q_m = 105.1026$

Partial capture rates leading to the 2^+ states ^{10}Be*(3.37, 5.96) are reported by (1981GI08).

18. ^{10}B(π^-, γ)^{10}Be $\qquad Q_m = 139.011$

The total radiative capture branching ratio for stopped pions is $(2.27 \pm 0.22)\%$. The γ-spectrum is dominated by the transition to ^{10}Be*(6.0) [$J^\pi = 2^+$] (1975BA52). See also (1979AL1M) and (1979TR1B).

19. ^{10}B(p, pπ^+)^{10}Be $\qquad Q_m = -140.124$

See (1979AJ01).

20. ^{10}B(d, 2p)^{10}Be $\qquad Q_m = -3.5637$

Angular distributions are reported at $E_d = 55$ MeV to ^{10}Be*(0, 3.37, 5.96, 9.4) (1979ST15).

21. ^{11}Li(β^-)^{11}Be $\to$ ^{10}Be + n

^{11}Li populates several states of ^{10}Be, via delayed neutron emission. Gamma rays have been observed for the transitions 6.18 $\rightarrow$ 5.96, 6.18 $\rightarrow$ 3.37, 5.96 (unres.) $\rightarrow$ 3.37 and 3.37 $\rightarrow$ g.s. with $I_\gamma = (0.95 \pm 0.35)$, (1.65 ± 0.70), (3.5 ± 1.0) and $(21 \pm 6)\%$, respectively (1980DE39). See also ^{11}Be in (1985AJ01).

22. ^{11}B(γ, p)^{10}Be $\qquad Q_{\rm m} = 11.2287$

Transitions to ^{10}Be*(3.4) from the upper region of the giant resonance in ^{11}B are reported to be about twice as intense as those from the lower region: see ^{11}B in (1975AJ02). Angular distributions of the p_0 and p_1 groups have been measured with $E_{\rm bs} = 18.5$ MeV and the yield of the 3.37 MeV γ-ray has been reported for $E_{\rm bs} = 100$ to 800 MeV: see (1979AJ01). See also (1982GO03; theor.).

23. ^{11}B(n, d)^{10}Be $\qquad Q_{\rm m} = -9.0042$

The angular distribution of the d_0 group has been measured at $E_{\rm n} = 14.4$ MeV: see (1974AJ01).

24. ^{11}B(p, 2p)^{10}Be $\qquad Q_{\rm m} = -11.2287$

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 (1974AJ01).

25. ^{11}B(d, ^{3}He)^{10}Be $\qquad Q_{\rm m} = -5.7352$

Angular distributions have been measured at $E_{\rm d} = 11.8$ and 22 MeV to ^{10}Be$_{\rm g.s.}$ [see (1974AJ01)] 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) (1975SC41).

26. ^{11}B(t, α)^{10}Be $\qquad Q_{\rm m} = 8.5853$

See (1979AJ01).

27. ^{11}B(^{14}N, ^{15}O)^{10}Be $\qquad Q_{\rm m} = -3.932$

See (1974AJ01). See also (1978MA1F).

28. ^{12}C(p, 3p)^{10}Be $\qquad Q_{\rm m} = -27.1849$

See (1979KO36).

29. ^{12}C(^{6}Li, ^{8}B)^{10}Be $\qquad Q_{\rm m} = -21.442$

At $E(^{6}{\rm Li}) = 80$ MeV, ^{10}Be*(0, 3.37, 5.96, 7.54, (9.4), 11.8) are populated and the angular distribution to $^{10}{\rm Be}_{\rm g.s.}$ has been measured: see (1979AJ01). See also (1982AL08).

^{10}B

(Figs. 20 and 22)

GENERAL: (See also (1979AJ01).)

Shell and deformed models: (1978FU13, 1979FL06, 1979KU05, 1980NI1F, 1981BO1Y, 1981DE2G, 1982BA52).

Cluster and α-particle models: (1979AD1A, 1980FU1G, 1980NI1F, 1980OKZZ, 1981KR1J, 1983RO1G).

Special states: (1979FL06, 1980BR21, 1980FU1G, 1980NI1F, 1980OKZZ, 1980RI06, 1981BA64, 1981BO1Y, 1981DE2G, 1981KU04, 1981SE06, 1982BA52, 1983GO1R).

Electromagnetic tranisitions and giant resonances: (1978FU13, 1979FL06, 1979KU05, 1980KO1L, 1980NI1F, 1980RI06, 1981BA64, 1981BO1Y, 1981KN06, 1982BA52, 1982RI04, 1982VE11).

Astrophysical questions: (1978BU1B, 1979MO04, 1979RA1C, 1980RE1B, 1981AU1D, 1981AU1G, 1981GU1D).

Applied work: (1979AT01, 1979FL1A, 1979FO1F, 1979JUZU, 1980MU1D, 1983ST1H).

Complex reactions involving ^{10}B: (1978BH03, 1978HE1C, 1979AL22, 1979BO22, 1979JA1C, 1979LO11, 1979SA27, 1979ST1D, 1979VI05, 1980GR10, 1980GU1E, 1980MI01, 1980OL1C, 1980RI06, 1980WI1L, 1981BL1G, 1981ME13, 1981MO20, 1981TA22, 1981VA1D, 1982CH1M, 1982FU04, 1982GO1E, 1982LU01, 1982LY1A, 1982MO1K, 1982VE11, 1983BE02, 1983SA06).

Muon and neutrino capture and reactions: (1979BE1N, 1979DE01, 1979GO1M, 1980MU1B, 1981GI08, 1981MU1E, 1981OL01, 1982NA01).

Pion and kaon capture and reactions (See also reactions 23, 24 and 47.): (1978AN20, 1978DA1A, 1978TS1A, 1979AL1J, 1979AL21, 1979BA16, 1979BE1N, 1979BO1P, 1979BO1N, 1979PI06, 1979TI1A, 1979TR1B, 1980CR03, 1980DE11, 1980LE02, 1980MA1F, 1980NA1B, 1980ST25, 1981BE63, 1981FR17, 1981GE1B, 1981GI15, 1981SI1D, 1981ST05, 1981YA1A, 1982RO04).

Hypernuclei: (1978DA1A, 1978PO1A, 1978SO1A, 1980IW1A, 1981WA1J, 1982ER1E, 1982KO11, 1982RA1L).

Other topics: (1980BR21, 1981AV02, 1981KU04, 1981SE06, 1982BA2G, 1982CH1M, 1982DE1N, 1982NG01, 1982VE02, 1983GO1R).

Ground-state properties of ^{10}B: (1978HE1D, 1979BE1N, 1979SA27, 1980FU1G, 1981AV02, 1981BO1Y, 1981OL01, 1981SE06, 1982BA2G, 1982LO13, 1982NG01).

$\mu = +1.80065 \pm 0.00001$ nm: see (1978LEZA)

$Q = +84.72 \pm 0.56$ mb: see (1978LEZA).

Mass of ^{10}B: (A.H. Wapstra (private communication) adopts 12050.0 ± 0.39 keV, and we shall too. See also (1983CH08).

^{10}*B*(0.72)*: $\mu = +0.63 \pm 0.12$ nm: see (1978LEZA). See also (1982VE11).

