Energy Levels of Light Nuclei
$A = 11$

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Abstract: An evaluation of $A = 11$–12 was published in *Nuclear Physics A*336 (1980), p. 1. This version of $A = 11$ differs from the published version in that we have corrected some errors discovered after the article went to press. Figures and introductory tables have been omitted from this manuscript. Reference key numbers have been changed to the NNDC/TUNL format.

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Table of Contents for $A = 11$

Below is a list of links for items found within the PDF document. Figures from this evaluation are not included in this PDF document but have been scanned in and are available on this website or via the link below.

^{11}He

(Not illustrated)

^{11}He has not been observed: see (1976IR1B; theor.).

^{11}Li

(Figs. 1 and 4)

^{11}Li has been observed in the bombardment of iridium by 24 GeV protons. Its mass excess is 40.94 ± 0.08 MeV (1975TH08). The cross section for its formation is $\approx 50\ \mu$b (1976THZS). ^{11}Li is bound: E_b for break up into ^{9}Li + 2n and ^{10}Li + n are 158 ± 80 and 960 ± 250 keV, respectively [see (1979AJ01) for discussions of the masses of ^{9}Li and ^{10}Li]. The half-life of ^{11}Li is 8.5 ± 0.2 msec (1974RO31): it decays to neutron unstable states of ^{11}Be [$P_n = (60.8 \pm 7.2)\%$: (1974RO31)]. Since systematics suggest $J^\pi = \frac{1}{2}^-$ for ^{11}Li$_{g.s.}$, the remainder of the decay is presumably to ^{11}Be*(0.32) ($J^\pi = \frac{1}{2}^-$). Log $ft = 5.0$ (1975TH08). (1977BA11; theor.) suggest that the ground state of ^{11}Li has large admixtures of higher configurations and that the mass of ^{11}Li should be used with caution in mass equations. These calculations predict a large fraction of high energy neutrons suggesting that the actual P_n is greater than 61% (1977BA11). See also (1973TO16, 1974HA1H, 1975AJ02) and (1973TA30, 1975BE31, 1975JE02, 1976IR1B; theor.).

^{11}Be

(Figs. 1 and 4)

GENERAL: (See also (1975AJ02).)

Model calculations: (1974TA1E, 1975MI12, 1976IR1B, 1977SE1D, 1978BO31, 1979BE1H).

Special reactions: (1975FE1A, 1976OS04, 1977AR06, 1977YA1B).

Muon capture (See also reaction 2.): (1978DE15).

Pion reactions: (1975CO06, 1976CO1M, 1977DO06, 1977GE1D).

Ground state of ^{11}Be: (1975BE31, 1978BO31).

1. ^{11}Be(β^-)^{11}B $\qquad Q_m = 11.508$

The decay proceeds to ^{11}B*(0, 2.12, 5.02, 6.79, 7.98, 9.88) with $J^\pi = \frac{3}{2}^-, \frac{1}{2}^-, \frac{3}{2}^-, \frac{1}{2}^+, \frac{3}{2}^+, \frac{3}{2}^+$, respectively: see Table 11.15 (1971AL07). The half-life is 13.81 ± 0.08 sec (1970AL21). The nature of the decay indicates $J = \frac{1}{2}$ or $\frac{3}{2}$, even parity for the ground state of ^{11}Be: see (1971AL07). See also (1977TE01; theor.).

Table 11.1: Energy Levels of ^{11}Be

E_x (MeV $\pm$ keV)	$J^\pi; T$	τ or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
0	$\frac{1}{2}^+; \frac{3}{2}$	$\tau_{1/2} = 13.81 \pm 0.08$ sec	β^-	1, 2, 4
0.3198 ± 0.2	$\frac{1}{2}^-$	$\tau_m = 0.18 \pm 0.06$ psec	γ	2, 4
1.778 ± 12	$(\frac{5}{2}, \frac{3}{2})^+$	$\Gamma = 100 \pm 20$	(n)	2, 4
2.69 ± 20	$(\frac{1}{2}^\pm, \frac{3}{2}^\pm, \frac{5}{2}^+)$	200 ± 20	(n)	2
3.41 ± 20	$(\frac{1}{2}^\pm, \frac{3}{2}^\pm, \frac{5}{2}^+)$	125 ± 20	(n)	2
3.887 ± 15	$\geq \frac{7}{2}$	< 10	(n)	2
3.956 ± 15	$\frac{3}{2}^-$	15 ± 5	(n)	2
5.240 ± 21		45 ± 10	(n)	2
(5.86)		≈ 300	(n)	2
6.51 ± 50		120 ± 50	(n)	2
6.705 ± 21		40 ± 20	(n)	2
7.03 ± 50		300 ± 100	(n)	2
8.816 ± 32		200 ± 50	(n)	2
10.59 ± 50		210 ± 40	(n)	2

2. ^{9}Be(t, p)^{11}Be $\qquad Q_m = -1.167$

Proton groups have been observed to many states of ^{11}Be: see Table 11.2 (1962PU01, 1972AJ01, 1978AJ02). The first excited state has an excitation energy of 319.8 ± 0.2 keV and $\tau_m = 0.18 \pm 0.06$ psec corresponding to a very strong E1 transition of 0.33 W.u. (1971HA25). The J^π of ^{11}Be*(0.32) is $\frac{1}{2}^-$, as determined by a study of the yield of 320 keV γ-rays as a function of time in μ^- capture by ^{11}B (1968DE20). The strength of the E1 transition fixes J^π of ^{11}Be$_{g.s.}$ to be $\frac{1}{2}^+$ or $\frac{3}{2}^+$, using the parity information obtained from the nature of the β^- decay of the ground state [see reaction 1]. ^{11}Be*(5.24, 6.71, 8.82) are strongly populated at $E_t = 20$ MeV indicating that these states have a large overlap with ^{9}Be$_{g.s.}$ + two neutrons (1972AJ01).

3. ^{10}Be(n, γ)^{11}Be $\qquad Q_m = 0.503$

See (1975AJ02).

4. ^{10}Be(d, p)^{11}Be $\qquad Q_m = -1.722$

Table 11.2: Levels of ^{11}Be from ^{9}Be(t, p)^{11}Be

E_x (keV) [a]	E_x (keV) [b]	E_x (keV) [c]	Γ_{lab} (keV) [a]	$\Gamma_{c.m.}$ (keV) [b]	J^π
0	0	0			$\frac{1}{2}^+$ [d]
319.8 ± 0.2 [g]	322 ± 10	318 ± 10			$\frac{1}{2}^-$ [d]
1780 ± 20	1790 ± 20	1764 ± 20	110 ± 15	130 ± 25	$(\frac{1}{2}, \frac{3}{2}, \frac{5}{2})^+$ [c,e]
2700 ± 25	2680 ± 30	[f]	250 ± 20	250 ± 50	$(\frac{1}{2}^\pm, \frac{3}{2}^\pm, \frac{5}{2}^+)$ [e]
3410 ± 25	3410 ± 30	[f]	150 ± 20	145 ± 30	$(\frac{1}{2}^\pm, \frac{3}{2}^\pm, \frac{5}{2}^+)$ [e]
3890 ± 20	3890 ± 30	3877 ± 30	< 10	≤ 10	$\geq \frac{7}{2}$ [c]
3960 ± 20	3960 ± 30	3943 ± 30	< 10	15 ± 5	$\frac{3}{2}^-$ [c]
	5250 ± 30	5231 ± 30		45 ± 5	
	(5860)	[f]		≈ 300	
	6510 ± 50	[f]		120 ± 50	
	6720 ± 30	6690 ± 30		40 ± 20	
	7030 ± 50	[f]		300 ± 100	
	8840 ± 50	8800 ± 40		200 ± 50	
		10590 ± 50		210 ± 40 [c]	

[a] (1962PU01): $E_t = 14$ MeV.
[b] (1972AJ01): $E_t = 20$ MeV.
[c] (1978AJ02): $E_t = 23$ MeV; angular distributions to ^{11}Be*(0, 0.32, 1.78, 3.89, 3.96, 5.24, 6.71, 8.82).
[d] See text.
[e] From angular distributions: see (1962PU01).
[f] This E_x region not studied (1978AJ02).
[g] (1971HA25).

Angular distributions of the p_0 and p_1 groups have been measured at $E_d = 6$ MeV (1970GO11: p_1 only) and 12 MeV (1970AU02): $l_n = 0$ [and therefore $J^\pi = \frac{1}{2}^+$ for ^{11}Be(0)] and 1, $S = 0.73 \pm 0.06$ and 0.63 ± 0.15, respectively (1970AU02). At $E_d = 25$ MeV ^{11}Be*(0, 0.32, 1.78) are strongly populated: $S = 0.77$, 0.96 and 0.50, respectively, $J^\pi = (\frac{5}{2}, \frac{3}{2})^+$ for ^{11}Be*(1.78) [$l_n = 2$] (1979ZW01).

5. ^{11}Li(β^-)^{11}Be $\qquad Q_m = 20.76$

See ^{11}Li.

6. ^{11}B(n, p)^{11}Be $\qquad Q_{\rm m} = -10.726$

See ^{12}B.

7. ^{13}C(^{6}Li, ^{8}B)^{11}Be $\qquad Q_{\rm m} = -25.886$

At $E(^{6}\text{Li}) = 80$ MeV, ^{11}Be*(0.32) is strongly populated and the angular distribution to this state has been measured (1977WE03). ^{11}Be*(2.69, 4.0) are also observed. It is suggested that these states have odd parity (1976WE09) [see, however, reaction 2 for evidence concerning the positive parity of ^{11}Be*(2.69)]. See also (1977WE1B).

8. ^{14}C(^{18}O, ^{21}Ne)^{11}Be $\qquad Q_{\rm m} = -12.206$

See (1974BA15).

^{11}B

(Figs. 2 and 4)

GENERAL: (See also (1975AJ02).)

Shell model: (1977BO07, 1977JA14, 1977TE01, 1978BO31).

Cluster, collective and rotational models: (1976BR26, 1977BO07, 1977NI1A, 1977OK1C, 1979NI06).

Special levels: (1976IR1B, 1977BO07, 1977JA14, 1977TE01, 1977TE02, 1978BO31, 1979NI06).

Electromagnetic transitions: (1974HA1C, 1977BO07, 1977DO06, 1977OK1C, 1977TE01, 1977TE02, 1978KI08, 1979NI06).

Astrophysical questions: (1975AR1E, 1975HA1N, 1975ME1E, 1975PR1B, 1975TR1A, 1976AU1B, 1976AU1C, 1976BO1E, 1976CO1B, 1976EP1A, 1976GI1C, 1976HA1F, 1976RO1J, 1976SI1C, 1976VI1A, 1977AU1B, 1977DW1A, 1977HA1L, 1977KO1L, 1977MA1H, 1977SC1D, 1978AU1C, 1978BO1K, 1978BU1B, 1978BY1A, 1978DI04, 1978DI1D, 1978DW1A, 1978DW1B, 1978ME1D, 1979MC1A).

Special reactions: (1975AB1D, 1975AR14, 1975HU14, 1975RA21, 1976BE1K, 1976BU16, 1976HE1H, 1976LE1F, 1976NA11, 1976OS04, 1976RA1C, 1976RO12, 1976YOZZ, 1977AR06, 1977FO04, 1977GE08, 1977GO07, 1977KU1D, 1977RE08, 1977SH1D, 1977ST1G, 1977UD1A, 1977YA1B, 1978BH03, 1978BI08, 1978GE1C, 1978GR1F, 1978HE1C, 1978KO01, 1978LE15, 1978PE1E, 1978TU06, 1978VO1D, 1978WE1D, 1978ZE02, 1979CR03, 1979DY01, 1979GA04, 1979GO11, 1979PA09, 1979SC08, 1979VI05, 1979WE06).

Muon and neutrino capture and reactions: (1974EN10, 1974WA1C, 1975DO1F, 1975DO1D, 1976DO1G, 1977CA1E, 1977DO06, 1977MU1A, 1977WA1G, 1978DE15, 1978LE04, 1979BE1N, 1979DE01).

Pion capture and reactions (See also reactions 27, 38 and 54.): (1975HU1D, 1975ZI1B, 1976BAYR, 1976CA1H, 1976KA1F, 1976MI15, 1976NO1D, 1977BA2H, 1977BA1Q, 1977BA2G, 1977BE1L, 1977DO06, 1977HO1B, 1977KO25, 1977MA35, 1977PI1D, 1977SI01, 1978CO02, 1978KI08, 1978KI13, 1978MO01, 1978SI1D, 1978TS1A, 1979BE1N, 1979BO1U, 1979EL1E, 1979HU02, 1979TI1A, 1979ZI1C).

Reactions and kaons and other mesons: (1975TA1C, 1976DE1D, 1978AT01, 1978DA1A).

Applied topics: (1975AU1C, 1979AN1L, 1979GR1E, 1979JA1F, 1979JUZU).

Ground state of ^{11}*B:* (1974DE1E, 1974EN10, 1974SHYR, 1975AL19, 1975BE31, 1975EP02, 1976BR26, 1976DO1G, 1976FU06, 1976PH01, 1977AN21, 1977MA35, 1977PA25, 1977YO1D, 1978AN07, 1978HE1D, 1978ZA1D, 1979NI06).

$$\mu = +2.68837\ (2)\ (1978LEZA);$$

$Q = 40.65\ (26)$ mb [(1970NE05; theor.): adopted by (1978LEZA); see also (1968SC18, 1969SC34)].

Table 11.3: Energy Levels of ^{11}B [a]

E_x (MeV ± keV)	$J^\pi; T$	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
g.s.	$\frac{3}{2}^-; \frac{1}{2}$	stable		1, 2, 8, 9, 10, 14, 15, 16, 17, 18, 19, 20, 27, 28, 29, 30, 31, 33, 34, 35, 36, 37, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74
2.1248 ± 0.4	$\frac{1}{2}^-$	$\Gamma = 0.128 \pm 0.010$ eV	γ	1, 8, 9, 10, 14, 15, 16, 17, 19, 20, 27, 28, 29, 36, 37, 39, 40, 41, 44, 45, 49, 53, 55, 57, 58, 59, 65, 66, 67, 69, 70, 72, 73
4.4451 ± 0.5	$\frac{5}{2}^-$	0.61 ± 0.04 eV	γ	1, 2, 8, 9, 10, 14, 15, 16, 20, 27, 28, 29, 31, 32, 37, 39, 40, 41, 44, 45, 49, 53, 54, 55, 57, 58, 59, 66, 67, 69, 70, 72, 73
5.0208 ± 0.5	$\frac{3}{2}^-$	2.16 ± 0.10 eV	γ	1, 8, 9, 10, 15, 16, 27, 28, 29, 31, 36, 37, 39, 40, 41, 44, 45, 53, 57, 58, 59, 66, 67, 69, 70, 73
6.7429 ± 0.6	$\frac{7}{2}^-$	0.043 ± 0.007 eV	γ	1, 2, 8, 15, 20, 28, 29, 31, 32, 40, 41, 44, 45, 53, 58, 66, 67, 70, 72
6.7929 ± 1.0	$\frac{1}{2}^+$	0.47 ± 0.06 eV	γ	1, 8, 15, 28, 29, 36, 40, 41, 45, 49, 57, 58, 67, 70, 73

Table 11.3: Energy Levels of ^{11}B [a] (continued)

E_x (MeV ± keV)	$J^\pi; T$	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
7.2856 ± 1.5	$(\frac{3}{2}, \frac{5}{2})^+$	1.46 ± 0.20 eV [b]	γ	1, 8, 14, 15, 28, 29, 39, 41, 45, 58, 73
7.9780 ± 1.3	$\frac{3}{2}^+$	1.46 ± 0.22 eV	γ	1, 15, 28, 36, 41
8.5594 ± 1.9	$\leq \frac{5}{2}^-$	1.04 ± 0.16 eV [c]	γ	1, 14, 15, 28, 39, 41, 45, 67
8.920 ± 1.5	$\frac{5}{2}^-$	4.78 ± 0.29 eV	γ, α	1, 2, 14, 15, 20, 28, 31, 39, 41, 66, 67
9.185 ± 1.5	$\frac{7}{2}^+$	0.3 ± 0.1 eV	γ, α	1, 2, 12, 28, 41, 70
9.274 ± 1.5	$\frac{5}{2}^+$	7 keV	γ, α	1, 2, 15, 28, 41, 70
9.875 ± 10	$\frac{3}{2}^+$	130 ± 30	α	7, 15, 36
10.26 ± 20	$\frac{3}{2}^{(-)}, \frac{1}{2}$	150 ± 40	γ, α	2, 7
10.33 ± 20	$(\frac{5}{2}, \frac{7}{2})^-$	70 ± 20	γ, α	2, 7, 28
(10.45 ± 50)		≈ 140	γ, α	2, 41
10.601 ± 10	$\frac{7}{2}^+$	70 ± 10	γ, α	2, 7
10.96 ± 50	$\frac{5}{2}^-$	4500	α	7
11.29 ± 30	$\frac{9}{2}^+$	90 ± 50	α	7
11.49 ± 50			α	7
11.61 ± 50	$\frac{5}{2}^+$	150 ± 30	n, α	3, 7, 21, 26, 27, 41
11.8	$\frac{7}{2}^+$	880	n, α	26
11.90 ± 20	$\frac{5}{2}^-$	150 ± 30	n, α	3, 7, 26
(12.18 ± 40)			γ, p	19
12.56 ± 30	$\frac{1}{2}^+(\frac{3}{2}^+); T = \frac{3}{2}$	240 ± 50	γ, p, α	7, 17, 19, 44
12.91 ± 20	$\frac{1}{2}^-; T = \frac{3}{2}$	240 ± 30	γ, p	19, 41, 44, 66
13.03 ± 60		270 ± 50	α	7
13.12	$\frac{9}{2}^-$	425	n, α	3, 21, 26
13.16	$\frac{5}{2}^+, \frac{7}{2}^+$	430	n, α	3, 21, 26
14.04 ± 100	$\frac{11}{2}^+$	500 ± 200	n, α	3, 7, 21, 26
14.33 ± 20	$\frac{5}{2}^{(+)}(\frac{3}{2}^-); T = \frac{3}{2}$	250 ± 40	γ, p	19, 44
14.53 ± 50		< 120	n, t, α	3, 25, 26, 44
15.32 ± 100	$(\frac{3}{2}, \frac{5}{2}, \frac{7}{2})^+; T = \frac{3}{2}$	635 ± 180	γ, p	19, 21, 26, 41
15.8 ± 200			n, α	3, 7, 22
(16.43 ± 15)		≈ 40	p, d, α	12, 41

