Energy Levels of Light Nuclei
$A = 11$

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Abstract: An evaluation of $A = 11$–12 was published in *Nuclear Physics A*506 (1990), 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 are in the NNDC/TUNL format.

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Below is a list of links for items found within the PDF document. Figures from this evaluation have been scanned in and are available via the link below. The introductory Table 2 is also available on this website via the link.

^{11}He

(not illustrated)

^{11}He has not been reported: see (1980AJ01). The ground state of ^{11}He is predicted to have $J^\pi = \frac{5}{2}^+$ (1985PO10).

^{11}Li

(Figs. 1 and 4)

GENERAL (See also (1985AJ01).)

The mass excess is 40.94 ± 0.08 MeV (1975TH08), 40.78 ± 0.12 MeV (1988WO09). A.H. Wapstra suggests (private communication) 40.85 ± 0.08 MeV and we adopt this value. ^{11}Li is then bound with respect to ^{9}Li + 2n by 247 ± 80 keV and with respect to ^{10}Li + n by 1050 ± 260 keV [see (1988AJ01) for the masses of ^{9}Li and ^{10}Li].

The magnetic moment of ^{11}Li is $\mu = 3.6673 \pm 0.0025$ nm (1987AR22). This value requires $J = \frac{3}{2}$ (1987AR22). Negative parity is certain from systematics.

The interaction nuclear radius of ^{11}Li is 3.16 ± 0.11 fm (1988TA10, 1985TA18), $E = 790$ MeV/A; [see also for derived nuclear matter, charge and neutron matter r.m.s. radii]. ^{11}Li has a much larger radius than other neighboring nuclei suggesting either a large deformation and/or a long tail in the matter distribution in ^{11}Li (1985TA18). See (1988SA2P) and (1987MI38, 1987TAZU, 1989TA1K). Charge radius and matter radius calculations in the $0\hbar\omega$ and $(0+2)\hbar\omega$ model spaces predict a gradual increase in matter radii with increasing A and do not support the idea of a neutron halo in ^{11}Li (1988POZS; prelim.). See, however, (1988TA1A).

Fragmentation cross sections of ^{11}Li into ^{9}Li, ^{8}Li, ^{8}He, ^{7}Li, ^{6}Li and ^{6}He have been studied by (1988KO10) [see for a discussion of neutron halos]. See also (1988TA1A, 1989KO1P).

See also (1986DU11, 1988ST06), (1986AN07, 1988HA1Q, 1988TA1C, 1989AJ1A) and (1985SA32, 1986EL1A, 1986SA30, 1987HA30, 1987SH1K, 1988BE09, 1988BE1O, 1988JO1C, 1988LO1C, 1988UC03, 1989BA1T, 1989BE03; theor.).

1. ^{11}Li(β^-)^{11}Be $\qquad Q_{\rm m} = 20.68$

Reported half-life measurements are 8.5 ± 0.2 ms (1974RO31), 8.83 ± 0.12 ms (1981BJ01), 7.7 ± 0.6 ms (1986CU01). We adopt 8.5 ± 0.2 ms. The β-decay is complex and the evidence is not unambiguous. It involves delayed n, t and α emission. Most of the decay ($\approx 97\%$) takes place to low-lying states in ^{11}Be [but it is not clear which are involved]. All but ^{11}Be*(0, 0.32) are unstable with respect to neutron emission: see (1985AJ01). A 2.9% branch is reported to ^{11}Be*(10.59) which then decays by neutron emission (possibly to ^{10}Be*(9.4)) and then delayed α-particles [(0.90 ± 0.05)%] are reported to ^{6}He or the decay is via 2n+2α[(2.0 ± 0.6)%] (1981LA11). A (0.30 ± 0.05)% branch is reported to a state in ^{11}Be at $\approx$ 18.5 MeV (Γ $\approx$ 0.5 MeV) which has three modes of decay: triton emission to ^{8}Li*(0, 0.98) [(0.010 ± 0.004)%], (α+n)-emission

Table 11.1: Energy Levels of ^{11}Li [a]

E_x (MeV)	$J^\pi; T$	$\tau_{1/2}$ (ms)	Decay	Reaction
g.s.	$\frac{3}{2}^-, \frac{5}{2}$	8.5 ± 0.2	β^-	1

[a] Excited states are calculated at $E_x = 2.68$, 3.13 and 3.62 MeV, with $J^\pi = \frac{5}{2}^+, \frac{3}{2}^+$ and $\frac{9}{2}^+$ [(0+1) $\hbar\omega$ model space] and at 4.58, 21.69 and 23.22 MeV, with $J^\pi = \frac{1}{2}^-, \frac{3}{2}^-$ and $\frac{5}{2}^-$ [(0+2) $\hbar\omega$ model space] (1985PO10).

to ^{6}He[(0.10 ± 0.03)%] and 3n emission [$(0.20 \pm 0.05$%] involving ^{10}Be*(11.76) (1981LA11, 1984LA27). [*Comment*: In view of the importance of understanding very neutron rich light nuclei it is necessary to determine the parameters (and the location) of the excited states of ^{11}Be with $E_x \lesssim 12$ MeV. One could then hope to unravel the β^- decay evidence.] See also ^{6}He, ^{8}Li and ^{10}Be in (AJ88), Table 11.2 in (1985AJ01), (1985HA1T, 1985HA1K) and (1984LI1N, 1988JO1C; theor.).

^{11}Be
(Figs. 1 and 4)

GENERAL: See also (1985AJ01).

Model calculations: (1984MI1H, 1984VA06, 1986WI04).

Electromagnetic transitions: (1984MI1H, 1984VA06, 1987HO1L).

Complex reactions involving ^{11}Be: (1985BO1A, 1986AV1B, 1987TR05, 1987WA09, 1988BA53, 1988RU01, 1988TA1N, 1988TR03, 1989SA10).

Muon and neutrino capture and reactions: (1984KO24).

Hypernuclei: (1985IK1A, 1986ME1F).

Other topics: (1984MI1H, 1985AN28, 1986AN07).

Ground-state properties of ^{11}Be: (1984FR13, 1987SA15, 1987VA26, 1989BE03).

The interaction matter radius of ^{11}Be is 2.86 ± 0.04 fm (1988TA10). See also (1989SA10, 1989TA1K).

1. ^{11}Be(β^-)^{11}B $\qquad Q_m = 11.506$

The decay is complex: see reaction 26 in ^{11}B and Table 11.12. The half-life is 13.81 ± 0.08 s (1970AL21). See also (1980AJ01).

Table 11.2: Energy Levels of ^{11}Be

E_x (MeV±keV)	$J^\pi; T$	τ or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
0	$\frac{1}{2}^+; \frac{3}{2}$	$\tau_{1/2} = 13.81 \pm 0.08$ s	β^-	1, 2, 3, 5, 7
0.32004 ± 0.1	$\frac{1}{2}^-$	$\text{fs}\tau_m = 166 \pm 15$ fs	γ	2, 3, 4, 5, 7, 8
1.778 ± 12	$(\frac{5}{2}, \frac{3}{2})^+$	$\Gamma = 100 \pm 20$	(n)	2, 3, 6, 7
2.69 ± 20	$(\frac{1}{2}, \frac{3}{2}, \frac{5}{2}^+)$	200 ± 20	(n)	2, 8
3.41 ± 20	$(\frac{1}{2}, \frac{3}{2}, \frac{5}{2}^+)$	125 ± 20	(n)	2, 7
3.887 ± 15	$\geq \frac{7}{2}$	< 10	(n)	2
3.956 ± 15	$\frac{3}{2}^-$	15 ± 5	(n)	2, 8
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, 4
10.59 ± 50		210 ± 40	n, α	2, 4
(≈ 18.5)		≈ 500	n, t, α	4

2. ^{9}Be(t, p)^{11}Be $\qquad Q_m = -1.165$

Proton groups have been observed to the states displayed in Table 11.2. τ_m for the first excited state is 166 ± 15 fs, corresponding to a very large E1 transition strength of 0.36 ± 0.03 W.u.; $E_\gamma = 320.04 \pm 0.10$ keV. 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. 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 26 in ^{11}B]. ^{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 $^{9}\text{Be}_{g.s.} + 2\text{n}$. See (1980AJ01, 1985AJ01) for references.

3. ^{10}Be(d, p)^{11}Be $\qquad Q_m = -1.720$

Angular distributions of the p_0 and p_1 groups have been measured at $E_d = 6$ MeV and 12 MeV: $l_n = 0$ [and therefore $J^\pi = \frac{1}{2}^+$ for ^{11}Be(0)] and l, $S = 0.73 \pm 0.06$ and 0.63 ± 0.15, respectively. 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) [$l_n = 2$]. See (1980AJ01) for references.

4. ^{11}Li(β^-)^{11}Be $\qquad Q_{\rm m} = 20.68$

See ^{11}Li.

5. ^{11}B(π^-, γ)^{11}Be $\qquad Q_{\rm m} = 128.063$

The photon spectrum from stopped pions includes a peak corresponding to ^{11}Be*($0 + 0.32$) (1986PE05).

6. ^{12}C(π^-, p)^{11}Be $\qquad Q_{\rm m} = 112.105$

See (1987BL07; $E_{\pi^-} = 145$ MeV).

7. ^{12}C(^{7}Li, ^{8}B)^{11}Be $\qquad Q_{\rm m} = -28.187$

At E(^{7}Li) $= 82$ MeV ^{11}Be*($0 + 0.32$, 1.8, 3.4) are populated (1985AL1G).

8. ^{13}C(^{6}Li, ^{8}B)^{11}Be $\qquad Q_{\rm m} = -25.884$

At E(^{6}Li) $= 80$ MeV, ^{11}Be*(0.32) is strongly populated and the angular distribution to this state has been measured. ^{11}Be*(2.69, 4.0) are also observed: see (1980AJ01).

^{11}B
(Figs. 2 and 4)

GENERAL: See also (1985AJ01).

Nuclear models: (1984ZW1A, 1985KW02, 1987KI1C, 1988OR1C, 1988WO04).

Special states: (1984ZW1A, 1985CH27, 1985GO1A, 1985HA1J, 1985SH24, 1987KI1C, 1988KW02, 1988ZH1B, 1989BA60, 1989OR02).

Electromagnetic transitions and giant resonances: (1983GM1A, 1984MO1D, 1984VA06, 1985GO1A, 1986ER1A, 1987KI1C, 1989BA60).

Astrophysical questions: (1982AU1A, 1982CA1A, 1984TR1C, 1985DW1A, 1985WA1K, 1987AR1J, 1987AU1A, 1987DW1A, 1987MA2C, 1987RO25, 1987WE1E, 1988AP1A, 1988BA86, 1988FE1A, 1988RE1B, 1989BO1F, 1989BO1M, 1989GU1Q, 1989JI1A).

Complex reactions involving ^{11}B: (1984AI1A, 1984FI17, 1984HO23, 1984RE14, 1984SI15, 1984XI1B, 1985AG1A, 1985BE40, 1985BH02, 1985JA18, 1985MC03, 1985MO08, 1985PO11, 1985SH1G, 1985SI19, 1985WA1F, 1985WA22, 1986AV1B, 1986BA69, 1986BI1A, 1986BO1B, 1986CH2G, 1986CS1A, 1986HA1B, 1986MA19, 1986ME06, 1986MO15, 1986PO06, 1986RE13, 1986SA30, 1986SH2B, 1986UT01, 1986WA1H, 1986WE1C, 1987AN1A, 1987AR19, 1987BA1G, 1987BA38, 1987BE58, 1987BE55, 1987BO1K, 1987BU07, 1987DE37, 1987FE1A, 1987GR1O, 1987JA06, 1987KI05, 1987KO15, 1987LY04, 1987MA2F, 1987MU1D, 1987NA01, 1987OS1E, 1987PA01, 1987PO23, 1987SH23, 1987SI1C, 1987ST01, 1987TE1D, 1987TR05, 1987VI02, 1987WA09, 1987WE1D, 1987YA16, 1988BA53, 1988BL09, 1988CA06, 1988FE1A, 1988FO03, 1988GA12, 1988KA1L, 1988KHZX, 1988KI05, 1988KI06, 1988MI28, 1988MO1K, 1988PAZS, 1988RA10, 1988RU01, 1988SA19, 1988TE03, 1988UT02, 1989BL1D, 1989CEZZ, 1989HA43, 1989PA06, 1989PO06, 1989SA10, 1989SE03, 1989ST1G, 1989YO02).

Applications: (1984CA1D, 1986NO1C, 1988XI1B).

Muon and neutrino capture and reactions: (1983GM1A, 1984KO24, 1985MI1D, 1986KE1Q, 1987KU23, 1987SU06, 1987WE1E, 1988RA1E, 1989MI1G).

Pion and kaon capture and reactions (see also reactions 20, 30, and 48): (1983GE1C, 1983GM1A, 1984BA1T, 1984BA1U, 1985CO16, 1986PE05, 1986RO03, 1987BO1X, 1988AB05, 1988GIZU).

Antinucleon interactions: (1985BA51).

Hypernuclei: (1983SH1E, 1984CH1G, 1984SH1J, 1984ZH1B, 1985AH1A, 1985GA1E, 1985GR10, 1986AN1R, 1986BA3L, 1986BI1G, 1986DA1H, 1986DA1G, 1986DA1B, 1986DU1P, 1986FR1J, 1986GA33, 1986GA1H, 1986KI1K, 1986KO1A, 1986ME1F, 1986PO1H, 1986SZ1A, 1986YA1F, 1987MI38, 1987PO1H, 1988MA1G, 1988MO1L, 1988TA29, 1988TA14, 1989MI30).

Other topics: (1984PO11, 1985AN28, 1985SH24, 1986AN07, 1988KW02, 1988OR1C, 1989BA60, 1989OR02).

Ground-state properties of ^{11}B: (1984AN1B, 1984ZI04, 1985AN28, 1985GO1A, 1985HA18, 1985FA01, 1985ZI05, 1986DO1E, 1986GL1A, 1986RO03, 1986WI04, 1987AB03, 1987FU06, 1987KI1C, 1988AR1I, 1988BI1A, 1988VA03, 1988WA08, 1988WO04, 1989SA10).

$$\mu = +2.688637(2) \text{ nm (1978LEZA)},$$

$$Q = 40.65(26) \text{ mb [see (1980AJ01)]},$$

$$B(\text{E2}; \tfrac{3}{2}^- \rightarrow \tfrac{1}{2}^-) = 2.6 \pm 0.4\ e^2 \cdot \text{fm}^4 \text{ (1980FE07)}.$$

Mass of ^{11}B: The mass excess of ^{11}B has been measured to be 9303.09 ± 1.30 μu (1984EL05) [mass spectrometer]. The mass excess listed by (1988WA18) is 8668.2 ± 0.3 keV, and we adopt it.

