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Energy Levels of Light Nuclei
$A = 12$

F. Ajzenberg-Selove

University of Pennsylvania, Philadelphia, Pennsylvania 19104-6396

Abstract: An evaluation of $A = 11$–12 was published in *Nuclear Physics A*433 (1985), p. 1. This version of $A = 12$ differs from the published version in that we have corrected some errors discovered after the article went to press. Figures and introductory tables have been omitted from this manuscript. Reference key numbers have been changed to the NNDC/TUNL format.

(References closed June 1, 1984)

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^{12}n, ^{12}He
(Not illustrated)

^{12}n has not been observed in the interaction of 0.7 and 400 GeV protons with uranium: see (1980AJ01). For ^{12}He see (1983ANZQ; theor.).

^{12}Li
(Not illustrated)

^{12}Li is not observed in the 4.8 GeV proton bombardment of a uranium target: it is particle-unstable. The calculated value of its mass excess is 52.93 MeV [see (1980AJ01)]: ^{12}Li would then be unstable with respect to ^{11}Li + n, ^{10}Li + 2n and ^{9}Li + 3n by 3.92, 2.96 and 3.76 MeV, respectively. See also (1980AJ01) and (1982KA1D, 1983ANZQ, 1984VA06; theor.).

^{12}Be
(Figs. 5 and 9)

GENERAL: (See also (1980AJ01).)

Theoretical papers: (1979KO29, 1981AV02, 1981SE06, 1982NG01, 1983ANZQ, 1983MI1E, 1984VA06).

Hypernuclei: (1980GA1P, 1982IK1A, 1982KA1D, 1982PO1C, 1983BR1E, 1983DO1B, 1983MI1E, 1984DO04).

Other topics: (1983OL1A, 1983WI1A, 1984HI1A).

Mass of ^{12}Be: (The Q-value of the ^{10}Be(t, p) reaction (-4809 ± 15 keV) (1978AL29) leads to an atomic mass excess of 25077 ± 15 keV for ^{12}Be.

1. ^{12}Be(β^-)^{12}B $\qquad Q_m = 11.708$

The half-life of ^{12}Be is 24.4 ± 3.0 msec (1978AL10): $\log ft = 3.84 \pm 0.06$ (M.J. Martin, private communication), assuming the decay is to ^{12}B$_{\text{g.s.}}$. The upper limit to a branch involving delayed neutrons is 1% (1978AL10).

2. ^{10}Be(t, p)^{12}Be $\qquad Q_m = -4.809$

Table 12.1: Energy Levels of ^{12}Be

E_x (MeV ± keV)	$J^\pi; T$	$\tau_{1/2}$	Decay	Reactions
0	$0^+; 2$	$\tau_{1/2} = 24.4 \pm 3.0$ msec	β^-	1, 2, 3, 4
2.102 ± 12	$2^+; 2$	[a]	γ	2, 3, 4
2.702 ± 17		[a]		2, 3, 4
4.56 ± 25		[b]		2
5.70 ± 25		[b]		2

[a] See discussion in (1982BE42).

[b] This state has an appreciable intrinsic width: see (1978AL29).

At $E_t = 12$ MeV ^{12}Be*(2.10) is populated [$E_x = 2110 \pm 15$ keV] and (p, γ) angular correlations lead to $J = 2$ (1978AL10). At $E_t = 17$ MeV proton groups are observed to the states shown in Table 12.1. The energy of ^{12}Be*(2.10) is measured to be 2089 ± 20 keV. The two highest states have an appreciable intrinsic width. From the measured atomic mass excess of ^{12}Be, d, the cubic factor in the IMME, is calculated to be $+2.8 \pm 8.6$ keV and the first $T = 2$ state in ^{12}N should occur at $E_x = 12.27 \pm 0.04$ MeV (1978AL29): compare with ^{12}O. See also (1980AJ01).

3. ^{12}C(π^-, π^+)^{12}Be $\qquad Q_m = -25.077$

See (1980NA1D, 1980NA12). See also (1980AJ01).

4. ^{14}C(^{14}C, ^{16}O)^{12}Be $\qquad Q_m = -14.300$

At $E(^{14}$C$) = 60$ MeV ^{12}Be*(0, 2.10, 2.68 ± 0.03) have been populated, the latter weakly. Angular distributions are poorly fitted by DWBA. An assignment of 0^+ is plausible but not proven for ^{12}Be*(2.69) (1982BE42).

^{12}B

(Figs. 6 and 9)

GENERAL: (See also (1980AJ01).)

Model calculations: (1980HA35, 1983SH38, 1984VA06).

Special states: (1980HA35, 1980OK01, 1981SE06, 1984VA06).

Complex reactions involving ^{12}*B:* (1979AL22, 1979BO22, 1980MA24, 1980NA1C, 1980TR1F, 1980WI1L, 1981GR08, 1981ME13, 1981MO20, 1982GO1E, 1982LY1A, 1983EN04, 1983MA06, 1983OL1A, 1983SA06, 1983WI1A, 1984GR08, 1984HI1A).

Muon and neutrino capture and reactions (See also reaction 17.): (1979HW02, 1979KI1G, 1979PA19, 1979PR1C, 1979WU10, 1980MU1B, 1981AM05, 1981CI05, 1981EI1A, 1981GI08, 1981PA1G, 1981RO05, 1981RO15, 1982BO1W, 1982MI05, 1982RO1F, 1982RO13, 1983FU17, 1983GM01, 1983KU1L, 1983NO12, 1984BO1M).

Pion and kaon capture and reactions (See also reactions 13 and 16.): (1978GO18, 1979AL21, 1980AR01, 1980DU20, 1980HA18, 1980OH07, 1980RA05, 1980SO05, 1980TR1A, 1981DE01, 1981DE1U, 1981DO1F, 1981DU1H, 1981EI01, 1981RA16, 1982AR06, 1982BE1D, 1982BO11, 1982GO1F, 1982GO01, 1982RA28, 1983BE1A, 1983CO1L, 1983DE2G, 1983GI08, 1983HS01, 1983MO1J, 1983SH2C, 1983TR1J).

Hypernuclei: (1978SO1A, 1979BU1C, 1980KI1F, 1982KA1D, 1983CH1T, 1983CO1L, 1983DO1B, 1983FE07, 1983HS01, 1983SH38).

Other topics: (1979HA58, 1979NO05, 1981DO1F, 1981SE06, 1981WA1J, 1982NG01).

Ground-state properties of ^{12}*B, including its polarization:* (1980FU1G, 1980TR1F, 1981AV02, 1981KO1D, 1981MI1C, 1981MI1D, 1981NE1B, 1981SE06, 1982BA37, 1982DE16, 1982NG01, 1982RE01, 1983ANZQ, 1983FU15, 1983KU1L, 1983MI28, 1983NO05, 1983TA1K, 1984KU07).

$$\mu = +1.00306\ (15)\ \text{nm (1978LEZA)},$$

$$Q = 1.34 \pm 0.14\ \text{fm}^2\ \text{[(1978MI19); see also (1978LEZA)]}.$$

1. ^{12}B(β^-)^{12}C $\qquad Q_{\rm m} = 13.369$

The half-life of ^{12}B is 20.20 ± 0.02 msec (1978AL01). The decay is complex. ^{12}B decays to ^{12}C*(0, 4.4, 7.7, 10.3): see Table 12.14. The transitions to ^{12}C*(0, 4.4) are allowed: hence the J^π of ^{12}B$_{\rm g.s.}$ is 1^+. See also (1983AD1B) and (1979HW03, 1979KI1G, 1979MA31, 1979NO01, 1979PR1C, 1979RH1A, 1980OK01, 1980SY02, 1981CH1B, 1981HO06, 1981KO27, 1982GU09, 1983MO1N; theor.).

Table 12.2: Energy levels of ^{12}B [a]

E_x in ^{12}B (MeV ± keV)	$J^\pi; T$	τ or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
0	$1^+; 1$	$\tau_{1/2} = 20.20 \pm 0.02$ msec	β^-	1, 2, 3, 7, 9, 13, 14, 16, 17, 18, 19, 20, 21, 23, 24, 25
0.95314 ± 0.60	2^+	$\tau_m = 260 \pm 40$ fsec	γ	2, 3, 7, 9, 13, 14, 16, 17, 19, 20, 22, 23, 24, 25
1.67365 ± 0.60	2^-	< 50 fsec	γ	2, 3, 7, 9, 13, 14, 16, 17, 19, 20
2.6208 ± 1.2	1^-	< 70 fsec	γ	2, 3, 7, 9, 13, 14, 17, 20
2.723 ± 11	0^+		γ	2, 3, 7, 9, 14, 20, 23
3.3883 ± 1.6	3^-	$\Gamma = 3.1 \pm 0.6$ eV	γ, n	2, 7, 9, 10, 11, 13, 14
3.759 ± 6	2^+	40 ± 4 keV	γ, n	7, 9, 10, 11, 13, 14, 23
4.301 ± 7	1^-	9 ± 4	γ, n	7, 9, 10, 11, 13, 16, 19
4.46	2^-	broad	n	11, 16, 19
4.518 ± 8	4^-	110 ± 20	γ, n	7, 9, 10, 11, 13, 14, 16, 19, 20
5.00 ± 20	1^+	50 ± 15	γ, n	7, 9, 10, 11, 13, 23
5.612 ± 8	3^+	110 ± 40	n	7, 9, 11, 13, 24
5.726 ± 8	3^-	50 ± 20	n	7, 9, 11
6.0	1^-	broad	n	11
6.6	1^+	140	n	11
7.06	1^-	broad	n	11
7.545 ± 20		≤ 14	n	7, 9, 11
(7.67)	2^-	45	n	11
7.836 ± 20	1^-	60 ± 40	n	7, 11
7.937 ± 20	(1^-)	27	n	7, 11
8.1 ± 100		900 ± 200	(n)	7
8.120 ± 20	(3^-)		n	7, 9, 11
8.24 ± 30	3^-	65	n	7, 11
8.376 ± 20		40 ± 20		7, 9

Table 12.2: Energy levels of ^{12}B [a] (continued)

E_x in ^{12}B (MeV $\pm$ keV)	$J^\pi; T$	τ or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
8.58 ± 30	(3^-)	75	n	7, 9, 11
8.707 ± 20	(3^-)		n	7, 11
9.04 ± 20	1^-	95 ± 20	n	7, 9, 11
9.175 ± 20	(2^-)		n	7, 11
9.43 ± 20		85 ± 30		7, 9
9.585 ± 5	3^-	34 ± 5	n	7, 9, 11
9.758 ± 20				7
(9.83)				7
10.00 ± 40		100	n	7, 11
10.11 ± 40				7
10.220 ± 20		< 25		7, 9
10.435 ± 20		75 ± 40		7
10.59 ± 20		< 30		6, 7, 9, 11
10.90 ± 20		30 ± 10		6, 7, 9
(11.08)				7
11.31 ± 30		130 ± 60		7
11.59 ± 20		75 ± 25		7
12.345 ± 25		100 ± 30	n	7, 9, 11
12.75 ± 50	$0^+; T = 2$	85 ± 40		7, 24
13.33 ± 30		50 ± 20		7
(13.4 ± 100)		broad		9
14.82 ± 100	$(2^+; T = 2)$	≤ 200		24
15.5				7

[a] See also Table 12.5.