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

E_x (MeV $\pm$ keV)	$J^\pi; T$	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
g.s.	$3^+; 0$	stable		1, 4, 5, 6, 11, 12, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 43, 44, 45, 48, 49, 50, 51, 52, 53, 55, 56, 57
0.71835 ± 0.04	$1^+; 0$	$\tau_m = 1.020 \pm 0.005$ nsec $g = +0.63 \pm 0.12$	γ	1, 4, 5, 6, 11, 12, 17, 18, 19, 20, 25, 26, 27, 29, 30, 35, 41, 43, 44, 45, 47, 48, 49, 50, 52, 55, 56, 57
1.74015 ± 0.17	$0^+; 1$	7 ± 3 fsec	γ	1, 4, 12, 17, 18, 19, 20, 23, 25, 26, 29, 41, 42, 43, 44, 45, 48, 49, 53, 56
2.1543 ± 0.5	$1^+; 0$	2.13 ± 0.20 psec	γ	1, 4, 12, 17, 18, 19, 20, 25, 26, 27, 29, 30, 35, 43, 44, 45, 47, 48, 49, 50, 52, 55, 56
3.5871 ± 0.5	$2^+; 0$	153 ± 12 fsec	γ	1, 4, 6, 12, 17, 18, 19, 25, 26, 27, 29, 30, 42, 43, 45, 48, 49, 50, 52, 55, 56
4.7740 ± 0.5	$3^+; 0$	$\Gamma = 8.7 \pm 2.2$ eV	γ, α	1, 4, 6, 17, 18, 19, 26, 27, 30, 45, 48, 49, 50, 55
5.1103 ± 0.6	$2^-; 0$	0.98 ± 0.07 keV	γ, α	1, 12, 17, 18, 26, 30, 45, 49
5.1639 ± 0.6	$2^+; 1$	$\tau_m < 6$ fsec	γ, α	1, 12, 17, 18, 23, 26, 27, 42, 45, 48
5.180 ± 10	$1^+; 0$	$\Gamma = 100 \pm 10$	γ, α	1, 3, 12, 17, 18, 27, 30, 45
5.9195 ± 0.6	$2^+; 0$	6 ± 1	γ, α	1, 3, 12, 17, 18, 19, 26, 27, 29, 30, 45, 48, 49, 50
6.0250 ± 0.6	4^+	0.05 ± 0.03	γ, α	1, 3, 17, 18, 19, 23, 25, 26, 27, 29, 30, 43, 45, 49, 50, 53, 55, 56
6.1272 ± 0.7	3^-	2.36 ± 0.03	α	3, 17, 18, 19, 26, 27, 29, 43, 45, 49, 56

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

E_x (MeV $\pm$ keV)	$J^\pi; T$	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
6.561 ± 1.9	$(4)^-$	25.1 ± 1.1	α	3, 17, 18, 19, 26, 27, 29, 30, 43, 45, 48, 49
6.873 ± 5	$1^-; 0+1$	120 ± 5	γ, p, d, α	1, 12, 14, 16, 17
7.002 ± 6	$(1, 2)^+; (0)$	100 ± 10	p, d, α	3, 16, 17, 19, 26, 27, 29, 45, 49, 55
7.430 ± 10	$2^{(-)}; 0+1$	100 ± 10	γ, p, d, α	1, 12, 16, 23
7.467 ± 10	1^+	65 ± 10	p	14, 45
7.479 ± 2	$2^+; 1$	74 ± 4	γ, p	12, 14, 23, 45
7.5607 ± 0.9	$0^+; 1$	2.65 ± 0.18	γ, p	12, 14, 17, 45
(7.67 ± 30)	$(1^+; 0)$	250 ± 20	p, d	14, 16
7.819 ± 20	1^-	260 ± 30	p	14, 17, 19, 45
8.07	2^+	800 ± 200	γ, p, d	16, 17, 23
(8.7)	$(1^+, 2^+)$	(≈ 200)	p	14, 16, 55
8.889 ± 6	$3^-; 1$	84 ± 7	γ, n, p, α	13, 14, 16, 19, 23, 48
8.895 ± 2	$2^+; 1$	40 ± 1	γ, p, α	12, 14, 16, 19, 23, 48
(9.7)	$(T = 1)$	(≈ 700)	n, p, α	13, 16
10.84 ± 10	$(2^+, 3^+, 4^+)$	300 ± 100	γ, n, p	12, 13, 14, 23, 45
11.52 ± 35		500 ± 100	(γ)	23, 43, 45
12.56 ± 30	$(0^+, 1^+, 2^+)$	100 ± 30	γ, p	12, 14, 23, 45
13.49 ± 5	$(0^+, 1^+, 2^+)$	300 ± 50	γ, p	12, 23, 45
14.4 ± 100		800 ± 200	γ, p, α	3, 12, 43, 45
(18.2 ± 200)		(1500 ± 300)		45
18.43	$2^-; 1$	340	γ, ^{3}He	6, 8
18.80	$2^+, 1^+$	< 600	γ, ^{3}He, α	6, 10
19.29	$2^-; 1$	190 ± 20	γ, n, ^{3}He, α	6, 7, 8, 10
20.2	$1^-; 1$	broad	γ, n, t, ^{3}He, α	6, 7, 8, 9, 10, 22
(21.1)			γ, ^{3}He	6
23.1		broad	γ, n	22

[a] See also Tables 10.6, 10.7 and 10.11.

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	≈ 100	[d]				≤ 0.009
6.13	3^-	≤ 21						≤ 0.009
[e]								

[a] For references see Table 10.6 in (1979AJ01).

[b] From Table 10.7.

[c] See also Table 10.8 here. Branching ratios and Γ_γ/Γ from (1979KE08). 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 (1979KE08).

[d] Other branches $< 3\%$.

[e] For γ-decay of higher ^{10}B states see Tables 10.8, 10.10, 10.11 and 10.12. See also Table 10.16.

Table 10.7: Lifetimes of ^{10}B states

^{10}B* (MeV)	τ_m	Reactions	Refs.
0.72	1.020 ± 0.005 nsec	mean	[a]
1.74	7 ± 3 fsec	^{6}Li(α, γ)	(1979KE08)
2.15	2.30 ± 0.26 psec	mean	(1979AJ01) [b]
	1.9 ± 0.3 psec	^{6}Li(α, γ)	(1979KE08)
	2.13 ± 0.20 psec	mean	all values
3.59	153 ± 13 fsec	mean	(1979AJ01)
	150 ± 30 fsec	^{6}Li(α, γ)	(1979KE08)
	153 ± 12 fsec	mean	all values
5.16	< 6 fsec	^{6}Li(α, γ)	(1979KE08)

[a] Weighted mean of last 7 values in Table 10.20 of (1966LA04) and of a new measurement by Vermeer, Bhalla and Polletti, $\tau_m = 1.020 \pm 0.005$ nsec. I am indebted to Prof. F.C. Barker for informing me of this new value.
[b] Table 10.9 in (1979AJ01).

1. ^{6}Li(α, γ)^{10}B $\quad Q_m = 4.4603$

Observed resonances are displayed in Table 10.8. See also (1981GA1A, 1981MU1F).

2. (a) ^{6}Li(α, n)^{9}B $\quad Q_m = -3.977 \quad E_b = 4.4603$
   (b) ^{6}Li(α, p)^{9}Be $\quad Q_m = -2.1262$
   (c) ^{6}Li(α, d)^{8}Be $\quad Q_m = -1.5671$

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 also ^{9}B, ^{9}Be and ^{8}Be. For reaction (a) see also (1979BA48). See (1979AJ01) for references.