Isotopic abundance: $(80.1 \pm 0.2)\%$ (1984DE53).

Table 11.3: Energy Levels of ^{11}B

E_x (MeV $\pm$ keV)	$J^\pi; T$	τ_m (fs) or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
0	$\frac{3}{2}^-; \frac{1}{2}$	stable		1, 2, 6, 7, 9, 13, 14, 15, 16, 17, 19, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 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, 64
2.124693 ± 0.027	$\frac{1}{2}^-$	$\tau_m = 5.5 \pm 0.4$	γ	1, 6, 7, 9, 13, 14, 15, 16, 17, 23, 24, 25, 26, 27, 29, 30, 32, 33, 36, 37, 38, 40, 47, 48, 49, 51, 52, 53, 55, 58, 59, 60, 61, 62, 63, 64
4.44489 ± 0.50	$\frac{5}{2}^-$	1.18 ± 0.04	γ	1, 2, 6, 7, 9, 13, 14, 15, 19, 23, 24, 25, 26, 27, 29, 30, 32, 33, 36, 37, 38, 40, 47, 49, 51, 53, 59, 60, 61
5.02031 ± 0.30	$\frac{3}{2}^-$	0.34 ± 0.01	γ	1, 6, 7, 9, 14, 15, 23, 24, 25, 26, 27, 29, 30, 32, 33, 36, 37, 38, 47, 48, 51, 52, 53, 55, 59, 60, 61
6.7429 ± 1.8	$\frac{7}{2}^-$	22 ± 5	γ	1, 2, 6, 14, 15, 19, 23, 24, 25, 26, 29, 33, 36, 37, 38, 47, 48, 53, 55, 59, 60, 61
6.79180 ± 0.30	$\frac{1}{2}^+$	1.7 ± 0.2	γ	1, 2, 6, 14, 15, 23, 24, 25, 27, 29, 33, 37, 40, 47, 48, 51, 55, 60

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

E_x (MeV ± keV)	$J^\pi; T$	τ_m (fs) or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
7.28551 ± 0.43	$\frac{5}{2}^+$	0.57 ± 0.04	γ	1, 2, 6, 13, 14, 15, 23, 24, 25, 27, 29, 33, 38, 48, 53
7.97784 ± 0.42	$\frac{3}{2}^+$	0.57 ± 0.06	γ	1, 2, 14, 23, 24, 27, 29, 33, 48, 53
8.5603 ± 1.8	$(\frac{3}{2}^-)$	0.70 ± 0.07	γ	1, 13, 14, 23, 24, 29, 30, 33, 48, 53, 60, 61
8.9202 ± 2.0	$\frac{5}{2}^-$	$\Gamma = 4.37 \pm 0.02$ eV	γ, α	1, 2, 13, 14, 19, 23, 24, 26, 29, 30, 33, 38, 55, 59, 60, 61
9.1850 ± 2.0	$\frac{7}{2}^+$	$1.9^{+1.5}_{-1.1}$ eV	γ, α	1, 2, 14, 23, 24, 26, 33, 62
9.2744 ± 2	$\frac{5}{2}^+$	4	γ, α	1, 2, 14, 23, 24, 33, 62
9.82 ± 25	$(\frac{1}{2}^+)$			48
9.876 ± 8	$\frac{3}{2}^+$	110 ± 15	α	5, 14, 27
10.26 ± 15	$\frac{3}{2}^-$	150 ± 25	γ, α	2, 5, 14, 61
10.33 ± 11	$\frac{5}{2}^-$	110 ± 20	γ, α	2, 5, 14, 24, 61
10.597 ± 9	$\frac{7}{2}^+$	100 ± 20	γ, α	2, 5, 14, 20, 22
10.96 ± 50	$\frac{5}{2}^-$	4500	α	5
11.265 ± 17	$\frac{9}{2}^+$	110 ± 20	α	5, 14
11.444 ± 19		103 ± 20	α	5, 14
11.600 ± 30	$\frac{5}{2}^+$	170 ± 30	n, α	3, 5, 14, 20, 22, 33, 61
11.886 ± 17	$\frac{5}{2}^-$	200 ± 20	n, α	3, 5, 14, 20, 22
12.0 ± 200	$\frac{7}{2}^+$	≈ 1000	n, α	5, 20, 22
12.557 ± 16	$\frac{1}{2}^+(\frac{3}{2}^+); \frac{3}{2}$	210 ± 20	γ, p, α	5, 14, 17, 18, 36
12.916 ± 12	$\frac{1}{2}^-; \frac{3}{2}$	200 ± 25	γ, p, α	5, 14, 17, 18, 33, 59, 61
13.137 ± 40	$\frac{9}{2}^-$	426 ± 40	n t, α	3, 14, 20, 21, 22
13.16	$\frac{5}{2}^+; \frac{7}{2}^+$	430	n, α	20, 22
14.04 ± 100	$\frac{11}{2}^+$	500 ± 200	n, α	3, 20, 22
14.34 ± 20	$\frac{5}{2}^+; \frac{3}{2}$	254 ± 18	γ, p	14, 17, 36

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

E_x (MeV $\pm$ keV)	$J^\pi; T$	τ_m (fs) or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
14.565 ± 15		≤ 30	n, t, α	3, 14, 20, 21, 22, 36, 61
15.29 ± 25	$(\frac{3}{2}, \frac{5}{2}, \frac{7}{2})^+; (\frac{3}{2})$	250 ± 50	γ, p, n, α	20, 22, 33, 61
16.437 ± 20	$T = \frac{3}{2}$	≤ 30	p, d, α	11, 14, 22, 30, 33, 61
17.33		≈ 1000	n, d, t, α	11, 21, 22
17.43 ± 50	$T = \frac{3}{2}$	100 ± 30	γ, n, p, d, α	3, 9, 11, 14
18.0	$T = \frac{3}{2}$	870 ± 100		14
18.37 ± 50	$(\frac{1}{2}, \frac{3}{2}, \frac{5}{2})^+$	260 ± 80	γ, d	9
19.13 ± 30	$(\pi = +); \frac{3}{2}$	115 ± 25		14, 61
19.7	$(\frac{1}{2}^+)$	broad	γ, d	9, 28
21.27 ± 50	$T = \frac{3}{2}$	300 ± 30		14
23.7	$(\frac{1}{2}, \frac{3}{2}, \frac{5}{2})^+$		γ, d	9
26.5		broad	γ, n	28

1. ^{6}Li(^{6}Li, p)^{11}B $\qquad Q_m = 12.215$

Angular distributions have been measured for the proton groups to the first eight states of ^{11}B at $E(^6\text{Li}) = 2$ to 16 MeV (1987DO05). For the earlier work see (1980AJ01). For excitation functions see ^{12}C. See also (1987DO07).

2. ^{7}Li(α, γ)^{11}B $\qquad Q_m = 8.6637$

Resonances for capture radiation are displayed in Table 11.5. See also (1984YA1A, 1985CA41, 1988BU01, 1988CA26; astrophys.).

3. ^{7}Li(α, n)^{10}B $\qquad Q_m = -2.7905 \qquad E_b = 8.6637$

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

Initial state	J^π	Γ_γ (total) (eV)	Branching ratios (%) to final state						
			g.s.	2.12	4.44	5.02	6.74	6.79	7.29
2.12	$\frac{1}{2}^-$	0.120 ± 0.009	100						
4.44 [b]	$\frac{5}{2}^-$	0.56 ± 0.02	100 [d]						
5.02 [b]	$\frac{3}{2}^-$	1.963 ± 0.067	85.6 ± 0.6 [e]	14.4 ± 0.6 [f]					
6.74 [b]	$\frac{7}{2}^-$	0.030 ± 0.007	70 ± 2 [g]	< 3	30 ± 2	< 1			
6.79 [b]	$\frac{1}{2}^+$	0.385 ± 0.044	67.5 ± 1.1	28.5 ± 1.1	< 0.04	4.0 ± 0.3			
7.29 [b]	$\frac{5}{2}^+$	1.149 ± 0.080	87.0 ± 2.0	< 1	5.5 ± 1	7.5 ± 1			
7.98 [b]	$\frac{3}{2}^+$	1.15 ± 0.15	46.2 ± 1.1	53.2 ± 1.2	< 0.06	< 0.09		< 0.10	0.85 ± 0.04
8.56 [b]	$(\frac{3}{2}^-)$ [i]	0.946 ± 0.090	56 ± 2	30 ± 2	5 ± 1	9 ± 1			
8.92 [b]	$\frac{5}{2}^-$	4.368 ± 0.021	95 ± 1 [h]	< 1	4.5 ± 0.5	< 1	< 1	< 1	
9.19 [c]	$\frac{7}{2}^+$	$0.17^{+0.06}_{-0.03}$	0.9 ± 0.3		86.6 ± 2.3		12.5 ± 1.1	< 1.3	
9.27 [c]	$\frac{5}{2}^+$	1.15 ± 0.16	18.4 ± 0.9		69.7 ± 1.4		11.9 ± 0.6	< 0.6	

[a] See discussion in (1982MI08). See also Table 11.4 in (1980AJ01) and Tables 11.5 and 11.13 here.

[b] See also (1965OL03).

[c] Weighted mean of branching ratios and Γ_γ (1984HA13). Earlier work is also included: see (1984HA13).

[d] $\delta = -0.19 \pm 0.03$.

[e] $\delta = 0.03 \pm 0.05$.

[f] $\delta = -0.05 \pm 0.02$.

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

[h] $\delta = -0.11 \pm 0.04$.

[i] This is probably the ^{11}B analog of ^{11}C*(8.10). If so $J^\pi = \frac{3}{2}^-$.

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

(1) *4.44 MeV*. $9.28 \to 4.44 \to 0$ 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). τ_m excludes $\frac{7}{2}$, branch to 2.12, $\frac{5}{2}$. Angular correlation fixes $\frac{3}{2}^-$.

(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 [$J^\pi = \frac{1}{2}^+$] requires $J^\pi \leq \frac{3}{2}^+$. The relatively strong γ-branch to ^{11}B*(2.12) favors $\frac{1}{2}^+$, $\frac{3}{2}^+$. 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→4.44). $J^\pi = \frac{5}{2}^+$ is consistent with $\log ft > 8.04$ in the ^{11}Be β-decay.
(6) *7.98 MeV*. Transitions to ^{11}B(0, 2.12) are predominantly E1; thus ^{11}B*(7.98) has even parity, and the 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 that 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. See also footnote [i] in Table 11.4.
(8) *8.92 MeV*. From ^{7}Li(α, γ)^{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).

The total cross section has been measured from threshold to $E_\alpha = 5.67$ MeV [see also reaction 22]: a broad maximum at $E_\alpha \approx 5.1$ MeV ($\sigma_{\rm max} = 40$ mb) is observed (1984OL05). For the earlier work see Tables 11.7 in (1980AJ01) and (1985AJ01). See also (1985CA41; astrophys.).

4. ^{7}Li(α, t)^{8}Be $\qquad Q_{\rm m} = -2.5597 \qquad E_{\rm b} = 8.6637$

Excitation functions have been measured for $E_\alpha = 14$ to 25 MeV (t_0) and 18 to 25 MeV (t_1): see (1980AJ01). See also ^{8}Be in (1988AJ01) and (1987DM1C).

5. ^{7}Li(α, α)^{7}Li $\qquad E_{\rm b} = 8.6637$

The elastic scattering and the scattering to ^{7}Li*(0.48) have been studied at many energies to $E_\alpha = 22.5$ MeV: see (1975AJ02, 1980AJ01, 1985AJ01). Observed resonances are displayed in Table 11.6. For α-^{7}Li correlations see (1987PO03) and the “General” section. See also (1987BU27), (1987EL1B; applied) and (1985CH27; theor.).

6. ^{7}Li(^{6}Li, d)^{11}B $\qquad Q_{\rm m} = 7.189$

Angular distributions have been measured for $E(^7{\rm Li}) = 3.3$ to 5.95 MeV: see (1975AJ02).

7. ^{7}Li(^{7}Li, t)^{11}B $\qquad Q_{\rm m} = 6.196$

Angular distributions have been measured at $E(^7{\rm Li}) = 2.10$ to 5.75 MeV. At $E(^7{\rm Li}) = 79.6$ MeV transitions are observed to several ^{11}B states. $^{11}{\rm B}_{\rm g.s.}$ is particularly strongly populated. See (1975AJ02) for references.

8. ^{8}Li(α, n)^{11}B $\qquad Q_{\rm m} = 6.6309$

See (1988MA1U; astrophysics). See also (1988SA2Q, 1989BO1K).

9. ^{9}Be(d, γ)^{11}B $\qquad Q_{\rm m} = 15.8153$

Table 11.5: Resonances in $^{7}Li(\alpha, \gamma)^{11}B$ [a]

E_{res} (keV)	$\Gamma_{c.m.}$ (keV)	$^{11}B^*$ (MeV)	J^{π}	$\omega\gamma$ (eV)	$\Gamma_{\gamma 0}$ (eV)	Percentage decay to $^{11}B^*$			
						0	4.44	6.74	6.79
401 ± 3 [b]	4.37 ± 0.02 eV	8.919	$\frac{5}{2}^{-}$	$(8.8 \pm 1.4) \times 10^{-3}$	4.15 ± 0.02 [f]	95 ± 1	4.5 ± 0.5		
814 ± 2 [b]	$1.8^{+1.5}_{-1.1}$ eV	9.182	$\frac{7}{2}^{+}$	0.310 ± 0.047	$0.17^{+0.05}_{-0.01}$ [e]	0.9 ± 0.3	90.8 ± 4.0	8.3 ± 1.0	< 1.3
953 ± 2 [b]	4	9.271	$\frac{5}{2}^{+}$	1.72 ± 0.24	0.20 ± 0.03 [f]	17.1 ± 1.0	71.7 ± 1.8	11.2 ± 0.6	< 0.6 [c]
2500 ± 20	433	10.26			17	[d]			
2620 ± 20	100	10.33			1.0	[d]			
2800 ± 50	≈ 140	10.45			$10/(2J+1)$				
(3040)	90	(10.60)			< 0.2	[d]			

[a] See Table 11.6 in (1980AJ01) for comments and references.