2. ^{6}Li(^{7}Li, p)^{12}B $\qquad Q_m = 8.334$

Eleven groups of protons are reported to known states of ^{12}B. Angular distributions have been measured at $E(^6\text{Li}) = 3.5$ to 5.95 MeV. The distributions are generally featureless: see (1975AJ02).

3. ^{7}Li(^{7}Li, d)^{12}B $Q_{\rm m} = 3.308$

Angular distributions for d_0, d_1, d_2, d_{3+4} have been measured at $E(^{7}\text{Li}) = 2.10$ to 5.75 MeV. See also (1975AJ02) and (1981KO1D).

4. ^{9}Be(t, n)^{11}B $Q_{\rm m} = 9.5589$ $E_{\rm b} = 12.928$

Thirteen resonances have been reported corresponding to $13.6 < E_{\rm x} < 14.7$ MeV: see table 12.3 in (1975AJ02). The yield of 2.12 MeV γ-rays has been measured for $E_{\rm t} = 1.5$ to 3.3 MeV and $E(^{9}\text{Be}) = 10$ to 16 MeV by (1983MI08): no resonances are observed.

5. (a) ^{9}Be(t, p)^{11}Be $Q_{\rm m} = -1.167$ $E_{\rm b} = 12.928$
(b) ^{9}Be(t, d)^{10}Be $Q_{\rm m} = 0.5548$
(c) ^{9}Be(t, t)^{9}Be
(d) ^{9}Be(t, α)^{8}Li $Q_{\rm m} = 2.927$
(e) ^{9}Be(t, ^{6}He)^{6}Li $Q_{\rm m} = -5.380$

Yields of elastically scattered tritons have been measured for $E_{\rm t} = 0.60$ to 2.1 MeV: see (1975AJ02). Differential cross sections and analyzing power for elastic tritons have been measured at $E_{\vec{\rm t}} = 15$ and 17 MeV (1978SC02). The yields of 0.32 MeV (reaction (a)), 0.98 MeV (reaction (d)) and 0.48 MeV γ-rays (from the (t, αn) reaction) have been studied for $E_{\rm t} = 1.5$ to 3.3 MeV and $E(^{9}\text{Be}) = 10$ to 16 MeV: no resonances are observed (1983MI08). The yields of α_0 and α_1 have also been reported for $E_{\rm t} = 0.52$ to 1.70 MeV: see (1975AJ02). The analyzing powers of the reactions leading to $^{6}\text{He}_{\rm g.s.}$ and ^{6}Li*(0, 3.56) have been measured at $E_{\vec{\rm t}} = 17$ MeV (1979FL03). See also (1983CE01), (1981ME1D, 1983WE02; theor.), ^{11}Be, and ^{6}He, ^{6}Li, ^{8}Li and ^{9}Be in (1984AJ01).

6. ^{9}Be(α, p)^{12}B $Q_{\rm m} = -6.886$

At $E_{\alpha} \approx 35$ MeV (1981HA1J) report the excitation of two sharp and strong groups to ^{12}B*(10.6, 10.9). See also (1983AU1C).

7. ^{9}Be(^{7}Li, α)^{12}B $Q_{\rm m} = 10.460$

Observed α-particle groups are displayed in Table 12.3. Angular distributions have been measured at $E(^7\text{Li}) = 3.3$ to 6.2 MeV, at 20 MeV and at 30.3 MeV: see (1975AJ02, 1980AJ01). At $E(^7\text{Li}) = 20$ MeV angular distributions to the first seven states are rather featureless and have approximate symmetry about $90°$. The integrated cross sections go as $2J_f + 1$ consistent with a compound nucleus mechanism for the transitions populating the low-lying states of ^{12}B. It is suggested that the sharp states of ^{12}B at high excitation energies correspond to states of high angular momenta with cluster configurations.

Table 12.3: Levels of ^{12}B from ^{9}Be(^{7}Li, α) and ^{10}B(t, p) [a]

E_x [b] (MeV ± keV)	$\Gamma_{c.m.}$ [b] (keV)	E_x [c] (MeV ± keV)	$\Gamma_{c.m.}$ [c] (keV)	L [c]	J^π [c]
0		0		2	$(1, 2, 4, 5)^+$
0.951 ± 15		0.955 ± 8		2	$(1, 2, 4, 5)^+$
1.674 ± 15		1.673 ± 8		1	$(2, 3, 4)^-$
2.625 ± 15		2.627 ± 8		3	$(0, 1, 5, 6)^-$
2.724 ± 15		2.72 [f]		4	$(0, 6, 7)^+$
3.390 ± 15		3.393 ± 8			
3.77 ± 20 [d]	40 ± 20	3.754 ± 8	42 ± 5	2	$(1, 2, 4, 5)^+$
4.305 ± 15	< 30	4.297 ± 8	≤ 15		
4.534 ± 15		4.514 ± 8	95 ± 15		
4.982 ± 15 [d]	40 ± 20	5.00 [g]	130 ± 40		
5.57 ± 30 [d]		5.612 ± 8	120 ± 20		
5.728 ± 15	50 ± 20	5.724 ± 8	70 ± 20		
7.545 ± 20	< 30	7.55 [f]			
7.836 ± 20	60 ± 40				
7.937 ± 20	< 40				
8.1 ± 100	900 ± 200				
8.120 ± 20		8.16 ± 30			
8.24 ± 30					
8.376 ± 20	40 ± 20	8.38 [f]			
8.58 ± 30		8.58 [f]			
8.707 ± 20					
9.03 ± 20		9.07 ± 30	95 ± 20		
9.175 ± 20					
9.43 ± 20 [e]	85 ± 30	9.44 ± 30			

Table 12.3: Levels of ^{12}B from ^{9}Be(^{7}Li, α) and ^{10}B(t, p) [a] (continued)

E_x [b] (MeV ± keV)	$\Gamma_{c.m.}$ [b] (keV)	E_x [c] (MeV ± keV)	$\Gamma_{c.m.}$ [c] (keV)	L [c]	J^π [c]
9.585 ± 20	60 ± 30	9.626 ± 20	34 ± 10		
9.758 ± 20					
(9.83)					
10.00 ± 40					
10.11 ± 40					
10.21 ± 30	50 ± 20	10.227 ± 20	< 25		
10.435 ± 20	75 ± 40				
10.58 ± 20	50 ± 30	10.61 ± 30	< 30		
10.887 ± 20	40 ± 20	10.91 ± 20	27 ± 10		
(11.08)					
11.31 ± 30	130 ± 60				
11.59 ± 20	75 ± 25				
12.33 ± 30	100 ± 30	12.36 ± 30			
12.77 ± 50	85 ± 40				
13.33 ± 30	50 ± 20	(13.4 ± 100)	broad		
15.5					

[a] For references see Tables 12.3 and 12.4 in (1980AJ01).
[b] ^{9}Be(^{7}Li, α)^{12}B.
[c] ^{10}B(t, p)^{12}B.
[d] $\theta_n^2 = 0.46 \pm 0.06$, 0.08 ± 0.03 and 0.10 ± 0.02 for ^{12}B*(3.76, 5.00, 5.61).
[e] Probably unresolved.
[f] Observed but E_x not determined.
[g] Not observed at $E_t = 23$ MeV.

8. (a) ^{10}Be(d, p)^{11}Be $\qquad Q_m = -1.722 \qquad E_b = 12.373$
(b) ^{10}Be(d, α)^{8}Li $\qquad Q_m = 2.372$

The cross sections for production of ^{8}Li (reaction (b)) and of ^{11}Be (reaction (a)) have been measured for $E_d = 0.67$ to 3.0 MeV and 2.3 to 12 MeV, respectively: the yields for both reactions vary smoothly with energy. No resonances are observed: see (1975AJ02).

9. ^{10}B(t, p)^{12}B $\qquad Q_m = 6.342$

Observed excited states are displayed in Table 12.3. Angular distributions have been studied at $E_t = 10$ and 23 MeV: see (1980AJ01).

10. ^{11}B(n, γ)^{12}B $\qquad Q_m = 3.369$

The thermal-neutron capture cross section is 5.5 ± 3.3 mb [see (1981MUZQ)]. The capture cross section shows resonances at $E_n = 20.8 \pm 0.5$ keV and at 0.43, 1.03, 1.28 and 1.78 MeV, with $\Gamma_\gamma = 25 \pm 8$ meV and 0.3, 0.3, 0.2 and 0.9 eV (±50%): see Table 12.4 and (1968AJ02). See also (1980DO1C; astrophys.).

11. ^{11}B(n, n)^{11}B $\qquad E_b = 3.369$

The thermal (bound) scattering cross section is 3.9 ± 0.2 b. The scattering amplitude (bound) is $a = 6.65 \pm 0.04$ fm, σ(free) $= 4.84 \pm 0.04$ b (1983KO17). Parameters of observed resonances are shown in Table 12.4. See also (1981MUZQ). Differential cross sections have been studied for $E_n = 75$ keV to 4.5 MeV [see (1980AJ01)] and for 2.6 to 8.0 MeV (1980WH01; n_0) and 4.86 to 7.55 MeV (1983KO03; n_0, n_1 and, at higher energies, n_2, n_3). Total cross-section measurements have been reported for $E_n = 0.3$ to 18.0 MeV [see (1968AJ02, 1980AJ01)] and 4.86 to 7.55 MeV (1983KO03). The polarization has been measured at $E_n = 75$ keV to 2.2 MeV: see (1980AJ01). See also (1983GO1H).

Results from the most recent R-matrix analysis are displayed in Table 12.4 (1983KO03). See also (1980WH01, 1983DA22). For a discussion of the earlier work see (1980AJ01). See also (1979GL1D, 1980HA35; theor.).

12. (a) ^{11}B(n, p)^{11}Be $\qquad Q_m = -10.726 \qquad E_b = 3.369$

(b) ^{11}B(n, d)^{10}Be $\qquad Q_m = -9.0042$

(c) ^{11}B(n, t)^{9}Be $\qquad Q_m = -9.5589$

(d) ^{11}B(n, α)^{8}Li $\qquad Q_m = -6.632$

The cross section for reaction (a) has been measured for $E_n = 14.7$ to 16.9 MeV and that for reaction (b) has been investigated for $E_n = 12.6$ to 20.0 MeV and at 25 and 38 MeV: see (1975AJ02). A recent study of reaction (d) at $E_n = 14.4$ MeV is reported by (1979AN18). See also (1980AJ01).