Table 11.3: Energy Levels of ^{11}B [a] (continued)

E_x (MeV ± keV)	$J^\pi; T$	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
(16.7 ± 300)		broad	n, t, α	3, 25, 26, 41
17.33		≈ 1000	n, p, d, t, α	12, 25, 26
17.50 ± 50		180 ± 40	γ, n, p, d, α	3, 10, 12
18.37 ± 50	$(\frac{1}{2}, \frac{3}{2}, \frac{5}{2})^+$	260 ± 80	γ, d	10
(19.6)	$(\frac{1}{2}^+)$	broad	γ, d	10, 38, 57
23.7	$(\frac{1}{2}, \frac{3}{2}, \frac{5}{2})^+$		γ, d	10
26.5		broad	γ, n	38

[a] See also Tables 11.4, 11.5 and 11.16.
[b] Assuming $J^\pi = \frac{5}{2}^+$: see Table 11.16.
[c] Assuming $J^\pi = \frac{3}{2}^-$: see Table 11.16.

1. ^{6}Li(^{6}Li, p)^{11}B $\quad Q_m = 12.218$

Angular distributions have been measured for proton groups to states with $E_x < 9.3$ MeV at $E(^6\text{Li}) = 2.4$ to 9.0 MeV (1966KI09). For γ-spectra and for τ_m see Tables 11.4 and 11.5. See also (1975AJ02) and (1976EP1A; astrophys.).

2. ^{7}Li(α, γ)^{11}B $\quad Q_m = 8.665$

Resonances for capture radiation are displayed in Table 11.6. Results of studies of angular correlations, distributions and branching ratios are displayed in Tables 11.6 and 11.4: see (1968AJ02) for a discussion of the results. See also (1978SC1D; applied).

3. ^{7}Li(α, n)^{10}B $\quad Q_m = -2.790 \quad E_b = 8.665$

Table 11.7 displays the thresholds and resonances observed in this reaction. See also (1976SE1E),(1974LO1B, 1975AJ02, 1977LI19).

4. ^{7}Li(α, p)^{10}Be $\quad Q_m = -2.5635 \quad E_b = 8.665$

See ^{10}Be in (1979AJ01).

Table 11.4: Electromagnetic transitions in ^{11}B [a]

Initial state	$J^\pi; T$	Γ_γ (total) [b] (eV)	Branching ratios (%) to final states						Refs. [a]
			g.s. $\frac{3}{2}^-; \frac{1}{2}$	2.12 $\frac{1}{2}^-; \frac{1}{2}$	4.45 $\frac{5}{2}^-; \frac{1}{2}$	5.02 $\frac{3}{2}^-; \frac{1}{2}$	6.74 $\frac{7}{2}^-; \frac{1}{2}$	6.79 $(\frac{1}{2}, \frac{3}{2})^+; \frac{1}{2}$	
2.12	$\frac{1}{2}^-; \frac{1}{2}$	0.128 ± 0.010	100						
4.45	$\frac{5}{2}^-; \frac{1}{2}$	0.61 ± 0.04	100 [f]	< 0.5					
5.02	$\frac{3}{2}^-; \frac{1}{2}$	2.16 ± 0.10	85 ± 2	15 ± 2	0.3				
			88 ± 2	12 ± 2					(1968EA03)
			88 ± 2.5 [g]	12 ± 2.5 [h]					(1968BE30)
			83 ± 5	17 ± 5					(1971AL07)
6.74	$\frac{7}{2}^-; \frac{1}{2}$	0.043 ± 0.007	70 ± 2 [c]	< 3	30 ± 2	< 1			
6.79	$\frac{1}{2}^+; \frac{1}{2}$	0.47 ± 0.06	66.0 ± 1.5	30.0 ± 1.5	< 0.5	4.1 ± 0.9			(1971AL07)
7.29	$(\frac{3}{2}, \frac{5}{2})^+; \frac{1}{2}$	1.46 ± 0.20 [i]	87 ± 2	< 1	5.5 ± 1	7.5 ± 1			
7.98	$\frac{3}{2}^+; \frac{1}{2}$	1.46 ± 0.22	47 ± 2	53 ± 2	< 1	< 1			
			45 ± 2	55 ± 2	< 1.6	< 1.6	< 1.5	< 1.4	(1971AL07)
8.56	$\leq \frac{5}{2}^-; \frac{1}{2}$	[b]	56 ± 2	30 ± 2	5 ± 1	9 ± 1			
8.92	$\frac{5}{2}^-; \frac{1}{2}$	4.78 ± 0.29	95 ± 1 [d]	< 1	4.5 ± 0.5	< 1	< 1	< 1	
9.19	$\frac{7}{2}^+; \frac{1}{2}$	0.3 ± 0.1 [a]	0.9 ± 0.3		82.8 ± 2.0		12.8 ± 0.4	< 1.3	(1962GR07)
9.27 [e]	$\frac{5}{2}^+; \frac{1}{2}$		19.7 ± 1.0		67.5 ± 2.0		12.8 ± 0.7	< 0.6	(1962GR07)

[a] (1965OL03) except where shown. See also Table 11.4 in (1975AJ02).

[b] From Table 11.16, corrected for branching to other states.

[c] $\delta = -0.45 \pm 0.18$ (1968CO09). This value leads to too large a value of Γ_γ for an M3 transition (P.M. Endt, private communication).

[d] $\delta = -0.11 \pm 0.04$ (1968CO09).

[e] See Tables 11.6, 11.11 and 11.16 for higher states.

[f] $\delta = -0.19 \pm 0.03$ (1968BE30).

[g] $\delta = 0.03 \pm 0.05$ (1968BE30).

[h] $\delta = -0.05 \pm 0.2$ (1968BE30).

[i] Assuming $J^\pi = \frac{5}{2}^+$.

Comments [mainly from (1962GR07, 1965OL03)]:

(1) *4.45 MeV.* $9.28 \rightarrow 4.45 \rightarrow 0$ angular distribution fixes $J = \frac{5}{2}$. Odd parity determined from direct interaction assignments.

(2) *5.02 MeV.* Internal pair correlation permit M1, E2 for the g.s. transition: $J^\pi \leq \frac{7}{2}^-$ (parity from l-assignments). $\tau_{\rm m}$ excludes $\frac{7}{2}$, branch to 2.12, $\frac{5}{2}$. Angular correlation (1968BE30) fixes $\frac{5}{2}^-$.

(3) *6.74 MeV.* Internal pairs indicate practically pure E2 g.s. radiation. Angular distributions and branching ratios (and l-assignments) all lead to $\frac{7}{2}^-$.

(4) *6.79 MeV.* The allowed β-decay from ^{11}Be indicates $J^\pi \leq \frac{7}{2}^+$. The relatively strong γ-branch to ^{11}B*(2.12) favors $\frac{1}{2}^+$, $\frac{3}{2}^+$. (1968EA03) finds that all γ's from this level are isotropic, suggesting $J^\pi = \frac{1}{2}^+$, but not excluding $\frac{3}{2}^+$.

(5) *7.29 MeV.* The g.s. transition is mainly E1, so $J^\pi \leq \frac{5}{2}^+$. The assignment $\frac{1}{2}^+$ is excluded by the strength of $(7.29 \rightarrow 4.45)$.

(6) *7.98 MeV.* Transitions to ^{11}B$_{\rm (g.s).}$ and (2.12) are predominantly E1; thus ^{11}B*(7.98) has even parity, and odd parity of ^{11}B*(2.12) is confirmed. The transition to ^{11}B*(2.12) is not isotropic, so $J^\pi = \frac{3}{2}^+$.

(7) *8.56 MeV.* Correlation of internal pairs indicate the the g.s. transition is M1 + E2 or E1 + M2, $J^\pi \leq \frac{5}{2}^+$ or $\leq \frac{7}{2}^-$; the lifetime to ^{11}B*(2.12) excludes $\frac{7}{2}^-$. If the level has even parity, the required M2 admixture is excessive. $J^\pi \leq \frac{5}{2}^-$ is favored.

(8) *8.92 MeV.* From ^{7}Li$(\alpha, \gamma)^{11}$B, $J^\pi = \frac{3}{2}^+, \frac{5}{2}^+, \frac{5}{2}^-$. The internal pair correlation confirms $\frac{5}{2}^-$. For higher states see comments under individual reactions and (1968AJ02).

Table 11.5: Lifetimes of some ^{11}B states [a]

^{11}B state	τ_m (fsec)	Refs.
2.12	5.1 ± 0.4	Table 11.4
4.45	1.08 ± 0.07	Table 11.4
5.02	0.31 ± 0.02	Table 11.4
6.74	15 ± 3	(1979MO1M)
6.79	1.4 ± 0.2	(1979MO1M)
7.29	0.45 ± 0.06	Table 11.4
7.98	0.45 ± 0.09	(1979MO1M)
8.56	1.04 ± 0.16	(1979MO1M)
8.92	0.14 ± 0.01	Table 11.4
9.19	0.3 ± 0.1	Table 11.4, (1965OL03)

[a] See also Table 11.5 in (1975AJ02).

5. ^{7}Li(α, d)^{9}Be $Q_m = -7.1507$ $E_b = 8.665$

See (1976LE1K) and ^{9}Be in (1979AJ01).

6. ^{7}Li(α, t)^{8}Be $Q_m = -2.559$ $E_b = 8.665$

Excitation functions have been measured for $E_\alpha = 14$ to 25 MeV (t_0) and 18 to 25 MeV (t_1) (1972VA34, 1974DM01). See also (1976LE1K) and ^{8}Be in (1979AJ01).

7. ^{7}Li(α, α)^{7}Li $E_b = 8.665$

The elastic scattering and the scattering to ^{7}Li*(0.48) have been studied at many energies to $E_\alpha = 22.5$ MeV: see (1968AJ02, 1975AJ02). Observed resonances are displayed in Table 11.8. See also (1968AJ02, 1975AJ02, 1975VO1B), (1977BE51, 1977NI1A; theor.) and ^{7}Li in (1979AJ01).

8. ^{7}Li(^{6}Li, d)^{11}B $Q_m = 7.192$

Table 11.6: Resonances in ^{7}Li(α, γ)^{11}B [a]

$E_{\rm r}$ (keV)	$\Gamma_{\rm c.m.}$ (keV)	^{11}B* (MeV)	J^{π}	$\omega\gamma_{\alpha}$ [d] (eV)	Γ_{γ_0} [c] (eV)	Percentage decay to ^{11}B* [f]			
						0	4.45	6.74	6.79
401 [b]	< 1 [b]	8.920	$(\frac{5}{2})^{-}$	0.04	[i]	93 ± 5	2.3 ± 1		
819 ± 1 [b]	3×10^{-3} [g]	9.186	$\frac{7}{2}^{+}$	0.55		0.9 ± 0.3	82.8 ± 2.0	12.8 ± 0.4	< 1.3
958 ± 1 [b]	7 [b]	9.275	$\frac{5}{2}^{+}$	3.5		19.7 ± 1.0	67.5 ± 2.0	12.8 ± 0.7	< 0.6 [k]
2500 ± 20 [c]	433	10.26			17	[h]			
2620 ± 20 [c]	100	10.33			1.0	[h]			
2800 ± 50 [c]	≈ 140 [i]	10.45			$10/2J+1$				
(3040) [c]	90	(10.60)			< 0.2	[h]			

[a] See also Tables 11.4, 11.8, 11.9 and 11.16 and Table 11.4 in (1968AJ02).

[b] (1951BE13).

[c] (1967PA19).

[d] $\omega\Gamma_{\gamma}\Gamma_{\alpha}/\Gamma$, in c.m. (1951BE13, 1959JO25).

[e] (1967PA19); based on analysis using $R = 4.9$ fm, $\gamma_{\rm w}^{2} = 1.0$ MeV.

[f] (1962GR07). See also Table 11.4.

[g] (1965OL03).

[h] $< 10\%$ to ^{11}B*(2.12) (1967PA19).

[i] Observed width (1967PA19).

[j] See Table 11.16.

[k] The decay to ^{11}B*(7.29, 7.98) [$J^{\pi} = \frac{5}{2}^{+}, \frac{3}{2}^{+}$] is also observed: $\approx 1\%$ and $\approx 0.03\%$ respectively (1977MO1K).

Table 11.7: Thresholds and resonances in ^{7}Li(α, n)^{10}B

(1959GI47)	(1963ME08)	
E_{α} (MeV ± keV)	E_{α} (MeV ± keV)	E_{x} (MeV ± keV)
	4.380 ± 20	thresh.
	[4.72]	11.67 ± 100
5.15 ± 70 [a]	[5.22] [c]	11.99 ± 100
(5.64)	5.5	thresh.
7.15 [b]	7.05 [c]	13.15 ± 100
	[8.44]	14.04 ± 100
	[9.21]	14.53 ± 50
	10.14	15.12 ± 100
	[11.33]	(15.88 ± 200)
	11.90	thresh.
	12.56	(16.7 ± 300)
	13.92	17.52 ± 30
	14.53	thresh.

[a] $J^{\pi} = \frac{3}{2}^{-}$ or $\frac{5}{2}^{+}$, $\Gamma_{n} \approx 20$ keV, $\Gamma_{\alpha} \approx 300$ keV formed by $l_{n} = 0$ or 1 (1959GI47) [comparison with ^{10}B(n, α)], $\Gamma_{lab} = 220$ keV (1957BI84).

[b] The width of this resonance is large.

[c] The n_0 yield shows the resonances at $E_{\alpha} \approx 5.2$ and 7.05 MeV: no others are seen in the interval $4.5 < E_{\alpha} < 8$ MeV (1972VA02).

Angular distributions have been measured for $E(^{7}\text{Li}) = 3.3$ to 5.95 MeV: see (1975AJ02). For γ-spectra and τ_{m} see Tables 11.4 and 11.5. See also ^{13}C in (1981AJ01).

9. ^{7}Li(^{7}Li, t)^{11}B $\qquad Q_{m} = 6.199$

Angular distributions have been measured at $E(^{7}\text{Li}) = 2.10$ to 5.75 MeV (1969CA1A: $t_0 \rightarrow t_3$). See also (1976CAZJ). At $E(^{7}\text{Li}) = 79.6$ MeV transitions are observed to several ^{11}B states. $^{11}B_{g.s.}$ is particularly strongly populated (1974CE06).