[b] Γ_{α}(c.m.)=$(5.9 \pm 0.9) \times 10^{-3}$, $1.6^{+1.5}_{-1.1}$, and 4×10^{3} eV for $^{11}B^*$(8.92, 9.19, 9.27) (1984HA13). See also Table 11.4.

[c] 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.

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

[e] Γ_{γ}, not $\Gamma_{\gamma 0}$. See also Table 11.4.

[f] See Table 11.4.

The $90°$ γ_0 differential cross section has been measured for $E_{\rm d} = 0.5$ to 11.9 MeV: see (1975AJ02). The behavior of the γ_0, γ_1, and γ_{2+3} total cross sections and of the angular distributions of these γ-rays indicate two resonances at $E_{\rm d} = 1.98 \pm 0.05$ and 3.12 ± 0.05 MeV with $\Gamma_{\rm lab} = 225 \pm 50$ 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 $E_{\rm d} = 2.5$ MeV. The maximum γ_0 cross section observed is 10.1 ± 3.5 μb at $E_{\rm d} \approx 0.96$ MeV. Resonant behavior is observed in the $90°$ γ_0 cross section at $E_{\rm d} \approx 3.4$ 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.

10. ^{9}Be(d, n)^{10}B $\qquad Q_{\rm m} = 4.3612 \qquad E_{\rm b} = 15.8153$

The cross section follows the Gamow function for $E_{\rm d} = 70$ to 110 keV. The fast neutron and γ-yield rise smoothly to $E_{\rm d} = 1.8$ MeV except for a possible "resonance" at $E_{\rm d} \approx 0.94$ MeV. The fast neutron yield then remains approximately constant to 3 MeV: see (1968AJ02) for references. The excitation functions for $\rm n_0 \rightarrow n_4$, and n to ^{10}B*(5.1, 6.57) have been measured for $E_{\rm d} = 14$ to 16 MeV; no strong fluctuations are observed: see (1975AJ02). Thick target yields for γ-rays have been measured at $E_{\rm d} = 48$ to 170 keV: see (1985AJ01). Thick target yields are also reported at $E_{\rm d} = 14.8$, 18.0 and 23.0 MeV: see (1980AJ01). Polarization measurements have been carried out at $E_{\rm d} = 0.4$ to 5.5 MeV [see (1975AJ02, 1980AJ01)] and at $E_{\vec{\rm d}} = 12.3$ MeV: see (1985AJ01). See also ^{10}B in (1988AJ01), (1985SM08, 1986BA40) and (1988ZVZZ; theor.).

11. (a) ^{9}Be(d, p)^{10}Be $\qquad Q_{\rm m} = 4.5874 \qquad E_{\rm b} = 15.8153$
(b) ^{9}Be(d, α)^{7}Li $\qquad Q_{\rm m} = 7.152$
(c) ^{9}Be(d, t)^{8}Be $\qquad Q_{\rm m} = 4.5919$

Measurements of proton yields have been carried out at $E_{\rm d}$ up to 6.0 MeV for $\rm p_0$ and $\rm p_1$ [see (1975AJ02, 1980AJ01, 1985AJ01)]. The $\rm p_0$ and $\rm p_1$ yields show a resonance at $E_{\rm d} = 750 \pm 15$ keV [^{11}B*(16.43), $\Gamma \approx 40$ keV] and the $\rm p_1$ yield resonates at 1.85 MeV [^{11}B*(17.33), $\Gamma_{\rm c.m.} \approx 1.0$ MeV] and 2.3 MeV [^{11}B*(17.70), sharp]. See also (1975AJ02, 1985AJ01) for other possible structures. Polarization of the protons has been measured at $E_{\rm d} = 1$ to 21 MeV [see (1975AJ02, 1980AJ01, 1985AJ01)] and at $E_{\vec{\rm d}} = 2.0$ to 2.8 MeV (1984DE46; VAP; $\rm p_0, p_1$). See also ^{10}Be in (1988AJ01) and (1984AN16).

The yield of α-particles (reaction (b)) has been measured for $E_{\rm d} = 0.3$ to 14.43 MeV [see (1975AJ02, 1980AJ01, 1985AJ01)]. The 0.75 MeV resonance, observed in reaction (a), is weakly populated in the α_0 yield. For polarization measurements see (1985AJ01) and (1984AN16: $E_{\rm d} = 2.0$ to 2.8 MeV; α_{0+1}; VAP). See also ^{7}Li in (1988AJ01).

Table 11.6: Structure in ^{7}Li(α, α)^{7}Li and ^{7}Li(α, α')^{7}Li [a]

E_α [b] (keV)	E_α [c] (keV)	$\Gamma_{\rm c.m.}$ (keV)	$E_{\rm x}$ (MeV $\pm$ keV)	J^π
1900 ± 10		130 ± 30	9.873 ± 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	3040	70 ± 10	10.599 ± 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) [d]	
6100 ± 30		150 ± 50	12.55 ± 30	
6850 ± 60		270 ± 50	13.03 ± 60	
(7200 ± 50) [e]		50 ± 50	(13.25 ± 50) [d]	
	7800 ± 100	500 ± 200	(13.63 ± 100) [d]	
(8450 ± 200) [f]		500 ± 200	(14.0 ± 200)	
(9450 ± 200) [f]		≤ 250	(14.7 ± 200)	
	9950 ± 20	500 ± 200	(15.00 ± 20) [d]	
(11200 ± 200) [f]			(15.8 ± 200)	

[a] Mostly from (1966CU02). For other parameters see Table 11.9 in (1975AJ02). See also Table 11.8 in (1985AJ01).

[b] ^{7}Li(α, $\alpha'\gamma$)^{7}Li: σ (total).

[c] ^{7}Li(α, α_0)^{7}Li.

[d] ^{7}Li(α, n)^{10}B threshold.

[e] Anomaly in angular distribution.

[f] Observed at $\theta = 60°$.

The cross section for reaction (c) has been measured for $E_{\rm d} = 0.15$ to 19 MeV: see (1968AJ02, 1975AJ02, 1980AJ01). Polarization measurements are reported at $E_{\vec{\rm d}} = 12$ and 15 MeV [see (1980AJ01)] and at $E_{\vec{\rm d}} = 2.0$ to 2.8 MeV (1984AN16; $\rm t_0$). There is no clear evidence of resonance structure. See also ^{8}Be in (1988AJ01).

12. ^{9}Be(d, d)^{9}Be $E_{\rm b} = 15.8153$

Excitation functions for elastically scattered deuterons have been measured for $E_{\rm d} = 0.4$ to 7.0 MeV and for 12.17 to 14.43 MeV (also $\rm d_1, d_2$) [see (1975AJ02, 1980AJ01)]. Polarization measurements have been reported at $E_{\vec{\rm d}} = 6.3$ to 15 MeV [see (1975AJ02, 1980AJ01)] and at $E_{\rm d} = 2.0$ to 2.8 MeV (1983DE50; $\rm d_0$; VAP). See also ^{9}Be in (1988AJ01).

13. ^{9}Be(t, n)^{11}B $Q_{\rm m} = 9.5580$

Angular distributions have been measured at $E_{\rm t} = 1.1$ to 1.7 MeV ($\rm n_0$, $\rm n_1$, $\rm n_2$, $\rm n_6$, $\rm n_8$, $\rm n_9$): see (1980AJ01).

14. ^{9}Be(^{3}He, p)^{11}B $Q_{\rm m} = 10.3218$

Observed proton groups are displayed in Table 11.7. Angular distributions have been obtained at a number of energies in the range $E(^3{\rm He}) = 1.0$ to 38 MeV [see (1980AJ01, 1985AJ01)] and at 3 to 6 MeV (1981LI1C; nine groups; DWBA). It is suggested that the $T = \frac{1}{2}$ strength is strongly fragmented (1982ZW02). See also (1985AJ01), ^{12}C, (1985MC1C; applied) and (1988KH11; theor.).

15. ^{9}Be(α, d)^{11}B $Q_{\rm m} = -8.0314$

Angular distributions have been measured at a number of energies in the range $E_\alpha = 23.4$ to 28.3 MeV [see (1980AJ01)] and at 30.2 MeV (1984VA07; $\rm d_0 \rightarrow d_3$). The predominant L-transfers are L=0, 2; 0; 0 for ^{11}B*(0, 2.12, 5.02). The angular distribution to ^{11}B*(4.44) is flat at $E_\alpha = 27$ MeV. At $E_\alpha = 48$ MeV, ^{11}B*(16.44, 17.69, 18.0, 19.15) are not excited suggesting that these states are rather pure $T = \frac{3}{2}$ states (1982ZW02): see Table 11.7.

16. ^{9}Be(^{6}Li, α)^{11}B $Q_{\rm m} = 14.3403$

Table 11.7: Energy levels of ^{11}B from ^{9}Be(^{3}He, p)^{11}B

E_x [a] MeV ± keV)	E_x [b] MeV ± keV)	$\Gamma_{c.m.}$ [b] (keV)	L
0			0
2.1243 ± 0.9			0
4.4434 ± 1.8			0
5.0187 ± 2.3			0
6.7411 ± 3.0			
6.7909 ± 3.1			1
7.285 ± 10			
7.975 ± 10			
8.553 ± 10			0
8.909 ± 10	8.934 ± 15		$0 + 2$
9.175 ± 10	9.183 ± 15		$(1) + 3$
9.264 ± 10	9.265 ± 15	10 ± 10	$1 + 3$
9.86 ± 20	9.887 ± 15	104 ± 15	1
	10.265 ± 25	168 ± 25	2
	10.337 ± 20	123 ± 20	$0 + 2$
	10.580 ± 20	122 ± 20	$1 + 3$
	11.254 ± 20	110 ± 20	3
	11.437 ± 20	103 ± 20	$(0 + 2)$
	11.588 ± 30	180 ± 30	$1 + 3$
	11.889 ± 20	204 ± 20	$0 + 2$
	12.563 ± 20 [c]	202 ± 25	1
	12.920 ± 20 [c]	155 ± 25	2
	13.137 ± 40	426 ± 40	$1 + 3$
	$\equiv 14.40$ [d]	261 ± 25	$1 + 3$
	14.565 ± 15	≤ 30	(1)
	16.437 ± 20 [c, e]	≤ 30	
	$\equiv 17.69$ [c, e]	91 ± 25	$(0 + 2)$
	18.0 ± 100 [c, e]	870 ± 100	$(1 + 3)$
	19.146 ± 30 [c, e]	115 ± 25	3
	21.27 ± 50 [c]	300 ± 30	$(1 + 3)$

[a] See Table 11.9 in (1980AJ01) for references and Table 11.15 here.
[b] $E(^3\text{He}) = 38$ MeV; DWBA analysis.
[c] $T = \frac{3}{2}$ state.
[d] This state may have mixed isospin ($T = \frac{1}{2} + T = \frac{3}{2}$).
[e] Not observed in ^{9}Be(α, d)^{11}B.

Angular distributions have been determined for seven α-groups at $E(^6\text{Li}) = 3$ to 4 MeV, and at 24 MeV to ^{11}B*(0, 2.12) and to a number of unresolved levels with $E_\text{x} \leq 13.2$ MeV: see (1968AJ02, 1975AJ02). For the breakup reactions see (1975AJ02).

17. ^{10}Be(p, γ)^{11}B $\qquad Q_\text{m} = 11.2279$

The yield of γ_0 has been measured at 90° for $E_\text{p} = 0.6$ to 6.3 MeV. Observed resonances are displayed in Table 11.8. $T = \frac{3}{2}$ assignments are made for the states at $E_\text{x} = 12.56$, 12.91, 14.33 and 15.32 MeV whose energies match those of the first four states of ^{11}Be [compare with the $T = \frac{3}{2}$ states reported in ^{9}Be(^{3}He, p)^{11}B - Table 11.7]. See also Table 11.15. Several known $T = \frac{1}{2}$ states in ^{11}B are not observed in this reaction: see Table 11.3.

18. ^{10}Be(p, n)^{10}B $\qquad Q_\text{m} = -0.2262 \qquad E_\text{b} = 11.2279$

The reaction cross section has been measured for $E_\text{p} = 0.89$ to 1.93 MeV: the excitation of ^{11}B*(12.56, 12.91) is reported (1986TE1A and G.M. Ter-Akopian, private communication; 1987ERZY). See also (1988DUO6; theor.).

19. ^{10}B(n, γ)^{11}B $\qquad Q_\text{m} = 11.4542$
$Q_0 = 11454.1 \pm 0.2$ keV (1986KO19)

The thermal capture cross section is 0.29 ± 0.04 b (1986KO19). The observed capture γ-rays are displayed in Table 11.9. See also (1988MU05; theor.).

20. ^{10}B(n, n)^{10}B $\qquad E_\text{b} = 11.4542$

The scattering amplitude (bound) $a = -0.2 \pm 0.4$ fm, the total scattering cross section $\sigma(\text{free}) = 2.23 \pm 0.06$ b (1983KO17). The total scattering cross section is constant at 2.23 ± 0.06 b for $E_\text{n} = 0.7$ to 10 keV and then rises to 2.97 b at $E_\text{n} = 127$ keV. For a display of cross sections and a listing of measurements see (1988MCZT).

Table 11.8: 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)	$(J+\frac{1}{2})(\Gamma_p/\Gamma)\Gamma_{\gamma_0}$ [a] (eV)	Γ_{γ_0} [a] (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 [d]	≤ 0.06	$\frac{1}{2}^-$
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} [c]			

[a] Values reported in (1970GO04) are here shown multiplied by 1.7: see (1973GO09). See also Table 11.15.
[b] May be due to ^{10}B*$(0.7) + \text{n}$ threshold.
[c] Assumes that $\sigma_{\text{total}} = 4\pi\ \text{d}\sigma/\text{d}\Omega(90°)$.
[d] 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 $J^\pi = \frac{1}{2}^-$; $T = \frac{3}{2}$, then $\Gamma_{\gamma_0} = 36 \pm 7$ eV (1975KA02).