Table 12.4: Resonances in ^{11}B(n, n)^{11}B [a]

E_n (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	^{12}B* (MeV)	l [a,e]	J^{π} [a,e]
0.0208 ± 0.5 [b,d]	$\ll 1.4$	3.3883 [f]	2	3^-
0.43 ± 10 [c,d]	37 ± 5	3.763	1	2^+
1.027 ± 11 [c,d]	9 ± 4	4.310	0	1^-
1.19 [e]	broad	4.46	0, 2	2^-
1.28 ± 20 [c,e]	130 ± 20	4.54	2	4^-
1.78 ± 20 [c,e]	60 ± 20	5.00	1	1^+
2.45 ± 20 [e]	110 ± 40	5.61	1	3^+
2.58 ± 20 [e]	55 ± 20	5.74	2	3^-
2.9 [e]	broad	6.0	0, 2	1^-
3.5 [e]	140	6.6	1	1^+
4.03 [e]	broad	7.06	0, 2	1^-
4.55	≤ 14	7.54	> 3	
4.70 [e]	45	7.67	0, 2	2^-
4.80 [e]	90	7.77	0, 2	1^-
4.93 [e]		(7.88)	0, 2	1^-
5.19 [e]		(8.12)	2	3^-
5.31 [e]	65	8.23	2	3^-
5.59 [e]	75	8.49	2	3^-
5.82 [e]		(8.70)	2	3^-
6.18 [e]	120	9.03	0, 2	1^-
6.25 [e]		(9.09)	0, 2	2^-
6.78 [e]	34 ± 5	9.578 [g]	2	3^-
7.18	100	9.94	> 0	
7.82	65	10.53	> 2	
9.72	120	12.27	> 2	

[a] For references see Table 12.5 in (1980AJ01).

[b] Also observed in ^{11}B(n, γ): $\Gamma_\gamma = 25 \pm 8$ meV, $\Gamma_n = 3.1 \pm 0.6$ eV.

[c] Also observed in ^{11}B(n, γ): see (1968AJ02).

[d] See also (1983KO03).

[e] From R-matrix analysis (1983KO03). See also (1980WH01) and the earlier work displayed in (1980AJ01).

[f] ±1.6 keV.

[g] ±5 keV.

Table 12.5: ^{12}B states from ^{11}B(d, p)^{12}B [a]

^{12}B* (MeV ± keV)	l_n	J^π	S	γ-decay (%)	τ_m (fsec)
0	1	1^+	0.69		
0.95314 ± 0.60	1	2^+	0.55	to g.s.	260 ± 40
1.67365 ± 0.60	0	2^-	0.57	3.2 ± 0.4 [$\rightarrow 0.95$]	< 50
				96.8 ± 0.4 [$\rightarrow$ g.s.]	
2.6208 ± 1.2	0	1^-	0.75	14 ± 3 [$\rightarrow 1.67$]	< 70
				80 ± 3 [$\rightarrow 0.95$]	
				6 ± 1 [$\rightarrow$ g.s.]	
2.723 ± 11	1	0^+	0.21	> 85 [$\rightarrow$ g.s.]	
3.383 ± 9	2	3^-	0.58		
3.76	1	2^+			
4.52	2				

[a] For references see Table 12.6 in (1980AJ01).

13. ^{11}B(p, π^+)^{12}B $\qquad Q_m = -136.980$

(1979MA38) have measured the cross section for π^+ production near threshold. At $E_p = 200$ MeV the population of ^{12}B*(0, 0.95, 1.67, 2.62, 3.39, 3.76, $4.30 + 4.52$, 5.00, 5.61) is reported by (1980SO05). See also the "GENERAL" section here.

14. ^{11}B(d, p)^{12}B $\qquad Q_m = 1.145$

Observed proton groups and γ-rays are displayed in Table 12.5. The J^π assignments for ^{12}B*(0.95, 1.67) are derived as follows [see (1968AJ02) for a listing of earlier references]: *0.95 MeV:* $l_n = 1$ leads to $J^\pi = 0^+, 1^+, 2^+$ or 3^+. The γ-radiation is anisotropic and therefore $J \neq 0$. τ_m is too short for pure E2 and hence $J \neq 3$, which is conformed by studies of the polarization of γ_1. The results are consistent with $J^\pi = 1^+$ and 2^+. The latter is fixed by $\gamma\gamma$ correlations in the cascade $1.67 \rightarrow 0.95 \rightarrow$ g.s. The mixing ratio $\delta = -0.08 \pm 0.06$. *1.67 MeV:* $l_n = 0$ and therefore $J^\pi = 1^-$ or 2^-. The state decays primarily to ^{12}B$_{g.s.}$. Gamma-gamma correlations lead to $J^\pi = 2^-$. An assignment of 1^- to ^{12}B*(2.62) is made in a similar manner.

See Table 12.12 in (1980AJ01) for a comparison of the properties of the first seven $T = 1$ states in ^{12}B and in ^{12}C. See also (1981HU1G) and (1982GO05; theor.).

15. ^{12}Be(β^-)^{12}B $\qquad Q_m = 11.708$

See ^{12}Be.

16. (a) ^{12}C(γ, π^+)^{12}B $\qquad Q_m = -152.937$
(b) ^{12}C(e, eπ^+)^{12}B $\qquad Q_m = -152.937$
(c) ^{12}C(π^-, γ)^{12}B $\qquad Q_m = 126.198$

Using monoenergetic photons with $E_\gamma = 210$ to 381 MeV (1982AR06) have measured the total cross section for π^+ emission and the spectra of the positive pions. The latter show the influence of quasi-free pion production and FSI processes. At $E_e = 195$ and 200 MeV the π^+ energy distributions show contributions from ^{12}B*(0, 0.95, ≈ 4.5, 7.0) (1980MI08, 1980SH22, 1983SH1W). The 2^- and 4^- states at $E_x \approx 4.5$ MeV are compared with their isobaric analogs in ^{12}C at $E_x \approx 19.5$ MeV (1980MI08). At $E_e = 400$ MeV (1983SC03, 1983SC11) have studied π^+ with $E_\pi = 32$ MeV: double differential cross sections are obtained for the transitions to ^{12}B*(0, 0.95, 1.67) and single differential cross sections to ^{12}B*(0, 0.95). (1983SC03) found that the cross section (at $\theta = 54°$) is the same whether virtual or real photons are used in producing the pions.

For the earlier work see (1980AJ01). See also (1979TR1B), (1979CH31, 1980NA11, 1981SI09; theor.) and the "GENERAL" section here.

17. ^{12}C(μ^-, ν)^{12}B $\qquad Q_m = 92.290$

Observations of γ-transitions have led to the determination of the capture rates to ^{12}B*(0, 0.95, 1.67, 2.62) [$J^\pi = 1^+, 2^+, 2^-, 1^-$] (1981GI08, 1981RO15). The ratio of the polarization of ^{12}B$_{\text{g.s.}}$, P_{av}, and of the longitudinal polarization, P_L, has been determined by (1981RO05, 1981RO15, 1982RO13): this ratio leads to a neutrino helicity, $h_\nu = -1.08 \pm 0.11$, in agreement with the partial conservation of axial-vector current (PCAC) hypothesis. See also the "GENERAL" section here. For the earlier work see (1980AJ01).

18. ^{12}C(n, p)^{12}B $\qquad Q_m = -12.587$

At $E_n = 59.6$ MeV (1982BR04) have determined the angular distribution of the p_0 group. Broad (unresolved) structures are also observed with $E_x < 10$ MeV (1984BR03). The use of this reaction for the production of polarized ^{12}B nuclei is discussed by (1982DE16). For the earlier work see (1980AJ01).

19. ^{12}C(d, 2p)^{12}B $Q_m = -14.812$

Angular distributions are reported at $E_d = 55$ MeV to ^{12}B*(0, 0.95, 4.5). ^{12}B*(1.67, 5.6 and 8.0) are also populated (1979ST15). At $E_d = 99.2$ MeV $\sigma(\theta)$ at forward angles have been measured for the transitions to ^{12}B*(0, 4.5). The differential cross sections are nearly the same for the two groups (1982BE33).

20. ^{12}C(^{7}Li, ^{7}Be)^{12}B $Q_m = -14.231$

At $E(^7\text{Li}) = 78$ MeV the population of ^{12}B*(0, 0.95, 4.52) is reported by (1984GA1N). In the earlier work of (1973BA34; $E(^7\text{Li}) = 52$ MeV) ^{12}B*(1.71, 2.70, 2.87) were also observed. See also (1982AL1G).

21. ^{12}C(^{14}N, ^{14}O)^{12}B $Q_m = -18.512$

See (1979NA1G).

22. ^{13}C(γ, p)^{12}B $Q_m = -17.533$

See (1983ZU02). See also ^{13}C in (1981AJ01, 1986AJ01).

23. ^{13}C(d, ^{3}He)^{12}B $Q_m = -12.040$

Angular distributions have been measured for the transitions to ^{12}B*(0, 0.95) at $E_d = 24.1$ to 29 and at 52 MeV. Distributions to ^{12}B*(2.72, 3.76, 5.00) have been reported at $E_d = 52$ MeV: see (1980AJ01). The spectroscopic factors for ^{12}B*(0, 0.95) are $S = 1.1 \pm 0.2$ and 2.0 ± 0.5. $C^2S = 1.09$ [assuming 1p$_{3/2}$], 2.17, 0.14, 0.07, 0.22 [assuming 1p$_{1/2}$] for ^{12}B*(0, 0.95, 2.72, 3.76, 5.00) [from measurements at $E_d = 52$ MeV]. See (1980AJ01) for references. For a discussion of analog states of ^{12}B and ^{12}C see reaction 67 in ^{12}C. See also ^{15}N in (1981AJ01), (1979SH1K, 1983AD1B) and (1980LE14; theor.).

24. ^{14}C(p, ^{3}He)^{12}B $Q_m = -17.992$

At $E_p = 54$ MeV, in addition to transitions to ^{12}B*(0, 0.95, 5.61), the population of $T = 2$ states at $E_x = 12.72 \pm 0.07$ and 14.82 ± 0.10 MeV is reported. The angular distribution of ^{3}He ions to ^{12}B*(12.75) is fitted by $L = 0$; that to ^{12}B*(12.82) is rather featureless [its $T = 2$ characater is assigned from the energies of the analog states]: both states have $\Gamma_{c.m.} \lesssim 200$ keV (1976AS01). See also reaction 72 in ^{12}C and (1983AR1K).

25. ^{14}N(^{12}C, ^{14}O)^{12}B $\qquad Q_m = -18.510$

See (1980AJ01).

26. ^{18}O(d, ^{8}Be)^{12}B $\qquad Q_m = -5.957$

See (1984NE1A).

^{12}C

(Figs. 7 and 9)

GENERAL: (See also (1980AJ01).)

Shell model: (1977ME05, 1978RA1B, 1979HA59, 1979IN05, 1980CA12, 1980GI05, 1980HA35, 1980OH07, 1981AM08, 1981BO1Y, 1981DE2G, 1981LU1B, 1981RA06, 1982AR03, 1982BA52, 1982BR08, 1983VA31, 1984DE04, 1984VA06).

Deformed models: (1979UE03, 1980BA1T, 1980BA44, 1980CA12, 1980FU1H, 1981DE2G, 1981RA06, 1981SE03, 1982AS03, 1982BR08, 1982KU1K, 1982SA1U, 1983LO04, 1983SA12, 1983SC08).

Cluster model: (1978RE1A, 1978TA1A, 1978UE02, 1979GO24, 1979GR1F, 1979KA21, 1979UE03, 1980BE58, 1980FU1H, 1980HA38, 1980IK1B, 1980KR1D, 1980TO1E, 1981CH1E, 1981EL1C, 1981KA03, 1981KA1P, 1981KH1F, 1981KN12, 1981MA1G, 1981NO13, 1982MA38, 1982SA1P, 1982SC1K, 1982SH01, 1982SU1B, 1982SU06, 1982VA11, 1983CA12, 1983CO1T, 1983GI06, 1983GL1C, 1983KA1K, 1983LI18, 1983PO03, 1983RO1G, 1983SA12, 1983SH38, 1984GA1P).