3. (a) ^{6}Li(α, α)^{6}Li $\quad E_b = 4.4603$
   (b) ^{6}Li(α, 2α)^{2}H $\quad Q_m = -1.4753$

Table 10.8: Levels of ^{10}B from ^{6}Li(α, γ)^{10}B [a]

$E_{\rm res}$ (keV)	$E_{\rm x}$ (MeV $\pm$ keV)	J^π; T	$\Gamma_{\rm lab}$ (keV)	Decay to $E_{\rm f}$	Branch (%)	$\omega\gamma$ (eV)	Γ_γ (eV)
500 ± 25	4.761	3^+; 0		0	0.5 ± 0.1		
				0.72	> 99		0.020 ± 0.004 [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	< 0.5	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	5.187	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		
4963 [h]	7.440 ± 20	$2^{(-)}$; $0+1$	150 ± 15	[h]			

[a] For earlier references see Table 10.7 in (1979AJ01).

[b] (1983NAZZ) and J. Napolitano, private communication.

[c] $\Gamma_\gamma/\Gamma = (2.3 \pm 0.3) \times 10^{-3}$; $\Gamma_\alpha = 8.4 \pm 1.8$ eV (E.K. Warburton and D.E. Alburger, private communication).

[d] Absolute error only.

[e] Branching ratios from (1979KE08); $\omega\gamma_{\rm c.m.} = 0.40 \pm 0.04$ eV (1979SP01), 0.43 ± 0.07 eV (prelim., J. Napolitano, private communication); $\Gamma_\alpha/\Gamma = 0.16 \pm 0.04$ (1979SP01).

[f] Values of $\omega\gamma$ (1966FO05) have been multiplied by 0.6 to convert them to the c.m. system. I am indebted to Prof. F.C. Barker for pointing out this problem.

[g] Branching ratios calculated from $0°$ relative intensities; $\Gamma_\alpha/\Gamma_{\rm p} = 1.25 \pm 0.12$.

[h] At $0°$ the branches to ^{10}B*(0, 0.72) are equally strong ($(50 \pm 12)\%$).

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

E_α (keV)	E_x (MeV)	Γ_{lab} (keV)	$J^\pi; T$
1210 ± 30	5.19	175	$1^+; 0$
2440 [b]	5.93	≈ 30	$2^+; 0$
2606.0 ± 1.5	6.025	0.09 ± 0.04	4^+
2785.5 ± 1.5 [c]	6.133	3.93 ± 0.05	3^-
3498.5 ± 1.6 [d]	6.561	41.8 ± 1.9	4^-, 2^-
4250 ± 15 [d]	7.012	183 ± 25	$(2)^+$; (0)
16000	14.1	broad	

[a] For references see Table 10.8 in (1979AJ01).
[b] $\Gamma_\alpha = 9.7 \pm 0.1$ keV (1981HE05).
[c] $\Gamma_\alpha = 2.45 \pm 0.12$ keV and $\Gamma_d = 0.08 \pm 0.05$ keV (1981HE05).
[d] There is evidence of broad structure near these states.

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 (1974AJ01). Reported anomalies are displayed in Table 10.9. Elastic scattering and VAP measurements are reported for $E_{\vec{d}} = 15.1$ to 22.7 MeV (1979EG01). Small anomalies are observed in the excitation function of the magnitude parameter (reaction (b)) corresponding to ^{10}B*(8.67, 9.65, 10.32, 11.65) (1983GO07). See, however, Table 10.5. See also ^{6}Li, (1980SK1A) and (1979NO1C, 1979SU09, 1979SU1F, 1980FU1G, 1982LE10, 1983SH04; theor.).

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

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 (1974AJ01) and ^{12}C in (1980AJ01). See also (1979WA13).

5. ^{6}Li(^{7}Li, t)^{10}B $\qquad Q_m = 1.992$

Angular distributions of the t_0 and t_1 groups have been measured at $E(^{6}\text{Li}) = 3.3$ MeV and $E(^{7}\text{Li}) = 3.78$ to 5.95 MeV: see (1974AJ01).

6. ^{7}Li(^{3}He, γ)^{10}B $\qquad Q_m = 17.7880$

Table 10.10: Resonances in ^{7}Li + ^{3}He [a]

E_{res} (MeV)	$\Gamma_{c.m.}$ (keV)	E_x (MeV)	$J^\pi; T$	Γ_γ (eV) for transition to				Γ_α (keV)	Γ_n	Γ_p	Γ_t
				g.s.	0.72	3.59	4.77				
0.92	340	18.43	$2^-; 1$	≥ 3			≥ 17				
1.45 [b]	< 600	18.80	$2^+; 1^+$		≥ 20	≥ 20 [d]		res < 80			
2.15 [b]	280 [c]	19.29	$2^-; 1$	≥ 12			≥ 49	res < 20	res n_0	(p)	
3.4	910 [c]	20.2	$1^-; 1$			≥ 350		res α_2	res n_0	(p)	res t_0
(4.7)		(21.1)			res						

[a] See references listed in Table 10.10 in (1974AJ01, 1979AJ01).
[b] See (1979LIZT, 1980LI1F; abstracts).
[c] $\Gamma_{c.m.} = 190 \pm 20$ and 350 ± 70 keV, respectively, from the n_0 yield.
[d] Assumes isotropy of angular distribution.

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 [$E_{res} = 0.92$ 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. 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 nbe no decay of these states via α_2 to ^{6}Li*(3.56) which has $J^\pi = 0^+$, $T = 1$: see reaction 10]. The assignment for ^{10}B*(18.8) [1.4 MeV resonance] is 1^+ or 2^+ but there apprears 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 (1974AJ01) for references.

7. ^{7}Li(^{3}He, n)^{9}B $\qquad Q_m = 9.351 \qquad E_b = 17.7880$

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, $\Gamma_{lab} = 270 \pm 30$ and 500 ± 100 keV. No other resonances are observed up to $E(^3\text{He}) = 5.5$ MeV. See Table 10.10 and (1974AJ01) for references.

8. ^{7}Li(^{3}He, p)^{9}Be $\qquad Q_m = 11.2015 \qquad E_b = 17.7880$

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. Polarization measurements are reported at $E(^3\text{He}) = 14$ MeV, and more recently at $E(^3\text{He}) = 13.6 - 13.7$ MeV (1981SL03) and 14.01 MeV (1983RI01). See also (1981VI1B). For the earlier references see (1974AJ01, 1979AJ01).

9. (a) ^{7}Li(^{3}He, d)^{8}Be $\qquad Q_{\rm m} = 11.7606 \qquad E_{\rm b} = 17.7880$

(b) ^{7}Li(^{3}He, t)^{7}Be $\qquad Q_{\rm m} = -0.881$

(c) ^{7}Li(^{3}He, ^{3}He)^{7}Li

Yields of deuterons have been measured for $E(^3\mathrm{He}) = 1.0$ 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 $E(^3\mathrm{He}) \approx 3.5$ MeV in the t$_0$ yield. See (1979AJ01) for references. Polarization measurements are reported at $E(^3\vec{\mathrm{He}}) = 33.3$ MeV for the deuteron groups to ^{8}Be*(16.63, 17.64, 18.15) (1981BA38) and for the triton and ^{3}He groups to ^{7}Be*(0, 0.43) and ^{7}Li*(0, 0.48, 4.63) (1981BA37). See also (1979KA1G).