10. ^{9}Be(d, γ)^{11}B $\qquad Q_{m} = 15.8159$

Table 11.8: Structure in ^{7}Li(α, α)^{7}Li and ^{7}Li(α, α')^{7}Li [a]

E_{α} [b] (keV)	E_{α} [c] (keV)	$\Gamma_{c.m.}$ (keV)	E_x (MeV ± keV)	J^{π}
1900 ± 10 [d]		130 ± 30	9.875 ± 10	$\frac{3}{2}^{+}$
2480 ± 50		150 ± 40	10.24 ± 50	$\frac{3}{2}^{(-)}, \frac{1}{2}$
	2630 ± 30	80 ± 30	10.34 ± 30	$\frac{5}{2}^{-}, \frac{7}{2}^{-}$
3040 ± 10 [d]	3040	70 ± 10	10.601 ± 10	$\frac{7}{2}^{+}$
3600 ± 50		4500	10.96 ± 50	$\frac{5}{2}^{-}$
	4120 ± 30	90 ± 50	11.29 ± 30	$\frac{9}{2}^{+}$
4430 ± 50	4430		11.49 ± 50	
4600 ± 50		150 ± 50	11.59 ± 50	
5050 ± 30		150 ± 50	11.88 ± 30	
	5300 ± 200	≈ 1000	12.0 ± 200	
	5500 ± 100	60 ± 50	(12.17 ± 100) [e]	
6100 ± 30		150 ± 50	12.55 ± 30	
6850 ± 60		270 ± 50	13.03 ± 60	
(7200 ± 50) [f]		50 ± 50	(13.25 ± 50) [e]	
	7800 ± 100	500 ± 200	(13.63 ± 100) [e]	
(8450 ± 200) [g]		500 ± 200	(14.0 ± 200)	
(9450 ± 200) [g]		≤ 250	(14.7 ± 200)	
	9950 ± 20	500 ± 200	(15.00 ± 20) [e]	
(11200 ± 200) [g]			(15.8 ± 200)	
[h]				

[a] (1966CU02), except where shown. See also Table 11.9 in (1975AJ02).
[b] ^{7}Li(α, $\alpha'\gamma$)^{7}Li: σ(total).
[c] ^{7}Li(α, α_0)^{7}Li.
[d] (1967PA19). Other values are listed in Table 11.8 of (1975AJ02).
[e] ^{7}Li(α, n)^{10}B threshold.
[f] Anomaly in angular distribution.
[g] Observed at $\theta = 60°$.
[h] For possible higher structures see (1971BI12, 1973KE13).

The 90° differential cross section has measured for $E_d = 0.5$ to 11.9 MeV: see (1975AJ02). The behavior of the γ_0, γ_1 and γ_{2+3} total cross sections of the angular distributions of these γ-rays indicate two resonances at $E_d = 1.98 \pm 0.05$ and 3.12 ± 0.05 MeV with $\Gamma_{lab} = 225 \pm 50$ and 320 ± 100 keV, corresponding to ^{11}B*(17.43, 18.37). The higher resonance was not observable in the $\gamma_2 + \gamma_3$ cross section which was not measured beyond $E_d = 2.5$ MeV. The maximum γ_0 cross section observed is 10.1 ± 3.5 μb at $E_d \approx 0.96$ MeV (1971BA72). (1974DE39) observe resonant behavior in the 90° γ_0 cross section at $E_d \approx 3.4$ and 9.65 MeV (^{11}B*(18.6, 23.7)) in addition to a wide structure at 4.7 MeV (^{11}B*(19.7)). The angular distributions of γ_0 from ^{11}B*(18.6, 23.7) are typical of E1 transitions. The (d, γ_0) reaction appears to proceed via excitation of the $T = \frac{1}{2}$ component of the giant dipole resonance in ^{11}B. See also (1974LO1B).

11. ^{9}Be(d, n)^{10}B $\qquad Q_m = 4.3607 \qquad E_b = 15.8159$

The cross section follows the Gamow function for $E_d = 70$ to 110 keV (1955RA14). The fast neutron and γ-yield rise smoothly to $E_d = 1.8$ MeV except for apossible "resonance" at $E_d \approx 0.94$ MeV. The fast neutron yield then remians approximately constant to 3 MeV: see (1968AJ02) for references. The exciation functions for $n_0 \rightarrow n_4$, and n to ^{10}B*(5.1, 6.57) have been measured for $E_d = 14$ to 16 MeV: no strong fluctuations are observed (1973PA14). Thick target yields are reported at $E_d = 14.8$, 18.0 and 23.0 MeV (1977LO10). Polarization measurements have been carried out at $E_d = 0.9$ to 5.5 MeV [see (1975AJ02)] and at 0.4 MeV (1977BA2K; n_0, n_1). See also (1975SA1C), (1977GR1F, 1977SA28, 1978BA1F, 1978HA1M, 1979CH11; applied) and ^{10}B in (1979AJ01).

12. (a) ^{9}Be(d, p)^{10}Be $\qquad Q_m = 4.5872 \qquad E_b = 15.8159$
(b) ^{9}Be(d, α)^{7}Li $\qquad Q_m = 7.151$
(c) ^{9}Be(d, t)^{8}Be $\qquad Q_m = 4.5921$

Measurements of proton yeilds have been carried out up to $E_d = 6.0$ MeV for p_0 and p_1 [see (1975AJ02)] and at 0.9 to 3.1 MeV (1975ZW01: σ_t, p_0, p_1). The p_0 and p_1 yields show a resonance at $E_d = 750 \pm 15$ keV [^{11}B*(16.43)], $\Gamma \approx 40$ keV (1974AN01) and the p_1 yield resonates at 1.85 MeV [^{11}B*(17.33)], $\Gamma_{c.m.} \approx 1.0$ MeV (1974FR02, 1975ZW01) and 2.3 MeV (1974FR02) [sharp state]. See also (1975AJ02) for other possible structures. Polarization of the protons have been measured at a number of energies for $E_d = 1$ to 21 MeV [see (1975AJ02)] and at $E_{\vec{d}} = 12$ MeV (1977BA39: TAP; p_0, p_1) and 15 MeV (1976DA15: VAP; p_0, p_1, p_{2+3}, p_{4+5}, p_6, p_7, p_9). See also ^{10}Be in (1979AJ01) and (1974BO35, 1974BO37, 1975BO20, 1975BO21; theor.).

The yields of α-particles [α_0, α_1], reaction (b), have been measured for $E_d = 0.3$ to12.4 MeV [see (1975AJ02)] and at $E_d = 2.25$ to 3.10 MeV (1977SL02: α_0, α_1) and 12.17 to 14.43 MeV (1978TA04: α_0, α_1, α_2, α_4). (1974AN01) report a weak indication of the 0.75 MeV resonance, observed in the proton yield, in the α_0 yield. See also ^{7}Li in (1979AJ01).

The cross section for reaction (c) has been measured for $E_d = 0.15$ to 19 MeV [see (1968AJ02, 1975AJ02)] and at 0.9 to 2.5 MeV (1975BO1C; t_0), 0.9 to 3.1 MeV (1975ZW01; t_0) and 12.17 to 14.43 MeV (1978TA04; t_0, t_1). Polarization studies have been carried out at $E_{\vec{d}} = 12$ MeV (1977BA39: TAP; t_0, t_1) and 15 MeV (1976DA15; VAP; t_0, t_1). There is no clear evidence of resonance structure. See also ^{8}Be in (1979AJ01). See also (1974CH1L).

13. ^{9}Be(d, d)^{9}Be $\qquad E_b = 15.8159$

Excitation functions for elastically scattered deuterons have been measured for $E_d = 0.4$ to 7.0 MeV [see (1975AJ02)] and for 12.17 to 14.43 MeV (1978TA12; also d_1, d_2). Polarization measurements involving the d_0 group have been reported at $E_d = 6.3$ to 12.6 MeV [see (1975AJ02)] and at $E_{\vec{d}} = 15$ MeV (1976DA15: TAP; d to ^{9}Be*(0, 2.43, 3.06)). See also ^{9}Be in (1979AJ01).

14. ^{9}Be(t, n)^{11}B $\qquad Q_m = 9.5586$

Angular distributions have been measured at $E_t = 1.1$ to 1.7 MeV (1977MA1N; n_0, n_1, n_2, n_6, n_8, n_9 [at 1.3 MeV]).

15. ^{9}Be(^{3}He, p)^{11}B $\qquad Q_m = 10.3224$

Proton groups have been observed to a number of ^{11}B states: see Table 11.9. Angular distributions of many of these proton groups have been studied at $E(^3\text{He}) = 1.0$ to 10.2 MeV [see (1968AJ02, 1975AJ02)] and at 3 to 6 MeV (1977LI1F) and 14 MeV (1977IR01; p_0, p_1). Gamma-ray branching ratios and multipolarities are displayed in Table 11.4: see the discussion in (1968AJ02). See also (1966YO1A) and (1976EP1A; astrophys.).

16. ^{9}Be(α, d)^{11}B $\qquad Q_m = -8.0308$

Angular distributions have been measured at $E_\alpha = 23.4$, 24.7, 25.2 MeV (1975VA19; d_0, d_1 (at two higher energies only)), 27.0 MeV (1975PU01; $d_0 \rightarrow d_6$) and 28.3 MeV (1965KA14; $d_0 \rightarrow d_3$). The predominant L-transfers are $L = 0, 2; 0; 0$ for ^{11}B*(0, 2.12, 5.02). The angular distribution for ^{11}B*(4.45) is flat (1975PU01). See also (1976LE1K) and (1978ZE03; theor.).

17. (a) ^{9}Be(^{6}Li, α)^{11}B $\qquad Q_m = 14.342$
(b) ^{9}Be(^{6}Li, 2α)^{7}Li $\qquad Q_m = 5.677$
(c) ^{9}Be(^{6}Li, αp)^{10}Be $\qquad Q_m = 3.114$
(d) ^{9}Be(^{6}Li, αt)^{8}Be $\qquad Q_m = 3.119$

Table 11.9: Energy levels of ^{11}B from ^{9}Be(^{3}He, p)^{11}B

(1959HI69) [a]	(1966BR18)	(1960HI08)
E_x (MeV ± keV)		L
0	0	0
2.130 ± 10	2.1243 ± 0.9	0
4.445 [b]	4.4434 ± 1.8	0
5.023 ± 10	5.0187 ± 2.3	0
6.739 ± 10	6.7411 ± 3.0	
6.791 ± 10	6.7909 ± 3.1	1
7.285 ± 10		
7.975 ± 10		
8.553 ± 10		0
8.909 ± 10		0
9.175 ± 10		
9.264 ± 10		
9.86 ± 20 [c]		

[a] The original results were normalized to the second excited state taken to be at 4.459 MeV. Here they are shown normalized to 4.445 MeV.
[b] (1966BR18).
[c] $\Gamma \approx 150$ keV.

Angular distributions have been determined for seven α-groups at $E(^{6}\text{Li}) = 3$ to 4 MeV: see (1968AJ02). Angular distributions have also been obtained at $E(^{6}\text{Li}) = 24$ MeV to ^{11}B*(0, 2.12) and to a number of unresolved levels with $E_x \leq 13.2$ MeV (1968DA20, 1967CH34). See also (1977EL10; theor.).

The breakup reactions have been studied at $E(^{6}\text{Li}) = 3.5$ MeV by (1968JA08): reaction (b) goes mainly via a sequential process process involving ^{11}B*(10.3, 11.4, 12.6, 13.16, 13.5). The results for reaction (c) are not conclusive. ^{11}B*(12.6, 13.16) may possibly contribute to reaction (d) (1968JA08).

18. (a) ^{9}Be(^{7}Li, αn)^{11}B $\qquad Q_m = 7.092$
(b) ^{9}Be(^{9}Be, ^{7}Li)^{11}B $\qquad Q_m = -0.880$

See (1975AJ02).

Table 11.10: Levels of ^{11}B from the ^{10}Be(p, γ_0)^{11}B reaction (1970GO04)

E_p (MeV ± keV)	E_x (MeV)	$\Gamma_{c.m.}$ (keV)	$(J+\frac{1}{2})(\Gamma_p/\Gamma)\Gamma_{\gamma_0}$ [e] (eV)	Γ_{γ_0} [a,e] (eV)	$\Gamma_{\gamma_1}/\Gamma_{\gamma_0}$	J^π
(1.05 ± 40) [b]	(12.18)	230 ± 90	$3.1^{+2.9}_{-2.0}$			
1.46 ± 30	12.56	230 ± 65	10^{+7}_{-5}	10^{+7}_{-5}	0.25 ± 0.08	$\frac{1}{2}^+(\frac{3}{2}^+)$
1.85 ± 20	12.91	235 ± 27	29 ± 9	29 ± 9 [f]	≤ 0.06	$\frac{1}{2}^-$ [c]
3.41 ± 20	14.33	255 ± 36	29 ± 9	14.5 ± 4.3	≤ 0.1	$\frac{5}{2}^{(+)}(\frac{3}{2}^-)$
4.5 ± 100	15.32	635 ± 180	53^{+34}_{-26} [d]			

[a] These values assume that $J \neq \frac{3}{2}$: see (1970GO04).

[b] May be due to ^{10}B*(0.7) + n threshold.

[c] See Table 11.3.

[d] Assumes that $\sigma_{total} = 4\pi d\sigma/d\Omega$ (90°).

[e] Values reported in (1970GO04) are here shown multiplied by 1.7: see (1973GO09).

[f] In the (e, e′) work of (1975KA02) a strong group is observed at $E_x = 13.0 \pm 0.1$ MeV. If it corresponds to the excitation of ^{11}B*(12.91) with $J^\pi = \frac{1}{2}^-$; $T = \frac{3}{2}$, $\Gamma_{\gamma_0} = 36 \pm 7$ eV (1975KA02).

19. ^{10}Be(p, γ)^{11}B $\qquad Q_m = 11.2287$

The yield of ground state γ-rays has been measured at 90° for $E_p = 0.6$ to 6.3 MeV. Observed resonances are displayed in Table 11.10. The four resonances correspond to states in ^{11}B whose energies match well with those of the first four states in ^{11}Be: $T = \frac{3}{2}$. Several known $T = \frac{1}{2}$ states in ^{11}B are not observed in this reaction: see Table 11.3 (1970GO04, 1973GO09). See also (1974LO1B).

20. ^{10}B(n, γ)^{11}B $\qquad Q_m = 11.4552$

The thermal capture cross section is 0.5 ± 0.2 b (1973MU14). For a listing of the observed capture γ-rays see Table 11.12 (1967TH05). For τ_m see Table 11.4. The yield of γ-rays at $E_n =$ 14 MeV shows a smaller fore-aft anisotropy than is observed in proton capture, suggesting that the forward peaking in the (p, γ) reaction is due mainly to direct rather than collective capture amplitudes (1975AR19). See also (1976MA1J).

21. ^{10}B(n, n)^{10}B $\qquad E_b = 11.4552$

Table 11.11: Neutron capture γ-rays from ^{10}B + n [a]

E_γ (keV)	ΔE_x (keV)	I_γ [b]	Assignment
11447 ± 2 [c]	11453 ± 2	6 ± 1	capt. $\rightarrow$ g.s.
8916 ± 2	8920 ± 2	15 ± 2	8.92 $\rightarrow$ g.s.
7006 ± 2	7008 ± 2	54 ± 3	capt. $\rightarrow$ 4.45
6739 ± 2	6741 ± 2	19 ± 1	6.74 $\rightarrow$ g.s.
	5020	< 2	5.02 $\rightarrow$ g.s.
4711 ± 2	4712 ± 2	25 ± 1	capt. $\rightarrow$ 6.74
4444 ± 2	4445 ± 2	65 ± 3	4.45 $\rightarrow$ g.s.
2534 ± 2	2534 ± 2	15 ± 2	capt. $\rightarrow$ 8.92
2295 ± 2	2296 ± 2	10 ± 3	6.74 $\rightarrow$ 4.45
	2120	< 3	2.12 $\rightarrow$ g.s.

[a] (1967TH05).

[b] Photons/100 captures.

[c] $\Gamma_\gamma = 0.01$ eV (1957BA18).

The "free" neutron scattering cross section, $\overline{\sigma_s} = 2.23 \pm 0.06$ b. The coherent scattering amplitude (bound) is $a = +1.4 \pm 0.5$ fm (1973MU14). The total scattering cross section is constant at 2.23 ± 0.06 b for $E_n = 0.7$ to 10 keV and then rises to 2.97 b at $E_n = 127$ keV (1970AS10).

Total cross section measurements in the range $E_n = 10$ to 500 keV confirm the broad maximum near $E_n = 0.23$ MeV, originally suggested by (1951BO45) and also observed in the (n, α) cross section (1966MO09). At higher energies the total cross section shows broad maxima at $E_n = 1.9$ and 2.8 MeV (1951BO45) and at 4.3 MeV (1961FO07): see Table 11.12. In the range $E_n = 5.5$ to 16 MeV σ_{tot} is constant at 1.5 b (1961FO07, 1979AU07). (1976GAYV) displays reported σ_{tot} measurements.

Polarization measurements (0.075 to 2.2 MeV and 2.63 MeV) and measurements of differential cross sections (0.075 to 4.4 MeV) by (1971LA10, 1973CO05, 1973HA64) have been analyzed using R-matrix calculations: the results are shown in Table 11.13. They are consistent with results from ^{10}B(n, n$'\gamma$) and ^{7}Li(α, n).

Elastic differential cross sections have also been reported at $E_n = 7.02$ to 9.72 MeV [see (1975AJ02)] and at 4 to 8 MeV (1978KN01; n_0, n_1) and 14.1 MeV (1974HY01). See also ^{10}B in (1979AJ01).