Special states: (1978RA1B, 1978TA1A, 1978UE02, 1979BO24, 1979DE1K, 1979HA53, 1979IN07, 1979IN05, 1979KA40, 1979KA1M, 1979KI10, 1979KU1D, 1979UE03, 1979WI1B, 1979WU1C, 1980CA12, 1980DE04, 1980FU1H, 1980HA35, 1980KI1F, 1980KR1D, 1980OH07, 1980PE05, 1980RI06, 1980SH1N, 1980SP04, 1981AM08, 1981BO1Y, 1981DE2G, 1981GR14, 1981GR15, 1981KA03, 1981RA06, 1981SE03, 1982BA52, 1982BA37, 1982BE1Z, 1982BR08, 1982IN01, 1982LE15, 1982MA38, 1982SA1P, 1982SH01, 1983AD1B, 1983AH1A, 1983AR07, 1983AU1A, 1983AU1B, 1983BA62, 1983GO1R, 1983NA1J, 1983RA1L, 1983SA12, 1983VA31, 1984CO02, 1984GO1M, 1984VA06).

Electromagnetic transitions: (1979KA40, 1979KU1D, 1979UE03, 1980DE04, 1980DE14, 1980DE45, 1980KO1L, 1980PE05, 1981AM08, 1981BO1Y, 1981GR14, 1981GR15, 1981LO04, 1981KN06, 1981LU1B, 1981SP1A, 1982AS03, 1982BA52, 1982BA37, 1982DE1G, 1982KO15, 1982KO22, 1982LA26, 1982SP1C, 1983LO04, 1984KU07).

Giant resonances: (1979DE1K, 1979HA1G, 1979KN1D, 1980BA1T, 1980LE25, 1981GR14, 1981KN12, 1981KO41, 1981MO12, 1982AR03, 1982BA52, 1982CA1H, 1982GO01, 1983DA23, 1983GO1B, 1983IS1F, 1983KA07, 1983NA1J, 1983OR03, 1984IS1B, 1984KL04).

Astrophysical questions: (1978VA1B, 1979BE1V, 1979GE1D, 1979LE1F, 1979MC1B, 1979PE1E, 1979RA1C, 1979SW1B, 1979TI1B, 1980CA1M, 1980CO1R, 1980GA1Q, 1980HE1D, 1980LA1G, 1980MC1G, 1980ME1B, 1980MO1L, 1980PE1F, 1981BE2K, 1981CR1B, 1981DE2C, 1981DU1E, 1981GA1C, 1981GA1H, 1981IB1A, 1981LA1L, 1981SC1M, 1981SN1B, 1981WA1N, 1981WA1Q, 1981WE1F, 1981WI1G, 1982HI1E, 1982IB1B, 1982JO1B, 1982NO1D, 1982SC1E, 1983AL1M, 1983BO1F, 1983HA1P, 1983IB1A, 1983SI1B, 1983SW1A).

Applied work: (1977MA1F, 1979AL1P, 1979KU20, 1979SW1C, 1980HE1E, 1980LA1K, 1980PU1A, 1980SE1E, 1981FR1D, 1981SC1D, 1982FR1L, 1983AM1A, 1983GI1E, 1983GO2D, 1983OS1G, 1983SK1B).

Complex reactions involving ^{12}C: (1978HE23, 1978KN1C, 1979AL22, 1979BA34, 1979BA2A, 1979BL1E, 1979BO24, 1979BO22, 1979BU1J, 1979BU1G, 1979FR12, 1979GE05, 1979GE1A, 1979HE1D, 1979KA21, 1979KO1M, 1979LA07, 1979NA1F, 1979PO16, 1979SA27, 1979SA26, 1979SC1D, 1979ST1D, 1979TA19, 1979WI10, 1980AK1C, 1980BA1G, 1980BR1P, 1980EL1D, 1980GR10, 1980GR1K, 1980ME1F, 1980MI01, 1980MO28, 1980RI06, 1980SC1G, 1980VO1D, 1981AB1G, 1981BH02, 1981BL1G, 1981BO1E, 1981BO18, 1981CE1D, 1981CI03, 1981DI1A, 1981EL1B, 1981EL1F, 1981GR08, 1981HU01, 1981LO1F, 1981MA1G, 1981ME15, 1981ME13, 1981NA07, 1981ST06, 1981TA16, 1981TA22, 1981UC01, 1982BI09, 1982BU02, 1982FA1D, 1982FI1J, 1982FU04, 1982GA15, 1982HI1G, 1982IN01, 1982LY1A, 1982MO1K, 1982SH01, 1982SH21, 1982ST06, 1982TA02, 1982VI01, 1982YU1A, 1983BH09, 1983CH23, 1983CH55, 1983DE26, 1983EF1A, 1983EN04, 1983FR1G, 1983FR1A, 1983FU04, 1983GA01, 1983HA1C, 1983IS1E, 1983JA05, 1983KA1V, 1983KH04, 1983KW01, 1983LE1F, 1983MA06, 1983MO1P, 1983OL1A, 1983PAZT, 1983RA1J, 1983SA06, 1983SC1L, 1983SC1M, 1983SI1A, 1983SO08, 1983ST1A, 1983VA23, 1983WI1A, 1984AL1N, 1984BE22, 1984GR08, 1984HI1A, 1984MU1G, 1984TS03).

Muon and neutrino capture and reactions: (1977GR1C, 1979BE1G, 1979BU1H, 1979DO1E, 1979HW02, 1979HW04, 1979KI1G, 1979MA1U, 1979PA19, 1979PR1C, 1979WU10, 1980BA36, 1980CH20, 1980MU1B, 1980OR01, 1980SC18, 1981AM05, 1981BE1Q, 1981CH1B, 1981CI05, 1981EI1A, 1981ER1C, 1981GI08, 1981OH06, 1981PA1G, 1981PH1C, 1981RO05, 1981RO15, 1981RU1B, 1982BO1W, 1982DU07, 1982GU09, 1982MI05, 1982NA01, 1982RO1F, 1982RO13, 1982RU06, 1982SC11, 1983FU17, 1983GM01, 1983MO1N, 1983NO12, 1984BO1M, 1984KE1D).

Pion capture and reactions (See also reactions 31, 36, 37 and 65.): (1977MA1F, 1978AN1C, 1978AR1J, 1978EP03, 1978GO18, 1978GR1D, 1978KE09, 1978KN1C, 1978LE1G, 1978WE1C, 1979AB09, 1979AK02, 1979AL21, 1979AM1B, 1979AN1G, 1979AN1F, 1979AN1H, 1979AV1A, 1979BL07, 1979BO23, 1979BO1N, 1979BR1E, 1979BU1C, 1979CH31, 1979CO1G, 1979CO1D, 1979DA1F, 1979DA16, 1979DE1G, 1979DE2A, 1979DR09, 1979EL12, 1979EP02, 1979FR1K, 1979GE03, 1979GE07, 1979GI1C, 1979GI11, 1979GL05, 1979GL08, 1979GR1H, 1979JO08, 1979KL06, 1979KL07, 1979KO1K, 1979KO1C, 1979LI1D, 1979MA1X, 1979MO15, 1979NA1F, 1979NA12, 1979NA1J, 1979OM01, 1979PE1D, 1979RA1G, 1979SI16, 1979TA19, 1979TR1B, 1979WA1G, 1979ZI05, 1980AK1B, 1980AL1D, 1980AL1G, 1980AN1D, 1980AN1Q, 1980AN1R, 1980AR01, 1980AS1A, 1980BA1R, 1980BA2P, 1980BE24, 1980BE56, 1980BR1P, 1980BU15, 1980BU19, 1980CA26, 1980CH1L, 1980CO1L, 1980CO18, 1980CR03, 1980DE04, 1980DE2A, 1980DE1V, 1980DE1X, 1980DU20, 1980ER02, 1980FR12, 1980GA12, 1980GI01, 1980GL02, 1980GO1M, 1980GO16, 1980GR1G, 1980GU22, 1980HA1F, 1980HA56, 1980HO1J, 1980HO26, 1980HO1L, 1980HO24, 1980JA11, 1980KE13, 1980KL03, 1980LA1C, 1980LE1H, 1980LE1L, 1980LI1J, 1980LU1D, 1980MA39, 1980MA2C, 1980MA1R, 1980MC03, 1980MC10, 1980MI11, 1980MO1N, 1980NA1D, 1980NA06, 1980NA11, 1980OB1B, 1980OH07, 1980OL1B, 1980PA05, 1980PE01, 1980PE1C, 1980PH02, 1980PI1B, 1980RA05, 1980SC1B, 1980SE11, 1980SI13, 1980SO03,

1980SP1A, 1980ST07, 1980ST25, 1980TH01, 1980TH1C, 1980TR1A, 1980ZA08, 1980ZI1B, 1981AB1B, 1981AK01, 1981AK1C, 1981AM02, 1981AN10, 1981AN14, 1981AN1F, 1981AN1H, 1981AS1D, 1981AS07, 1981AS1G, 1981BA2M, 1981BA2R, 1981BE1F, 1981BE63, 1981BE1N, 1981BE2P, 1981BE1X, 1981BL1E, 1981BO06, 1981BO1L, 1981BO1N, 1981BU1E, 1981BU18, 1981BU1G, 1981CH1D, 1981CH1E, 1981CO14, 1981CO1R, 1981DE01, 1981DE1R, 1981DE1U, 1981DU1H, 1981DZ03, 1981FE2A, 1981FO1C, 1981FR1F, 1981GA1F, 1981GI1E, 1981GI15, 1981GO1F, 1981GO1G, 1981GR1E, 1981GU1H, 1981HA1L, 1981HA29, 1981HO1F, 1981HU1E, 1981IO01, 1981KA05, 1981KA1N, 1981KA27, 1981KA43, 1981LE12, 1981LI1Y, 1981MA23, 1981MC09, 1981MO1D, 1981MO17, 1981NG1A, 1981NI03, 1981PE1C, 1981PI05, 1981PI1C, 1981PR02, 1981SA01, 1981SA14, 1981SC1F, 1981SE1H, 1981SE1B, 1981SI05, 1981SI09, 1981ST05, 1981ST14, 1981ST1K, 1981TH1B, 1981TO1H, 1981TO01, 1981VO1D, 1981WE1C, 1981WE1H, 1981WH01, 1981ZI01, 1982AN1J, 1982AP1A, 1982AP1B, 1982BE51, 1982BE1D, 1982BI08, 1982BL1G, 1982BO11, 1982BU20, 1982CA03, 1982CH13, 1982CH1Q, 1982DA18, 1982DA27, 1982DE1K, 1982DI1C, 1982DO01, 1982EL07, 1982ER04, 1982FR02, 1982FR16, 1982GO1E, 1982GO1F, 1982GO01, 1982GO15, 1982GR1F, 1982GRZW, 1982GR1Q, 1982GR1R, 1982HA35, 1982HE1E, 1982IL02, 1982IN1A, 1982IS10, 1982KH1D, 1982LE15, 1982LI10, 1982MA1F, 1982MA1K, 1982MA22, 1982MA1U, 1982MO01, 1982MO1G, 1982MO1H, 1982MO25, 1982MO1W, 1982NA16, 1982NA18, 1982OH06, 1982OS01, 1982OS1C, 1982PI03, 1982PI1F, 1982PI04, 1982RA28, 1982SE09, 1982THZZ, 1982VO1G, 1982WE09, 1983AG1D, 1983AK03, 1983AL07, 1983AS01, 1983AS02, 1983AS1C, 1983AU1A, 1983AZ1B, 1983BA1V, 1983BA13, 1983BI1J, 1983BI1K, 1983BI1N, 1983BL08, 1983BL10, 1983BO1K, 1983CA24, 1983CE04, 1983CO08, 1983CO12, 1983DE06, 1983DE2F, 1983ER1D, 1983FR22, 1983GA17, 1983GE12, 1983GI08, 1983GU1A, 1983HE17, 1983HUZZ, 1983JE04, 1983KA19, 1983KO02, 1983MA04, 1983MA2C, 1983MA56, 1983MO1F, 1983MO1M, 1983NE1F, 1983PE14, 1983PI1A, 1983RA20, 1983RA31, 1983RI1C, 1983SC03, 1983SC11, 1983SE10, 1983SE11, 1983SH2C, 1983SH2G, 1983SP06, 1983SU08, 1983TO17, 1983YO04, 1983ZA1D, 1983ZE1C, 1983ZIZZ, 1983ZI1B, 1983ZI1D, 1984BE07, 1984BU1D, 1984CO02, 1984CO1U, 1984DIZZ, 1984MIZW, 1984PO05, 1984SH02, 1984TO03).