Table 11.9: Neutron capture γ-rays from $^{10}\text{B} + \text{n}$ [a]

E_γ (keV)	I_γ [b]	I_γ [c]	Assignment	E_x (keV)
11447.35 ± 0.52	4.6 ± 0.3	4.7 ± 0.3	capt. → g.s.	
8916.80 ± 0.27	13 ± 1	13.4 ± 0.9	8.92 → g.s.	8920.44 ± 0.27
6738.34 ± 0.50	19 ± 2	19.0 ± 0.9	6.74 → g.s.	6741.76 ± 0.24
4444.03 ± 0.12	67 ± 4	65.7 ± 2.4	4.44 → g.s.	4444.95 ± 0.15
7006.75 ± 0.10	56 ± 2	55.4 ± 1.7	capt. → 4.44	
4711.17 ± 0.10	28 ± 2	25.6 ± 0.9	capt. → 6.74	
2533.49 ± 0.23	12 ± 4	14.4 ± 1.8	capt. → 8.92	
2296.61 ± 0.59	7 ± 4	8.9 ± 2.4	6.74 → 4.44	

[a] (1986KO19). For the earlier work see Table 11.12 in (1975AJ02): I_γ for 5.02 → g.s. and 2.12 → g.s. are < 2 and < 3, respectively (1967TH05).
[b] Photons/100 captures.
[c] Adopted: weighted mean of (1967TH05) and (1986KO19).

Table 11.10: Resonances in ^{10}B + n [a]

^{10}B(n, n′γ)^{10}B		^{10}B(n, α)^{7}Li		Yield of	^{11}B*
E_{res} (MeV)	Γ (keV)	E_{res} (MeV)	Γ (keV)		(MeV)
		0.23 [b]		σ_t, α	11.66
		0.53 [b, c]	140	σ_0, α_1	11.94
1.93	260	1.86	570	σ_t, α_0, α_1, t, n′	13.2
(2.6)	broad	2.79	530	σ_t, 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, α_0, α_1, n′	15.2
4.73				n′	15.75
		5.7	broad	α_0, t	16.6
		6.4	broad	α_0, t	17.3

[a] See also Table 11.11. For references see Table 11.12 in (1980AJ01).
[b] (1984OL05) [see reaction 21] report $E_R = 241 \pm 18$ and 493 ± 4 keV, $\Gamma = 166 \pm 40$ and 194 ± 6 keV: E_x are then 11.673 and 11.902 MeV.
[c] See footnote [b] in Table 11.11.

Total cross section measurements in the range $E_n = 10$ to 500 keV show a broad maximum near $E_n = 0.23$ MeV, also observed in the (n, α) cross section. At higher energies the total cross section shows broad maxima at $E_n = 1.9$, 2.8 and 4.3 MeV: see Table 11.10. In the range $E_n = 5.5$ to 16 MeV σ_{tot} is constant at 1.5 b.

Polarization measurements (0.075 to 2.2 MeV and 2.63 MeV) and measurements of differential cross sections (0.075 to 4.4 MeV) have been analyzed using R-matrix calculations: the results are shown in Table 11.11. They are consistent with results from ^{10}B(n, n′γ) and ^{7}Li(α, n). See (1980AJ01) for references.

Elastic and inelastic cross sections have also been reported at $E_n = 4$ to 14.1 MeV [see (1980AJ01)], at $E_n = 3.0$ to 12.0 MeV (1986SAZR, 1987SAZX; prelim.), at 8.0 to 13.9 MeV (1982GL02) and at 10 to 17 MeV (1986MU08; also polarization measurements at 10 and 15 MeV; prelim.). The yield of 0.7 MeV γ-rays has been studied from threshold to $E_n = 5.2$ MeV: observed resonances are displayed in Table 11.10. 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 (1988AJ01), (1986BAYL, 1986DR10), (1983GO1H, 1988MA1H), (1988RE09; computer code) and (1985CH27, 1988HAZT; theor.).

21. (a) ^{10}B(n, p)^{10}Be $Q_m = 0.2262$ $E_b = 11.4542$
    (b) ^{10}B(n, t)^{4}He^{4}He $Q_m = 0.3226$

Table 11.11: R-matrix analysis of resonant state in $^{10}B + n$ [a]

E_n (MeV)	E_x (MeV)	J^π	l_n	Γ_n (c.m., MeV)	$\Gamma_{\alpha 0}$ (c.m., MeV)	Γ_{α_1} (c.m., MeV)	$\Gamma_{c.m.}$ (keV)
	10.60	$\frac{7}{2}^+$	0	0.120	0.030	0.070	220
0.17	11.61	$\frac{5}{2}^+$	0	0.004	0.296	0.0	300
0.37	11.79	$\frac{7}{2}^+$	0	0.770	0.001	0.113	884
0.53 [b]	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	$(\frac{3}{2}, \frac{5}{2}, \frac{7}{2})^+$	2	0.500	0.100	0.100	700

[a] 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-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 11.10.

[b] (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 thermal cross section for reaction (a) is 6.4 ± 0.5 mb (1987LA16); that for reaction (b) is $4.47{\pm}0.15$ mb (1989CL01) [see also for other references], $7{\pm}2$ mb (1987KA32). The cross section for reaction (b) has also been studied for $E_n = 1.4$ to 8.2 MeV [see Table 11.10 and (1968AJ02)] and 3 to 8 MeV (1986QA01 ; prelim.). For various breakup processes see (1984TU02). For a display of cross sections and a listing of measurements see (1988MCZT). See also (1985BO1D, 1988MA1H, 1988SUZY).

22. ^{10}B(n, α)^{7}Li $Q_m = 2.7905$ $E_b = 11.4542$

The "recommended" value of the thermal isotopic absorption cross section is 3837 ± 9 b (1981MUZQ). The α_0/α_1 branching for thermal neutrons is (6.723 ± 0.011)% [mean of values listed in (1985AJ01)]. At $E_n = 2$ and 24 keV the values are (7.05 ± 0.16)% and (7.13 ± 0.15)%, respectively (1979ST03).

The cross section for this reaction has been measured for $E_n = 0.025$ eV to 14.8 MeV [see (1975AJ02, 1980AJ01, 1985AJ01)]: for observed and deduced structures see Tables 11.10 and 11.11. For a display of cross sections and a listing of measurements see (1988MCZT). For a review see (1986CA28). "Detailed balance" [from ^{7}Li(α, n) measurements] has led to the determination of the ^{10}B(n, α_0) cross section from $0 < E_n \leq$0.78 MeV: two resonances are inferred at $E_R = 241 \pm 18$ and 493 ± 4 keV, with $\sigma_R = 17 \pm 3$ and 112 ± 3 mb and $\Gamma = 166 \pm 40$ and 194 ± 6 keV (1984OL05).

A study of the reaction involving polarized thermal neutrons and a polarized ^{10}B target shows that the transition to ^{7}Li*(0.48) proceeds almost totally through the $J = \frac{7}{2}$ channel (1986KO19). The ratio of the ^{10}B(n, α) cross section to the ^{6}Li(n, t) cross section has been measured from $E_n \approx 1$ to 45 eV (1986CA29; prelim.).

Parity violation has been studied using polarized thermal neutrons: the P-odd asymmetries for the transitions to ^{7}Li*(0, 0.48) are $< 3.7 \times 10^{-6}$ and $< 6.1 \times 10^{-7}$, respectively (1986ER05): see also (1983VE10), and (1985AJ01) for the earlier work. See also ^{7}Li in (1988AJ01), (1984AL1M, 1984XI1A, 1986CO1M, 1986DR1G, 1986GR1F, 1986OL1B, 1986WI1B; applied) and (1986AB1E, 1986MI1G, 1988MA1H).

23. ^{10}B(p, π^+)^{11}B $\qquad Q_m = -128.897$

Angular distributions have been obtained at $E_p = 168$ to 800 MeV to several states of ^{11}B [see (1980AJ01, 1985AJ01)] as have cross sections for π^+ production near threshold. At $E_{\vec{p}} = 200$ to 260 MeV, angular distributions and analyzing powers have been measured for the groups to ^{11}B*(0, 2.12) (1985ZI04).

24. ^{10}B(d, p)^{11}B $\qquad Q_m = 9.2296$

Reported proton groups are displayed in Table 11.14 of (1980AJ01). Angular distributions have been studied at many energies in the range $E_d = 0.17$ to 28 MeV [see (1968AJ02, 1975AJ02, 1980AJ01)]. 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.

25. (a) ^{10}B(t, d)^{11}B $\qquad Q_m = 5.1969$

(b) ^{10}B(α, ^{3}He)^{11}B $\qquad Q_m = -9.1236$

See (1968AJ02, 1975AJ02).

26. (a) ^{10}B(^{7}Li, ^{6}Li)^{11}B $\quad Q_{\rm m} = 4.204$

(b) ^{10}B(^{9}Be, ^{8}Be)^{11}B $\quad Q_{\rm m} = 9.7888$

(c) ^{10}B(^{13}C, ^{12}C)^{11}B $\quad Q_{\rm m} = 6.5078$

See (1980AJ01, 1985AJ01).

27. ^{11}Be(β^-)^{11}B $\quad Q_{\rm m} = 11.506$

^{11}Be decays to many states of ^{11}B: see Table 11.12 for the observed β- and γ-transitions (1982MI08). ^{11}B*(9.88) decays via α-emission for ^{7}Li*(0, 0.48) with branching ratios $(87.4 \pm 1.2)\%$ and $(12.6 \pm 1.2)\%$, respectively (1981AL03). A study of the $\beta\nu$ angular correlation in the first-forbidden decay of ^{11}Be to the $\frac{1}{2}^-$ state ^{11}B*(2.12) has been performed: the β-transition is dominated by rank-0 matrix elements and is of interest as a test of meson-exchange effects: see (1985AJ01). See also (1988WA1E).

28. (a) ^{11}B(γ, n)^{10}B $\quad Q_{\rm m} = -11.4542$

(b) ^{11}B(γ, p)^{10}Be $\quad Q_{\rm m} = -11.2279$

(c) ^{11}B(γ, d)^{9}Be $\quad Q_{\rm m} = -15.8153$

(d) ^{11}B(γ, t)^{8}Be $\quad Q_{\rm m} = -11.2234$

The giant dipole resonance is shown to consist mainly of $T = \frac{1}{2}$ states in the lower energy region and of $T = \frac{3}{2}$ states in the higher energy region by observing the decay to states in ^{10}B and ^{10}Be [reactions (a) and (b)]. Absolute measurements of the ^{11}B(γ, all n) cross section have been carried out from threshold to 35 MeV: 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 $\cdot$ mb: see (1980AJ01) and (1988DI02). See also (1984AL22). 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. The yield of 3.37 MeV γ-rays [from ^{10}Be*(3.37), reaction (b)] has been measured for $E_{\rm bs} = 100$ to 800 MeV. See also (1984AL22, 1986AL24). For reaction (d) see (1986AL24). See (1980AJ01, 1985AJ01) for references and for other photonuclear processes. See also (1985CH27, 1985GO1A, 1987KI1C, 1987LU1B, 1988DU04; theor.).

29. ^{11}B(γ, γ)^{11}B

Widths of excited states are displayed in Table 11.13. See also (1984AL22, 1988BEYY).

Table 11.12: Beta decay of ^{11}Be (1982MI08) [a]

^{11}B (keV)	J^{π} [b]	Branching ratio (%) [c]	log ft	E_{γ} (keV)	I_{γ} (%) [c]	Transition to ^{11}B* (MeV)
g.s.	$\frac{3}{2}^-$	54.7 ± 2.0 [d]	6.830 ± 0.016			
2124.693 ± 0.027	$\frac{1}{2}^-$	31.4 ± 1.8	6.648 ± 0.025	2124.473 ± 0.027	100	g.s.
4444.89 ± 0.50	$\frac{5}{2}^-$	0.054 ± 0.004	10.93 ± 0.03 [e]	4443.90 ± 0.50	100	g.s.
5020.31 ± 0.30	$\frac{3}{2}^-$	0.282 ± 0.020	7.934 ± 0.031	5018.98 ± 0.40	85.6 ± 0.6	g.s.
				2895.30 ± 0.40	14.4 ± 0.6	2.12
6791.80 ± 0.30 [f]	$\frac{1}{2}^+$	6.47 ± 0.45	5.938 ± 0.030	6789.81 ± 0.50	67.5 ± 1.1	g.s.
				4665.90 ± 0.40	28.5 ± 1.1	2.12
				1771.31 ± 0.30	4.0 ± 0.3	5.02
7285.51 ± 0.43	$\frac{5}{2}^+$	< 0.03	> 8.04	7282.92	87.0 ± 2.0	g.s.
7977.84 ± 0.42 [g]	$\frac{3}{2}^+$	4.00 ± 0.30	5.576 ± 0.033	7974.73	46.2 ± 1.1	g.s.
				5851.47 ± 0.42	53.2 ± 1.2	2.12
				692.31 ± 0.10	0.85 ± 0.04	7.29
9.876	$\frac{3}{2}^+$	3.1 ± 0.4 [h]	4.04 ± 0.08			

[a] See also Tables 11.15 in (1980AJ01) and 11.13 in (1985AJ01).

[b] From Table 11.3.

[c] Adopted by (1982MI08); based on their work and on the earlier work.

[d] From the relative intensities of the γ-rays and $I_{2.13}/I_{\text{total } \beta} = 0.355 \pm 0.018$.

[e] Log $f_1 t$.

[f] Transition to ^{11}B*(4.44) is < 0.04%.

[g] Transitions to ^{11}B*(4.44, 5.02, 6.79) are < 0.06, < 0.09 and < 0.10%.

[h] From the relative intensities of the γ-rays and $I_{\alpha}/I_{2.12}$ of (1981AL03).

30. (a) ^{11}B(e, e)^{11}B

(b) ^{11}B(e, ep)^{10}Be $\qquad Q_m = -11.2279$

Table 11.13: Gamma widths from ^{11}B(γ, γ)^{11}B and ^{11}B(e, e)^{11}B [a]

E_x (MeV)	J^π	Γ_{γ_0} (eV)	Reaction
2.12	$\frac{1}{2}^-$	0.120 ± 0.009 [b]	(γ, γ)
4.44	$\frac{5}{2}^-$	0.58 ± 0.04	(γ, γ)
		0.55 ± 0.02	(γ, γ)
		0.60 ± 0.09 (M1)	(e, e)
		$\underline{\pm 0.016 \pm 0.002}$ (E2)	
		0.56 ± 0.02 [b]	
5.02	$\frac{3}{2}^-$	1.80 ± 0.13	(γ, γ)
		1.64 ± 0.07	(γ, γ)
		1.73 ± 0.14 (M1)	(e, e)
		$\underline{< 0.0034}$ (E2)	
		1.68 ± 0.06 [b]	
6.74	$\frac{7}{2}^-$	0.021 ± 0.005	(γ, γ)
6.79	$\frac{1}{2}^+$	0.26 ± 0.03	(γ, γ)
7.29	$\frac{5}{2}^+$	1.00 ± 0.07 [b]	(γ, γ)
7.98	$\frac{3}{2}^+$	0.53 ± 0.07	(γ, γ)
8.56	($\frac{3}{2}^-$)	0.53 ± 0.05	(γ, γ)
8.92	$\frac{5}{2}^-$	4.15 ± 0.20 [b]	(γ, γ); (e, e)

[a] See also Table 11.4 here, and Table 11.16 in (1980AJ01). For references see Table 11.14 in (1985AJ01).