10. ^{7}Li(^{3}He, α)^{6}Li $\qquad Q_{\rm m} = 13.328 \qquad E_{\rm b} = 17.7880$

Excitation functions have been measured for $E(^3\mathrm{He}) = 1.3$ to 18.0 MeV: see (1974AJ01). 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 6]: 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. Recent (unpublished) excitation studies have been reported at $E(^3\mathrm{He}) = 0.6$ to 2.5 MeV for the α_0, α_1, α_2 and α_4 groups: the α_4 group shows possible resonances at $E(^3\mathrm{He}) = 1.45$ and 2.15 MeV. $J^\pi = 2^+$; $T = 1$ is suggested for the lower structure (1979LIZT, 1980LI1F). Polarization measurements are reported at $E(^3\vec{\mathrm{He}}) = 33.3$ MeV to ^{6}Li*(0, 2.19, 3.56) (1981BA38).

11. ^{7}Li(α, n)^{10}B $\qquad Q_{\rm m} = -2.7898$

Angular distributions have been measured for $E_\alpha = 4.78$ to 13.9 MeV [see (1974AJ01)] and more recently for $E_\alpha = 4.4$ to 5.1 MeV (1981SE04). See also (1979AJ01).

12. ^{9}Be(p, γ)^{10}B $\qquad Q_{\rm m} = 6.5865$

Parameters of observed resonances are listed in Tables 10.11 and 10.12. Table 10.6 summarizes the γ-transitions from this and other reactions. For references to the discussion below, see (1974AJ01, 1979AJ01).

The $E_{\rm p} = 0.32$ MeV resonance (^{10}B* $= 6.87$ MeV) is ascribed to s-wave protons because of its comparitively 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. See (1982RI04) for the $5.16 \rightarrow 1.74$ decay (Table 10.6).

Table 10.11: Resonances in ^{9}Be(p, γ)^{10}B [a]

E_p (MeV ± keV)	E_x (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	$J^\pi; T$	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	7.479	72 ± 4	$2^-; 1$ [c]	≈ 0.65	25.8
1.0832 ± 0.4	7.5607	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	8.895	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 (1979AJ01). See Table 10.12 for decay schemes.

[b] Unpublished Ph.D. thesis.

[c] See (1974AJ01). This state is assigned $J^\pi = 2^+$ on the basis of the (e, e′) work (see Table 10.16). I am indebted to Dr. D. Kurath for his comments.

Table 10.12: Radiative transitions in ^{9}Be(p, γ)^{10}B [a]

Initial state (MeV)	$J^{\pi}; T$	Γ_{γ} (tot) (eV)	Relative intensities to final states								
			ground	0.72	1.74	2.15	3.59	5.11	5.16	5.18	5.92
			$3^+; 0$	$1^+; 0$	$0^+; 1$	$1^+; 0$	$2^+; 0$	$2^-; 0$	$2^+; 1$	$1^+; 0$	$2^+; 1$
6.87 $E_{\rm p} = 0.32$	$1^-; 0+1$	4.8 [b]	< 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 $E_{\rm p} = 0.94$	$2^{(-)}; 0+1$	[2.4]	< 2	1.3	[< 0.14]	0.62	0.5			[< 1]	
7.48 $E_{\rm p} = 0.99$	$2^+; 1$	[25.8]	25	0.3	[< 0.14]	0.49	0			[< 1]	
7.56 $E_{\rm p} = 1.08$	$0^+; 1$	[8.5]	< 0.2	6.7	< 0.3	0.8	< 0.2			1.0	
7.75 [c] $E_{\rm p} = 1.29$	$(2^-; 1)$	[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 (1979AJ01).
[b] See, however, Table 10.8, footnote [f].
[c] See, however, Table 10.14.

The proton-capture data near $E_\mathrm{p} = 1$ MeV appears to require at least five resonant states, at $E_\mathrm{p} = 938$, (980), 992, 1083 and 1290 keV. The narrow $E_\mathrm{p} = 1083$ 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 10.12) indicate $T = 1$. The width of ^{10}B*(5.18) observed in the decay is 100 ± 10 keV.

The excitation function for the ground-state radiation shows resonance at $E_\mathrm{p} = 992$ ($\Gamma = 80$ keV) and 1290 keV ($\Gamma = 230$ keV). Elastic scattering studies indicate s-wave formation and $J^\pi = 2^-$ for both. For the lower level ($E_\mathrm{x} = 7.48$ 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 $E_\mathrm{p} = 980$ keV.

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

Transitions to ^{10}B*(0.7) [γ_1] show resonances at $E_\mathrm{p} = 992$, 1290 adn 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 $E_\mathrm{p} = 2.567 \pm 0.003$ ($E_\mathrm{x} = 8.895$ 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 $E_\mathrm{p} = 4.72 \pm 0.01$ MeV, $\Gamma \approx 0.5$ MeV.

In the range $E_\mathrm{p} = 4$ to 18 MeV, the γ_0 yield at 90° shows the resonance at $E_\mathrm{p} = 4.7$ MeV ($E_\mathrm{x} = 10.7$ MeV) and shows fluctuations suggesting states at $E_\mathrm{x} \approx 14.6$, 15.6 and 19.7 MeV. It is suggested that ^{10}B*(19.7) 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 $E_\mathrm{x} \approx 14.5$ MeV. Fluctuations in the γ_1 yield are reported at $E_\mathrm{x} \approx 12.6$, 13.3 and 14.1 MeV. These states presumably decay by M1 to ^{10}B*(0.7) [$J^\pi = 1^+$] and therefor $J^\pi_\mathrm{i} = 0^+$, 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 $E_\mathrm{x} = 15$ MeV (maximum 90° differential cross section ≈ 0.5 μb/sr) and possibly some structure near $E_\mathrm{x} = 20$ MeV. The γ_3 yield (to ^{10}B*(2.15) [$J^\pi = 1^+$]) increases to ≈ 0.4 μb/sr at $E_\mathrm{x} \approx 16$ MeV and seems to remain constant beyond that energy, with some suggestion of a fluctuation corresponding to $E_\mathrm{x} \approx 12.9$ 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 (unpublished Ph.D. thesis).

The magnetic moment of ^{10}B*(0.72) has been studied via $\gamma - \gamma$ correlations from ^{10}B*(7.56): g $= +0.63 \pm 0.12$.

13. ^{9}Be(p, n)^{9}B $\qquad Q_\mathrm{m} = -1.851 \qquad E_\mathrm{b} = 6.5865$

Resonances in the neutron yield occur at $E_\mathrm{p} = 2562 \pm 6$, 4720 ± 10 and, possibly, at 3500 keV with $\Gamma_\mathrm{c.m.} = 84 \pm 7$, ≈ 500 and ≈ 700 keV. These three resonances correspond to ^{10}B*(8.891, 10.83, 9.7): see Table 10.13 in (1974AJ01). Cross-section measurements for the (p, n) and (p, n_0) reactions have been obtained by (1983BY01; $E_\mathrm{p} = 8.15$ to 15.68 MeV) [see also for a review of earlier work]. They indicate possible structure in ^{10}B near 13–14 MeV (1983BY01).

The $E_p = 2.56$ MeV resonances is considerably broader than that observed at the same energy in ^{9}Be(p, α) and ^{9}Be(p, γ) and the two resonances are believed to be distinct. The shape of the resonance and the magnitude of the cross section an 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 (1974AJ01).

The analyzing power for n_0 has been measured for $E_{\vec{p}} = 2.7$ to 17 MeV (1980MA33, 1981BY1B, 1981BY1C, 1981MU1D), as has P^y near 8.1 MeV. See also (1983BY01). The polarization transfer coefficient has been studied for $E_{\vec{p}} = 3.9$ to 15.1 MeV by (1976LI08): negative values of $K_y^{y'}(0)$ are reported near $E_p = 7$ MeV in a region where several states are known to exist in ^{10}B; a spin-flip mechanism may also be involved. Polarization measurements are also reported at $E_{\vec{p}} = 135$ MeV (1981MA1J) and 800 MeV (1981RI06). See also ^{9}B, (1979AJ01), (1979BA68), (1980WA1K, 1981WA1G, 1982BY1A) and (1978BA1F, 1981UL1B; applications).