Kaon capture and reactions (See also reaction 38.): (1978FU1F, 1978GR1D, 1978LE1G, 1978SO1A, 1979CH1H, 1979CH34, 1979DO18, 1979DU1B, 1979GS1A, 1979RA18, 1979WA1G, 1980CO04, 1980DE11, 1980DO1A, 1980DO1F, 1980DO1G, 1980EI1B, 1980HE1B, 1980HU1H, 1980KI1C, 1980PO1A, 1980RO15, 1980SA27, 1980ZA08, 1981AB1C, 1981BE45, 1981BE1T, 1981BE17, 1981BO09, 1981DA1C, 1981DE1E, 1981DO1F, 1981HU1C, 1981MI15, 1981PA16, 1981PO1F, 1981SA41, 1982AB07, 1982BA1R, 1982BA17, 1982BE1U, 1982BE1V, 1982BO1U, 1982CO1W, 1982DO1L, 1982DO1M, 1982GR1G, 1982MA16, 1982SA10, 1982WU1C, 1983AU1A, 1983BA71, 1983BA2P, 1983BE1A, 1983BR1E, 1983CH26, 1983CO1L, 1983DO1B, 1983FE07, 1983GA17, 1983GE13, 1983MA1V, 1983PO1D, 1983YA1C, 1984AM06, 1984BE07, 1984DO04, 1984MIZW, 1984SIZZ).

Antiproton and antineutron reactions (See also reaction 41.): (1978GR1D, 1981AI01, 1981YA1C, 1982IL1A, 1982IL1B, 1982ZH1G, 1983MO1K, 1983NI07, 1983SU04, 1984CO1M, 1984MA17, 1984WO01).

Table 12.6: Energy levels of ^{12}C [a]

E_x in ^{12}C (MeV $\pm$ keV)	$J^\pi; T$	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
g.s.	0^+; 0	—	stable	3, 8, 9, 10, 11, 17, 18, 19, 20, 21, 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, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94
4.43891 ± 0.31	2^+; 0	$(10.8 \pm 0.6) \times 10^{-6}$	γ	3, 8, 9, 10, 11, 17, 18, 19, 20, 21, 25, 26, 27, 28, 29, 34, 35, 37, 38, 39, 40, 41, 43, 45, 46, 47, 48, 49, 50, 51, 52, 53, 58, 63, 64, 65, 66, 67, 68, 69, 75, 76, 78, 79, 81, 82, 84, 85, 86, 87, 88, 90
7.6542 ± 0.15	0^+; 0	$(8.5 \pm 1.0) \times 10^{-3}$	γ, π, α	3, 8, 9, 10, 11, 17, 18, 19, 21, 26, 27, 29, 35, 37, 39, 40, 45, 46, 47, 50, 63, 65, 67, 69, 76, 81, 86, 87, 88
9.641 ± 5	3^-; 0	34 ± 5	γ, α	8, 9, 10, 17, 18, 19, 21, 25, 26, 27, 28, 35, 37, 38, 39, 40, 41, 45, 46, 47, 50, 52, 65, 69, 74, 86, 87, 88
10.3 ± 300	(0^+); 0	3000 ± 700	α	8, 29, 63
10.844 ± 16	1^-; 0	315 ± 25	α	8, 9, 17, 25, 26, 27, 35, 39, 40, 43, 45, 46, 47, 74

Table 12.6: Energy levels of ^{12}C [a] (continued)

E_x in ^{12}C (MeV ± keV)	$J^\pi; T$	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
(11.16 ± 50)	(2^+); 0	430 ± 80		26
11.828 ± 16	2^-; 0	260 ± 25	γ, α	9, 17, 19, 25, 26, 27, 34, 39, 40, 43, 45, 46, 47, 74
12.710 ± 6 [b]	1^+; 0	$(18.1 \pm 2.8) \times 10^{-3}$	γ, α	17, 18, 19, 25, 26, 27, 34, 35, 37, 39, 40, 42, 43, 45, 46, 47, 63, 65, 66, 67, 69, 76
13.352 ± 17	(2^-) [h]; 0	375 ± 40	γ, α	17, 26, 34, 39, 40, 47
14.083 ± 15	4^+; 0	258 ± 15	α	8, 17, 35, 39, 40, 42, 46, 47, 50, 53, 65, 76, 81, 86, 88
15.110 ± 3 [b]	1^+; 1	$(43.6 \pm 1.3) \times 10^{-3}$	γ, α	12, 13, 18, 19, 25, 26, 27, 35, 37, 39, 40, 41, 43, 45, 46, 63, 64, 65, 66, 67, 68
15.44 ± 40	$(2^+; 0)$	1500 ± 200		35, 37, 40, 45, 46
16.1067 ± 0.5	2^+; 1	$5.2^{+0.5}_{-0.3}$	γ, p, α	11, 13, 21, 25, 26, 27, 35, 37, 39, 40, 45, 46, 64, 65, 66, 67, 81
16.57	2^-; 1	300	γ, p, α	17, 21, 23, 35, 40, 45
17.23	1^-; 1	1150	γ, p, α	21, 23, 25, 34
17.76 ± 20	0^+; 1	80 ± 20	p, α	11, 21, 23, 35, 66, 81
18.13	$(1^+; 0)$	600 ± 100	γ, p	21, 35
18.35 ± 50	3^-; 1	220 ± 50	γ, p, α	17, 21, 23, 25, 26, 27, 37, 40, 43, 45, 50
18.35 ± 50	2^-; $0 + 1$	350 ± 50	p	17, 23, 25, 26, 27, 37, 40, 43, 45, 50
(18.6 ± 100)	(3^-)	300		35
18.71	$(T = 1)$	100	p, α	21
18.80 ± 40	2^+; 1	100 ± 10	γ, n, p	21, 22, 23, 66
19.2	$(1^-; 1)$	≈ 1100	γ, n, p, α	21, 22, 23, 26, 40, 45, 65

Table 12.6: Energy levels of ^{12}C [a] (continued)

E_x in ^{12}C (MeV ± keV)	$J^\pi; T$	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
19.40 ± 30 [f]	$(2^-; 1)$	480 ± 40	γ, p, α	21, 35, 40, 42
19.55 ± 50 [f,g]	$(4^-; 1)$	490 ± 60	γ, p, α	25, 26, 35, 37
19.69	1^+	230 ± 35	n, p	22
20.0 ± 100	(2^+)	≈ 100	γ, n, p	22, 23, 35
20.27 ± 50	$(1^+; 1)$	140 ± 50	n, p	22, 23, 40
20.5 ± 100	$(3^+; 1)$	180	γ, p, α	17, 21, 25, 35, 65
20.62 ± 60	$(3^-; 1)$	200 ± 40	γ, n, p, α	21, 22, 23, 25, 26, 40, 43, 65
20.98		270	n, p	22
21.60 ± 100 [e]	3^-, 2^+	1200 ± 150	γ, n, p, α	21, 22, 23, 35, 40, 42, 45, 46, 66
22.0 ± 100	$1^-; 1$	800 ± 100 [i]	γ, n, p	22, 23, 35, 40, 42, 43
22.40 ± 40	$1^-; 1$	275 ± 40	n, p	22, 23, 26, 40, 42, 46, 66
22.65 ± 70	$1^-; 1$	3200	γ, n, p, α	21, 22, 30, 31, 35, 40
23.04	$(2^-; 1)$	60	n, p	22
23.52 ± 30	$1^-; 1$	230 ± 80	γ, n, p, α	11, 21, 22, 35, 40, 45
23.92 ± 80	$(1^-; 1)$	400 ± 100	γ, n, p	22, 35, 40
24.43		100	n, p	22
24.92		920	n, p	22
25.3 ± 150	$(1^-; 1)$	510 ± 100	n, p	22
25.4	$1^-; 1$	≈ 2000 [d]	γ, n, p	21, 30, 31, 40, 45, 46
25.95		≈ 400	n, p, d, α	13, 16, 22
26.8		270	n, p, d, α	16, 22, 42
27.0 ± 300	$(1^-; 1)$	1400 ± 200	γ, p	21, 43, 46
27.5950 ± 2.4	$0^+; 2$	≤ 30		11, 72
27.9		≈ 350	γ, n, p, ^{3}He	4, 21
28.2	$1^-; 1$	1600	γ, ^{3}He	3
28.83 ± 40		1540 ± 90	γ, p, d, ^{3}He, α	3, 16, 21, 45, 46
29.4 ± 300		1400 ± 200	γ, n, p, t, ^{3}He	4, 5, 21, 40
29.63 ± 50	$T = 2$	$\lesssim 200$		72

Table 12.6: Energy levels of ^{12}C [a] (continued)

E_x in ^{12}C (MeV ± keV)	$J^\pi; T$	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
30.29 ± 30		1960 ± 150	γ, ^{3}He, α	1, 3
31.16 ± 30		2100 ± 150	γ, ^{3}He	3
32.29 ± 40		1320 ± 230	γ, ^{3}He	3
33.47 ± 210 [c]		1930 ± 50	γ, ^{3}He	3

[a] See also Table 12.7 here and Table 12.12 in (1980AJ01).
[b] See also Table 12.10.
[c] See also reaction 2.
[d] See, however, Table 12.11.
[e] Probably unresolved states: see footnote [g] in Table 12.19.
[f] See the discussion in (1983NE11).
[g] (1983BA62) suggests an isospin-mixed doublet with $J^\pi = 4^-$.
[h] Probably 4^- (D.J. Millener, private communication). I am indebted to Dr. Millener for his comments on the states of ^{12}C.
[i] See, however, Table 12.12.