[b] Mean of values shown in Table 11.14 (1985AJ01).

$$\langle r^2\rangle^{1/2} = 2.43 \pm 0.11 \text{ fm} \ \ \text{(1986DO1E; prelim.)}.$$

[See also unpublished result in (1980AJ01).]

Magnetic elastic scattering at $\theta = 180°$ shows strong M3 effects: the derived ratio of static M3/M1, $2.9{\pm}0.2$ fm^2, suggests a j-j coupling scheme for ^{11}B(g.s.). The quadrupole contribution to the elastic form factor is best accounted for by the undeformed shell model, $Q = 3.72(\pm 20\%)$ fm^2, $\langle r^2\rangle^{1/2} = 2.42$ fm. See (1980AJ01) for references. A recent study of the elastic scattering for

$q = 2.0$ to 3.9 fm^{-1} is reported by (1988HI02): the M3 component is dominant in the elastic form factor for $q > 1.5$ fm^{-1}.

The excitation of ^{11}B*(2.1, 4.4, 5.0, 8.6, 8.9) has been studied. 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. At $E_e = 121$, 186 and 250 MeV form factors (and $B(E\lambda)\uparrow$) are obtained for ^{11}B*(4.4, 6.7, 8.5, 8.9, 13.00 ± 0.15) and the excitation of ^{11}B*(14.50 ± 0.15, 16.7 ± 0.2) is also reported: see (1985AJ01). See also (1984DO20, 1987DE43).

For Γ_{γ_0} see Table 11.13. For reaction (b) see (1975AJ02). See also (1985KE1E, 1986HA1M, 1986KE1F, 1987AL1M, 1987DO12; theor.).

31. ^{11}B(π^+, π^+)^{11}B

The proton matter distribution in ^{11}B$_{\text{g.s.}}$ has a radius of 2.368 ± 0.021 fm, assuming that for ^{12}C to be 2.44 fm. The result is not sensitive to the details of the optical-model calculations (1980BA45; $E_{\pi^+} = 38.6$ and 47.7 MeV). See also the "General" section.

32. ^{11}B(n, n)^{11}B

Angular distributions have been reported for $E_n = 75$ keV to 14.1 MeV [see (1980AJ01, 1985AJ01)] and at $E_n = 8.0$ to 13.9 MeV (1982GL02; $n_0 \rightarrow n_3$). Recent work (prelim.) is reported to 17 MeV (1986MU08; n_0). See also ^{12}B, (1985WA1P) and (1988HAZT; theor.).

33. (a) ^{11}B(p, p)^{11}B

(b) ^{11}B(p, 2p)^{10}Be	$Q_m = -11.2279$
(c) ^{11}B(p, pn)^{10}B	$Q_m = -11.4542$

Observed proton groups are displayed in Table 11.14. Angular distributions have been measured for $E_p = 6$ to 185 MeV [see (1980AJ01)] and at 1 GeV (1985AL16). For reactions (b) and (c) at 1 GeV see (1985BE30, 1985DO16). For pion production see (1988AB05). See also ^{12}C, (1988BE2B), (1985MUZZ) and (1985AJ01).

34. ^{11}B(d, d)^{11}B

Elastic scattering has been studied at $E_d = 5.5$ and 11.8 MeV: see (1980AJ01).

35. ^{11}B(t, t)^{11}B

The elastic scattering has been studied at $E_{\rm t} = 1.8$ and 2.1 MeV: see (1980AJ01).

36. ^{11}B(^{3}He, ^{3}He)^{11}B

The elastic scattering has been studied at $E(^{3}\text{He}) = 8$ to 74 MeV: see (1975AJ02, 1980AJ01). At $E(^{3}\text{He}) = 17.5$ and 40 MeV angular distributions have also been studied for the ^{3}He ions to ^{11}B*(2.12, 4.44, 5.02, 6.74). $T = \frac{3}{2}$ states observed in this reaction are displayed in Table 11.15. See also (1985AJ01). There is a weak indication of a state at $E_{\rm x} = 14.51$ MeV: see (1975AJ02). See also (1986JA14) and (1987TR01; theor.).

37. ^{11}B(α, α)^{11}B

Angular distributions have been reported at $E_{\alpha} = 24$ to 31.2 MeV: [see (1975AJ02, 1980AJ01, 1985AJ01)] and at 48.7 and 54.1 MeV (1987AB03; α_0). See also (1983SA07) and (1985SH1D; theor.).

38. (a) ^{11}B(^{6}Li, ^{6}Li)^{11}B
(b) ^{11}B(^{7}Li, ^{7}Li)^{11}B

The elastic scattering has been studied at $E(^{6}\text{Li}) = 28$ MeV: see (1975AJ02). At $E(^{7}\text{Li})=$ 34 MeV angular distributions have been reported to ^{11}B*(0, 2.12, 4.44, 5.02, 6.74, 7.29, 8.92) (1987CO02, 1987CO16). See also (1988HN01; theor.).

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

For reaction (a) see (1984DA17, 1986CU02). For fusion cross sections (reactions (b) and (c)) see (1989SZ01). See also (1975AJ02, 1980AJ01), (1985BE1A, 1985CU1A) and (1984HA43, 1986RO12; theor.).

40. (a) ^{11}B(^{12}C, ^{12}C)^{11}B
(b) ^{11}B(^{13}C, ^{13}C)^{11}B

Table 11.14: States of ^{11}B from ^{11}B(p, p′)^{11}B*, ^{13}C(d, α)^{11}B and ^{14}C(p, α)^{11}B [a]

E_x (keV) [b]	E_x (keV) [c]	E_x (keV) [d]	$\Gamma_{c.m.}$ (keV) [d]
0	0	0	
2124.7 ± 0.5	2125.4 ± 1.4	2120 ± 10	
4445.2 ± 0.5	4444.5 ± 1.6	4450 ± 10	
5021.1 ± 0.6	5020.2 ± 1.9	5025 ± 8	
6743.0 ± 0.7 [e]	6745.8 ± 3.4	6746 ± 5 [f]	
6792.6 ± 1.6	6795 ± 3.0		
7285.6 ± 1.5			
7978.0 ± 1.7			
8559.4 ± 1.9	8520 ± 70	8560 ± 10 [g]	
8920.2 ± 2.0	8910 ± 60	8920 ± 10 [h]	
9185.0 ± 2.0			
9274.4 ± 2.0			
10450 ± 150		10300 ± 60 [i]	133 ± 10
11650 ± 150		11620 ± 30	186 ± 25
12850 ± 100		12920 ± 20	238 ± 15
		14560 ± 15	42 ± 27
15200 ± 150		15290 ± 25	282 ± 15
16400 ± 150		16500 ± 50	201 ± 10
		19070 ± 50	294 ± 10

[a] For references see Table 11.17 in (1980AJ01).

[b] ^{11}B(p, p′)^{11}B.

[c] ^{13}C(d, α)^{11}B.

[d] ^{14}C(p, α)^{11}B (1985AR03) at $E_p = 41.9$ MeV.

[e] Values below are normalized to $E_x = 4445.3$, 5020.0 and 6743.4 keV.

[f] Very strongly excited.

[g] Very weakly excited.

[h] On the basis of the similarity with the angular distribution to ^{11}B*(4.44), $J^\pi = \frac{5}{2}^-$ is assigned.

[i] This state and the ones below may be unresolved.

The elastic scattering has been studied at $E(^{11}\text{B}) = 18.8$ to 50 MeV and at $E(^{12}\text{C}) = 15$ to 24 MeV and 87 MeV [see (1980AJ01, 1985AJ01)] as well as at $E(^{11}\text{B}) = 10.4$, 12.4 and 14.6 MeV (1985JA01), at $E_{\text{c.m.}} = 25$ MeV (1986MA13), at $E(^{11}\text{B}) = 42.5$ to 100 MeV (1985MA10) and at $E(^{12}\text{C}) = 65$ MeV (1985GO1H; prelim.; involving various states of ^{12}C) [see ^{12}C]. The population of ^{11}B*(2.12, 4.44, 6.79) is also reported. For yields, fusion and breakup studies see (1985AJ01) and (1985MA10, 1986MA13). For reaction (b) see (1984DEZX, 1984HAZK; prelim.). See also (1987PO15), (1984FR1A, 1984HA53, 1985BE1A, 1985CU1A, 1988MA07), (1982BA1D, 1985BA1T; astrophys.) and (1984HA43, 1984IN03, 1985KO1J, 1986BA69, 1986HA13; theor.).

41. $^{11}\text{B}(^{14}\text{N}, ^{14}\text{N})^{11}\text{B}$

The elastic scattering has been investigated at $E(^{14}\text{N}) = 41$, 77 and 133 MeV: see (1975AJ02, 1985AJ01). See also (1985BE1A, 1985CU1A) and (1984HA43; theor.).

42. (a) $^{11}\text{B}(^{16}\text{O}, ^{16}\text{O})^{11}\text{B}$
(b) $^{11}\text{B}(^{18}\text{O}, ^{18}\text{O})^{11}\text{B}$

The elastic scattering in reaction (a) has been studied at $E(^{16}\text{O}) = 14.5$ to 60 MeV and at $E(^{11}\text{B}) = 41.6$, 49.5 and 115 MeV. The elastic scattering in reaction (b) is reported at $E(^{11}\text{B}) = 115$ MeV. For references see (1975AJ02, 1980AJ01, 1985AJ01).

43. $^{11}\text{B}(^{20}\text{Ne}, ^{20}\text{Ne})^{11}\text{B}$

The elastic angular distribution has been studied at $E(^{11}\text{B}) = 115$ MeV: see (1985AJ01).

44. (a) $^{11}\text{B}(^{24}\text{Mg}, ^{24}\text{Mg})^{11}\text{B}$
(b) $^{11}\text{B}(^{25}\text{Mg}, ^{25}\text{Mg})^{11}\text{B}$
(c) $^{11}\text{B}(^{26}\text{Mg}, ^{26}\text{Mg})^{11}\text{B}$
(d) $^{11}\text{B}(^{27}\text{Al}, ^{27}\text{Al})^{11}\text{B}$
(e) $^{11}\text{B}(^{28}\text{Si}, ^{28}\text{Si})^{11}\text{B}$

The elastic angular distributions for reactions (a) to (d) have been studied at $E(^{11}\text{B}) = 79.6$ MeV: see (1985AJ01). See also (1987PO15). For reaction (e) see (1984TE1A).

45. (a) ^{11}B(^{40}Ar, ^{40}Ar)^{11}B
(b) ^{11}B(^{40}Ca, ^{40}Ca)^{11}B

For reaction (a) see (1985MO1K; prelim.). Angular distributions have been reported in reaction (b) at E(^{11}B) $= 51.5$ MeV to ^{11}B*(0, 2.12): see (1985AJ01).

46. ^{11}C(β^+)^{11}B $Q_{\rm m} = 1.982$

See ^{11}C.

47. (a) ^{12}C(γ, p)^{11}B $Q_{\rm m} = -15.9572$
(b) ^{12}C(e, p)^{11}B $Q_{\rm m} = -15.9572$

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 $E_{\rm b.s.} = 21.7$ to 42 MeV: the ground state is predominantly populated: see (1980AJ01). The predominant population of ^{11}B$_{\rm g.s.}$ has also recently been observed at $E_\gamma = 28$ MeV (1989FE01). Analog states are populated similarly in the (γ, n) and (γ, p) reactions. Angular distributions for the protons to several states of ^{11}B have been measured at $E_\gamma = 21.7 \rightarrow 31$ MeV and at 60, 80 and 100 MeV [see (1980AJ01, 1985AJ01)] as well as in the giant resonance region [see ^{12}C] (1986KE06; p$_0$) and at 60 MeV (1988SH08; p to ^{11}B*(0, 2.12, 5.0, 6.8 (unres.)). The relative population of ^{11}B*(6.8) is much greater than that reported in (e, ep) (1988SH08). Spectra have also been studied by (1986AN25, 1986MC15). For reaction (b) see (1985AJ01). See also ^{12}C, (1987VO08) and (1984BO18, 1987GO37, 1988OR02, 1989PIZZ; theor.).

48. ^{12}C(e, ep)^{11}B $Q_{\rm m} = -15.9572$

(1988VA09) have studied the $l = 1$ knockout to ^{11}B*(0, 2.12, 5.02) at $E_{\rm e} = 284.5$ to 481.1 MeV. One-third to one-half of the sum-rule strength predicted by the independent-particle shell model is observed. See (1988VA09) also for a review of spectroscopic factors. ^{11}B*(4.44) is not observed: the two-step processes which are necessary to excite it in this reaction appear to be weak (1985VA16, 1988VA21). Weak transitions have been studied to states at $E_{\rm x} = 6.751$ (unresolved), 7.278, 7.954, 8.61, 9.820 (± 25 keV, except ± 50 keV for 8.61) and to a broad structure at 11.5 MeV. $l = 0$ and 1 are suggested for the structures at 9.8 and 11.5 MeV (1988VA21; also S_α). See also the earlier work in (1985VA05). The effects of the nuclear medium have been studied by (1986VA17, 1987UL03, 1988VA09): see ^{12}C. See ^{12}C and (1984CA34, 1987CAZY) for the decay of ^{12}C states to ^{11}B*(0, 2.12). See also (1985DE56, 1986DE1U, 1986LA1T, 1988HA12, 1989BOZZ) and

(1984LA16, 1985CA32, 1985LA1F, 1986DE05, 1987BL10, 1987GOZO, 1987VA15, 1988HO10, 1988SU02, 1989RY03; theor.).