14. (a) ^{9}Be(p, p)^{9}Be $E_b = 6.5865$

(b) ^{9}Be(p, pn)^{8}Be $Q_m = -1.6655$

The elastic scattering has been studied for $E_p = 0.2$ to 9.5 MeV [see (1974AJ01, 1979AJ01)] and (1980BO1L; $E_p = 2.31 \rightarrow 2.73$ MeV; p_0). 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 10.13. Pronounced minima at $E_p = 2.48$ and 2.55 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 10.13.

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 (1974AJ01, 1979AJ01)] and at $E_{\vec{p}} = 780$ MeV (1982RA20) as well as at 1 GeV (1983BE16). See also ^{9}Be. A_y and K_y^y have been measured at $E_{\vec{p}} = 225$ MeV (1981RO1M; p_0). Total reaction cross sections have been measured at eight energies in the range $E_p = 225$ to 557 MeV (1979SC07). Inclusive cross sections have been measured by (1979FR12, 1979KO21, 1980NI09). Polarization transfer parameters have been measured at $E_p = 800$ MeV (1981RI06). Hadron multiple production has been studied by (1978AR1J). For pion and kaon production at 400 GeV see (1980NI09). For reaction (b) see ^{9}Be and (1982PE1F). See also (1981BA1R, 1981CO1D, 1981NA05, 1981WA1G, 1982BA2T, 1983SEZW), (1983LE28; astrophysics) and (1978BH1B, 1979BY01, 1979WE1C, 1981BO1C, 1981KR17, 1983BY01; theor.).

15. (a) ^{9}Be(p, t)^{7}Be $Q_m = -12.082$ $E_b = 6.5865$

(b) ^{9}Be(p, ^{3}He)^{7}Li $Q_m = -11.201$

Polarization measurements (reaction (b)) are reported at $E_{\vec{p}} = 23.06$ MeV (1983RI01). See also (1979AR04, 1981BA1R, 1981SL03, 1983SEZW).

Table 10.13: Resonances in ^{9}Be(p, p)^{9}Be [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	7.468	65 ± 10	1^+	1.0
980 ± 10	7.468	80 ± 8	2^- [d]	0.90 ± 0.05
1084 ± 2	7.561	2.7	0^+	1.0
(1200 ± 30)	(7.66)	250 ± 20	(1^+)	0.30 ± 0.10
1370 ± 20	7.819	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		$\geq 2; (1)$ [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 (1979AJ01).
[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 (1977KI04).
[d] See, however, Table 10.16 and footnote [a] in Table 10.13 of (1979AJ01).

16. (a) ^{9}Be(p, d)^{8}Be $\quad Q_m = 0.5591 \quad E_b = 6.5865$
(b) ^{9}Be(p, α)^{6}Li $\quad Q_m = 2.126$

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 $\pm 5 - 6\%$ 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 10.9], 310 keV (1^-) and 410 keV (1^+; 2^+ or 3^+ possible) (1973SI27).

Measurements of excitation functions for deuterons and α-particles have been reported at a number of energies to $E_p = 15$ MeV: see (1974AJ01, 1979AJ01), Observed resonances are displayed in Table 10.14.

Polarization measurements have been made in the range $E_p = 0.30$ to 15 MeV and at 185 MeV: see (1974AJ01, 1979AJ01). See also ^{6}Li, ^{8}Be and (1979AR04, 1983SEZW).

Table 10.14: 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)	$J^\pi; T$	Γ_p/Γ	θ^2_p	θ^2_d	θ^2_α
0.34	6.89		$1^-; 0$	0.30	0.34	0.15	0.055
0.46	7.00		$1^+(2^+, 3^+)$ [d]		0.3	0.3	0.1
(0.68)	(7.20)						
0.94	7.43	140	$(2^-; 0)$	0.7	0.04	0.02	
1.15	7.62	225 ± 50	$(1^+; 0)$	≈ 0.4	≈ 0.1		
1.65	8.07	800 ± 200	$(2^-; 0)$	≈ 0.07	0.18	0.21	
(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 references see Table 10.14 in (1979AJ01).
[b] (1977KI04) have analyzed the ($\alpha_2\gamma$) and p_0 yields with an R-matrix formalism and find the following parameters:

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

[c] Resonance for α_2 to ^{6}Li*(3.56), $J^\pi = 0^+$, $T = 1$.
[d] See, however, Table 10.9.

17. ^{9}Be(d, n)^{10}B $\qquad Q_m = 4.3620$

Neutron groups are observed corresponding to the ^{10}B states listed in Table 10.15. Angular distributions have been measured for $E_d = 0.5$ to 16 MeV: see (1974AJ01, 1979AJ01). Observed γ-transitions are listed in Table 10.16 of (1979AJ01). See Tables 10.6 and 10.7 here for the parameters of radiative transitions and for τ_m.

From all the various experiments the follwoing 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 (1966LA04, 1966WA10)].

For polarization measurements see (1981BR1E) and ^{11}B in (1980AJ01, 1985AJ01). See also (1977BA1L, 1978PL1B) and (1978BA1F, 1979WA1F, 1982OV1A, 1982SM1F; applications).

18. ^{9}Be(^{3}He, d)^{10}B $\qquad Q_m = 1.0930$

Table 10.15: 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]		$J^{\pi}; T$
	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	1.42	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^+	0.10	$3^+; 0$
			(3) [e]	≤ 0.82	
5.11	0	0.14	$0+2$	0.34, 0.14	$2^-; 0$
5.16 }	1	0.43	1	0.86	$2^+; 1$
5.18 }					$1^+; 0$
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 (1979AJ01). See that table for additional information and for references.

[b] S_{rel} from experiment at $E_d = 12.0 - 16.0$ MeV. (1974KE06) have reanalyzed the results for ^{10}B*(0, 1.74) and find S_{rel} (ave.) $= 1.0$ and 1.36. For values at other energies see Table 10.15 in (1979AJ01).

[c] (1980BL02; $E(^{3}\mathrm{He}) = 18$ 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 (1979AJ01).

[d] State observed in (d, n) reaction; l_p not determined.

[e] Angular distribution poorly fitted by DWBA (1980BL02).

[f] See (1980BL02) 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 observed strengths. Neither $l_p = 2$ or 1 gives a good DWBA fit.

[g] Group shown corresponds to unresolved states in ^{10}B.

Deuteron groups have been observed to a number of states of ^{10}B: see Table 10.15. Angular distributions have been reported at $E(^3\text{He}) = 10$ to 25 MeV, at $E(^3\text{He}) = 33.3$ MeV [see (1974AJ01, 1979AJ01)] and at $E(^3\text{He}) = 18$ MeV (1980BL02). Spectroscopic factors obtained in the (d, n) and (^{3}He, d) reactions are not in good agreement: see the discussions in (1974KE06, 1980BL02).

19. ^{9}Be(α, t)^{10}B $\qquad Q_\text{m} = -13.2275$

Angular distributions have been studied at $E_\alpha = 27$, 28.3 and 43 MeV [see (1979AJ01)], at $E_\alpha = 30.1$ MeV (1983VA1H; α_0, α_1, α_3, α_4) and at 65 MeV (1980HA33). 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 (1980HA33; see also for a comparison with the (d, n) and (^{3}He, d) results). See also (1978ZE03; theor.).