Hypernuclei: (1978SO1A, 1979BU1C, 1979CH1H, 1979CH34, 1979DO18, 1980DO1A, 1980IW1A, 1980KI1F, 1980MA2D, 1980PA1G, 1980PO1A, 1980ZH1C, 1981BE45, 1981BE17, 1981BO09, 1981DA1C, 1981PO1F, 1981WA1J, 1981ZH1C, 1982BA17, 1982BE1U, 1982BO1U, 1982BR1Q, 1982DO1C, 1982DO1M, 1982ER1B, 1982ER1E, 1982GR1G, 1982JO1C, 1982KA1D, 1982KO1K, 1982KO11, 1982MU1F, 1982PO1C, 1982WU1C, 1982ZH1F, 1982ZO1B, 1983AU1A, 1983BA2P, 1983BR1E, 1983FE07, 1983GA17, 1983JO1E, 1983MA1F, 1983PO1D, 1983SH38, 1983SI1E, 1983SI1H, 1983YA1C, 1983ZH1B, 1984BE07, 1984DI1B, 1984DO04, 1984MIZW, 1984SIZZ).

Other topics: (1979DO1J, 1979GA1E, 1979GO24, 1979HA53, 1979HA59, 1979KA40, 1979KA43, 1979LO13, 1979NO05, 1979WU1C, 1979ZH1B, 1980BO1N, 1980DO1A, 1980GI05, 1980HE07, 1981AU05, 1981BE1M, 1981CA1H, 1981GR15, 1981GU1C, 1981LO04, 1981MU1H, 1981PO1F, 1981ST1G, 1981ST1N, 1982BA1Q, 1982BA2G, 1982BA17, 1982BE17, 1982BO01, 1982BR08, 1982DE1G, 1982DE1N, 1982DE42, 1982LU02, 1982MU1F, 1982NG01, 1982PO1C, 1982SH1H, 1982SP1C, 1982SU06, 1982VE02, 1983AD1B, 1983AG1C, 1983AR07, 1983BO1J, 1983DA23, 1983GO1R, 1983GR26, 1983KE1E, 1983LO04, 1983SH2D, 1983WO1C, 1984CO1P, 1984DE04, 1984DU04, 1984SC1A).

Ground-state properties of ^{12}C: (1978SH1B, 1979HA53, 1979HA59, 1979IN07, 1979JO08, 1979KA40, 1979KA1M, 1979SA27, 1979UE03, 1980BA45, 1980BO1N, 1980GI05, 1980HA38, 1980SC18, 1981AM08, 1981AT1A, 1981AV02, 1981BA2T, 1981DU16, 1981LO04, 1981KA03,

1981MO12, 1981ST1N, 1982AR03, 1982BA2G, 1982BA37, 1982BO01, 1982DE35, 1982FR01, 1982LO13, 1982MA38, 1982NG01, 1982SC11, 1982SC1K, 1982SH1H, 1982SI13, 1982ZE1A, 1983ANZQ, 1983AR07, 1983AU1B, 1983CO09, 1983CO1T, 1983FR1B, 1983GI06, 1983KU06, 1983MI08, 1983TO1L, 1983VA31, 1984BU1N, 1984MI1B, 1984WE04).

$\langle r^2\rangle^{1/2} = 2.4832 \pm 0.0018$ fm (1982RU06). See also reaction 35.

The static electric quadrupole moment of ^{12}C*(4.4), $Q_{2^+} = 6{\pm}3\ e{\cdot}\text{fm}^2$, indicating a substantial oblate deformation (1983VE01).

1. (a) ^{6}Li(^{6}Li, n)^{11}C	$Q_\text{m} = 9.450$	$E_\text{b} = 28.171$
(b) ^{6}Li(^{6}Li, p)^{11}B	$Q_\text{m} = 12.215$	
(c) ^{6}Li(^{6}Li, d)^{10}B	$Q_\text{m} = 2.985$	
(d) ^{6}Li(^{6}Li, α)^{8}Be	$Q_\text{m} = 20.804$	
(e) ^{6}Li(^{6}Li, nα)^{7}Be	$Q_\text{m} = 2.768$	
(f) ^{6}Li(^{6}Li, pα)^{7}Li	$Q_\text{m} = 3.550$	
(g) ^{6}Li(^{6}Li, 2α)^{4}He	$Q_\text{m} = 20.896$	
(h) ^{6}Li(^{6}Li, 2d)^{4}He^{4}He	$Q_\text{m} = -2.951$	

For the earlier work see (1980AJ01). (1983MI10) (reaction (d)) report a structure in the excitation function attributed to a state of ^{12}C at 30.3 MeV. Cross sections for reaction (e) and the (^{6}Li, ^{5}He) reaction have been measured by (1977RU1A, 1979RU07) for $E(^6\text{Li}) = 2.3$ to 15 MeV. (1983WA09) have studied the 3α and $2\alpha + 2$d reactions (reactions (g) and (h)) at $E(^6\text{Li}) = 97.5$ MeV. The single-spectator pole model describes the 3α results well. The yield of the $2\alpha + 2$d reaction is lower at this energy than in the earlier work at 40 MeV: this is associated with the rise in the cross section for reaction (g). See also (1979WA13, 1981WA15, 1982LA19) and ^{8}Be in (1984AJ01). See also (1981NO06, 1981NO1E) and (1983KA1G, 1983KAZF).

2. (a) ^{6}Li(^{6}Li, ^{6}He)^{6}Be	$Q_\text{m} = -7.795$	$E_\text{b} = 28.171$
(b) ^{6}Li(^{6}Li, ^{6}Li)^{6}Li		

Broad structures are reported in the excitation functions for reaction (b) at $E(^6\text{Li}) \approx 13$ and ≈ 26 MeV. Total reaction cross sections for the elastic scattering have been measured at $E(^6\text{Li}) = 2.0$ to 5.5 MeV (1983NO08). Polarization measurements have been studied at $E(^6\vec{\text{Li}}) = 20.0$ MeV for the transitions to ^{6}Li*(0, 2.19) (1981AV1B). See also (1980AJ01), ^{6}He and ^{6}Li in (1979AJ01) and (1979DO1J; theor.).

Table 12.7: The decay of some ^{12}C levels [a]

E_x (MeV)	Widths	E_x (MeV)	Widths
4.44	$\Gamma_\gamma = 10.8 \pm 0.6$ meV	15.11	$\Gamma_\gamma(15.11 \rightarrow 7.65) = 1.09 \pm 0.14$ eV [f]
7.65	$\Gamma_\pi/\Gamma = (6.8 \pm 0.7) \times 10^{-6}$		$\Gamma_\gamma(15.11 \rightarrow 12.71) = 0.59 \pm 0.14$ eV [f]
	$\Gamma_\pi = (60.5 \pm 3.9)\ \mu$eV		$\Gamma_\gamma = 41.8 \pm 1.2$ eV [f]
	$\Gamma_{\rm rad}/\Gamma = (4.13 \pm 0.11) \times 10^{-4}$ [b]		$\Gamma_\alpha/\Gamma = 0.041 \pm 0.009$ [f]
	$\Gamma = 8.3 \pm 1.0$ eV		$\Gamma_\alpha = 1.8 \pm 0.3$ eV
	$\Gamma_{\rm rad} = 3.7 \pm 0.5$ meV		$\Gamma = 43.6 \pm 1.3$ eV
9.64	$\Gamma_{\rm rad}/\Gamma < 4.1 \times 10^{-7}$	16.11 [g]	$\Gamma = 5.2^{+0.5}_{-0.3}$ keV
	$\Gamma_{\rm rad} < 14$ meV [c]		$\Gamma_{\gamma0}/\Gamma_{\gamma1} = (4.6 \pm 0.7)\%$
	$\Gamma_{\gamma0} = (3.1 \pm 0.4) \times 10^{-4}$ eV		$\Gamma_{\gamma1}/\Gamma = (2.42 \pm 0.29) \times 10^{-3}$
12.71	$\Gamma_{\gamma0}/\Gamma = (1.93 \pm 0.12) \times 10^{-2}$		$\Gamma_\gamma(16.11 \rightarrow 9.64)/\Gamma_{\gamma1} = (2.4 \pm 0.4)\%$
	$\Gamma_{\gamma1}/\Gamma_{\gamma0} = 0.150 \pm 0.018$ [d]		$\Gamma_\gamma(16.11 \rightarrow 12.71)/\Gamma_{\gamma1} = (1.46 \pm 0.25)\%$
	$\Gamma_{\gamma0} = 0.35 \pm 0.05$ eV		$\Gamma_{\gamma0} = 0.37 \pm 0.05$ eV
	$\Gamma_{\gamma1} = 0.053 \pm 0.010$ eV		$\Gamma_{\gamma1} = 12.6 \pm 1.8$ eV
	$\Gamma = 18.1 \pm 2.8$ eV		$\Gamma_\gamma = (16.11 \rightarrow 9.64) = 0.30 \pm 0.07$ eV
	$\Gamma_\alpha = 17.7 \pm 2.8$ eV [e]		$\Gamma_\gamma(16.11 \rightarrow 12.71) = 0.19 \pm 0.04$ eV
15.11	$\Gamma_{\gamma0} = 38.5 \pm 0.8$ eV [h]	16.57	$\Gamma_{\gamma0} = (48 \pm 8) \times 10^{-3}$ eV
	$\Gamma_{\gamma1} = 0.96 \pm 0.13$ eV [f]		

[a] For references see Table 12.8 in (1980AJ01). See also Tables 12.8, 12.11 and 12.15 here.

[b] $\Gamma_{\rm rad} \equiv \Gamma_\gamma + \Gamma_\pi$.

[c] Based on $\Gamma = 34 \pm 5$ keV: Table 12.6.

[d] The branching ratios for the $12.71 \rightarrow 4.44$ and $12.71 \rightarrow 0$ transitions are $(13.0 \pm 1.4)\%$ and $(87.0 \pm 1.4)\%$, respectively (1977AD02).

[e] Assuming $\Gamma_\alpha + \Gamma_{\gamma0} + \Gamma_{\gamma1} = \Gamma$.

[f] Based on $\Gamma_{\gamma0}$ of (1983DE53) and on branching ratios of (1972AL03): ^{12}C*(15.11) $\rightarrow$ ^{12}C*(0, 4.4, 7.65, 12.71) are (92 ± 2), (2.3 ± 0.3), (2.6 ± 0.7) and $(1.4 \pm 0.4)\%$, respectively. In addition, an undetected branching of 1.6% to ^{12}C*(10.3) is indicated by the β-decay work (1972AL03). See also (1980AJ01).

[g] We are grateful to E.G. Adelberger for his comments.

[h] (1983DE53).

Table 12.8: Resonances in ^{9}Be(^{3}He, γ)^{12}C [a]

$E(^{3}\mathrm{He})$ (MeV ± keV)	Res. in	E_{x} (MeV)	$\Gamma_{\mathrm{c.m.}}$ (MeV)
2.55 [b]	γ_0, γ_2	28.2	1.6
3.40 ± 40	γ_0, γ_2	28.83	1.54 ± 0.09
5.35 ± 30	γ_1	30.29	1.96 ± 0.15
6.51 ± 30	γ_0	31.16	2.10 ± 0.15
8.02 ± 40	γ_1, γ_2	32.29	1.32 ± 0.23
9.60 ± 210	γ_1, γ_2	33.47	1.93 ± 0.05

[a] See (1980AJ01) for references.
[b] $\Gamma_\gamma \geq 11.8$ eV [γ_0], ≥ 4.6 eV [γ_1], ≥ 11.3 eV [γ_2], assuming $J = 1$, $\Gamma(^{3}\mathrm{He}) = \Gamma$; $J^\pi = 1^-$; $T = 1$.