22. ^{10}B(n, n$'$)^{10}B* $\qquad E_b = 11.4552$

Table 11.12: Resonances in ^{10}B + n [a]

^{10}B(n, n′γ)^{10}B (1960DA08)		^{10}B(n, α)^{7}Li (1961DA16)		Yield of	^{11}B* (MeV)
E_{res} (MeV)	Γ (keV)	E_{res} (MeV)	Γ (keV)		
		0.23 [b]		σ_t, α	11.66
		0.53 [f]	140	α_0, α_1	11.94
1.93	260	1.86 [e]	570	σ_t [c], α_0, α_1, t, n′	13.2
(2.6)	broad	2.79	530	σ_t [c], α_0, α_1, n′	14.0
3.31	370	3.43	< 120	α_0, t, n′	14.57
4.1		4.1	800	σ_t [c], α_0, α_1, n′	15.2
4.73		[d]		n′	15.75
		5.7	broad	α_0, t	16.6
		6.4	broad	α_0, t	17.3

[a] See also Table 11.13.
[b] (1951BO45, 1966MO09, 1970NE03).
[c] (1951BO45). See also (1979AU07).
[d] (1961FO07).
[e] $J^\pi \geq \frac{11}{2}^+$ (1961DA16). See, however, Table 11.13.
[f] See footnote [c] in Table 11.13.

The yield of 0.7 MeV γ-rays has been studied from thrreshold to $E_n = 5.2$ MeV: observed resonances are displayed in Table 11.12 (1960DA08). Inelastic scattering cross sections for formation of various ^{10}B states have been measured at a number of energies in the range $E_n = 1.45$ to 14.8 MeV: see (1975AJ02). See also ^{10}B in (1979AJ01).

23. ^{10}B(n, p)^{10}Be $\qquad Q_m = 0.2265 \qquad E_b = 11.4552$

The thermal cross section is < 0.2 b (1973MU14). See also (1976SL2A).

24. ^{10}B(n, d)^{9}Be $\qquad Q_m = -4.3607 \qquad E_b = 11.4552$

See ^{9}Be in (1979AJ01) and (1976SL2A).

25. (a) ^{10}B(n, t)^{8}Be $\qquad Q_m = 0.2314 \qquad E_b = 11.4552$
(b) ^{10}B(n, t)^{4}He^{4}He $\qquad Q_m = 0.3233$

Table 11.13: R-matrix analysis of resonant states in ^{10}B + n [a]

E_n (MeV)	E_x (MeV)	J^π	l_n	Γ_n	Γ_{α_0}	Γ_{α_1}	$\Gamma_{c.m.}$ (keV)
				(c.m., MeV)			
	10.60	$\frac{7}{2}^+$	0		0.030	0.070	100
0.17	11.61	$\frac{5}{2}^+$	0	0.004	0.296	0.0	300
0.37 [b]	11.79	$\frac{7}{2}^+$	0	0.770	0.001	0.113	884
0.53 [c]	11.94	$\frac{5}{2}^-$	1	0.031	0.080	0.090	201
1.83	13.12	$\frac{9}{2}^-$	1	0.100	0.275	0.050	425
1.88	13.16	$\frac{5}{2}^+, \frac{7}{2}^+$	2	0.080	0.200	0.150	430
2.82	14.02	$\frac{11}{2}^+$	2	0.800	0.045	0.010	855
4.2	15.3	$(\frac{3}{2}, \frac{3}{2}, \frac{7}{2})^+$	2	0.500	0.100	0.100	700

[a] (1971LA10, 1972HA04, 1973CO05, 1973HA64): analysis based on polarization and differential cross-section measurements of the elastic scattering, and on results from ^{10}B(n, α_0) and (n, α_1). The analysis used a two-level, four-channel R-matrix formalism with a non-diagonal background R^0 matrix: see (1973HA64). This analysis does not include ^{11}B*(14.53) because the resonance is weak, narrow and almost entirely in the α-channel (1973CO05). See also Table 11.12.

[b] See also (1976SE06).

[c] (1978SC31) report $E_{res} = 495 \pm 5$ keV, $\Gamma = 140 \pm 15$ keV, σ_{max} [in (n, $\alpha_1\gamma$)] $= 94 \pm 6$ mb.

The cross section for reaction (b) has been measured for $E_n = 1.4$ to 8.2 MeV by (1961DA16). Fluctuations are observed at some of the resonant energies in the ^{10}B(n, α) reaction: see Table 11.12. For a display of the cross section see (1976GAYV). See also (1975BI07) and (1976LI1H, 1976SL2A).

26. ^{10}B(n, α)^{7}Li $\qquad Q_m = 2.790 \qquad E_b = 11.4552$

The "recommended" value of the thermal isotropic absorption cross section is 3837 ± 9 b (1973MU14). The ground state branching for thermal neutrons is $(6.308 \pm 0.006)\%$ (1967DE15), $(6.699 \pm 0.012)\%$ (1979ST03). At $E_n = 2$ and 24 keV the values are $(7.05 \pm 0.16)\%$ and $(7.13 \pm 0.15)\%$, respectively (1979ST03). The cross section for $E_n = 10$ eV to 200 keV is given by the expression

$$13.837/\sqrt{E} = 0.312 - 1.014 \times 10^{-2}\sqrt{E} + \frac{2.809\times10^5}{\sqrt{E}[(170.3-E)^2+2.243\times10^4]} \text{b (1970SO1A).}$$

See also (1974ST1F).

The total cross section for the (n, α) reaction is displayed in (1976GAYV). The cross section has been measured for E_n = 1.03 to 300 keV (1974CO1C; $\alpha_1\gamma$; no evidence for resonances), 4.70 to 630.64 keV (1978SC31; $\alpha_1\gamma$), 0.15 to 1.25 MeV (1975SE1H, 1976SE06; α_0, α_1; 0°, 120°; evidence for broad resonance at $E_n \approx 0.4$ MeV in the α_1 (0°) cross section) and at higher energies up to 14.8 MeV: see (1975AJ02) and Tables 11.12 and 11.13. At $E_n = 0.79$ MeV, the ratio for the α_1/α_{tot} yield is 0.66 ± 0.03 (1975LA08). See ^{7}Li in (1979AJ01), (1975AJ02, 1976LI1H, 1976SL2A), (1975FR1C), (1976BO1L, 1976DA1F; applied) and (1975HA1L, 1977LO1C; theor.).

27. ^{10}B(p, π^+)^{11}B $\qquad Q_m = -128.894$

Angular distributions for proton capture to ^{11}B*(0, 2.15 ± 0.10) have been measured at E_p = 168 to 186 MeV. The population of ^{11}B*(4.45 + 5.02) and of unresolved higher states is also observed at 186 MeV but an attempt to observe $T = \frac{3}{2}$ analogue states in ^{11}B and ^{11}N (the latter populated via (p, π^-)) was unsuccessful (1974DA27, 1979HO09). Polarization measurements are reported by (1979PIZZ). See also (1977BE1X, 1979BE1W, 1979JO1C, 1979PI06, 1979SOZY) and (1979BO1V; theor.).

28. ^{10}B(d, p)^{11}B $\qquad Q_m = 9.2306$

Reported proton groups are displayed in Table 11.14. Angular distributions have been studied at many energies in the range E_d = 0.17 to 28 MeV [see (1968AJ02, 1975AJ02)] and at 0.75 to 2.5 MeV (1977AR12; $p_0 \rightarrow p_3$). The lowest five levels are formed by $l_n = 1$ except for ^{11}B*(2.12) which appears to involve a spin-flip process. They are presumed to comprise the set $\frac{3}{2}^-$, $\frac{1}{2}^-$, $\frac{5}{2}^-$, $\frac{3}{2}^-$, $\frac{7}{2}^-$ expected as the lowest p^7 levels ($a/K \approx 4.0$). ^{11}B*(9.19, 9.27) [$J^\pi = \frac{7}{2}^+, \frac{5}{2}^+$] show strong $l = 0$ stripping and are ascribed to capture of a 2s neutron by ^{10}B: see (1968AJ02) for a listing of all the relevant references. Studies of pγ correlations are discussed in reaction 14 of (1968AJ02) and displayed in Table 11.4 of this paper. See also ^{12}C and (1975ZA06).

29. ^{10}B(t, d)^{11}B $\qquad Q_m = 5.1979$

At E_t = 5.5 MeV, deuteron groups are observed to the ground state of ^{11}B and to states at E_x = 2.126, 4.449, 5.027, 6.769, 6.806 and 7.301 MeV (±10 keV). All the angular distributions appear to be characteristics of $l_n = 1$ (1961BA10). See also ^{13}C in (1981AJ01).

30. ^{10}B(α, ^{3}He)^{11}B $\qquad Q_m = -9.1226$

Table 11.14: ^{11}B levels from ^{10}B(d, p)^{11}B

E_x (MeV ± keV) [a]	(1962HI07)		(1960BI08)	
	l_n	$(2J+1)\theta^2$	l_n	$(2J+1)\theta^2$
0	1	0.120	1	1.00
2.1246 ± 1.1				0.09
4.4458 ± 2.1	1	0.048		0.46
5.0192 ± 2.4	(1)	(0.010)		0.11
6.7439 ± 2.2	1	0.210	1	1.72
6.7938 ± 2.2				
7.298 ± 6	(2?)	(0.022)		
7.987 ± 9			isotropic	
8.568 ± 5	(2?)		2	
8.927 ± 5	1	0.186	0, 2	
9.191 ± 5	0	0.242	0	
9.276 ± 5	0	0.175	0	
10.32 ± 20 [b]				

[a] (1951VA1A, 1953EL12, 1966BR18). See also Table 11.15 in (1975AJ02) and (1977AR12).
[b] $\Gamma = 54 \pm 17$ keV (1953EL12).

Angular distributions have been measured at $E_\alpha = 56$ MeV for the ground state transitions in this, and in the analog (α, t) reactions: the average ratio of the (α, ^{3}He) to the (α, t) differential cross sections is 1.2 ± 0.1 (1969GA11).

31. (a) ^{10}B(^{6}Li, ^{5}Li)^{11}B $\qquad Q_m = 5.79$
(b) ^{10}B(^{7}Li, ^{6}Li)^{11}B $\qquad Q_m = 4.205$

At $E(^7\text{Li}) = 24$ MeV angular distributions are reported to ^{11}B*(0, 6.74, 8.92). ^{11}B*(4.45, 5.02) are also populated. The (^{7}Li, ^{6}He) reaction [see reaction 16 in ^{11}C] has also been studied (1977KO27). See also (1975AJ02).

32. ^{10}B(^{13}C, ^{12}C)^{11}B $\qquad Q_m = 6.5088$

Total cross section measurements involving ^{11}B*(4.45, 6.74) have been carried out for $E(^{13}C) =$ 8.0 to 12.7 MeV: $S_1S_2 = 0.6$ and 1.7, respectively (1975SE03). τ_m for ^{11}B*(6.74) < 50 fsec (1975SE04): see Table 11.5.

33. ^{10}B(^{14}N, ^{13}N)^{11}B $Q_m = 0.902$

See (1975NA15, 1977MO1A). See also ^{13}N in (1976AJ04, 1981AJ01), (1975AJ02) and (1975OS01; theor.).

34. ^{10}B(^{16}O, ^{15}O)^{11}B $Q_m = -4.209$

See (1975NA15), ^{15}O in (1976AJ04) and (1977OK1D; theor.).

35. (a) ^{10}B(^{18}O, ^{17}O)^{11}B $Q_m = 3.411$
(b) ^{10}B(^{19}F, ^{18}F)^{11}B $Q_m = 1.024$

Angular distributions have been measured at $E(^{18}O)$ and $E(^{19}F) = 20$ and 24 MeV (1971KN05). See also (1975AJ02).

36. ^{11}Be(β^-)^{11}B $Q_m = 11.508$

^{11}Be decays to ^{11}B*(0, 2.12, 5.02, 6.79, 7.98, 9.88): see Table 11.15 for the parameters of the observed β and γ transitions (1971AL07). Delayed α-particles are also observed with a total I_α of 3.0%/decay. These α-particles are not observed to be in coincidence with 478 keV γ-rays [upper limit = 5% for $E_\alpha > 0.3$ MeV], suggesting that they result from the decay of ^{11}B*(9.88) to $^{7}\text{Li}_{\text{g.s.}}$ (1971AL07).

37. ^{11}B(γ, γ)^{11}B

Mean gamma widths of low-lying states obtained by resonance scattering and transmission studies are listed in Table 11.16 (1978KU12, 1979MO1M). The excitation energies of ^{11}B*(2.13, 4.45, 5.02) are 2126.5 ± 1.5, 4446.4 ± 1.8 and $5.021.1 \pm 1.8$ keV (1977WE1C). See also (1975BR1F, 1979MOZX).

Table 11.15: Beta decay of ^{11}Be (1971AL07) [a]

^{11}B* [b] (keV)	J^π [c]	I_β (%)	log ft	E_γ (keV)	I_γ [d] (%)	Transition to ^{11}B*
g.s.	$\frac{3}{2}^-$	57 ± 3	6.81 ± 0.02			
2125.0 ± 0.7	$\frac{1}{2}^-$	29 ± 3	6.68 ± 0.04	2124.8 ± 0.7	33 ± 3	g.s.
4445	$\frac{5}{2}^-$	< 0.06	> 10.9 [e]			
5020.1 ± 1.7	$\frac{3}{2}^-$	0.28 ± 0.11	7.94 ± 0.14	5019.3 ± 1.7	0.47 ± 0.09	g.s.
				2893.1 ± 0.8	0.093 ± 0.028	2125
6742.7 ± 1.8 [g]	$\frac{7}{2}^-$	< 0.08				
6792.6 ± 1.8	$\frac{1}{2}^+$	6.8 ± 0.8	5.91 ± 0.05	6790.5 ± 1.8	4.51 ± 0.69	g.s.
				4666.3 ± 1.8	2.00 ± 0.28	2125
				1772.2 ± 0.7	0.28 ± 0.06	5020
7286	$(\frac{3}{2}, \frac{5}{2})^+$	< 0.16				
7978.1 ± 1.9	$\frac{3}{2}^+$	3.9 ± 0.5	5.58 ± 0.05	7974.7 ± 1.9	1.74 ± 0.30	g.s.
				5851.8 ± 1.9	2.13 ± 0.34	2125
8559	$\leq \frac{5}{2}^-$	< 0.06	> 7.0			
8920	$\frac{5}{2}^-$	< 0.02	> 8.5 [e]			
9875	$\frac{3}{2}^+$	3.0 ± 0.7 [f]	4.03 ± 0.15 [f]			

[a] See also Table 11.12 in (1968AJ02).
[b] When errors are indicated the excitation energies are determined in this experiment from the measured E_γ.
[c] From Table 11.3.
[d] Intensity in % per β-decay, normalized to (33 ± 3)% for the 2.13 MeV γ-intensity.
[e] log f_1t. Q_0 assumed to be 11.506 ± 0.007 MeV.
[f] Assuming that the breakup of ^{11}B*(9.88) is solely to ^{7}Li$_{\rm g.s.}$. If the inelasticity for the breakup of ^{11}B*(9.88) is that suggested by (1966CU02), then the β-branch is 15 ± 3.5%, log $ft = 3.33 \pm 0.15$, and the β branches to the other ^{11}B states have to be recalculated: see (1971AL07).
[g] Energy derived from $E_{\rm x}$ of ^{11}B*(6.79) and known ΔE of 4th and 5th excited states (1970BR23) [49.9 keV].

38. (a) ^{11}B(γ, π^-)^{11}C $\quad Q_{\rm m} = -141.549$
(b) ^{11}B(γ, n)^{10}B $\quad Q_{\rm m} = -11.4552$
(c) ^{11}B(γ, p)^{10}Be $\quad Q_{\rm m} = -11.2287$
(d) ^{11}B(γ, d)^{9}Be $\quad Q_{\rm m} = -15.8159$
(e) ^{11}B(γ, t)^{4}He + ^{4}He $\quad Q_{\rm m} = -11.1319$
(f) ^{11}B(γ, α)^{7}Li $\quad Q_{\rm m} = -8.665$

For reaction (a) see (1975YE1A) and reaction 20 in ^{11}C. The giant dipole resonance is shown to consist mainly of $T = \frac{1}{2}$ states ion the lower energy region and of $T = \frac{3}{2}$ sattes in the higher energy region by observing the decay to states in ^{10}B and ^{10}Be [reactions (b) and (c)] (1971PA10). See also (1979BR1D). Absolute measurements of the ^{11}B(γ, all n) cross section from threshold to 35 MeV have been carried out by (1973HU09, 1976KN04): the cross section exhibits a main peak at $E_\gamma = 25$ to 28 MeV and weak shoulders at 13 and 16 MeV. The integrated cross section to 35 MeV is 69.1 ± 0.8 MeV · mb (1976KN04). See also (1975AD04) and (1974BU1A, 1976BE1H). For other structures reported in the (γ, n) and (γ, p) cross sections see (1975AJ02). The (γ, d_0) cross section peaks at ≈ 19 MeV, lower than it would if $T = \frac{3}{2}$ states were involved (1974DE01). The yield of 3.37 MeV γ-rays [from ^{10}Be*(3.37), reaction (c)] has been measured for $E_{bs} = 100$ to 800 MeV (1975AD04). See also (1977BR1J). Double positron-electron pair production by 6.6 MeV γ-rays in boron has been studied by (1976RO1N). See (1959AJ76) for reactions (e) and (f). See also (1975AJ02) and (1978DI06).