49. ^{12}C(π^+, π^+p)^{11}B $Q_{\rm m} = -15.9572$

At $E_{\pi^+} = 100$ to 200 MeV the reaction proceeds primarily to ^{11}B$_{\rm g.s.}$. At $E_\pi = 200$ MeV the ratios for σ_n/σ_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^+. At $E_{\pi^+} = 60$ to 300 MeV ^{11}B*(4.44) [$J^\pi = \frac{5}{2}^-$] is strongly populated as is the analog state in the mirror reaction: see (1980AJ01, 1985AJ01) for references. At $E_{\pi^\pm} = 220$ MeV the quasi-elastic nature of the scattering has been studied by (1984FA11). See also the studies by (1984ZI1B, 1987HU02), ^{12}C, (1984GO1F), (1986CH1J) and (1985CO03; theor.).

50. ^{12}C(n, d)^{11}B $Q_{\rm m} = -13.7326$

See (1985FR07, 1987FR16, 1989ROZW) and in ^{13}C in (1986AJ01, 1991AJ01). See also (1986DO12, 1988YOZX).

51. ^{12}C(p, 2p)^{11}B $Q_{\rm m} = -15.9572$

At $E_{\rm p} = 98.7$ MeV groups are observed to ^{11}B*(0, 2.12, 4.44, 5.02, 6.79). DWIA lead to relative spectroscopic factors of 2.0, 0.37, 0.15, 1.08, 0.25 for these states. No evidence is seen for multistep reaction processes which would be necessary to populate ^{11}B*(4.44, 6.74): see (1985AJ01). At $E_{\rm p} = 1$ GeV the separation energy between 6 and 14 MeV broad $1{\rm p}_{3/2}$ and $1{\rm s}_{1/2}$ groups is 18 MeV (1985BE30, 1985DO16). See also (1984VD01, 1986VDZY; $E_{\rm p} = 50$ MeV), (1989TEZZ) and (1985DE56, 1987VD1A).

52. ^{12}C(d, ^{3}He)^{11}B $Q_{\rm m} = -10.4637$

Angular distributions of ^{3}He ions have been measured for $E_{\rm d} = 20$ to 80 MeV and spectroscopic factors have been derived for ^{11}B*(0, 2.12, 5.02): see (1975AJ02, 1980AJ01, 1985AJ01).

53. ^{12}C (t, α)^{11}B $Q_{\rm m} = 3.8568$

Angular distributions have been measured at $E_t = 33$ and 38 MeV to ^{11}B*(0, 2.12, 4.44, 5.02, 6.74, 7.29, 7.98, 8.56). As expected, the $\frac{5}{2}^-$ and $\frac{7}{2}^-$ states ^{11}B*(4.44, 6.74) are populated by two-step processes. The best J^π value for ^{11}B*(8.56) is $\frac{3}{2}^-$ but this assumes some direct population which may not be the case (1987FO21, 1988SI08) [see for spectroscopic factors]. For the earlier work see (1975AJ02).

54. ^{12}C(α,^{5}Li)^{11}B $\qquad Q_m = -17.92$

See (1987GA20) and (1985AJ01).

55. ^{12}C(^{6}Li, ^{7}Be)^{11}B $\qquad Q_m = -10.351$

At $E(^6\text{Li}) = 93$ MeV, ^{11}B*(0, 2.12, 5.0, 6.8, 8.9) are populated (1988BUZI; prelim.). See also (1986GL1E; prelim.).

56. ^{12}C(^{12}C, ^{13}N)^{11}B $\qquad Q_m = -14.0134$

Angular distributions involving ^{11}Bg.s. have been measured at $E(^{12}\text{C}) = 93.8$ and 114 MeV: see (1985AJ01). See also (1987WIZW).

57. ^{12}C(^{13}C, ^{14}N)^{11}B $\qquad Q_m = -8.4066$

See (1987AD07, 1988VO08) and ^{14}N in (1991AJ01). See also (1989VO1D).

58. ^{12}C(^{19}F, ^{20}Ne)^{11}B $\qquad Q_m = -3.108$

At $E(^{19}\text{F}) = 40$, 60 and 68.8 MeV angular distributions involving ^{11}B*(0, 2.12) and ^{20}Ne*(0, 1.63) have been measured: see (1980AJ01). See also (1986HE1A, 1988DI08; theor.).

59. ^{13}C(p,^{3}He)^{11}B $\qquad Q_m = -13.1855$

At $E_\mathrm{p} = 50.5$ MeV, in addition to ^{11}B*(0, 2.12, 4.44, 5.02, 6.74, 8.92), a state is observed at $E_\mathrm{x} = 12.94 \pm 0.05$ MeV, $\Gamma = 350 \pm 50$ keV. Comparison of the angular distributions of the ^{3}He and of the tritons [to the analog state] at $E_\mathrm{p} = 43.7$ and 50.5 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: see Table 11.15. Angular distributions have been measured at $E_\mathrm{p} = 26.9$ to 49.6 MeV involving the above states except for ^{11}B*(8.92) and at $E_{\vec{\mathrm{p}}} = 65$ MeV (to ^{11}B*(0, 2.12)): see (1975AJ02, 1980AJ01, 1985AJ01). See also ^{14}N in (1986AJ01) and (1985HA1J).

60. ^{13}C(d, α)^{11}B $\qquad Q_\mathrm{m} = 5.1677$

Observed proton groups are displayed in Table 11.14. Angular distributions are reported at $E_\mathrm{d} = 0.41$ to 14.1 MeV: see (1975AJ02). See also (1985HA1J).

61. ^{14}C(p, α)^{11}B $\qquad Q_\mathrm{m} = -0.7842$

Observed states are displayed in Table 11.14 (1985AR03). It is suggested ^{11}B*(12.92, 15.29, 16.50, 19.07) are $T = \frac{3}{2}$, negative-parity states. Spectroscopic factors have also been derived (1985AR03).

62. (a) ^{14}N(n, α)^{11}B $\qquad Q_\mathrm{m} = -0.1583$
(b) ^{14}N(n, 2α)^{7}Li $\qquad Q_\mathrm{m} = -8.8220$

Angular distributions have been measured for $E_\mathrm{n} = 4.9$ to 18.8 MeV [see (1975AJ02, 1980AJ01, 1985AJ01)] and at 12.2, 14.1 and 18.0 MeV (1986RU1B; α_0, α_1). At $E_\mathrm{n} = 14.1$ and 15.7 MeV various states of ^{11}B with $8.9 < E_\mathrm{x} < 14.5$ MeV appear to be involved in the sequential decay to ^{7}Li. Angular correlation results are consistent with $J = \frac{7}{2}$ and $\frac{5}{2}$ for ^{11}B*(9.19, 9.27) respectively: see (1975AJ02). See also (1985HA1J).

63. ^{14}N(p, p^{3}He)^{11}B $\qquad Q_\mathrm{m} = -20.7361$

See (1986VDZY; prelim.; 50 MeV).

64. ^{16}O(d, ^{7}Be)^{11}B $\qquad Q_\mathrm{m} = -16.038$

At $E_\mathrm{d} = 80$ MeV angular distributions have been measured to ^{11}B* (0, 2.12, $4.44 + 5.02$, $6.74 + 6.79 + 7.29$): see (1980AJ01).

Table 11.15: $T = \frac{3}{2}$ states in ^{11}B [a]

Reaction	E_x (MeV ± keV)	$\Gamma_{c.m.}$ (keV)
^{9}Be(^{3}He, p)^{11}B	12.563 ± 20	202 ± 25
^{10}Be(p, γ)^{11}B	12.56 ± 30	230 ± 65
^{11}B(^{3}He, ^{3}He)^{11}B*	12.51 ± 50	260 ± 50
	12.557 ± 16 [b]	215 ± 21 [b]
^{9}Be(^{3}He, p)^{11}B	12.920 ± 20	155 ± 25
^{10}Be(p, γ)^{11}B	12.91 ± 20	235 ± 27
^{13}C(p, ^{3}He)^{11}B	12.94 ± 50	350 ± 50
^{13}C(p, ^{3}He)^{11}B	12.91 ± 30	260 ± 50
^{14}C(p, α)^{11}B	12.92 ± 20 [e]	238 ± 15
	12.916 ± 12 [c]	155 ± 25 [d]
^{9}Be(^{3}He, p)^{11}B	14.40 [d]	261 ± 25
^{10}Be(p, γ)^{11}B	14.33 ± 20	255 ± 30
^{11}B(^{3}He, ^{3}He)^{11}B*	14.40 ± 50	220 ± 50
	14.34 ± 20 [b]	254 ± 18 [b]
^{10}Be(p, γ)^{11}B	15.32 ± 100 [c]	635 ± 180
^{14}C(p, α)^{11}B	15.29 ± 25 [c]	282 ± 15
^{9}Be(^{3}He, p)^{11}B	16.437 ± 20 [f]	≤ 30
^{9}Be(^{3}He, p)^{11}B	17.69	91 ± 25
^{9}Be(^{3}He, p)^{11}B	18.0 ± 100	870 ± 100
^{9}Be(^{3}He, p)^{11}B	19.146 ± 30 [f]	115 ± 25
^{9}Be(^{3}He, p)^{11}B	21.27 ± 50	300 ± 30

[a] See also Table 11.18 in (1980AJ01). See Table 11.16 in (1985AJ01) for references.

[b] Mean value.

[c] "Best" value.

[d] May have mixed isospin ($T = \frac{1}{2} + T = \frac{3}{2}$).

[e] See Table 11.3.

[f] See also reaction 61 (1985AR03).

^{11}C

(Figs. 3 and 4)

GENERAL: (See also (1985AJ01).)

Model calculations: (1988WO04)

Special states: (1985SH24, 1986AN07, 1988KW02)

Astrophysical Questions: (1987RA1D)

Complex reactions involving ^{11}C: (1981AS04, 1985AR09, 1985HI1C, 1985MO08, 1986AV1B, 1986AV07, 1986BA3G, 1986HA1B, 1986HI1D, 1986UT01, 1987AR19, 1987BA38, 1987DE37, 1987NA01, 1987RI03, 1987SN01, 1987ST01, 1987YA16, 1988CA06, 1988KI05, 1988KI06, 1988SA19, 1988SM07, 1988VUZZ, 1989AR1G, 1989HA43, 1989SA10, 1989SE03, 1989YO02)

Applications: (1985TA1D, 1986WE1E, 1987BO16, 1987HI1B, 1988FA1C, 1988HI1F, 1988VO1D, 1989TR1B, 1989WO1B)

Pion and kaon capture and reactions (see also reactions 19, 20 and 27): (1984OH04, 1988AB05, 1988GIZU)

Hypernuclei: (1984AS1D, 1984ZH1B, 1985GA1E, 1986DA1H, 1986DA1G)

Other topics: (1985AN28, 1985SH24, 1985TA26, 1986HE01, 1988KW02)

Ground-state properties of ^{11}C: (1984ZI04, 1985AN28, 1985HA18, 1985FA01, 1985ZI05, 1986GL1A, 1987FU06, 1987SA15, 1988VA03, 1988WA08, 1988WO04, 1989SA10)

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

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

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

The half life of ^{11}C is 1223.1 ± 1.2 s. Log $ft = 3.599 \pm 0.002$. The ratio of K-capture to positron emission is $(0.230^{+0.014}_{-0.011})\%$. See (1980AJ01) for references. See also (1985AJ01) and (1987BO1Y).

2. ^{6}Li(^{6}Li, n)^{11}C $\qquad Q_{\rm m} = 9.450$

At E(^{6}Li) $= 4.1$ MeV 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, nγ- coincidences via ^{11}C*(8.42) [and an 8.42 MeV γ-ray] are reported. ^{11}C*(8.10) was not observed. The lifetimes, $\tau_{\rm m}$, for ^{11}C*(4.32, 6.90, 7.50) are $< 140, < 69$ and < 91 fs, respectively. See (1980AJ01) for references. For yields see ^{12}C and (1987DO05).

Table 11.16: Energy levels of ^{11}C [a]

E_x in ^{11}C (MeV $\pm$ keV)	$J^\pi;T$	τ or $\Gamma_{c.m.}$	Decay	Reactions
0	$\frac{3}{2}^-;\frac{1}{2}$	$\tau_{1/2} = 20.39 \pm 0.02$ min	β^+	1, 2, 4, 6, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 31
2.0000 ± 0.5	$\frac{1}{2}^-$	$\tau_m = 10.3 \pm 0.7$ fs	γ	2, 5, 6, 12, 13, 14, 15, 16, 20, 21, 22, 23, 24, 25, 28, 29
4.3188 ± 1.2	$\frac{5}{2}^-$	< 12 fs	γ	2, 5, 6, 12, 13, 15, 16, 17, 19, 20, 21, 22, 23, 28
4.8042 ± 1.2	$\frac{3}{2}^-$	< 11 fs	γ	2, 5, 12, 15, 16, 17, 20, 21, 23, 28
6.3392 ± 1.4	$\frac{1}{2}^+$	< 110 fs	γ	2, 5, 13, 23
6.4782 ± 1.3	$\frac{7}{2}^-$	< 8 fs	γ	2, 5, 6, 12, 13, 15, 16, 20, 21, 23, 27, 28
6.9048 ± 1.4	$\frac{5}{2}^+$	< 69 fs	γ	2, 5, 12, 13, 16, 21, 23
7.4997 ± 1.5	$\frac{3}{2}^+$	< 91 fs	γ	2, 5, 13, 16, 21, 23, 28
8.1045 ± 1.7	$\frac{3}{2}^-$	0.06 ± 0.04 fs [b]	γ, α	4, 13, 17, 21, 23
8.420 ± 2	$\frac{5}{2}^-$	0.043 ± 0.011 fs [b]	γ, α	2, 4, 5, 12, 13, 15, 21, 23
8.655 ± 8	$\frac{7}{2}^+$	$\Gamma \leq 5$ keV	(γ)	12, 13, 15, 21
8.699 ± 10	$\frac{5}{2}^+$	15 ± 1	γ, p	6, 12, 13, 15
9.20 ± 50	$\frac{5}{2}^+$	500 ± 100	γ, p	6
9.65 ± 50	$(\frac{3}{2}^-)$	210 ± 50	γ, p, α	6, 8, 11, 21
9.78 ± 50	$(\frac{5}{2}^-)$	240 ± 60	γ, p	6, 8, 11, 21
9.97 ± 50	$(\frac{7}{2}^-)$	120 ± 20	γ, p	6, 21
10.083 ± 5	$\frac{7}{2}^+$	≈ 230	γ, p, α	6, 8, 11, 13, 21
10.679 ± 5	$\frac{9}{2}^+$	200 ± 30	γ, p, α	6, 8, 11, 12, 21
11.03 ± 30	$T = \frac{1}{2}$	300 ± 60		21, 23, 28

Table 11.16: Energy levels of ^{11}C [a] (continued)

E_x in ^{11}C (MeV $\pm$ keV)	$J^\pi; T$	τ or $\Gamma_{c.m.}$	Decay	Reactions
11.44 ± 10		360	p, α	11, 21
12.16 ± 40	$T = \frac{3}{2}$[c]	270 ± 50	p	5, 9, 17
12.4	$\pi = -$	$1 - 2$ MeV	γ, p	6, 23
12.51 ± 30	$\frac{1}{2}^-; \frac{3}{2}$	490 ± 40 keV	p	5, 9, 17, 20, 28
12.65 ± 20	$(\frac{7}{2}^+)$	360	p, ^{3}He, α	6, 10, 11
(13.01)			γ, p	6
13.33 ± 60		270 ± 80		20, 28
13.4		1100 ± 100	p, α	11, 21
13.90 ± 20	$(T = \frac{3}{2})$	200 ± 100	p	6, 9, 17, 28
14.07 ± 20		135 ± 50	n, p	7, 28
14.76 ± 20		≈ 450	n, p, ^{3}He	5, 7, 9, 10
15.35 ± 50	$\pi = -$	broad	γ, n, p	6, 7, 9, 23
15.59 ± 50		≈ 450	n, p	7, 9
16.7	$\pi = -$	800 ± 100	γ, p	6
(18.2)			γ, p	6
(23.0)				23
(28.0)				23

[a] See also Table 11.17.