3. ^{9}Be(^{3}He, γ)^{12}C $\qquad Q_{\mathrm{m}} = 26.2788$

Observed resonances are displayed in Table 12.8. ^{12}C*(28.2) appears to be formed by s- and d-wave capture. The γ_0 and γ_2 transitions to the 0^+ states ^{12}C*(0, 7.7) are strong and show a similar energy dependence. A strong non-resonant contribution is necessary to account for the γ_1 yield. The resonance structure reported by (1974SH01) appears to confirm the role of 3p3h configurations for ^{12}C excitations somewhat above the giant resonance region. The γ_3 yield is relatively unstructured. See also (1983MAZZ) and (1975AJ02).

4. (a) ^{9}Be(^{3}He, n)^{11}C $\qquad Q_{\mathrm{m}} = 7.558 \qquad E_{\mathrm{b}} = 26.2788$
   (b) ^{9}Be(^{3}He, p)^{11}B $\qquad Q_{\mathrm{m}} = 10.3227$
   (c) ^{9}Be(^{3}He, 2p)^{10}Be $\qquad Q_{\mathrm{m}} = -0.9061$

Excitation functions for neutrons, production cross sections for ^{11}C and polarizations have been measured for $E(^{3}\mathrm{He}) = 1.2$ to 10 MeV for several neutron groups: see (1968AJ02, 1975AJ02) for a listing of the earlier references. No sharp structure is observed but there is some suggestion from angular distribution data and excitation functions at forward angles for a broad structure ($\Gamma \approx 350$ keV) at $E(^{3}\mathrm{He}) \approx 2$ MeV: $E_{\mathrm{x}} = 27.8$ MeV. The total cross section for ^{11}C production shows a broad maximum, $\sigma = 113$ mb at $E(^{3}\mathrm{He}) = 4.3$ MeV. In the range $E(^{3}\mathrm{He}) = 5.7$ to 40.7 MeV it decreases monotonically (1981AN16). Excitation functions and angular distributions for protons (reaction (b)) have been measured for $E(^{3}\mathrm{He}) = 1.0$ to 10.2 MeV for a number of proton groups: see (1968AJ02, 1975AJ02) for a listing of the earlier references. No pronounced structures are reported. (1982HA06) have measured the polarization of the protons for $E(^{3}\mathrm{He}) = 13.6$ MeV.

The results are in agreement with earlier measurements of the analyzing power of the ^{11}B($\vec{\rm p}$, ^{3}He) reaction. The equal values for the polarization and the analyzing power are in agreement with the time-reversal invariance (1982HA06). This is confirmed by (1984TR03) [E(^{3}He) $= 14$ MeV]. See also, however, (1981SL03, 1983LE17, 1983RI01, 1984PO02). Polarization measurements are also reported at E(^{3}He) $= 13.0$ to 14.2 MeV (1983PO13) and $E(^3\vec{\rm He}) = 14$ MeV (1983RO22). See also (1983HA1H). For reaction (c) see (1980CO12).

5. (a) ^{9}Be(^{3}He, d)^{10}B $\quad Q_{\rm m} = 1.0930 \quad E_{\rm b} = 26.2788$

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

Analyzing powers have been measured at $E(^3\vec{\rm He}) = 33.3$ MeV for nine proton groups. The cross section for ground-state tritons (reaction (b)) inceases monotonically for E(^{3}He) $= 2.5$ to 4.2 MeV and then shows a broad maximum at E(^{3}He) ≈ 4.5 MeV: see (1980AJ01) for references.

6. ^{9}Be(^{3}He, ^{3}He)^{9}Be $\quad E_{\rm b} = 26.2788$

The elastic scattering function decreases monotonically for E(^{3}He) $= 4.0$ to 9.0 MeV and 15.0 to 21.0 MeV. At $\theta_{\rm c.m.} = 111°$ a slight rise is observed for E(^{3}He) $= 19$ to 21 MeV. Polarization measurements have been reported at E(^{3}He) $= 18$, 31.4 and 32.8 MeV: see (1980AJ01) for references, and (1979KA1G).

7. ^{9}Be(^{3}He, α)^{8}Be $\quad Q_{\rm m} = 18.9123 \quad E_{\rm b} = 26.2788$

Excitation functions for the α_0 group have been reported for E(^{3}He) $= 2$ to 10 MeV. Analyzing powers have been measured at $E(^3\vec{\rm He}) = 33.3$ MeV: see (1980AJ01) for references and additional information. See also ^{8}Be in (1984AJ01).

8. ^{9}Be(α, n)^{12}C $\quad Q_{\rm m} = 5.7010$

Neutron groups have been observed to ^{12}C*(0, 4.4, 7.7, 9.6, (10.1), (10.8)). Angular distributions of neutron groups have been measured at many energies in the range $E_\alpha = 1.75$ to 23 MeV: see (1968AJ02, 1975AJ02) for references. At $E_\alpha = 35$ MeV the members of the $K^\pi = 0^+$ band and ^{12}C*(9.63) are strongly populated (1981HA1J). See also (1981HA1K) and (1980JA1G, 1982SA1M; applied).

9. ^{9}Be(^{6}Li, t)^{12}C $\qquad Q_{\rm m} = 10.483$

At $E(^{9}{\rm Be}) = 26$ MeV, $\theta_{\rm lab} = 10°$, ^{12}C*(0, 4.4, 7.7, 9.6, 10.8, 11.8) are populated: the strongest transition is to ^{12}C*(9.6) (1975VE10). See also (1981KE1F).

10. ^{9}Be(^{9}Be, ^{6}He)^{12}C $\qquad Q_{\rm m} = 5.103$

At $E(^{9}{\rm Be}) = 26$ MeV, $\theta = 10°$, strong transitions are observed to ^{12}C*(4.4, 7.7, 9.6) (1975VE10). See also (1981BR1H; theor.).

11. ^{10}Be(^{3}He, n)^{12}C $\qquad Q_{\rm m} = 19.467$

At $E(^{3}{\rm He}) = 13$ MeV neutron groups are observed to ^{12}C*(0, 4.4, 7.7, 16.1, 17.8) and to excited states at $E_{\rm x} = 23.53 \pm 0.04$ [$\Gamma < 0.4$ MeV] and 27.611 ± 0.020 MeV. The latter is formed with a $0°$ cross section of ≈ 200 μb/sr and is taken to be the first 0^{+}, $T = 2$ state of ^{12}C (1974GO23).

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

The (d, $\gamma\gamma$) excitation function [via the $J^{\pi} = 1^{+}$, $T = 1$ state at $E_{\rm x} = 15.1$ MeV] has been measured for $E_{\rm d} = 2.655$ to 2.91 MeV. The non-resonant yield of 15 MeV γ-rays is due to a direct capture process or to a very broad resonance: see (1975AJ02).

13. ^{10}B(d, n)^{11}C $\qquad Q_{\rm m} = 6.465 \qquad E_{\rm b} = 25.1858$

The thin-target excitation function in the forward direction in the range $E_{\rm d} = 0.3$ to 4.6 MeV shows some indication of a broad resonance near $E_{\rm d} = 0.9$ MeV. Above $E_{\rm d} = 2.4$ MeV, the cross section increases rapidly to 210 mb/sr at 3.8 MeV, and then remains constant to 4.6 MeV. Excitation functions have also been measured for $E_{\rm d} = 3.2$ to 9.0 MeV [see (1975AJ02)] and 7.0 to 16.0 MeV (1981AN16). (1982CE02) report thick-target yields for 4.3 MeV γ-rays for $E_{\rm d} = 111$ to 170 keV; astrophysical S-factors were also calculated. See aslo (1983SZZY; astrophys.), (1979LE1D; applied) and ^{11}C.

14. ^{10}B(d, p)^{11}B $\qquad Q_{\rm m} = 9.2297 \qquad E_{\rm b} = 25.1858$

Thick-target yields have been measured for $E_d = 91$ to 161 keV (1981CE04; also calculated astrophysical S-factor). Yields of protons have been measured for $E_d = 0.14$ to 12 MeV. No clear resonance structure is observed: see (1968AJ02, 1975AJ02) [see also for polarization studies]. See also ^{11}B.

15. ^{15}B(d, d)^{10}B $E_b = 25.1858$

The yield of elastically scattered deuterons has been measured for $E_d = 1.0$ to 2.0 MeV (there is some suggestion of resonances) and for $E_d = 14.0$ to 15.5 MeV. Excitation functions for the deuterons to ^{10}B*(1.74, 2.15) [J^π; $T = 0^+$; 1 and 1^+; 0, respectively] have been measured at several angles for $E_d = 4.2$ to 16 MeV; they are characterized by rather broad, slowly-varying structures: see (1980AJ01) [and see for polarization measurements]. See also ^{10}B in (1984AJ01).

16. (a) ^{10}B(d, α)^{8}Be $Q_m = 17.8193$ $E_b = 25.1858$

(b) ^{10}B(d, 2α)^{4}He $Q_m = 17.9111$

Excitation functions have been measured for the α_0 and α_1 groups for $E_d = 0.4$ to 12 MeV. Broad maxima in the α_0 yield are reported at $E_d \approx 1$ ($\Gamma \approx 0.5$), 2 and 4.5 MeV ($\Gamma \gtrsim 1$ MeV) as well as, possibly, at 6 MeV. Involvement of the isoscalar giant quadrupole resonance [$E_x \approx 28$ MeV, $\Gamma \approx 4$ MeV] is suggested: see (1980AJ01). For reaction (b) see ^{8}Be in (1984AJ01) and (1980AJ01).

17. (a) ^{10}B(^{3}He, p)^{12}C $Q_m = 19.6923$

(b) ^{10}B(^{3}He, pα)^{8}Be $Q_m = 12.3258$

(c) ^{10}B(^{3}He, 2p)^{11}Be $Q_m = 3.7361$

(d) ^{10}B(^{3}He, pn)^{11}C $Q_m = 0.972$

Proton groups are displayed in Table 12.9. Angular distributions of many of these groups have been measured for $E(^{3}\mathrm{He}) = 1.4$ to 14 MeV: see (1968AJ02) for references. Reactions (b) and (c) have been used to study the α- and the p-decay of a number of ^{12}C states. For a study of the matrix element between ^{12}C*(12.7, 15.1) see Table 12.10. See also (1979SH1K, 1983CH08).

18. ^{10}B(α, d)^{12}C $Q_m = 1.3391$

Angular distributions have been measured at $E_\alpha = 15.1$ to 25.2 MeV [see (1980AJ01)] and at 29.5 MeV (1982VA1F). See also Table 12.9 and (1983BE1Q; theor.).