20. ^{9}Be(^{7}Li, ^{6}He)^{10}B $\qquad Q_\text{m} = -3.388$

At $E(^7\text{Li}) = 34$ 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 ($\text{p}_{1/2}$ or $\text{p}_{3/2}$), 1.40 and 0.46 ($\text{p}_{1/2}$), 0.54 ($\text{p}_{3/2}$) for ^{10}B*(0, 0.74, 1.74, 2.15) (FRDWBA analysis) (1977KE09).

21. ^{10}Be(β^-)^{10}B $\qquad Q_\text{m} = 0.5568$

See ^{10}Be.

22. (a) ^{10}B(γ, n)^{9}B $\qquad Q_\text{m} = -8.437$
(b) ^{10}B(γ, p)^{9}Be $\qquad Q_\text{m} = -6.5865$
(c) ^{10}B(γ, d)^{8}Be $\qquad Q_\text{m} = -6.0274$
(d) ^{10}B(γ, α)^{6}Li $\qquad Q_\text{m} = -4.4603$

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 $E_\gamma = 16$ to 35 MeV (1976KN04). The giant resonance is broad with the major structure contained in two peaks at $E_\text{x} = 20.1 \pm 0.1$ and 23.1 ± 0.1 MeV ($\sigma_\text{max} \approx 5.5$ mb for each of the two maxima). For reaction (b) see (1974AJ01); for reactions (c) and (d) see (1959AJ76, 1966LA04). See also (1978DI1A, 1979TA1C) and (1981KE16, 1983GO1T; theor.).

Table 10.16: Radiative widths for ^{10}B(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	$2^+; 1$ [c]	M1	11.75 ± 0.75
8.07	2^+ [d]	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 [c]		M1 or C2	
11.56 [c]		(M1)	11.4 ± 2.3 [c]
12.6			
13.3			

[a] (1979AN08; E_e = 67 to 194 MeV). See also Table 10.18 in (1979AJ01) and (1978SH14).

[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 (1979AJ01).

[c] (1976FA13, 1979AN08).

[d] Determined by (1979AN08); $\Gamma \approx 760$ keV.

23. (a) ^{10}B(e, e)^{10}B
    (b) ^{10}B(e, en)^{9}B $\qquad Q_m = -8.437$
    (c) ^{10}B(e, ep)^{9}Be $\qquad Q_m = -6.5865$
    (d) ^{10}B(e, eπ^+)^{10}Be $\qquad Q_m = -140.124$

Inelastic electron groups are displayed in Table 10.16 (1979AN08). For reactions (b) and (c) see (1978SH14); for reaction (c) see (1978NA05); for reaction (d) see ^{10}Be (1982ZU03). See also (1979AJ01, 1979TI1A, 1979TR1B) and (1978BO09, 1978FU13, 1981KE15; theor.).

24. ^{10}B($\pi^\pm$, $\pi^\pm$)^{10}B

See (1981GE1B).

25. ^{10}B(n, n$'$)^{10}B

Angular distributions have been studied for $E_{\rm n}$ = 1.5 to 14.1 MeV: see (1974AJ01, 1979AJ01). See also ^{11}B in (1985AJ01), (1979GLZY, 1981DAZZ) and (1979GLZV; theor.).

26. (a) ^{10}B(p, p$'$)^{10}B

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

Angular distributions have been measured for $E_{\rm p}$ = 3.0 to 49.5 MeV [see (1974AJ01, 1979AJ01)] and at 6.0 (1977SA1B) and 800 MeV (1979MO1E). Table 10.17 displays the states observed in this reaction. The earlier γ-decay results are presented in (1979AJ01) and in Table 10.6 here. See also ^{11}C in (1985AJ01), (1980FA07, 1981HO13) and (1979GLZV, 1980KO1V; theor.). For reaction (b) see ^{9}Be and (1974AJ01).

27. ^{10}B(d, d$'$)^{10}B

Angular distributions have been reported at $E_{\rm d} = 4$ to 28 MeV: see (1974AJ01, 1979AJ01). Observed deuteron groups are displayed in Table 10.17. 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 (1974AJ01).

28. ^{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 (1974AJ01).

29. ^{10}B(^{3}He, ^{3}He$'$)^{10}B

Angular distributions have been measured at $E(^{3}{\rm He}) = 4$ to 32.5 MeV [see (1974AJ01, 1979AJ01)] and at 41 MeV (1980TR02; elastic) and 46.1 MeV (1979GO07). $L = 2$ gives a good fot to the distributions of ^{3}He ions to ^{10}B*(0.72, 2.15, 3.59, 6.03): derived $\beta_{\rm L}$ are shown in Table 10.19 of (1979AJ01). See also Table 10.17 here.

30. (a) ^{10}B(α, α')^{10}B

(b) ^{10}B(α, 2α)^{6}Li $\qquad Q_{\rm m} = -4.4603$

Table 10.17: ^{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]	$\Gamma_{\text{c.m.}}$ (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 (1979AJ01).
[b] From (p, p′).
[c] See results obtained from (^{3}He, ^{3}He′) in Table 10.19 of (1979AJ01).
[d] Also observed in (d, d′) and (^{3}He, ^{3}He′).
[e] $E_x = 718.35 \pm 0.04$ (1979RI12; from E_γ).
[f] $E_x = 718.5 \pm 0.2$ and 1740.0 ± 0.6 keV (1966FR09; 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 $J^\pi = 2^-$.

Angular distributions have been measured for $E_\alpha = 5$ to 56 MeV [see (1974AJ01, 1979AJ01)] and at $E_\alpha = 31.2$ MeV (1981KO1U; α_0). ^{10}B*(1.74) is not observed. S_α for $^{10}\mathrm{B}_{\mathrm{g.s.}} = 0.16$ (1976WO11).

Reaction (b) has been studied at $E_\alpha = 24$ MeV [see (1979AJ01)] and at 700 MeV (1979DO04). Using a width parameter of 141 MeV/c, (1979DO04) find that the effective number of α + d clusters for $^{10}\mathrm{B}_{\mathrm{g.s.}}$, $n_{\mathrm{eff}} = 1.19 \pm 0.23$; the results are very model dependent. See also (1978ZE03, 1981LA13; theor.).

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

Elastic scattering angular distributions have been studied at $E(^6\mathrm{Li}) = 5.8$ and 30 MeV and at $E(^7\mathrm{Li}) =$ 24 MeV: see (1979AJ01).

32. ^{10}B(^{9}Be, ^{9}Be)^{10}B

Elastic scattering angular distributions have been reported at $E(^{10}\mathrm{B}) = 20.1$ and 30.0 MeV (1980BO14).

33. (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 $E(^{10}\mathrm{B}) = 8$, 13 and 21 MeV. For yields and reaction (b) see (1979AJ01). See also (1979SH22) and (1978TA1B; theor.).

34. (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 $E(^{10}\mathrm{B}) = 18$ and 100 MeV [see (1979AJ01)] for reaction (a) and at 18, 25, 32, 39 and 46 MeV for reaction (b) (1982MA20).For fusion measurements see (1979AJ01) and (1981MA18, 1982MA20). See also (1978VA1A, 1981DE13, 1982HA42; theor.).

35. ^{10}B(^{14}N, ^{14}N)^{10}B

Angular distributions are reported at $E(^{10}\mathrm{B}) = 100$ MeV [see (1979AJ01)] and at $E(^{14}\mathrm{N}) = 73.9$ and 93.6 MeV (1979MO14; to ^{10}B*(0, 0.72, 2.15)). For fusion cross-section measurements see (1979AJ01) and (1980PA19, 1982BE54, HO82F, 1982HO1F, 1982OR02). See also (1978TA1B) and (1981AB1A; theor.).