[b] $\Gamma_{c.m.} = \Gamma_\alpha + \Gamma_\gamma = 11 \pm 7$ eV and 15.2 ± 3.8 eV for ^{11}C*(8.10, 8.42): see reaction 4.

[c] I am grateful to Professor F.C. Barker for his comments.

3. ^{7}Li(^{7}Li, 3n)^{11}C $\qquad Q_m = -5.050$

At $E(^7$Li$) = 82$ MeV no states of ^{11}C are populated (1987AL10).

4. ^{7}Be$(\alpha, \gamma)^{11}$C $\qquad Q_m = 7.543$

At the resonances at $E_\alpha = 0.884 \pm 0.008$ and 1.376 ± 0.003 MeV [^{11}C*(8.106, 8.419)], $\omega\gamma = 0.331 \pm 0.041$ and 3.80 ± 0.57 eV, $\Gamma_\gamma = 0.350 \pm 0.056$ and 3.1 ± 1.3 eV for these two states and $\Gamma_\alpha = 6^{+12}_{-2}$ and 12.6 ± 3.8 eV, respectively (1984HA13). See also (1983HA1B, 1984YA1A, 1985CA41, 1988BU01, 1988CA26; astrophysics).

5. ^{9}Be(^{3}He, n)^{11}C $\qquad Q_m = 7.5572$

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 (1980AJ01). The dominant L-values 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 $T = \frac{3}{2}$ states have been reported at $E_x = 12.17 \pm 0.05$ [see, however, reaction 28], 12.55 ± 0.05 MeV and 14.7 ± 0.1 MeV: see Table 11.18.

Gamma branching ratios and multipolarities for ^{11}C levels up to $E_x = 7.5$ MeV have been studied by (1965OL03): see Table 11.17. Together with evidence from reactions 12 and 21 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) and reaction 3 in (1968AJ02) for a summary of the evidence concerning these assignments. See (1980AJ01) for references. See also ^{12}C and (1984SUZZ).

6. ^{10}B(p, γ)^{11}C $\qquad Q_m = 8.6896$

This reaction has been investigated for $E_p = 0.07$ to 17.0 MeV. Reported resonances are displayed in Table 11.19. Observed capture γ-rays are displayed in Table 11.17 [see also for τ_m measurements]. Capture measurements for $E_p = 0.07$ to 2.20 MeV are consistent with five new resonances (see Tables 11.19 and 11.17), the lowest two (at $E_p = 10$ and 560 keV) of which are s-wave resonances. Thermonuclear reaction rates for $T = (0.01 \rightarrow 5) \times 10^9$ K are deduced from the results (1983WI09; see also for spectroscopic factors).

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: see (1980AJ01). See also (1984YA1A, 1985CA41, 1988CA26; astrophysics).

7. ^{10}B(p, n)^{10}C $\qquad Q_m = -4.4305 \qquad E_b = 8.6896$

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 11.19). The cross

Table 11.17: Gamma decay of ^{11}C levels [a]

$E_{\rm i}$ (MeV)	J^π	$\tau_{\rm m}$ (fs)	$E_{\rm f}$ (MeV)	Branch
2.00	$\frac{1}{2}^-$	10.3 ± 0.7 fs	0	100
4.32 [b]	$\frac{5}{2}^-$	< 12 [h]	0	100
4.80	$\frac{3}{2}^-$	< 11 [h]	0	85.2 ± 1.4
			2.00	14.8 ± 1.4
6.34 [c]	$\frac{1}{2}^+$	< 110	0	66.5 ± 2.1
			2.00	33.5 ± 2.1
6.48 [d]	$\frac{7}{2}^-$	< 8 [h]	0	88.5 ± 1.4
			4.32	11.5 ± 1.4
6.90 [e]	$\frac{5}{2}^+$	< 69	0	91 ± 2
			4.32	4.5 ± 1
			4.80	4.5 ± 1
7.50 [f]	$\frac{3}{2}^+$	< 91	0	36 ± 2
			2.00	64 ± 2
8.10 [i]	$\frac{3}{2}^-$	0.06 ± 0.04	0	74 ± 12
			2.00	26 ± 5
8.42 [i, l]	$\frac{5}{2}^-$	0.043 ± 0.011	0	100 [j]
8.70 [k, l]	$\frac{5}{2}^+$		0	42 ± 10
			4.32	42 ± 10
			4.80	2.4 ± 1.5
			6.48	13.6 ± 4.6
9.20 [k]	$\frac{5}{2}^+$		0	74 ± 18
			4.32	6 ± 5
			6.48	20 ± 10
9.65 [g, k]	$(\frac{3}{2}^-)$		0	60 ± 5
			4.32	32 ± 10
			4.80	8 ± 4
9.78 [g, k]	$(\frac{5}{2}^-)$		0	76 ± 16
			4.32	8 ± 2
			4.80	4 ± 2
			6.48	12 ± 4
9.97 [k]	$(\frac{7}{2}^-)$		4.32	90 ± 10

Table 11.17: Gamma decay of ^{11}C levels [a] (continued)

E_i (MeV)	J^π	τ_m (fs)	E_f (MeV)	Branch
			6.48	10 ± 7
10.08 [k]	$\frac{7}{2}^+$		4.32	67 ± 8
			6.48	13 ± 6
10.68 [k]	$\frac{9}{2}^+$		6.48	100

[a] Mostly from (1965OL03) and (1968EA03): see Table 11.20 in (1980AJ01) for other references and additional information.

[b] Cascade via ^{11}C*(2.0) is $< 2\%$.

[c] Cascade via ^{11}C*(4.32) is $< 7\%$; that through ^{11}C*(4.80) is $< 3\%$.

[d] Cascades via ^{11}C*(2.00, 4.80) are $< 2\%$.

[e] Cascade via ^{11}C*(2.00, 6.34, 6.48) are < 1, < 5, $< 5\%$, respectively. The cascade via ^{11}C*(4.80) is not reported by (1965OL03) [they suggest $< 3\%$].

[f] Cascades via ^{11}C*(4.32, 4.80, 6.34, 6.48, 6.90) are < 1, < 1, < 3, < 3 and $< 4\%$.

[g] See also (1979AN16).

[h] (1979AN16). See also (1981CA06) for τ_m of ^{11}C*(4.32, 4.80, 6.48).

[i] (1984HA13).

[j] Branching ratio to ^{11}C*(4.32) is $< 7\%$ (1984HA13).

[k] (1983WI09).

[l] $\Gamma_\gamma/\Gamma = 0.20 \pm 0.05$, < 0.06 and ≤ 0.1 for ^{11}C*(8.42, 8.66, 8.70), respectively: $\Gamma_{\text{total}}(\text{c.m.}) \leq 4.5$, ≤ 4.5 and 15 ± 1 keV (1983WI09).

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. For references see (1980AJ01). For n_0 and n_1 excitiation curves from $E_p = 13.7$ to 14.7 MeV see (1985SC08). See also (1984BA1R, 1984BA1U).

8. ^{10}B(p, p)^{10}B $\qquad E_b = 8.6896$

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 11.19. At higher energies (to $E_p = 10.5$ MeV) a single broad resonance is reported at $E_p \approx 5$ MeV. Polarization measurements are reported at 30.3 MeV: optical model parameters have been derived. The depolarization parameter D has been measured for polarized protons at 26 and 50 MeV. For references see (1980AJ01, 1985AJ01). See also (1984BA1U) and (1986MU08).

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

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

[a] See also Table 11.15 for $T = \frac{3}{2}$ states in ^{11}B, and Table 11.21 in (1980AJ01). For references see Table 11.19 in (1985AJ01).
[b] Mean.

9. ^{10}B(p, p′)^{10}B $E_b = 8.6896$

The yield of 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: see Table 11.19. 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. See however (1975AJ02). 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 in the range $E_p = 4$ to 12 MeV [see (1975AJ02)].

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 $E_x = 12.16$ [see however reaction 28] and 12.50 MeV [see Table 11.18]: these do not occur in the yield of p$_1$ and p$_3$. Yield curves for inelastically scattered protons have also 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. For references see (1980AJ01, 1985AJ01).

Table 11.19: Resonances in ^{10}B + p [a]

$E_{\rm res}$ (MeV±keV)	$E_{\rm x}$ (MeV)	J^{π}	$\Gamma_{\rm lab}$ (keV)	Decay
0.010 ± 2 [b]	8.699 ± 10	$\frac{5}{2}^{+}$	16 ± 1 [e]	γ
0.56 ± 60 [b]	9.20 ± 50	$\frac{5}{2}^{+}$	550 ± 100	γ
1.05 ± 60 [b]	9.64 ± 50	$(\frac{3}{2}^{-})$	230 ± 50	γ, (p_0, α_0)
1.20 ± 50 [b]	9.78 ± 50	$(\frac{5}{2}^{-})$	260 ± 60	γ, (p_0, α_0)
1.41 ± 50 [b]	9.97 ± 50	$(\frac{7}{2}^{-})$	130 ± 20	γ
1.533 ± 5	10.083	$\frac{7}{2}^{+}$	≈ 250	p_0, α_0, α_1
2.189 ± 5	10.679	$\frac{9}{2}^{+}$	220 ± 30	p_0, α_0, α_1
3.03 ± 10	11.44		400	α_0, α_1
3.9 ± 10	12.20	$T = \frac{3}{2}$		p_2
4.1 ± 100	12.45	$T = \frac{3}{2}$	440 ± 100	p_2
4.1 [c, d]	12.4	$\pi = -$	1–2 MeV	γ_0
4.36 ± 20	12.65	$(\frac{7}{2}^{+})$	400	γ_1, α_0, α_1, ^{3}He
(4.75)	(13.01)			γ_0
5.2	13.4		1200 ± 100	α_0, α_1
5.73 ± 20	13.90		≈ 500	γ_1, p
5.92 ± 20	14.07		broad	n
6.68 ± 40	14.76		≈ 500	n, p, ^{3}He
7.33 ± 50 [d]	15.35	$\pi = -$	broad	γ_0, n, p
7.60 ± 50	15.59		≈ 500	n, p
8.8 [d]	16.7	$\pi = -$	900 ± 100	γ_0
(10.5)	(18.2)			γ_0

[a] See also Table 11.17 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). For references see Table 11.22 in (1980AJ01). For unpublished work and other references see Table 11.20 in (1985AJ01). (1988ABZW) [in (p, p′γ) and (p, $\alpha\gamma$); $E_{\rm p} = 2$ to 5 MeV prelim.] report 5 states with energies 11.84, 11.37(?), 12.63, 12.75, and 13.1 MeV.

[b] (1983WI09).

[c] $\Gamma_{\rm p}\Gamma_{\gamma}/\Gamma \approx 20$ eV.

[d] Probably part of the E1 giant resonance.

[e] $\Gamma_{\gamma}/\Gamma_{\rm tot} = (2.6 \pm 0.15) \times 10^{-4}$: see (1983WI09). $\Gamma_{\gamma}/\Gamma_{\rm tot} = 0.20 \pm 0.05$ and < 0.06, respectively for ^{11}C*(8.42, 8.66), respectively: $\Gamma_{\rm tot} \leq 5$ keV for both states (1983WI09).

10. (a) ^{10}B(p, d)^{9}B $\qquad Q_{\rm m} = -6.212 \qquad E_{\rm b} = 8.6896$

(b) ^{10}B(p, ^{3}He)^{8}Be $\qquad Q_{\rm m} = -0.5330$

Polarization measurements (reaction (a)) have been carried out at $E_{\rm p} = 49.6$ MeV for the deuterons to ^{9}B*(0, 2.36): see (1975AJ02). In reaction (b) two strong maxima are observed at $E_{\rm p} \approx 4.5$ and 6.5 MeV: see Table 11.19. See also (1975AJ02).

11. ^{10}B(p, α)^{7}Be $\qquad Q_{\rm m} = 1.1462 \qquad E_{\rm b} = 8.6896$

The total cross section for this reaction has been measured for $E_{\rm p} = 60$ to 180 keV: the extrapolated cross section at the Gamow energy, taken to be 19.1 keV, is $\approx 10^{-12}$ b. The thick target yield for $E_{\rm p} = 75$ keV to 3 MeV shows that 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 11.19. The ground state (α_0) α-particles exhibit broad resonances at $E_{\rm p} = 1.17$, 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 $E_{\rm p} = 4$ MeV to about 7.5 MeV. A study of the yield of 0.43 MeV γ-rays for $E_{\rm p} = 2.0$ to 4.1 MeV suggests that the 3.0 MeV resonance, which is asymmetric, is due to two broad states. A weak structure at $E_{\rm p} = 2.5$ MeV is also reported. For references see (1980AJ01, 1985AJ01). See also ^{7}Be in (1988AJ01) and (1984YA1A, 1985CA41; astrophysics).