Table 11.16: Gamma widths [a] from ^{11}B(γ, γ)^{11}B and ^{11}B(e, e)^{11}B

E_x (MeV)	J^π	$\Gamma_{\gamma 0}$ (eV)	Reaction	Refs.
2.12	$\frac{1}{2}^-$	0.137 ± 0.020	$\gamma\gamma$	(1965KE05)
		0.12 ± 0.02	$\gamma\gamma$	(1968CR07)
		0.11 ± 0.02	$\gamma\gamma$	(1978KU12)
		0.125 ± 0.04	$\gamma\gamma$	(1979MO1M)
		0.14 ± 0.04	ee	(1975KA02)
		0.17 ± 0.034	ee	(1962ED02)
		0.128 ± 0.010		mean
4.45	$\frac{5}{2}^-$	0.73 ± 0.07 (M1)	ee	(1975KA02)
		$+0.020 \pm 0.002$ (E2)		
		0.60 ± 0.09 (M1)	ee	(1967SP02)
		$+0.016 \pm 0.002$ (E2)		
		0.58 ± 0.04	$\gamma\gamma$	(1978KU12)
		0.58 ± 0.04	$\gamma\gamma$	(1979MO1M)
		0.61 ± 0.04		mean
5.02	$\frac{3}{2}^-$	1.73 ± 0.14 (M1)	ee	(1967SP02)
		< 0.0034 (E2)		
		2.12 ± 0.21	ee	(1975KA02)
		1.80 ± 0.13	$\gamma\gamma$	(1978KU12)
		1.88 ± 0.17	$\gamma\gamma$	(1979MO1M)
		1.84 ± 0.07		mean
6.74	$\frac{7}{2}^-$	0.030 ± 0.005	$\gamma\gamma$	(1979MO1M)
6.79	$\frac{1}{2}^+$	0.31 ± 0.04	$\gamma\gamma$	(1979MO1M)
7.29	$(\frac{3}{2}, \frac{5}{2})^+$	1.17 ± 0.26	$\gamma\gamma$	(1978KU12)
		1.34 ± 0.22 [b]	$\gamma\gamma$	(1979MO1M)

Table 11.16: Gamma widths [a] from ^{11}B(γ, γ)^{11}B and ^{11}B(e, e)^{11}B (continued)

E_x (MeV)	J^π	Γ_{γ_0} (eV)	Reaction	Refs.
		1.27 ± 0.17		mean
7.98	$\frac{3}{2}^+$	0.67 ± 0.10	$\gamma\gamma$	(1979MO1M)
8.56	$\leq \frac{5}{2}^-$	0.73 ± 0.07 (M1)	ee	(1975KA02)
		$+0.23 \pm 0.03$ (E2)		
		0.58 ± 0.09 [c]	$\gamma\gamma$	(1979MO1M)
8.92	$\frac{5}{2}^-$	4.0 ± 0.6 (M1)	ee	(1966SP02)
		4.93 ± 0.50	ee	(1975KA02)
		4.20 ± 0.52	$\gamma\gamma$	(1978KU12)
		5.00 ± 0.60	$\gamma\gamma$	(1979MO1M)
		4.54 ± 0.28		mean

[a] See also Tables 11.4 and 11.5, and Table 11.17 in (1975AJ02).
[b] Assuming $J^\pi = \frac{5}{2}^+$.
[c] Assuming $J^\pi = \frac{3}{2}^-$.

39. (a) ^{11}B(e, e)^{11}B
(b) ^{11}B(e, ep)^{10}Be $\qquad Q_m = -11.2287$

The charge-scattering radius leads to an oscillator length parameter of 1.55 fm (1959ME24). Magnetic elastic scattering at $\theta = 180°$ shows strong M3 effects: the derived ratio of static M3/M1, 2.9 ± 0.2 fm^2, suggests a $j - j$ coupling scheme for ^{11}B$_{\text{g.s.}}$ (1966RA29). The quadrupole contribution to the elastic form factor is best accounted for by the undeformed shell model, $Q = 3.72$ ($\pm 20\%$) fm^2, r(r.m.s.) $= 2.42$ fm (1966IS1A, 1966ST12). See also (1979BE1N, muonic X-rays): $\langle r^2 \rangle^{1/2} = 2.47 \pm 0.04$ fm. The excitation of ^{11}B*(2.1, 4.4, 5.0, 8.6, 8.9) has been studied by (1975KA02: $E_e = 52$ to 90 MeV). The giant resonance region, centered at ≈ 18 MeV, is characterized by a lack of prominent features except for a pronounced peak at $E_x = 13.0 \pm 0.1$ MeV (mixed M1–E2) and a broad transverse group at $E_x = 15.5$ MeV (1975KA02).

Ground state transition widths are listed in Table 11.16. For reaction (b) see (1975AJ02). See also (1974DE1E) and (1974WA1C, 1975DO1D, 1976DO1G, 1977TE02, 1977WA1G, 1978BO09, 1978TA1D; theor.).

40. ^{11}B(n, n$'$)^{11}B*

Angular distributions of neutrons have been measured for $E_{\rm n} = 7.55$, 9.72 and 14.1 MeV [see (1975AJ02)] and for $E_{\rm n} = 4$ to 8 MeV (1976LA1C, 1976WH1A, 1977WH1A, 1977WHZZ; n_0), 5.46, 5.62 and 6.00 MeV (1979KOZU; n_1), 8 to 14 MeV (1978GL1D; $n_0 \rightarrow n_3$) and 14.1 MeV (1974HY01; $n_0 \rightarrow n_3$, n_{4+5}). See also ^{12}B.

41. (a) ^{11}B(p, p′)^{11}B*
(b) ^{11}B(p, 2p)^{10}Be $\quad Q_{\rm m} = -11.2287$
(c) ^{11}B(p, pn)^{10}B $\quad Q_{\rm m} = -11.4552$

Observed proton groups are displayed in Table 11.17. Angular distributions have been measured for $E_{\rm p} = 12$ to 185 MeV [see (1975AJ02)] and at $E_{\rm p} = 6$ MeV (1977SA1B; p_0) and 30 MeV (1975CA08: to states shown in column 1 of Table 11.17, except ^{11}B*(8.92)). See also (1976AL1G, 1977CO1G). The analysis of the $\frac{3}{2}^- \rightarrow \frac{1}{2}^-$ transition [^{11}B*($0 \rightarrow 2.12$)] at $E_{\overline{\rm p}} = 32$ MeV shows less spin flip than predicted by DWBA (1977MO09). For reaction (b) see ^{10}Be in (1979AJ01). For reaction (c) see (1977WA05). See also (1978AL1G) and (1976PH01, 1977PH02; theor.).

42. ^{11}B(d, d)^{11}B

The elastic scattering has been studied at $E_{\rm d} = 5.5$ MeV (1971HIZF) and 11.8 MeV (1967FI07). See also (1974CH58; theor.).

43. ^{11}B(t, t)^{11}B

The elastic scattering has been studied at $E_{\rm t} = 1.8$ and 2.1 MeV (1969HE08, 1969SI12).

44. ^{11}B(^{3}He, ^{3}He)^{11}B

The elastic scattering has been studied has been studied at $E(^3{\rm He}) = 8$ to 74 MeV [see (1975AJ02)], at 17.5 and 40.0 MeV (1977SH09) and at 46.1 MeV (1979GO07). In the recent work angular distributions have also been studied for the ^{3}He ions to ^{11}B*(2.12, 4.45, 5.02, 6.74) (1977SH09). $T = \frac{3}{2}$ states populated in this reaction are displayed in Table 11.18. There is a weak indication also of a state at $E_{\rm x} = 14.51$ MeV (1971WA21). See also (1975AJ02).

45. ^{11}B(α, α)^{11}B

Angular distributions have been reported at $E_\alpha = 28.3$ to 29.0 MeV [see (1975AJ02)] and at 24 MeV (1976DE34: $\alpha_0 \rightarrow \alpha_3$, α_{4+5}). See also (1978ZE03; theor.).

Table 11.17: States of ^{11}B from ^{11}B(p, p′)^{11}B* and ^{13}C(d, α)^{11}B [a]

(1971BR41, 1974KA15) [b]	(1970BR23) [c]
E_x (keV)	
0	0
2124.7 ± 0.5	2125.4 ± 1.4
4445.2 ± 0.5	4444.5 ± 1.6
5021.1 ± 0.6	5020.2 ± 1.9
6743.0 ± 0.7 [d]	6745.8 ± 3.4
6792.6 ± 1.6	6795 ± 3.0
7285.6 ± 1.5	
7978.0 ± 1.7	
8559.4 ± 1.9	8520 ± 70
8920.2 ± 2.0	8910 ± 60
9185.0 ± 2.0	
9274.4 ± 2.0	
10450 ± 150 [e]	
11650 ± 150	
12850 ± 100	
15200 ± 150	
16400 ± 150	

[a] See also Table 11.18 in (1975AJ02).
[b] ^{11}B(p, p′)^{11}B.
[c] ^{13}C(d, α)^{11}B.
[d] Values below are normalized to E_x = 4445.3, 5020.0 and 6743.4 keV.
[e] This value and the values below are from (1969SU03).

Table 11.18: Possible $T = \frac{3}{2}$ states in ^{11}B [a]

Reaction	E_x (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	References
^{10}Be(p, γ)^{11}B	12.56 ± 30	230 ± 65	(1970GO04)
^{11}B(^{3}He, ^{3}He)^{11}B*	12.51 ± 50	260 ± 50	(1971WA21)
	12.56 ± 30	240 ± 50	"best"
^{10}Be(p, γ)^{11}B	12.91 ± 20	235 ± 27	(1970GO04)
^{11}B(^{3}He, ^{3}He)^{11}B*	12.98 ± 90	390 ± 120	(1971WA21)
^{13}C(p, ^{3}He)^{11}B	12.94 ± 50	350 ± 50	(1968CO26)
^{13}C(p, ^{3}He)^{11}B	12.91 ± 30	260 ± 50	(1974BE20)
	12.91 ± 20	240 ± 30	"best"
^{10}Be(p, γ)^{11}B	14.33 ± 20	255 ± 36	(1970GO04)
^{11}B(^{3}He, ^{3}He)^{11}B*	14.40 ± 50	220 ± 50	(1971WA21)
	14.33 ± 20	250 ± 40	"best"
^{10}Be(p, γ)^{11}B	15.32 ± 100	635 ± 180	(1970GO04)

[a] These states have also been seen in other reactions: see Table 11.3. The parameters shown in that table reflect all the pertinent data. See also Table 11.21 for $T = \frac{3}{2}$ states in ^{11}C.

46. ^{11}B(^{6}Li, ^{6}Li)^{11}B

The elastic scattering has been measured at $E(^{6}\text{Li}) = 28$ MeV (1972BA52).

47. ^{11}B(^{9}Be, ^{9}Be)^{11}B

See (1975AJ02).

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

See (1976HI05). See also (1975AJ02).

49. ^{11}B(^{12}C, ^{12}C)^{11}B

The elastic scattering has been studied at $E(^{11}\text{B}) = 18.8$ to 34.1 MeV (1978FR20) and 28 MeV (1969VO07, 1969VO10), at $E(^{12}\text{C}) = 15$ to 24 MeV (1974BO15, 1975DU11) and at $E(^{12}\text{C}) = 87$ MeV (1971LI11). The population of ^{11}B*(2.12, 4.45, 6.79) and of ^{12}C*(0, 4.43) are also reported: see (1969VO07). See also (1976ST12), (1978RO1D; astophys.) and (1975RE04, 1978AV1A, 1978VA1A; theor.).

50. ^{11}B(^{14}N, ^{14}N)^{11}B

The elastic scattering has been investigated at $E(^{14}\text{N}) = 41$, 77 and 133 MeV (1971LI11).

51. ^{11}B(^{16}O, ^{16}O)^{11}B

The elastic scattering has been studied at $E(^{16}\text{O}) = 14.5$ to 60 MeV [see (1975AJ02)] and at $E(^{11}\text{B}) = 115$ MeV (1979BR03).

52. ^{11}C(β^+)^{11}B $\qquad Q_\text{m} = 1.982$

See ^{11}C.

53. ^{12}C(γ, p)^{11}B $\qquad Q_\text{m} = -15.9569$

The fraction of transitions to the ground and to excited states of ^{11}B [and to ^{11}C states reached in the (γ, n) reaction] has been measured at $E_\text{bs} = 24.5$, 27, 33 and 42 MeV: the ground state is predominantly populated. The population of analog states in the (γ, n) and (γ, p) reactions are similar: see ^{11}C (1970ME17). See also (1979GO1N: $E_\text{bs} = 21.7$ to 31.0 MeV) and (1978KI03: E_bs to 120 MeV). Differential cross sections have been measured at $E_\gamma = 60$, 80 and 100 MeV (1976MA34, 1974FI17; p_0, p_1, $\text{p}_2 + \text{p}_3 + \text{p}_4$). See also (1975MA1E, 1979KI1H), ^{12}C and (1975AJ02).

54. ^{12}C(π^+, π^+p)^{11}B $\qquad Q_\text{m} = -15.9569$

At $E_{\pi^+} = 100$ MeV the reaction proceeds primarily to $^{11}\text{B}_\text{g.s.}$ (1978CO02). At $E_\pi = 200$ MeV the ratios for $\sigma_\text{n}/\sigma_\text{p}$ for the first excited states in ^{11}C/^{11}B are 1.4 ± 0.2 for π^- and $1/1.8 \pm 0.2$ for π^+ (1979LI11). At $E_{\pi^+} = 60$ to 300 MeV ^{11}B*(4.45) [$J^\pi = \frac{5}{2}^-$] is strongly populated, as is the analog state in the mirror reaction (1978MO01). See also reaction 25 in ^{11}C.

55. ^{12}C(e, ep)^{11}B $\qquad Q_{\rm m} = -15.9569$

At $E_{\rm e} = 497$ MeV ^{11}B*(0, 2.1, 5.0) are populated: $l = 1$ (1976MO17). See also (1978SH14), (1975AJ02), ^{12}C and (1975RO18, 1979BO07; theor.).

56. ^{12}C(n, d)^{11}B $\qquad Q_{\rm m} = -13.7323$

See (1974KI1A, 1975MC19, 1976KI1D).

57. ^{12}C(p, 2p)^{11}B $\qquad Q_{\rm m} = -15.9569$

Gross structure is seen in the summed proton spectrum corresponding to ^{11}B$_{\rm g.s.}$ and to an excited state with $J^\pi = \frac{1}{2}^+$ at $E_{\rm x} \approx 19.5$ MeV: see (1975AJ02). A high resolution experiment at $E_{\rm p} = 100$ MeV shows groups corresponding to ^{11}B*(0, 2.12, 4.45, 5.02, 6.79) (1977DE1M) [see (1975AJ02) for the earlier work]. See also (1977DE1L, 1978DE1P). At $E_{\rm p} = 100$ MeV DWIA gives reasonably good agreement with angular correlation distributions (p_0, p_1, p_{2+3}, p_{4+5}) (1976BH02). See also ^{12}C, (1976SI1A, 1977MC1F, 1977RO1E) and (1975PI1A, 1977RE1A, 1978HA35, 1979FA1B, 1979MA20; theor.).

58. ^{12}C(d, ^{3}He)^{11}B $\qquad Q_{\rm m} = -10.4634$

Angular distributions of ^{3}He ions have been measured for $E_{\rm d} = 20$ to 50 MeV [see (1975AJ02)] and at $E_{\overline{\rm d}} = 29$ MeV (1978CO13: to ^{11}B*(0, 2.12, 4.45)) and $E_{\rm d} = 52$ MeV (1968HI01, 1975MA41: to ^{11}B*(0, 2.12, 4.45, 5.02, 6.74 + 6.79, 7.29)) and 80 MeV [(1974AS04: to ^{11}B*(0, 4.45)), (1976DI05: to ^{11}B*(0, 2.12, 5.02))]. Reported C^2S for ^{11}B$_{\rm g.s.}$ are 3.22 or 4.42 depending on the choice of parameters (1978CO13: $E_{\overline{\rm d}} = 29$ MeV; see also (d, t) results in reaction 28 of ^{11}C), and 2.98, 0.69, 0.31 for ^{11}B*(0, 2.12, 5.02) (1975MA41: $E_{\rm d} = 52$ MeV, DWBA). See also (1975LU07, 1976CHZH, 1977CH01; theor.).

59. ^{12}C(t, α)^{11}B $\qquad Q_{\rm m} = 3.8571$

Angular distributions have been measured for $E_{\rm t} = 1$ to 3.4, 10.1 and 13 MeV: see (1975AJ02). For electromagnetic transitions see Table 11.4 (1968BE30).