36. (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 distribution (reaction (a)) have been studied at $E(^{16}\mathrm{O}) = 15.0$ to 32.5 MeV and at $E(^{10}\mathrm{B}) = 100$ MeV [see (1979AJ01)] as well as at $E(^{10}\mathrm{B}) = 33.7$, 41.6, 49.5 MeV (1980PA01) and 65.8 MeV (1977MO1A, 1979MO14). The ground-state quadrupole moment of ^{10}B is observed to influence the scattering (1980PA01). The elastic scattering for reaction (c) has been studied at $E(^{18}\mathrm{O}) = 20$, 24 and 30.5 MeV: see (1974AJ01). For fusion cross-section measurements and excitation functions see (1979GO09, 1981THZY) for reaction (a) and (1980WI09, 1982CH07) for reaction (b). See also (1981ST1P) and (1979HU1B, 1980VA03, 1981VA1E, 1983CI08; theor.).

37. (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 $E(^{19}\mathrm{F}) = 20$ and 24 MeV [see (1974AJ01)] (reaction (a)) and for $E(^{10}\mathrm{B}) = 65.9$ MeV (1979MO14) (reaction (b)).

38. (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 $E(^{10}\mathrm{B}) = 87.4$ MeV (1982FU09).

39. (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 $E(^{10}\mathrm{B}) = 41.6$ and ≈ 50 MeV (1979PA09; also 33.7 MeV for reaction (b)). See also (1980GL03).

40. ^{10}B(^{40}Ca, ^{40}Ca)^{10}B

The elastic scattering angular distribution has been measured for $E(^{10}\mathrm{B}) = 46.6$ MeV (1980GL03).

41. ^{10}C(β^+)^{10}B $\qquad Q_{\mathrm{m}} = 3.6488$

The half-life of ^{10}C is 19.255 ± 0.53 sec (1975HA45) [and see (1974AJ01, 1979AJ01)]: the decay is to ^{10}B*(0.72, 1.74) with branching ratios of $(98.53 \pm 0.02)\%$ and $(1.465 \pm 0.014)\%$ 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 (1979AJ01). 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] (1969FR02). See (1979AJ01) for a further discussion of the decay. See also (1979DE15, 1979FE02, 1979KU05; theor.).

42. ^{11}B(γ, n)^{10}B $\qquad Q_{\rm m} = -11.454$

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 resonances 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 (1980AJ01). (1979BR1D) report observation of the 1.02 MeV line from the decay of ^{10}B*(1.74). See also ^{11}B in (1985AJ01) and (1982GO03, 1983GO1T; theor.).

43. ^{11}B(p, d)^{10}B $\qquad Q_{\rm m} = -9.230$

Angular distributions of deuteron groups have been measured at several energies in the range $E_{\rm p} = 17.7$ to 154.8 MeV: see (1979AJ01). The population of the first five states of ^{10}B and ^{10}B*(5.18(u), 6.04(u), 6.56, 7.5, 11.4 ± 0.2, 14.1 ± 0.2) is reported. For VAP measurements see (1982BU03) in ^{12}C (1985AJ01).

44. ^{11}B(d, t)^{10}B $\qquad Q_{\rm m} = -5.197$

Angular distributions have been measured at $E_{\rm d} = 11.8$ MeV (t$_0 \rightarrow$ t$_3$; $l = 1$; $S = 1.88$, 0.94, 1.35, 1.35, respectively): see (1974AJ01).

45. (a) ^{11}B(^{3}He, α)^{10}B $\qquad Q_{\rm m} = 9.124$

(b) ^{11}B(^{3}He, 2α)^{6}Li $\qquad Q_{\rm m} = 4.663$

Reported levels are displayed in Table 10.18. Angular distributions have been measured at a number of energies between $E(^3\text{He}) = 1.0$ and 33 MeV: see (1974AJ01). For the decay of observed states see Table 10.6.

The $\alpha\alpha$ 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 16, and see (1974AJ01) for the references.

Table 10.18: ^{10}B levels from ^{11}B(^{3}He, α)^{10}B [a]

E_x (MeV $\pm$ 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 (1979AJ01) for references.

46. ^{12}C(γ, pn)^{10}B $\qquad Q_{\rm m} = -27.4104$

See (1982DO08), ^{12}C in (1985AJ01) and (1981KH08; theor.).

47. ^{12}C($\pi^{\pm}$, $\pi^{\pm}$d)^{10}B $\qquad Q_{\rm m} = -25.1858$

At $E_{\pi^+} = 180$ MeV and $E_{\pi^-} = 220$ MeV, ^{10}B*(0.72, 2.15) are populated (1981ST05). See also (1979EL12, 1982EL07).

48. (a) ^{12}C(p, ^{3}He)^{10}B $\qquad Q_{\rm m} = -19.6923$

(b) ^{12}C(p, pd)^{10}B $\qquad Q_{\rm m} = -25.1858$

Angular distributions of ^{3}He ions have been measured for $E_{\rm p} = 39.8, 51.9$ and 185 MeV: see (1979AJ01). ^{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 (1981ER10; 670 MeV) and (1979AJ01). See also (1978GO14; theor.).

49. ^{12}C(d, α)^{10}B $\qquad Q_{\rm m} = -1.3391$

Alpha groups have been observed to most of the known states of ^{10}B below $E_{\rm x} = 7.1$ MeV: see Table 10.23 in (1974AJ01). Angular distributions have been measured for $E_{\rm d} = 5.0$ to 40 MeV: see (1979AJ01). 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) (1976VA07; ZRDWBA). A study of the $m_{\rm s} = 0$ yield at $E_{\overline{\rm d}} = 14.5$ MeV ($\theta = 0°$) leads to assignments of 3^+, 2^- and $(3^+, 4^-)$ for ^{10}B*(4.77, 5.11, 6.56) (1975KU15). VAP measurements are reported at $E_{\overline{\rm d}} = 52$ MeV (1982MA25): see ^{14}N in (1986AJ01).

The population of the isospin forbidden group to ^{10}B*(1.74) [α_2] has been studied with $E_{\rm d}$ up to 30 MeV: see ^{14}N in (1976AJ04). See also (1981JO02, 1982BA24; theor.).

50. ^{12}C(α, ^{6}Li)^{10}B $\qquad Q_{\rm m} = -23.7105$

Angular distributions have been reported at $E_\alpha = 42$ and 46 MeV: see (1979AJ01). At $E_\alpha = 65$ 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 (1978SA26).

51. ^{12}C(^{10}B, 3α)^{10}B $\qquad Q_{\rm m} = -7.2747$

See (1978BE1G).

52. (a) ^{12}C(^{12}C, ^{14}N)^{10}B $\quad Q_{\rm m} = -14.9134$

(b) ^{12}C(^{14}N, ^{16}O)^{10}B $\quad Q_{\rm m} = -4.4495$

Angular distributions (reaction (a)) involving ^{10}B*(0, 0.7) have been studied at $E(^{12}{\rm C}) = 49.0$ to 75.5 MeV (1979CL06, 1980CO10) and 93.8 MeV (1979FU04). Angular distributions (reaction (b)) involving ^{10}B*(0, 0.72, 2.15, 3.59) have been measured at $E(^{14}{\rm N}) = 53$ MeV [see (1979AJ01)] and 78.8 MeV (1979MO14; not to ^{10}B*(3.59)).