12. ^{10}B(d, n)^{11}C $\qquad Q_{\rm m} = 6.4650$

Table 11.20 presents the results obtained in this reaction and in the (^{3}He, d) reaction. Information on $\tau_{\rm m}$ and on the γ-decay of ^{11}C states is displayed in Table 11.17: see (1968AJ02, 1975AJ02) for references. See also (1986WE1E; applied) and ^{12}C.

13. ^{10}B(^{3}He, d)^{11}C $\qquad Q_{\rm m} = 3.1961$

Table 11.20 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]: $\Gamma_{\rm c.m.}$ are $\ll 9$ keV and 15 ± 1 keV, respectively, for ^{11}C*(8.66, 8.70): see (1975AJ02) for references.

Table 11.20: Energy levels of ^{11}C from ^{10}B(d, n)^{11}C and ^{10}B (^{3}He, d)^{11}C [a]

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

[a] See Table 11.23 in (1980AJ01) for references.

[b] From (d, n) work summarized in Table 11.20 of (1968AJ02).

[c] $S_{d,\ n}$ obtained at $E_d = 5.8$ MeV, $S_{^3He,\ d}$ obtained at $E(^3He) = 11.0$ MeV [both ±30%]. When $S_{d,\ n}$ and $S_{^3He,\ d}$ differ appreciably, the more reliable value is underlined.

[d] $E(^3He) = 21$ MeV; when two values are shown for $S_{^3He,\ d}$, they are in order of descending j.

[e] $\Gamma \approx 200$ keV.

14. ^{10}B(α, t)^{11}C $\qquad Q_m = -11.1244$

Angular distributions have been measured at $E_\alpha = 25.1$ and 56 MeV [see (1980AJ01)] and at 24.8 and 30.1 MeV (1983VA28; t_0, t_1). See also (1984BE23; theor.)

15. ^{10}B(^{7}Li, ^{6}He)^{11}C $\qquad Q_m = -1.285$

Angular distributions of ^{6}He ions have been measured at $E(^7\text{Li}) = 3.0$ to 3.8 MeV and at 24 MeV [to ^{11}C*(0, 4.32, 6.48)]. ^{11}C*(2.0, 4.80, 8.42, $8.66 + 8.70$) are also populated: see (1980AJ01) for references.

16. ^{11}B(p, n)^{11}C $\qquad Q_m = -2.7646$

Angular distributions have been measured at many energies up to 49.5 MeV [see (1980AJ01, 1985AJ01)] and at $E_p = 14.0$, 14.3 and 14.6 MeV (1985SC08; n_0, n_1, n_2, n_3, (n_{4+5}), n_6, n_7), 15.8 and 18.6 MeV (1988KA30; n_0, n_1) and 16 to 26 MeV (1985GR09; n_0, n_1, n_2, n_3) [see also for a study of the GT matrix elements]. For $0°$ cross sections at $E_p = 492$ and 590 MeV see (1989RA09). See also ^{12}C, (1984BA1R, 1985GU1C), (1988CA26; astrophysics), (1984TAZS, 1986MU08, 1987RA32) and (1986HU06; theor.).

17. ^{11}B(^{3}He, t)^{11}C $\qquad Q_m = -2.0008$

Angular distributions of t_0 and t_1 have been measured at $E(^3\text{He}) = 10$, 14, and 217 MeV [the latter also for the triton groups to ^{11}C*(4.3, 4.8, 6.48, 8.10] and at $E(^3\vec{\text{He}}) = 33$ MeV. At $E(^3\text{He}) = 26$ MeV the known states of ^{11}C below $E_x = 11$ MeV are populated and triton groups are also observed to the possibly $T = \frac{3}{2}$ states displayed in Table 11.18 as well as a state at 14.15 MeV. For references see (1980AJ01, 1985AJ01).

18. (a) ^{12}C(γ, n)^{11}C $\qquad Q_m = -18.7215$

(b) ^{12}C(e, en)^{11}C $\qquad Q_m = -18.7215$

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 reactions 24 and 25 in (1980AJ01) (1985AJ01), (1988HA01) in ^{12}C and (1985CA32, 1987GOZO, 1987GO37, 1987VA15; theor.).

19. (a) ^{12}C($\pi^{\pm}$, $\pi^{\pm}$n)^{11}C $\quad Q_{\rm m} = -18.7215$

(b) ^{12}C(n, 2n)^{11}C $\quad Q_{\rm m} = -18.7215$

(c) ^{12}C(p, pn)^{11}C $\quad Q_{\rm m} = -18.7215$

^{11}C*(4.32)[$\frac{5}{2}^-$] (and the analog state in ^{11}B) is surprisingly strongly populated for $E_{\pi^+} = 60$ to 300 MeV: see (1980AJ01, 1985AJ01). For reaction (b) see ^{13}C in (1986AJ01). In reaction (c) at 1 GeV the separation energy between 6 and 13 MeV broad $1{\rm p}_{3/2}$ and $1{\rm s}_{1/2}$ groups is ≈ 17 MeV (1985BE30, 1985DO16). See also ^{12}C and (1984GO1F).

20. ^{12}C(π^+, p)^{11}C $\quad Q_{\rm m} = 121.629$

Angular distributions at $E_{\pi^+} = 49.3$, 90 and 180 MeV have been obtained to ^{11}C*(0, 2.0, $4.3{+}4.8$, 6.5, 8.5). At the same momentum transfer this reaction and the (p, d) reaction give similar intensities to the low lying states of ^{11}C. $T = \frac{3}{2}$ states have been suggested at $E_{\rm x} = 12.5 \pm 0.3$ and 13.3 MeV: see (1985AJ01). See also (1982DO01).

21. ^{12}C(p, d)^{11}C $\quad Q_{\rm m} = -16.4972$

Angular distributions have been measured for $E_{\rm p}$ =19 to 800 MeV [see (1968AJ02, 1975AJ02, 1980AJ01, 1985AJ01) for references], at $E_{\vec{\rm p}} = 497$ MeV (1984OH06; ${\rm p}_0$; also $A_{\rm y}$) and at $E_{\rm p} = 800$ MeV (1984SM04; to ^{11}C* (0, 2.0, 4.3, 4.8, 6.5, 8.1, $8.66 + 8.70$, 9.98 ± 0.2, 10.56 ± 0.2)). In the latter experiment ^{11}C*(8.4) and a state at 13.22 ± 0.25 MeV ($\Gamma \approx 2$ MeV) are also reported (1984SM04). Earlier observed states of ^{11}C are displayed in Table 11.24 of (1980AJ01). See also ^{13}N in (1991AJ01), (1987CA20) and (1984RE14).

22. ^{12}C(d, t)^{11}C $\quad Q_{\rm m} = -12.4645$

At $E_{\rm d} = 28$ MeV the ${\rm t}_0$ 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. At $E_{\rm d} = 29$ MeV the ${\rm t}_0$ angular distribution leads to spectroscopic factor $C^2S = 2.82$ or 3.97 depending on different sets of parameters for ^{11}C$_{\rm g.s.}$. ^{11}C*(2.0, 4.32) are also populated. See also ^{14}N in (1986AJ01), (1980AJ01) for references, and (1984KO1M).

Table 11.21: Levels of ^{11}C from ^{12}C(^{3}He, α)^{11}C [a]

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

[a] See Table 11.17 for γ-decay work. Higher excited states are also reported: see text. See Table 11.25 in (1980AJ01) for references and for additional information.
[b] At $E(^3$He$) = 18$ MeV.
[c] Assuming $J^\pi = \frac{3}{2}^-$.
[d] Assuming $J^\pi = \frac{5}{2}^-$.

23. (a) ^{12}C(^{3}He, α)^{11}C $\qquad Q_m = 1.8560$
(b) ^{12}C(^{3}He, tp)^{11}C $\qquad Q_m = -17.9577$

Angular distributions have been measured at many energies to $E(^3$He$)= 217$ MeV [see (1968AJ02, 1975AJ02, 1980AJ01, 1985AJ01) for references]. Observed states are displayed in Table 11.21. In addition the excitation of states at $E_x = 11.2$, 12.4, 15.3, 23, and (28) MeV has also been suggested: see (1980AJ01).

At $E(^3$He$)= 35.6$ MeV one finds 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^+]: see (1980AJ01).

Alpha-γ correlations have been studied for $E(^3$He$)= 4.7$ to 12 MeV. Their results are summarized in Table 11.17 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). $\tau_m = 10.3 \pm 0.7$ fs for ^{11}C*(2.00). See also ^{12}N, and ^{15}O in (1986AJ01).

Reaction (b) has been studied at $E(^3\text{He}) = 75$ MeV: transitions to ^{11}C*(0, 2.0, 4.3, 4.8, 6.3) are observed by looking at p, t angular correlations: see (1985AJ01). See also (1984BE1A; applied).

24. ^{12}C(^{6}Li, ^{7}Li)^{11}C $\quad Q_{\text{m}} = -11.471$

The angular distributions involving $^7\text{Li}_{\text{g.s.}}+^{11}\text{C}_{\text{g.s.}}$ and $^7\text{Li*}_{0.48}+^{11}\text{C*}_{2.00}$ have been studied at $E(^6\text{Li}) = 36$ MeV: see (1980AJ01). See also (1986GL1E).

25. ^{12}C(^{10}B, ^{11}B)^{11}C $\quad Q_{\text{m}} = -7.2673$

At $E(^{10}\text{B}) = 100$ MeV, angular distributions have been measured involving $^{11}\text{B}_{\text{g.s.}}+^{11}\text{C}_{\text{g.s.}}$, $^{11}\text{B}_{\text{g.s.}}+^{11}\text{C}_{2.00}$ and $^{11}\text{C}_{\text{g.s.}}+^{11}\text{B}_{2.12}$. Both ^{12}C(^{10}B, ^{11}B)^{11}C (with ^{11}B detected in the forward direction) and ^{12}C(^{10}B, ^{11}C)^{11}B (with ^{11}C detected in the forward direction) were measured. In each case, $^{11}\text{B}_{\text{g.s.}}+^{11}\text{C}_{2.00}$ and $^{11}\text{C}_{\text{g.s.}}+^{11}\text{B}_{2.12}$ were not resolved, but the authors argues that the (^{10}B, ^{11}B) case would have little contribution from $^{11}\text{C}_{\text{g.s.}}+^{11}\text{B}_{2.12}$ (because of the spins of ^{10}B and $^{11}\text{B}_{2.12}$), so that it essentially gives the $^{11}\text{B}_{\text{g.s.}}+ {}^{11}\text{C}_{2.00}$ angular distribution, and similarly for the other case. See (1985AJ01) and (1987OS1E; theor.)

26. ^{12}C(^{12}C, ^{13}C)^{11}C $\quad Q_{\text{m}} = -13.7751$

Angular distributions involving $^{11}\text{C}_{\text{g.s.}}$ have been studied at $E(^{12}\text{C}) = 93.8$ and 114 MeV [see (1980AJ01, 1985AJ01)], at 20 MeV/A (1985BO39) and at 25, 35, and 50 MeV/A (1988WI09, 1989WI07). The strongest peak observed is due to the unresolved $^{13}\text{C*}(3.68 + 3.85)+^{11}\text{C*}(4.32)$ (1988WI09, 1989WI07). The results are in agreement with the predictions of the exact FRDWBA. Above ≈ 30 MeV/A the angle-integrated cross sections fall off with an approximately exponential shape (1988WI09).

27. ^{13}C(π^+, d)^{11}C $\quad Q_{\text{m}} = 118.908$

At $E_{\pi^+} = 32$ MeV angular distributions have been obtained for the deuterons to ^{11}C*(0, 6.48): see (1985AJ01).

28. ^{13}C(p, t)^{11}C $\quad Q_{\text{m}} = -15.1863$

At E_p = 43.7 to 50.5 MeV 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 $E_x = 12.47$ MeV [see Table 11.18] 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}Be*$_{\rm g.s.+0.4}$ is also observed. Angular distributions have also been measured for $E_p = 26.9$ to 65 MeV [see (1980AJ01, 1985AJ01)]. At $E_p = 46.7$ MeV the $T = \frac{3}{2}$ state is also observed by (1974BE20) who, in addition, report the population of states with $E_x = 11.03 \pm 0.03$, 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]. See also (1989AR1G).

29. (a) ^{14}N(p, α)^{11}C $\quad Q_m = -2.9228$
(b) ^{14}N(p, pt)^{11}C $\quad Q_m = -22.737$

Angular distributions have been reported at a number of energies in the range $E_p = 5.0$ to 44.3 MeV for the α_0 and α_1 groups: see (1975AJ02, 1980AJ01). For reaction (b) see (1986VDZY; $E_p = 50$ MeV; prelim.). See also (1984RE14, 1985HA1J), (1986MA1P, 1987HI1B; applied), (1988CA26; astrophysics) and (1986GO28; theor.).

30. ^{14}N(α, ^{7}Li)^{11}C $\quad Q_m = -20.269$

See (1988SH1E; theor.).

31. ^{14}N(^{10}B, ^{13}C)^{11}C $\quad Q_m = 1.139$

This reaction has been studied at $E(^{10}\mathrm{B}) = 100$ MeV; see (1980AJ01). See also (1987OS1E; theor.).

32. ^{16}O(α, ^{9}Be)^{11}C $\quad Q_m = -24.3099$

See (1987KW01, 1987KW03; theor.).

^{11}N
(Fig. 4)

The ^{14}N(^{3}He, ^{6}He)^{11}N reaction has been studied at $E(^3\mathrm{He}) = 70$ 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 0.5μb/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 ^{11}Be(g.s.) would be expected to be much broader (1974BE20). This ^{11}N state is unbound with respect to decay into ^{10}C + p by 2.24 MeV. (1988WA18) adopt an atomic mass excess of 24.89 ± 0.14 MeV for $^{11}\mathrm{N}_{\mathrm{g.s.}}$ [This value assumes that the first excited state in ^{11}N is at $E_\mathrm{x} = 0.34$ MeV.] We suggest an uncertainty of ± 0.2 MeV because the E_x of the first excited state in ^{11}N may be depressed relative to ^{11}Be*. The *ground state* is then unstable with respect to ^{10}C + p by 1.90 MeV. See also (1985AN28, 1986AN07; theor.).

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

These nuclei have not been observed: see (1980AJ01, 1985AJ01) and (1986AN07, 1987SA15; theor.).

References

(Closed 01 June 1989)

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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