60. (a) ^{12}C(α, ^{5}Li)^{11}B $\quad Q_{\rm m} = -17.92$
(b) ^{12}C(α, αp)^{11}B $\quad Q_{\rm m} = -15.9569$

At $E_\alpha = 65$ MeV, ^{11}B*(0, 2.12, $6.74 + 6.79$) are strongly populated (1978SA26). For reaction (b) see (1977YA1A, 1979KU08).

61. ^{12}C(^{10}B, ^{11}C)^{11}B $\quad Q_{\rm m} = -7.266$

See reaction 31 in ^{11}C (1975NA15, 1975VO05, 1976NA09).

62. ^{12}C(^{12}C, ^{13}N)^{11}B $\quad Q_{\rm m} = -14.014$

The angular distribution involving the ground state transitions has been measured at $E(^{12}\text{C}) = 114$ MeV (1974AN36). See also (1979HEZX).

63. ^{12}C(^{14}N, ^{15}O)^{11}B $\quad Q_{\rm m} = -8.660$

See (1975AJ02) and ^{15}O in (1981AJ01).

64. ^{12}C(^{16}O, ^{17}O)^{11}B $\quad Q_{\rm m} = -12.595$

See (1977ZE1A; theor.).

65. ^{12}C(^{19}F, ^{20}Ne)^{11}B $\quad Q_{\rm m} = -3.1123$

At $E(^{19}\text{F}) = 40$, 60 and 68.8 MeV angular distributions involving $^{20}\text{Ne}_{\rm g.s.} + {}^{11}\text{B}_{\rm g.s.}$, $^{20}\text{Ne}^*_{1.63} + {}^{11}\text{B}_{\rm g.s.}$ and $^{20}\text{Ne}_{\rm g.s.} + {}^{11}\text{B}^*_{2.12}$ ($E = 68.8$ MeV only) have been measured by (1972SC03). See also (1975PU02).

66. ^{13}C(p, ^{3}He)^{11}B $\quad Q_{\rm m} = -13.1851$

At $E_p = 50.5$ MeV, in addition to ^{11}B*(0, 2.12, 4.45, 5.02, 6.74, 8.92), a state is observed at $E_x = 12.94 \pm 0.05$ MeV, $\Gamma = 350 \pm 50$ keV. Comparison of the angular distributions of the ^{3}He and of the tritons [in the analog reaction] at $E_p = 43.7$ and 50.3 MeV lead to the assignments $J^\pi = \frac{1}{2}^-$, $T = \frac{3}{2}$ for this state and for ^{11}C*(12.50): the strong proton and the weak α-decay are consistent with this assignment (1968CO26). See Table 11.18 and (1974BE20). Angular distributions have been measured to ^{11}B*(2.12, 4.45, 5.02), at $E_p = 26.9$ to 49.6 MeV [see (1975AJ02)] and at $E_{\overline{p}} = 49.6$ MeV (1974MA12; also to ^{11}B*(6.74, 12.94)). See also reaction 34 in ^{11}C for the mirror reaction, and see ^{14}N in (1981AJ01).

67. ^{13}C(d, α)^{11}B $\qquad Q_m = 5.1680$

Observed proton groups are displayed in Table 11.17 (1970BR23). Angular distributions are reported at $E_d = 0.41$ to 14.1 MeV: see (1975AJ02). See also ^{15}N in (1981AJ01).

68. ^{13}C(^{17}O, ^{19}F)^{11}B $\qquad Q_m = -4.865$

See (1977CH22).

69. ^{14}C(p, α)^{11}B $\qquad Q_m = -0.7839$

Angular distributions of the $\alpha_0 \rightarrow \alpha_3$ groups have been measured at $E_p = 18$ MeV (1962BR34).

70. (a) ^{14}N(n, α)^{11}B $\qquad Q_m = -0.1580$
(b) ^{14}N(n, 2α)^{7}Li $\qquad Q_m = -8.823$

Angular distributions have been measured for $E_n = 4.9$ to 18.8 MeV [see (1975AJ02)] and at 13.9 MeV (1978MO09; $\alpha_0 \rightarrow \alpha_3$). At $E_n = 14.1$ and 15.7 MeV various states of ^{11}B with $8.9 < E_x < 14.5$ MeV appear to be involved in the sequential decay to ^{7}Li. Angular correlation results are consistent with $J^\pi = \frac{7}{2}$ and $\frac{5}{2}$ for ^{11}B*(9.19, 9.27) respectively (1971SC16). See also (1979SUZW), ^{7}Li in (1979AJ01), ^{15}N in (1981AJ01), and (1975AJ02).

71. ^{14}N(^{10}B, ^{13}N)^{11}B $\qquad Q_m = 0.902$

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

72. ^{15}N(α, ^{8}Be)^{11}B $\qquad Q_{\rm m} = -11.0832$

At $E_\alpha = 72.5$ MeV angular distributions are reported to ^{11}B*(0, 2.10 ± 0.04, 4.50 ± 0.07, 6.75 ± 0.04): $S = 0.23$, 0.12, 0.29, 0.45 (unresolved groups) (1974WO1C, 1976WO11).

73. ^{16}O(d, ^{7}Be)^{11}B $\qquad Q_{\rm m} = -16.039$

At $E_{\rm d} = 80$ MeV angular distributions have been measured to ^{11}B*(0, 2.12, $4.45 + 5.02$, $6.74 + 6.79 + 7.29$) (1978OE1A).

74. ^{19}F(^{12}C, ^{20}Ne)^{11}B $\qquad Q_{\rm m} = -3.1123$

See ^{20}Ne in (1978AJ03).

^{11}C

(Figs. 3 and 4)

GENERAL: (See also (1975AJ02).)

Special levels: (1976IR1B).

Astrophysical questions: (1976VI1A, 1977SC1D, 1977SI1D, 1978BU1B).

Special reactions: (1975HU14, 1976BE1K, 1976BU16, 1976DI01, 1976HE1H, 1976LE1F, 1976SM07, 1977AR06, 1977AS03, 1977SC1G, 1978DI06, 1978GE1C, 1978HE1C, 1979KA07, 1979VI05).

Muon and neutrino capture and reactions: (1975DO1F, 1976DO1G).

Pion capture and reactions (See also reactions 25 and 26.): (1975BA66, 1975BH03, 1975HU13, 1975KA1G, 1975PA1D, 1975SC1N, 1975SI18, 1975ZI1B, 1976MI15, 1977BA2H, 1977LE1G, 1977MA1M, 1978AM01, 1978HI03, 1978MO01, 1978WA1B, 1979AN1J, 1979HU02).

Applied topics: (1975AL1B, 1975CH1H, 1977MA1P, 1977WO1A, 1978LO1D, 1978TI1A, 1978WI1F, 1978WO1C, 1979AL1Q, 1979WI1G).

Other topics: (1976IR1B, 1979BE1H).

Ground state of ^{11}C: (1969SC34, 1974SHYR, 1975BE31, 1976DO1G, 1977KA07, 1977YO1D).

$$\mu = -0.964 \pm 0.001 \text{ nm (1969WO03);}$$

$$Q = 34.26 \text{ mb (1978LEZA).}$$

1. ^{11}C(β^+)^{11}B $\qquad Q_m = 1.982$

The half-life of ^{11}C is 1223.1 ± 1.2 sec [mean of previously reported values (see (1975AJ02)); mainly based on $\tau_{1/2} = 1222.9 \pm 1.2$ sec (1975AZ01)]. See also (1975BE28). Log ft = 3.599 ± 0.002 (1975AZ01) based on E_{β^+}(max) $= 960 \pm 1$ keV (from Q_m). See also (1975AZ01). (1975BE28) measure E_{β^+}(max) $= 960.8 \pm 2.6$ keV. The ratio of K-capture to positron emission is $(0.230^{+0.014}_{-0.011})\%$ (1967CA09). See also (1975AJ02, 1977BA48, 1978RA2A) and (1975KR14, 1975WI1E, 1976BE1E, 1976DO1G, 1977RI08, 1977YO1D, 1977YO1E, 1979DE15; theor.).

2. (a) ^{6}Li(^{6}Li, n)^{11}C $\qquad Q_m = 9.453$

(b) ^{7}Li(^{6}Li, 2n)^{11}C $\qquad Q_m = 2.203$

(c) ^{7}Li(^{7}Li, 3n)^{11}C $\qquad Q_m = -5.048$

At $E(^6\text{Li}) = 4.1$ MeV [reaction (a)] angular distributions have been obtained for the neutrons to ^{11}C*(2.00, 4.32, 4.80, $6.34 + 6.48$, 6.90, 7.50). In addition, n-γ coincidences via ^{11}C*(8.42) [and a 8.42 MeV γ-ray] are reported. ^{11}C*(8.10) was not observed (1967BA53). The lifetimes, τ_m, for ^{11}C*(4.32, 6.90, 7.50) are < 140, < 69 and < 91 fsec, respectively.The upper limits for τ_m of ^{11}C*(6.34, 6.48) [which were unresolved] are 0.5 psec. The ground state transition from ^{11}C*(7.50) has $E_\gamma = 7505 \pm 8$ keV (1969TH01). For reaction (b) see (1968AJ02). For reaction (c) see (1974CE06).

Table 11.19: Energy levels of ^{11}C [a]

E_x (MeV ± keV)	$J^\pi; T$	τ or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
g.s.	$\frac{3}{2}^-; \frac{1}{2}$	$\tau_{1/2} = 20.40 \pm 0.04$ min	β^+	1, 2, 4, 5, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39
2.0000 ± 0.5	$\frac{1}{2}^-$	$\tau_m < 0.5$ psec	γ	2, 4, 5, 12, 13, 14, 16, 21, 22, 25, 26, 27, 28, 29, 30, 31, 34, 35, 38
4.3188 ± 1.2	$\frac{5}{2}^-$	< 0.14 psec	γ	2, 4, 5, 12, 13, 16, 21, 22, 25, 26, 27, 28, 29, 34, 38
4.8042 ± 1.2	$\frac{3}{2}^-$	< 0.5 psec	γ	2, 4, 12, 16, 21, 22, 27, 29, 34, 38
6.3392 ± 1.4	$\frac{1}{2}^+$	< 0.11 psec	γ	2, 4, 13, 21, 26, 27, 29, 38
6.4782 ± 1.3	$\frac{7}{2}^-$	< 0.25 psec	γ	2, 4, 5, 12, 13, 16, 21, 22, 26, 27, 29, 34, 38
6.9048 ± 1.4	$\frac{5}{2}^+$	< 69 fsec	γ	2, 4, 12, 13, 17, 27, 29, 34, 38
7.4997 ± 1.5	$\frac{3}{2}^+$	< 91 fsec	γ	2, 4, 13, 27, 29, 34
8.1045 ± 1.7	$\frac{3}{2}^-$		(γ)	4, 13, 22 27, 29
8.424 ± 8	$\frac{5}{2}^-$		γ	2, 4, 12, 13, 16, 26, 27, 29
8.655 ± 8	$\frac{7}{2}^+$	$\Gamma << 9$ keV	(γ)	12, 13, 16, 26, 27
8.701 ± 20	$\frac{5}{2}^+$	15 ± 1		12, 13, 16, 26, 27
9.732 ± 5	$(\frac{5}{2}^+)$	450 ± 50	γ, p, α	5, 7, 11, 27
10.084 ± 5	$\frac{7}{2}^+$	≈ 230	p, α	7,11, 13, 27
10.680 ± 5	$\frac{9}{2}^+$	200 ± 30	p, α	7, 11, 12, 27

Table 11.19: Energy levels of ^{11}C [a] (continued)

E_x (MeV ± keV)	$J^\pi; T$	τ or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
11.03 ± 30	$T = \frac{1}{2}$	300 ± 60		27, 29, 34
11.44 ± 10		360	p, α	11, 27, 29
(12.16 ± 40)	$(T = \frac{3}{2})$	270 ± 50	p	4, 8, 22, 26
12.4	$\pi = -$	1–2 MeV	γ, p	5
12.51 ± 30	$\frac{1}{2}^-; \frac{3}{2}$	490 ± 40	p, α	4, 8, 22, 26, 29, 34
12.65 ± 20	$(\frac{7}{2}^+)$	360	p, ^{3}He, α	10, 11, 26
(13.01)			γ, p	5
13.33 ± 60		270 ± 80		34
13.4		1100 ± 100	p, α	11
13.90 ± 20	$(T = \frac{3}{2})$	200 ± 100	p	4, 8, 22, 34
14.07 ± 20		135 ± 50	n, p	6, 34
14.76 ± 40		≈ 450	n, p, ^{3}He	4, 6, 8, 10
15.35 ± 50	$\pi = -$	broad	γ, n, p	5, 6, 8, 29
15.59 ± 50		≈ 450	n, p	6, 8
16.7	$\pi = -$	800 ± 100	γ, p	5
(18.2)			γ, p	5
(23.0)				29
(28.0)				29

[a] See also Table 11.20.

3. ^{7}Be(α, γ)^{11}C $\qquad Q_m = 7.545$

See (1972PA1C, 1975FO19).

4. ^{9}Be(^{3}He, n)^{11}C $\qquad Q_m = 7.558$

Reported neutron groups are listed in Table 11.16 of (1968AJ02). Angular distributions have been studied in the range $E(^3\text{He}) = 1.3$ to 13 MeV: see (1975AJ02) and (1979OS10). The dominant L-values from the angular distributions reported by (1974FU11) are 0 for ^{11}C*(0, 8.10), 1 for ^{11}C*(6.34, 7.50), 2 for ^{11}C*(2.00, 4.32, 4.80, 6.48, 8.42) and 3 for ^{11}C*(6.90). Neutron groups to

Table 11.20: Gamma decay of ^{11}C levels

E_i (MeV)	J^π	τ_m [b] (psec)	E_f (MeV)	Branch [a] (%)	Mult. [a]	Branch [c] (%)	X [c]
2.00	$\frac{1}{2}^-$	< 0.5	0	100			
4.32	$\frac{5}{2}^-$	< 0.5	0	100	M1	100	$+0.17 \pm 0.03$ [g]
		< 0.14 [h]	2.00	< 2		< 2	
4.80	$\frac{3}{2}^-$	< 0.5	0	83 ± 4	M1	86 ± 2 [f]	[e]
			2.00	17 ± 4		14 ± 2 [f]	[e]
6.34	$\frac{1}{2}^+$	< 0.11	0	65 ± 3	E1	68 ± 3	
			2.00	35 ± 3		32 ± 3 [d]	
			4.32			< 7	
			4.80	< 4		< 3	
6.48	$\frac{7}{2}^-$	< 0.25	0	89 ± 2	E2	88 ± 2	-0.01 ± 0.06
			2.00	< 2		< 4	
			4.32	11 ± 2		12 ± 2	
			4.80			< 2	
6.90	$\frac{5}{2}^+$	< 0.16	0	89 ± 3	E1	91 ± 2	0.02 ± 0.03
		< 0.07 [h]	2.00	< 2		< 1	
			4.32	11 ± 3		4.5 ± 1	
			4.80	< 3		4.5 ± 1	
			6.34	< 5			
			6.48	< 5			
7.50	$\frac{3}{2}^+$	< 0.5	0	36 ± 2	E1	37 ± 3	-0.04 ± 0.04
		< 0.09 [h]	2.00	64 ± 2	E1	63 ± 8	0 ± 0.03
			4.32	< 3		< 1	
			4.80	< 3		< 1	
			6.34	< 3			
			6.48	< 3			
			6.90	< 4			
9.73 [i]	$(\frac{5}{2}^+)$		0	65 ± 15			
			2.00	3			
			4.32	12 ± 2			
			6.48	20			

[a] From ^{9}Be(^{3}He, n)^{11}C and ^{10}B(d, n)^{11}C (1965OL03): includes earlier measurements, except for ^{11}C*(9.73): see footnote [i].

[b] (1966WA10).

[c] (1968EA03): ^{12}C(^{3}He, α)^{11}C: $X \equiv$ amplitude ratio of $(L+1)/L$.

[d] The cascade id through ^{11}C*(2.0) and not ^{11}C*(4.3) (1968EA03).

[e] See ^{12}C(^{3}He, α)^{11}C.

[f] (86 ± 3), $(14 \pm 3)\%$ (1966GA19); (89 ± 3), $(16 \pm 3)\%$ (1967BL22).

[g] $+0.16$ $(-0.02, +0.06)$ (1966GA19); 0.13 ± 0.04 (1967BL22).

[h] (1969TH01).

[i] (1961JA11): ^{10}B(p, γ)^{11}C.

to $T = \frac{3}{2}$ states have been reported by (1971WA21) [$E_x = 12.17 \pm 0.05$ and 12.55 ± 0.05 MeV] and by (1969BR30) [$E_x = 12.5 \pm 0.1$, 13.7 ± 0.1 and 14.7 ± 0.1 MeV]: see Table 11.22.