53. ^{13}C(p, α)^{10}B $\quad Q_{\rm m} = -4.0609$

Angular distributions have been measured for $E_{\rm p} = 5.8$ to 18 MeV and 43.7 and 50.5 MeV: see (1979AJ01). Polarization measurements are reported at $E_{\vec{\rm p}} = 65$ MeV (1980KA03; p_0): see ^{14}N in (1986AJ01).

54. ^{14}N(p, pα)^{10}B $\quad Q_{\rm m} = -11.6115$

See (1978GO14; theor.).

55. ^{14}N(d, ^{6}Li)^{10}B $\quad Q_{\rm m} = -10.136$

At $E_{\rm d} = 80$ MeV angular distributions are reported to ^{10}B*(0, 0.72, 2.15, 3.59, 4.8, 6.04, 7.05, 8.68) (1979OE01; see for S_α).

56. ^{14}N(^{3}He, ^{7}Be)^{10}B $\quad Q_{\rm m} = -10.024$

At $E(^{3}{\rm He}) = 41$ MeV groups to ^{10}B*(0, 0.72, 2.15, 3.59, 6.1) have been observed. The transition to ^{10}B*(1.74) is very weak: see (1979AJ01).

57. ^{16}O(^{14}N, ^{20}Ne)^{10}B $\quad Q_{\rm m} = -6.877$

At $E(^{14}{\rm N}) = 76.2$ MeV angular distributions involving ^{10}B*(0, 0.7) are presented by (1979MO14).

^{10}C

(Figs. 21 and 22)

GENERAL: (See also (1979AJ01).)

Model calculations: (1981DE2G, 1982SA1U).

Electromagnetic transitions: (1982RI04).

Astrophysical questions: (1979MO04, 1979RA1C).

Complex reactions involving ^{10}C: (1979BO22, 1981MO20).

Reactions involving pions (See also reactions 2 and 6.): (1979AL1J, 1979LI1D, 1980LE02, 1981AU1C, 1982COZV, 1982RO04).

Other topics: (1979NOZZ, 1980NO1A, 1982DE1N, 1982NG01).

Mass of ^{10}C: Based on Q_0 for ^{10}B(p, n)^{10}C and ^{12}C(p, t)^{10}C and the Wapstra masses for n, t and ^{10}B, the atomic mass excess of ^{10}C is 15698.8 ± 0.5 keV.

1. ^{10}C(β^+)^{10}B $\qquad Q_{\rm m} = 3.6488$

^{10}C decays with a half-life of 19.255 ± 0.053 sec to ^{10}B*(0.7, 1.7): the branching ratios are $(98.53 \pm 0.02)\%$ and $(1.465 \pm 0.014)\%$, respectively (1972RO03): see reaction 41 in ^{10}B.

2. ^{9}Be(p, π^-)^{10}C $\qquad Q_{\rm m} = -136.6296$

Angular distributions of π^- groups have been measured at $E_{\rm p} = 185$ MeV (1973DA09; to ^{10}C*(0, 3.36, 5.28, 6.63)), at $E_{\rm p} = 200$ MeV (1980SJ02; ^{10}C$_{\rm g.s.}$) and at $E_{\rm p} = 800$ MeV (1979HO13; to ^{10}C*(0, 3.35, 5.3, 6.6)). $A_{\rm y}$ measurements have been reported at $E_{\rm p} = 200$ MeV (1980SJ02; ^{10}C$_{\rm g.s.}$) and 200, 225 and 250 MeV (1982LO02; ^{10}C*(0, 3.35, 5.28, 6.6)). See also (1979AJ01, 1979JO1C, 1979ME2A, 1981AU1C, 1981BO1D, 1982HO1C, 1982NA1K).

3. ^{10}B(γ, π^-)^{10}C $\qquad Q_{\rm m} = -143.2161$

See (1982RO04).

4. ^{10}B(p, n)^{10}C $\qquad Q_{\rm m} = -4.411$

$Q_0 = -4430.17 \pm 0.34$ keV: P.H. Barker (private communication).

Table 10.19: Energy levels of ^{10}C

E_x (MeV ± keV)	$J^\pi; T$	τ or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
g.s.	$0^+; 1$	$\tau_{1/2} = 19.255 \pm 0.053$ sec	β^+	1, 2, 3, 4, 5, 6, 7, 8
3.3536 ± 0.9	2^+	$\tau_m = 155 \pm 25$ fsec	γ	2, 4, 5, 6, 7, 8
5.22 ± 40	[a]	$\Gamma = 225 \pm 45$ keV		2, 4, 5, 7
5.38 ± 70	[a]	300 ± 60		2, 4, 5, 7
6.580 ± 20	(2^+)	200 ± 40		2, 5, 7

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

The E_x of ^{10}C*(3.35) $= 3352.7 \pm 1.5$ keV, $\tau_m = 155 \pm 25$ fsec, $\Gamma_\gamma = 4.25 \pm 0.69$ meV. Angular distributions have been measured for 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 (1974AJ01, 1979AJ01).

5. ^{10}B(^{3}He, t)^{10}C $\qquad Q_m = -3.6674$

Angular distributions have been measured at $E(^3\text{He}) = 14$ MeV and 217 MeV: see (1979AJ01). The latter [to ^{10}C*(0, 3.35, 5.6)] have been compared with microscopic calculations using a central + tensor interaction [$J^\pi = 0^+, 2^+, 2^+$] (1976WI05). 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] (1975SC27). [It is not clear which of the 5.2–5.4 MeV states is the 2^+ state studied by (1976WI05).]

6. ^{12}C(π^+, d)^{10}C $\qquad Q_m = 110.7327$

See (1982DO01).

7. ^{12}C(p, t)^{10}C $\qquad Q_m = -23.3597$

$Q_0 = -23360.74 \pm 0.5$ keV: J.A. Nolen (private communication).

Angular distributions have been reported at $E_p = 30.0$ to 54.1 MeV [see (1974AJ01, 1979AJ01)] and at $E_p = 80$ MeV (1979SH09; t to ^{10}C*(0, 3.35, 5.28). $L = 0$, 2 and 2 thus leading to 0^+, 2^+ and 2^+ for these states [but note that the "5.28 MeV" states is certainly unresolved]: see reaction 5 and Table 10.19. ^{10}C*(6.6) is also populated. The excitation energy of ^{10}C*(3.4) is 3353.3 ± 1.0 keV (1974BE66), 3354.1 ± 1.1 keV (1978RO08) [based on Q_m]. See also (1979NOZZ, 1980NO1A) and (1982BE1Z; theor.).

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

At $E(^3\mathrm{He}) = 70.3$ 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: multi-step processes may be important 1973KA16). (1976DE27) suggest, on the basis of an FRDWBA analysis, that the process can be interpreted as a direct-cluster transfer to both final states.

^{10}N, ^{10}O, ^{10}F, ^{10}Ne

(Not illustrated)

Not observed: see (1979AJ01). A.H. Wapstra (private communication) suggests 39.5 MeV for the atomic mass excess of ^{10}N. See also (1982NG01; theor.).

References

(Closed 1 June 1983)

References are arranged and designated by the year of publication followed by the first two letters of the first-mentioned author's name and then by two additional characters. Most of the references appear in the National Nuclear Data Center files (Nuclear Science References Database) and have NNDC key numbers. Otherwise, TUNL key numbers were assigned with the last two characters of the form 1A, 1B, etc. In response to many requests for more informative citations, we have, when possible, included up to ten authors per paper and added the authors' initials.

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