Gamma branching ratios and multipolarities for ^{11}C levels up to $E_x = 7.5$ MeV have been studied by (1965OL03, 1965RO07): see Table 11.20. Together with evidence from reactions 12 and 27 they lead to assignments of $J^\pi = \frac{1}{2}^-, \frac{5}{2}^-, \frac{3}{2}^-, \frac{1}{2}^+, \frac{7}{2}^-, \frac{5}{2}^+, \frac{3}{2}^+$ for ^{11}C*(2.00, 4.32, 4.80, 6.34, 6.48, 6.90, 7.50): see (1965OL03, 1965RO07) and reaction 3 in (1968AJ02) for a summary of the evidence concerning these assignments. See also (1977ZA1B; applied), (1977OS08; theor.) and ^{12}C.

5. ^{10}B(p, γ)^{11}C $Q_m = 8.691$

The thick target yield for this reaction has been measured for $E_p = 0.27$ to 3.0 MeV (1975PE1A): see also reaction 11. A broad resonance is reported at $E_p = 1.15$ MeV: see Table 11.22. Capture γ-rays are observed corresponding to the ground state transition and to cascades via ^{11}C*(2.00, 4.32, 6.48): see Table 11.21 (1961JA11). The 90° yield of γ_0 has been measured for $E_p = 2.6$ to 17 MeV and angular distributions have been obtained for $E_p = 2.8$ to 14 MeV. The excitation function is consistent with the giant resonance centered at $E_x \approx 16$ MeV. In addition to weak structures at $E_p = 4.75$ MeV and 10.5 MeV, there are three major peaks at $E_p = 4.1$, 7.0 and 8.8 MeV ($\Gamma = 1 - 2$ MeV) [$E_x = 12.4$, 15.0, 16.7 MeV]. At ^{11}C*(12.4). the γ_0 angular distribution is essentially isotropic: $\Gamma_p\Gamma_\gamma/\Gamma \approx 200$ eV, $\Gamma_\gamma \approx 5$ keV (assuming $\Gamma_p \approx 10$ keV). The $E_p = 4.1$ MeV resonance is probably part of the E1 giant resonance and is formed by s-wave capture. At the two higher resonances the angular distributions are characteristic of E1 giant resonances in light nuclei. The ^{10}B(p, γ_1) cross section is small for $E_p = 2.6$ to 17 MeV (1970KU09). See also (1974LO1B, 1975AJ02), (1976RO1Q; astrophysics) and (1977YO1F; applied).

6. ^{10}B(p, n)^{10}C $Q_m = -4.434$ $E_b = 8.691$

The total (p, n) cross section has been measured to $E_p = 10.6$ MeV: broad maxima are observed at $E_p = 5.92 \pm 0.02$, 6.68 ± 0.04, 7.33 ± 0.05 and 7.60 ± 0.05 MeV (see Table 11.23) (1963EA01).

Table 11.21: Possible $T = \frac{3}{2}$ states in ^{11}C [a]

Reaction	E_x (MeV)	$\Gamma_{c.m.}$ (keV)	Refs.
^{9}Be(^{3}He, n)^{11}C	12.17 ± 0.05	200 ± 100	(1971WA21)
^{10}B(p, p$_2$)^{10}B**	12.20 ± 0.10		(1971WA21)
^{11}B(^{3}He, t)^{11}C	12.15 ± 0.05	290 ± 50	(1971WA21)
	12.16 ± 0.04 [b]	270 ± 50	mean
^{9}Be(^{3}He, n)^{11}C	12.55 ± 0.05	350 ± 100	(1971WA21)
^{10}B(p, p$_2$)^{10}B**	12.45 ± 0.10	400 ± 100	(1971WA21)
^{11}B(^{3}He, t)^{11}C	12.57 ± 0.07	370 ± 90	(1971WA21)
^{13}C(p, t)^{11}C	12.47 ± 0.06	550 ± 50	(1968CO26) [c]
^{13}C(p, t)^{11}C	12.48 ± 0.04	540 ± 60	(1974BE20)
	12.51 ± 0.03	490 ± 40	mean
^{9}Be(^{3}He, n)^{11}C	13.7 ± 0.1		(1969BR30)
^{11}B(^{3}He, t)^{11}C	13.92 ± 0.05	260 ± 50	(1971WA21) [a]

[a] See also Table 11.18 for $T = \frac{3}{2}$ states in ^{11}B.

[b] See, however, reaction 34 (1974BE20).

[c] See also (1974MA12).

The cross section for formation of ^{10}C$_{g.s.}$ measured up to 12 MeV shows similar behavior to 8 MeV. At $E_p \approx 8$ MeV, a sharp maximum is observed. The cross section for production of 3.35 MeV γ-rays (from ^{10}C*) does not appear to show structure for $E_p = 8.5$ to 12 MeV (1966SE03). See also ^{10}C in (1979AJ01).

7. ^{10}B(p, p)^{10}B $\qquad E_b = 8.691$

Below $E_p = 0.7$ MeV the scattering can be explained in terms of pure s-wave potential scattering but the possibility of a state near $E_p = 0.27$ MeV ($E_x = 8.95$ MeV) cannot be excluded. The elastic scattering then shows two conspicuous anomalies at $E_p = 1.50 \pm 0.02$ MeV and at 2.18 MeV [$E_x = 10.05$ and 10.67 MeV] with $J^\pi = \frac{7}{2}^+$ and $\frac{9}{2}^+$: see Table 11.22 (1962OV02: $E_p = 0.15$ to 3.0 MeV). At higher energies (to $E_p = 10.5$ MeV) a single broad resonance is reported at $E_p \approx 5$ MeV (1969WA11) while (1970BO17) suggest additional structure. Polarization measurements are reported at 30.3 MeV (1976DE15, 1977PH02): optical model parameters are derived. The depolarization parameter D has been measured for polarized protons with $E_p = 26$ MeV (1976BI1E) and 50 MeV (1970BA05). See also (1977SA1B) and (1975BL10; theor.).

Table 11.22: Resonances [a] in ^{10}B + p

E_{res} (MeV ± keV)	E_x (MeV)	J^π	Γ_{lab} (keV)	Decay	Refs.
1.145 ± 5	9.732	$(\frac{5}{2}^+)$	500 ± 50	γ, p_0, α_0	A
1.533 ± 5	10.084	$\frac{7}{2}^+$	≈ 250	p_0, α_0, α_1	A
2.189 ± 5	10.680	$\frac{9}{2}^+$	220 ± 30	p_0, α_0, α_1	A
3.03 ± 10	11.44		400	α_0, α_1	(1962OP03, 1964JE01)
3.9 ± 100	12.20	$T = \frac{3}{2}$		p_2	(1971WA21)
4.1 ± 100	12.45	$T = \frac{3}{2}$	440 ± 100	p_2	(1971WA21)
4.1 [b,c]	12.4	$\pi = -$	1–2 MeV	γ_0	(1970KU09)
4.36 ± 20	12.65	$(\frac{7}{2}^+)$	400	α_0, α_1, ^{3}He	A
(4.75)	(13.01)			γ_0	(1970KU09)
5.2	13.4		1200 ± 100	α_0, α_1	A
5.73 ± 20	13.90		≈ 500	p	A
5.92 ± 20	14.07		broad	n	A
6.68 ± 40	14.76		≈ 500	n, p, ^{3}He	A
7.33 ± 50 [c]	15.35	$\pi = -$	broad	γ_0, n, p	A
7.60 ± 50	15.59		≈ 500	n, p	A
8.8 [c]	16.7	$\pi = -$	900 ± 100	γ_0	(1970KU09)
(10.5)	(18.2)			γ_0	(1970KU09)

A: See references listed for this resonance in Table 11.23 (1975AJ02).

[a] See also Table 11.20 here, and Tables 11.23 and 11.24 in (1975AJ02). Table 11.23 displays some other reported resonances; Table 11.24 gives detailed parameters for ^{11}C*(9.73, 10.08, 10.68, 12.65).

[b] $\Gamma_p \Gamma_\gamma / \Gamma \approx 20$ eV (1970KU09).

[c] Probably part of the E1 giant resonance (1970KU09).

8. ^{10}B(p, p′)^{10}B $E_b = 8.691$

The yield γ_1 [from ^{10}B*(0.72)] rises monotonically from $E_p = 1.5$ to 4.1 MeV and then shows resonance behavior at $E_p = 4.36$ and 5.73 MeV (1962OP03: see Table 11.22). For $E_p = 6$ to 12 MeV, the cross section for γ_1 shows several sharp maxima superposed on a broad maximum ($\Gamma \approx 2.5$ MeV) at $E_p \approx 7.2$ MeV (1966SE03). [The cross section below $E_p = 10$ MeV appears to be in error: see (1969WA23).] Yields of five other γ-rays involved in the decay of ^{10}B*(1.74, 2.16, 3.59, 5.18) have also been measured by (1966SE03) in the range $E_p = 4$ to 12 MeV.

Yield curves for inelastically scattered protons have been measured at $E_p = 5.0$ to 16.4 MeV (p_1, p_2, p_3), 6.6 to 16.4 MeV (p_4), 8.9 to 16.4 MeV (p_5) and 10.9 to 16.4 MeV (p to ^{10}B*(6.03)): the principal feature for all groups, except that to ^{10}B*(6.03), is a structure at $E_p \approx 7.5$ MeV, $\Gamma \approx 4$ MeV. In addition narrower structures are observed, including three at $E_p = 5.75$, 6.90 and 7.80 MeV (± 0.2 MeV) and widths of ≈ 500 keV (1969WA23). It had previously been suggested by (1966SE03) that the formation of $T = 1$ states was relatively suppressed in this reaction. (1969WA23) find that the isotopic spin effect disappears when a correction factor $(2J_f + 1)$ is included. Excitation curves for the p_1, p_2 and p_3 groups have been measured for $E_p = 3.5$ to 5.0 MeV. Possible resonances are observed in the p_2 yield [to the $T = 1$ state ^{10}B*(1.74)] corresponding to the first $T = \frac{3}{2}$ states at $E_x = 12.16$ and 12.50 MeV [see Table 11.21]: these do not occur in the yield of p_1 and p_3 (1971WA21). See also (1976DE15), ^{10}B in (1979AJ01) and (1975AJ02).

9. ^{10}B(p, d)^{9}B $Q_m = -6.211$ $E_b = 8.691$

Polarization measurements have been carried out at $E_p = 49.6$ MeV for the deuterons to ^{9}B*(0, 2.36) (1971SQ02). See also ^{9}B in (1979AJ01).

10. ^{10}B(p, ^{3}He)^{8}Be $Q_m = -0.5323$ $E_b = 8.691$

The ground-state yield shows slight maxima at energies similar to those in the (p, α) yield in the range $E_p = 4$ to 10 MeV. However, the angular distributions do not vary strongly over the region and it is suggested that a direct interaction mechanism dominates (1963JE01). (1966SE03) report two strong maxima at $E_p \approx 4.5$ and 6.5 MeV. See also ^{8}Be in (1979AJ01).

11. ^{10}B(p, α)^{7}Be $Q_m = 1.146$ $E_b = 8.691$

The total cross section for this reaction has been measured for $E_p = 60$ to 180 keV by (1972SZ02): the extrapolated cross section at the Gamow energy, taken to be 19.1 keV, is $\approx 10^{-12}$ b. The thick target yield for $E_p = 75$ keV to 3 MeV has been measured by (1975PE1A): the ^{7}Be yield constitutes a potential problem if natural boron is used as fuel in CTR devices.

The parameters of observed resonances are displayed in Table 11.22. The ground state (α_0) α-particles exhibit broad resonances at $E_p = 1.17$, 1.53, 2.18, 3.0, 4.4, 5.1 and 6.3 MeV. Alpha particles to ^{7}Be*(0.43) [α_1] and 0.43-MeV γ-rays exhibit all but the 1.2 MeV resonance: see (1975AJ02). A broad maximum dominates the region from $E_p = 4$ MeV to about 7.5 MeV (1966SE03). For spallation studies see (1976BO08, 1977AV01). See also (1976GRZR, 1976IN04) and (1976RO1Q; astrophysics).

12. ^{10}B(d, n)^{11}C $\qquad Q_m = 6.466$

Table 11.23 presents the results obtained in this reaction and in the (^{3}He, d) reaction (1955MA76, 1963OV02, 1970BO34). Information on the γ-decay of ^{11}C states has been summarized by (1965OL03) and is incorporated in Table 11.20. For the earlier work see (1959AJ76, 1968AJ02 [particularly Table 11.20], 1975AJ02). See also (1972RE1C) and (1974LO1B).

13. ^{10}B(^{3}He, d)^{11}C $\qquad Q_m = 3.197$

Table 11.23 displays the information derived from this reaction and from the (d, n) reaction. The study of the angular distributions of the deuterons to ^{11}C*(8.66, 8.70) shows that these levels are the analogs, respectively, of ^{11}B*(9.19, 9.27) whose J^π are $\frac{7}{2}^+$ and $\frac{5}{2}^+$ [the ^{11}B states were studied in the (d, p) reaction]: $\Gamma_{c.m.}$ are $\ll 9$ keV and 15 ± 1 keV, respectively, for ^{11}C*(8.66, 8.70) (1973FO02). Singlet deuteron emission has been studied at $E(^3\text{He}) = 8$, 10 and 11 MeV by (1970BO07). For the earlier work see (1975AJ02).

14. ^{10}B(α, t)^{11}C $\qquad Q_m = -11.123$

Angular distributions have been measured at $E_\alpha = 25.1$ MeV (1974DM01; t_1) and at 56 MeV (1969GA11; t_0). See also (1975AJ02).

15. ^{10}B(^{6}Li, ^{5}He)^{11}C $\qquad Q_m = 4.10$

See (1957NO17).

16. ^{10}B(^{7}Li, ^{6}He)^{11}C $\qquad Q_m = -1.284$

Table 11.23: Energy levels of ^{11}C from ^{10}B(d, n)^{11}C and ^{10}B(^{3}He, d)^{11}C

E_x (MeV ± keV)	J^π	l [f]	l [g]	$S_{d,n}$ [g]	$S_{^3He,d}$ [g]	l [i]	$S_{^3He,d}$ [i]
0	$\frac{3}{2}^-$	1	1	1.12	0.88	1	1.09
2.0006 ± 0.9 [a]	$\frac{1}{2}^-$	(1)	(1)	(0.18)	(0.036)		
			(3)		≤ 0.09	(3)	< 0.40
4.322 ± 10 [b]	$\frac{5}{2}^-$	1	1	0.27	0.20	1	0.17, 0.19
4.808 ± 10 [b]	$\frac{3}{2}^-$	1	1	< 0.02		(1)	< 0.08
						(3)	< 0.35
6.345 ± 10 [b]	$\frac{1}{2}^+$		2		0.07	2	0.08
6.476 ± 10 [b]	$\frac{7}{2}^-$	1	1	0.86	0.56	1	0.73, 0.79
6.903 ± 10 [b]	$\frac{5}{2}^+$	(1)				2	0.06
						0	< 0.04
7.498 ± 10 [b]	$\frac{3}{2}^+$					2	0.08
8.107 ± 10 [b]	$\frac{3}{2}^-$ [k]					1	0.07
8.424 ± 8 [c]	$\frac{5}{2}^-$	1	1	0.65	0.46	1	0.73, 0.79
8.655 ± 8 [c,d]	$\frac{5}{2}^+$	0	0	$\underline{0.84}$	0.45		
			2	0.8	$\underline{0.32}$		
	$\frac{7}{2}^+$ [j]		0	$\underline{0.63}$	0.33	2	0.41
			2	0.6	$\underline{0.24}$	0	< 0.34
8.701 ± 20 [d]	$\frac{5}{2}^+$ [j]	(0)	0	$\underline{0.40}$	0.14	0	< 0.8
			2	≤ 0.2	0.13		
	$\frac{7}{2}^+$		0	$\underline{0.30}$	0.11		
			2	≤ 0.15	0.10		
10.08 [h]							
10.68 [d,e]			(0, 2)				

[a] (^{3}He, d): (1970BR23).
[b] (^{3}He, d): (1961HI08). $E(^{3}\text{He}) = 9.84$ MeV.
[c] (d, n): neutron threshold measurements (1955MA76); based on Q_m.
[d] (d, n): observed by time-of-flight technique (1963OV02).
[e] $\Gamma \approx 200$ keV (1963OV02).
[f] From (d, n) work summarized in Table 11.20 of (1968AJ02).
[g] From (1970BO34): $S_{d,n}$ obtained at $E_d = 5.8$ MeV, $S_{^3He,d}$ obtained at $E(^{3}\text{He}) = 11.0$ MeV [both ±30%]. When $S_{d,n}$ and $S_{^3He,d}$ differ appreciably, the more reliable value is underlined.
[h] See (1971CO07).
[i] From $E(^{3}\text{He}) = 21$ MeV work of (1971CO07); when two values are shown for $S_{^3He,d}$, they are in order of descending j.
[j] Value determined by (1973FO02).
[k] See (1970FO05).

Angular distributions of ^{6}He ions have been measured at $E(^7\text{Li}) = 3.0$ to 3.8 MeV (1968ST12; to $^{11}\text{C}_{\text{g.s.}}$) and at 24 MeV (1977KO27: to ^{11}C*(0, 4.32, 6.48)). ^{11}C*(2.0, 4.80, 8.42, $8.66 + 8.70$) are also populated (1977KO27).

17. ^{10}B(^{14}N, ^{13}C)^{11}C $\quad Q_{\text{m}} = 1.140$

See (1975NA15, 1977MO1A), (1975AJ02) and ^{13}C in (1981AJ01).

18. ^{10}B(^{16}O, ^{15}N)^{11}C $\quad Q_{\text{m}} = -3.437$

See (1975NA15). See also ^{15}N in (1981AJ01) and (1977OK1D; theor.).

19. ^{10}B(^{19}F, ^{18}O)^{11}C $\quad Q_{\text{m}} = 0.697$

See (1968GA03).

20. ^{11}B(γ, π^-)^{11}C $\quad Q_{\text{m}} = -141.549$

Yields of ^{11}C have been measured from threshold to $E_\gamma = 169$ MeV (1976MI15; see it also for other references).

21. ^{11}B(p, n)^{11}C $\quad Q_{\text{m}} = -2.764$

Neutron groups have been observed to ^{11}C*(0, 2.008, 4.320, 4.806, 6.330, 6.481) (± 20 keV) (1965OV01; $E_{\text{p}} = 10.9$ MeV). Angular distributions of the n_0 group have been measured at many energies up to 49.5 MeV [see (1975AJ02)] and at $E_{\text{p}} = 3.15$ to 4.85 MeV (1978VA12). See also (1977ME1C) and ^{12}C.

22. ^{11}B(^{3}He, t)^{11}C $\quad Q_{\text{m}} = -2.001$

Angular distributions of t_0 and t_1 have been measured at $E(^3\text{He}) = 10$ MeV (1967CR04), 14 MeV (1970NU02) and 217 MeV (1976WI05; also to ^{11}C*(4.3, 4.8, 6.48, 8.10)). The latter have been compared with microscopic calculations and calculations of two-step processes (1976WI05). At $E(^3\text{He}) = 26$ MeV the known states of ^{11}C below $E_{\text{x}} = 11$ MeV are populated and triton groups are also observed to states, assumed to be $T = \frac{3}{2}$, at $E_{\text{x}} = 12.15$, 12.57 and 13.92 MeV [see Table 11.21] and, possibly, 14.15 MeV (1971WA21).

23. ^{11}B(^{6}Li, ^{6}He)^{11}C $\qquad Q_m = -5.489$

See (1975AJ02).

24. ^{12}C(γ, n)^{11}C $\qquad Q_m = -18.721$

The fraction of transitions to the ground and to excited states of ^{11}C [and to ^{11}B states reached in the (γ, p) reaction] has been measured at $E_{bs} = 24.5$, 27, 33 and 42 MeV: the ground state is predominantly populated. The population of analog states in the (γ, n) and (γ, p) reactions are similar. And a significant decay strength is found to the positive parity states with $6 < E_x < 8$ MeV. In general the main contribution to the strength of the transitions to the various excited states of ^{11}B, ^{11}C lies in rather localized energy bands in ^{12}C which are a few MeV wide (1970ME17). See also (1975SC05, 1979KI1H). For the (e, n) reaction see (1978KL03).

25. (a) ^{12}C(e, en)^{11}C $\qquad Q_m = -18.721$
(b) ^{12}C(π^+, π^+n)^{11}C $\qquad Q_m = -18.721$
^{12}C(π^-, π^-n)^{11}C
(c) ^{12}C(n, 2n)^{11}C $\qquad Q_m = -18.721$
(d) ^{12}C(p, pn)^{11}C $\qquad Q_m = -18.721$

For reaction (a) see (1977KN04, 1978SH14). (1978MO01) report the strong population of the $\frac{5}{2}^-$ state ^{11}C*(4.32) (and of the analog state in ^{11}B) for $E_{\pi^+} = 60$ to 300 MeV. See also (1973HO43, 1979LI11) for reactions (b), reaction 54 in ^{11}B and the "GENERAL" section here. For reaction (c) see ^{13}C in (1981AJ01). For reaction (d) see (1976MCZP). See also (1975AJ02) and ^{12}C.

26. ^{12}C(π^+, p)^{11}C $\qquad Q_m = 121.628$

At $E_{\pi^+} = 49.3$ MeV angular distributions have been obtained to ^{11}C*(0, 2.0 ± 0.2, 4.35 ± 0.2, 6.4 ± 0.2, 8.5 ± 0.2, 12.5 ± 0.3). At the same momentum transfer this reaction and the (p, d) reaction give similar intensities to the low-lying energy states of ^{11}C (1978AM01). See also (1979AN1K, 1979AN1M).

27. ^{12}C(p, d)^{11}C $\qquad Q_m = -16.497$

Table 11.24: Levels of ^{11}C from ^{12}C(p, d)^{11}C [a]

E_x (MeV ± keV)	J^π [c]	S_{rel}	C^2S [d]
0	$\frac{3}{2}^-$	100	2.5
1.9997 ± 0.5 [b]	$\frac{1}{2}^-$	17.4	0.61
4.30 ± 50	$\frac{5}{2}^-$	< 0.06	(0.08)
4.80 ± 50	$\frac{3}{2}^-$	9.7	0.33
(6.34)	$\frac{1}{2}^+$	< 0.03	
6.49 ± 50	$\frac{7}{2}^-$	0.6	
6.92 ± 50	$\frac{5}{2}^+$	0.7	
7.53 ± 50	$\frac{3}{2}^+$	0.4	
8.13 ± 50	$\frac{3}{2}^-$	0.7	
8.43 ± 50	$\frac{5}{2}^-$	0.08	
8.67 ± 80	$\frac{7}{2}^+ + \frac{5}{2}^+$		
9.3 ± 100			
9.7 ± 100	$(\frac{5}{2}^+)$		
10.1 ± 200	$\frac{7}{2}^+$		
10.7 ± 200	$\frac{9}{2}^+$		
11.0 ± 100			
11.5 ± 200			

[a] (1971KA56): $E_p = 185$ MeV.
[b] (1974NO07).
[c] From Table 11.19.
[d] (1975RO27).

Angular distributions have been measured for $E_p = 19$ to 700 MeV [see (1968AJ02, 1975AJ02)] and recently at 65 MeV (1975RO27; see Table 11.24), 121.2 MeV (1976ANZP) and 650 and 800 MeV (1978IG1A, 1978WH1A, 1979BO1A). Observed states of ^{11}C are displayed in Table 11.24. See also (1975AJ02, 1975BE1Q, 1975IG1A, 1977HA1P, 1977MO1F, 1978AZ02, 1978IG1B, 1978SH1F, 1979WH1A), (1977HA1N [in ^{13}N, (1981AJ01)], and (1975GE1H, 1975RO29, 1976GR1G, 1976SHZQ, 1976WA15, 1977KA07, 1977LU1A, 1978CO1J, 1978LU1B; theor.).

28. ^{12}C(d, t)^{11}C $\qquad Q_m = -12.464$

At $E_d = 28$ MeV the t_0 angular distribution has been measured and a detailed comparison has been made with the results for the mirror reaction ^{12}C(d, ^{3}He)^{11}B (1968GA13, 1966DE1C). At

$E_{\bar{d}} = 29$ MeV the t_0 angular distribution leads to spectroscopic factors $C^2S = 2.82$ or 3.97 depending on different sets of parameters for $^{11}C_{g.s.}$. $^{11}C^*(2.0, 4.32)$ are also populated (1978CO13). See also ^{14}N in (1981AJ01), and (1975AJ02).

29. $^{12}C(^3He, \alpha)^{11}C$ $\qquad Q_m = 1.856$

Angular distributions have been measured at many energies to $E(^3He) = 217$ MeV [see (1968AJ02, 1975AJ02) for the earlier results] and at 11.0 MeV (1978CU02: α_0, α_1), 18, 20 and 22 MeV (1977AD07: α_0, α_1), at $E(\overline{^3He}) = 33$ MeV (1976KA23: α_0, α_1), and at $E(^3He) = 35.6$ MeV (1978FO13: see Table 11.25), 82.1 MeV (1976TA12: α_0, α_1, α_{2+3}, α_{4+5}) and at 217 MeV (1978VA05: α_0, α_1). See also (1976STYX: 60 MeV) and (1978CH1P: 132 MeV). At $E(^3He) \approx 217$ MeV (1975GE16, 1978VA05) also report the population of unresolved low-lying states, as well as the excitation of states with $E_x = 11.2$, 12.4, 15.3, 23 and (28) MeV. See Table 11.25 for a display of the results.

At $E(^3He) = 35.6$ MeV (1978FO13) find good fits by DWBA for strong $l = 1$ transitions, and reasonable agreement in the forward direction, as well as with $S_{theor.}$, for weak $l = 1$ transitions. Transitions involving $l = 0$ or 2 (and 3) are weak and the agreement with theory is poor. It is suggested that $^{11}C^*(8.10)$ $[\frac{3}{2}^-]$ is predominantly a $p_{3/2}$ hole state coupled to $^{12}C^*(7.65)$ $[0^+]$ (1978FO13).

Alpha-γ correlations have been studied for $E(^3He) = 4.7$ to 12 MeV: see, in particular, (1968EA03). Their results are summarized in Table 11.20 and are discussed in detail in reaction 22 of (1968AJ02). A measurement of the linear polarization of the 2.00 MeV γ-ray (together with knowledge of the τ_m) fixes $J^\pi = \frac{1}{2}^-$ for $^{11}C^*(2.00)$ (1968BL09). See also (1976RO1L, 1977MO1F) and ^{15}O in (1981AJ01).

30. $^{12}C(^6Li, ^7Li)^{11}C$ $\qquad Q_m = -11.471$

At $E(^6Li) = 36$ MeV the angular distributions involving $^7Li_{g.s.} + ^{11}C_{g.s.}$ and $^7Li^*_{0.48} + ^{11}C^*_{2.00}$ have been studied by (1973SC26).

31. $^{12}C(^{10}B, ^{11}B)^{11}C$ $\qquad Q_m = -7.266$

At $E(^{10}B) = 100$ MeV, angular distributions have been measured involving $^{11}B_{g.s.} + ^{11}C_{g.s.}$, $^{11}B_{g.s.} + ^{11}C_{2.00}$ and $(^{11}C_{g.s.} + ^{11}B_{2.12}) + (^{11}B_{g.s.} + ^{11}C_{2.00})$ [unresolved], as well as unresolved groups involving the first few states of ^{11}B and ^{11}C (1975NA15, 1975VO05, 1976NA09). See also (1975AJ02).

Table 11.25: Levels of ^{11}C from $^{12}C(^3He, \alpha)^{11}C$ [a]

E_x (MeV ± keV)	l [d]	S_{rel}				S
		$E(^3He) = 16$ MeV [f]	24 MeV [g]	28 MeV [g]	35.6 MeV [h]	33 MeV [i]
0	1	1	1	1	1.00	3.06
1.999 ± 4 [b]	1	0.10	≤ 0.6	≤ 0.6	0.19	0.65
4.3188 ± 1.2 [c]	3 [d,h]	0.057	(0.04)	(0.06)	(0.031)	
4.8042 ± 1.2 [c]	1	0.11	0.22	0.22	0.13	
6.3392 ± 1.4 [c]	0	0.003 [j]	≤ 0.07	≤ 0.07	($\lesssim 0.2$)	
6.4782 ± 1.4 [c]	3 [d,h]	0.11 [j]	0.06	(0.06)	(0.21)	
6.9048 ± 1.4 [c]	2	0.018	(0.15)	(0.17)	(0.054)	
7.4997 ± 1.5 [c]	2	0.006 [j]	(0.07)	(0.09)	(0.046)	
8.1045 ± 1.7 [c]	1 [e]	0.017 [j,k]			(0.035)	
8.42	3 [e,h]	0.034 [j,l]			(0.041)	

[a] See Table 11.20 for γ-decay work (1968EA03). Higher excited states are reported by (1978VA05): see text.
[b] (1968EA03).
[c] (1970BR23).
[d] (1970BO34).
[e] (1970FO05).
[f] (1970GR08).
[g] (1973FU02).
[h] (1978FO13).
[i] (1976KA23). Polarized ^{3}He.
[j] At $E(^3He) = 18$ MeV.
[k] Assuming $J^\pi = \frac{3}{2}^-$.
[l] Assuming $J^\pi = \frac{5}{2}^-$.

32. ^{12}C(^{12}C, ^{13}C)^{11}C $\qquad Q_{\rm m} = -13.775$

The angular distribution involving the ground state transitions has been studied at $E(^{12}{\rm C}) =$ 114 MeV (1974AN36). See also (1979HEZX).

33. ^{12}C(^{14}N, ^{15}N)^{11}C $\qquad Q_{\rm m} = -7.888$

See (1967BI06, 1974AN36) and ^{15}N in (1981AJ01).

34. ^{13}C(p, t)^{11}C $\qquad Q_{\rm m} = -15.186$

At $E_{\rm p} = 43.7$ to 50.5 MeV (1968CO26, 1968FL02) and at $E_{\bar{\rm p}} = 49.6$ MeV (1974MA12) angular distributions of the tritons have been studied to ^{11}C*(0, 2.00, 4.32, 4.80, 6.48, 6.90, 7.50) and to a $T = \frac{3}{2}$ state at $E_{\rm x} = 12.47$ MeV [see Table 11.21] whose J^π is determined to be $\frac{1}{2}^-$ [it is thus the analog of ^{11}Be*(0.32)]. The state decays primarily by p $\rightarrow$ ^{10}B*(1.74). Alpha decay to $^{7}{\rm Be}^*_{\rm g.s.+0.4}$ is also observed (1968CO26). Angular distributions have also been measured for $E_{\rm p} = 26.9$ to 43.1 MeV (1975MI01: $\rm t_0 \rightarrow t_3$). At $E_{\rm p} = 46.7$ MeV the $T = \frac{3}{2}$ state is also observed by (1974BE20) who, in addition, report the population of states with $E_{\rm x} = 11.03 \pm 0.03$, 13.33 ± 0.06, 13.90 ± 0.04 and 14.07 ± 0.04 MeV [$\Gamma = 300 \pm 60$, 270 ± 80, 150 ± 50 and 135 ± 50 keV, respectively]. However, the $T = \frac{3}{2}$ state at $E_{\rm x} = 12.16$ MeV reported by (1971WA21) in reactions 4, 8 and 22 is not observed by (1974BE20). See also ^{14}N in (1981AJ01).

35. ^{14}N(p, α)^{11}C $\qquad Q_{\rm m} = -2.922$

Angular distributions have been reported at a number of energies in the range $E_{\rm p} = 5.00$ to 44.3 MeV for the α_0 and α_1 groups: see (1975AJ02) for the earlier work and (1974HU02: 9.0 to 12.0 MeV; α_0). See also ^{15}O in (1981AJ01), (1976IN01; astrophys.), (1975CH1H; applied) and (1975KU1L; theor.).

36. ^{14}N(^{10}B, ^{13}C)^{11}C $\qquad Q_{\rm m} = 1.140$

This reaction has been studied at $E(^{10}{\rm B}) = 100$ MeV: see (1975NA15, 1976NA09) and ^{13}C in (1981AJ01).

37. ^{16}O(p, ^{6}Li)^{11}C $\qquad Q_{\rm m} = -22.185$

See (1975AJ02).

38. ^{16}O(d, ^{7}Li)^{11}C $\qquad Q_{\rm m} = -17.159$

At $E_{\rm d} = 80$ MeV angular distributions involving ^{11}C*(0, 2.0, $4.3 + 4.8$, $6.3 + 6.5 + 6.9$) have been measured (1978OE1A).

39. ^{16}O(α, ^{9}Be)^{11}C $\qquad Q_{\rm m} = -24.310$

At $E_{\alpha} = 42$ MeV, the angular distribution involving the two ground state transitions has been measured (1972RU03).

^{11}N
(Fig. 4)

The ^{14}N(^{3}He, ^{6}He)^{11}N reaction has been studied at $E(^{3}{\rm He}) = 70$ MeV. A ^{6}He group is observed which corresponds to a state in ^{11}N with an atomic mass excess of 25.23 ± 0.10 MeV and $\Gamma = 740 \pm 100$ keV. The cross section for forming this state is 0.5 μb/sr at $10°$. The observed state is interpreted as being the $J^{\pi} = \frac{1}{2}^{-}$ mirror of ^{11}Be*(0.32) because of its width; the $\frac{1}{2}^{+}$ mirror of ^{11}Be$_{\rm g.s.}$ would be expected to be much broader (1974BE20). The ^{11}N state is unbound with respect to decay into ^{10}C + p by 2.24 MeV. See also (1975BE31, 1975HU14, 1976IR1B, 1978GU10, 1979BE1H; theor.) and (1974DA27).

^{11}O, ^{11}F, ^{11}Ne
(Not illustrated)

These nuclei have not been observed: see (1975BE31, 1976IR1B; theor.).

References

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