Table 12.9: ^{12}C states from ^{10}B(^{3}He, p)^{12}C

E_x (MeV $\pm$ keV)	$\Gamma_{c.m.}$ (keV)	Alpha decay to		Parity	J^π; T
		^{8}Be$_{g.s.}$	^{8}Be*(2.9)		
4.44					
7.65		yes		natural	0^+
9.64	36 ± 6	yes	yes	natural	
10.849 ± 25	320 ± 30	strong	yes	natural	
11.841 ± 25	245 ± 30	no	yes	unnatural	
12.713 ± 6 [b,c]	≈ 350 [a]	no	yes [c]	unnatural	1^+
13.29 ± 30		no	yes	unnatural	≥ 1
14.083 ± 15 [c]	252 ± 15	yes	yes [c]	natural	≥ 2
15.108 ± 6 [b,c]					1^+; 1
16.108 ± 6 [b,c]		weak	yes [c]	natural	2^+
16.58		yes	yes	natural	
≈ 18.5 [c,d]	broad	(yes)			
≈ 19.5 [c]	broad		(yes)		
20.5 ± 100 [a,c,e]			yes		
22 [c,f]		(yes)			

[a] For references and additional information see Table 12.10 in (1980AJ01).

[b] $\Gamma_\gamma/\Gamma = 0.025 \pm 0.01, > 0.95$ and $(2.6 \pm 0.5) \times 10^{-3}$ for ^{12}C*(12.7, 15.1, 16.1) respectively. See Table 12.7 for branching ratios.

[c] (1982KA1M): $E(^3\text{He}) = 19$ MeV

[d] (1982KA1M) report the p_0 decay of ^{12}C*(18.3, 20.6) and the p_2 [to ^{11}B*(4.45)] decay of ^{12}C*(20.6, 22). See also reactions 27 and 76.

[e] A (^{3}He, pn) study suggests $J^\pi = 3^+, T = 1$ for this state (1970BO39).

[f] The α_0 decay of states with $20 < E_x < 25$ MeV is very unlikely, consistent with the population of $T = 1$ states: see reaction 21 in (1980AJ01).

Table 12.10: Charge-dependent matrix element between ^{12}C*(12.71, 15.11) ($J^\pi = 1^+$; $T = 0$ and 1, respectively) [a]

	Reaction	Reference
110 ± 30 keV	^{10}B(^{3}He, p)	(1977AD02)
285 ± 30 keV	^{10}B(α, d)	(1977LI02)
$130 \rightarrow 165$ keV	^{12}C(e, e)	(1979FL08)
148 ± 29 keV	^{12}C($\pi^\pm$, $\pi^\pm$)	(1981MO07)
324 ± 33 keV	^{12}C(d, d)	(1977LI02)
180 ± 80 keV	^{13}C(d, t)	(1977LI02)
120 ± 30 keV	^{13}C(d, t)	(1979CO08)
340 ± 60 keV	^{13}C(^{3}He, α)	(1974BA42)

[a] See also reactions 44 and 86 in (1980AJ01).

19. ^{10}B(^{6}Li, α)^{12}C $\qquad Q_m = 23.7105$

At $E(^6\text{Li}) = 4.9$ MeV angular distributions have been obtained for the α-particles to ^{12}C*(0, 4.4, 7.7, 9.6). The population of ^{12}C*(11.8, 12.7) is also reported, as is that of ^{12}C*(15.11) [$T = 1$]: see (1975AJ02) for references.

20. (a) ^{10}B(^{13}C, ^{11}C)^{12}C $\qquad Q_m = 4.526$
(b) ^{10}B(^{14}N, ^{12}C)^{12}C $\qquad Q_m = 14.9134$
(c) ^{10}B(^{16}O, ^{14}N)^{12}C $\qquad Q_m = 4.4495$

For reaction (a) see (1983DA20). Reaction (b) has been studied at energies to $E(^{14}\text{N}) = 93.6$ MeV, involving ^{12}C*(0, 4.4): see (1980AJ01). See also (1983KL1A). Reaction (c) has been investigated at $E(^{16}\text{O}) = 26$ to 32.5 MeV, involving ^{14}N$_{\text{g.s.}}$ and ^{12}C*(0, 4.4): see (1980AJ01). See also (1978BE1G).

21. (a) ^{11}B(p, γ)^{12}C $\qquad Q_m = 15.956$
(b) ^{11}B(p, α)^{8}Be $\qquad Q_m = 8.590$ $\qquad E_b = 15.956$
(c) ^{11}B(p, α)^{4}He^{4}He $\qquad Q_m = 8.681$

Table 12.11: Resonances [a] in ^{11}B(p, γ)^{12}C and ^{11}B(p, α)^{8}Be

Peak no.	E_p (MeV)	$\Gamma_{c.m.}$ (keV)	$\sigma(\gamma_0)$ (μb)	$\sigma(\gamma_1)$ (μb)	$\sigma(\alpha_0)$ (mb)	$\sigma(\alpha_1)$ (mb)	Γ_{γ_0} (eV)	Γ_{γ_1} (eV)	Γ_{α_0} (keV)	Γ_{α_1} (keV)	Γ_p (keV)	^{12}C* (MeV)	$J^\pi; T$
1	0.163 [b]	$5.2^{+0.5}_{-0.3}$	5.5	152	res.	res.	0.58 [c]	12.6 $\pm$1.8 [c]	0.290 $\pm$0.045	(6.3 $\pm$0.5)	0.0217 $\pm$0.0018	16.1059 $\pm$1.0 keV	$2^+; 1$
2	0.675	300	non-res.	48	non-res.	600	< 0.4	8.0	< 0.27	150	150	16.57	$2^-; 1$
3	1.388	1150	[27] [d]	3	3.3	≈ 180	44	5	10	140	1000	17.23	$1^-; 1$
4	2.00 [e]	96 ± 5	non-res.	non-res.	9.0	(25)			4.6	11.4	76	17.79	$0^+; 1$
5	2.37	600 ± 100		0.77 [f]								18.13	$(1^+; 0)$
6	2.64 [g]	≈ 400	weak?	res.	32.4 ± 4.8	270 ± 40	$\approx 2 \times 10^{-3}$	3.2	65	177	68	18.38	$3^-; 1$
7	2.66	43	non-res.	non-res.	non-res.	non-res.	< 0.5	< 0.5	< 1	< 5	33	18.39	0^-
8	3.01	100	non-res.	non-res.	3.4						< 10	18.71	n.π. [j]; (1)
9	3.12	100	weak	[20] [d]	non- res.	non-res.	(0.4)	2.0	< 0.2	< 1.5	97	18.81	$2^+; 1$
10	3.5	1100	[20] [d]	res.	5.2	res.	25	10	50	200	300	19.2	$(1^-; 1)$
11	3.75	(1100)	non-res.	res.	7.4 ± 1.1	300 ± 40	< 3	3	20	450	450	19.39	$(2^+; 0)$
12	4.93	180	non-res.	res.	res.	170 ± 40						20.47	
13	5.11	275	non-res.	[35] [d]	6.0 ± 0.9	non-res.						20.64	$(3^-; 1)$
14	5.85	300			res.							(21.31)	
15	6.0		res.	non-res.	res.							21.5	
16	6.7	500	res.	[35] [d]	res.							22.1	
17	7.25	3200	120	non-res.		res.	≥ 2500 [i]					22.6	$(1^-; 1)$
18	8.3		res.	res.	res.							23.6	
19	10.3	≈ 6500	[60] [d]	83								25.4	
20	11.76 [k]		non-res.	45 [h]	res.							26.72	(1^-)
21	12.5 [l]	≈ 700	21 [h]	non-res.								27.4	
22	13.0	≈ 6000			res.							27.9	
23	13.09		19 [h]	38 [h]								27.94	
24	13.8 [l]	≈ 2500	non-res.	25 [h]								28.6	
25	14.3 [k]		16 [h]	non-res.								29.0	
26	14.8	broad	res.									29.5	

[a] For references see (1975AJ02, 1980AJ01).

[b] E_{res}(c.m.) $= 149.8 \pm 0.2$ keV.

[c] See Table 12.7.

[d] Estimated.

[e] Decays via ^{12}C*(12.71) [$J^\pi; T = 1^+$; 0]: $\Gamma_\gamma = 3.7 \pm 1.5$ eV.

[f] Decays via ^{12}C*(15.11) [1^+; 1]: $(2J + 1)\ \Gamma_\gamma \geq 2.8 \pm 0.6$ eV.

[g] Γ_γ to ^{12}C*(9.6) $= 5.7 \pm 2.3$ eV, consistent with $J^\pi = 3^-$, $T = 1$.

[h] $4\pi \times \sigma(90^\circ)$.

[i] Assuming a single resonance.

[j] Natural parity.

[k] Resonant in γ_2.

[l] Resonant in γ_3.

In view of the complexity of the available information on these three reactions, we will first summarize the recent experimental results and then review the evidence for the parameters of ^{12}C states observed as resonances: see Table 12.11. See (1975AJ02, 1980AJ01) for references.

(a): In the range 4 MeV $< E_{\rm p} < 14.5$ MeV $\sigma(\gamma_0)$ is dominated by the giant dipole resonance at $E_{\rm p} = 7.2$ MeV ($E_{\rm x} = 22.6$ MeV, $\Gamma_{\rm c.m.} = 3.2$ MeV), while the giant resonance in γ_1 occurs at $E_{\rm p} \approx 10.3$ MeV ($E_{\rm x} = 25.4$ MeV, $\Gamma_{\rm c.m.} \approx 6.5$ MeV). Absolute cross-section measurements from $E_{\rm p} = 5$ to 14 MeV suggest that $\mathrm{d}\sigma/\mathrm{d}\Omega(90^\circ_{\rm L}) = 13.1 \pm 1.3$ μb/sr be used as a standard at the $E_{\rm p} = 7.25$ MeV peak of the GDR (1982CO11; also derived σ(E2) for $E_{\rm p} = 7$ to 14 MeV).

A study of the giant dipole resonance region with polarized protons ($E_{\rm p} = 6$ to 14 MeV) sets new limits on the configuration mixing in the γ_0 giant resonance. The analysis of γ_1 is more complicated: the asymmetry results are constant either with a single $J^\pi = 2^-$ state or with interference of pairs of states such as $(1^-, 3^-)$, $(2^-, 3^-)$ and $(1^-, 2^-)$. The 90° yield of γ_0, γ_1, γ_2 and γ_3 [to ^{12}C*(0, 4.4, 7.7, 9.6)] has been studied by (1977SN01): the γ_2 yield shows a peak at $E_{\rm p} \approx 14.3$ MeV with a cross section $\approx 2.3\%$ that of γ_0 [in γ_0 yield, $E_{\rm res} = 15.0$ MeV (1977SN01)] and perhaps as well a low-intensity structure at $E_{\rm p} = 11.8$ MeV. The γ_3 yield exhibits two asymmetric peaks at $E_{\rm p} = 12.5$ and 13.8 MeV ($\Gamma \approx 0.7$ and 2.5 MeV) and a weaker structure at ≈ 9.8 MeV (1977SN01).

(1983AN09) have measured the cross sections for γ_0 and γ_1 for $E_{\rm p} = 18$ to 43 MeV. They report giant resonances based on various excited states of ^{12}C at $E_{\rm x} = 22.5$ and 25.5 MeV (γ_0) 25.5, 27.4 and (31) MeV (γ_1), 27.4, 31 and (37) MeV (γ_3), as well as in the γ-yield to higher states (1983AN09). At $E_{\vec{\rm p}} = 28.7$ MeV (1980BL1B) and at $E_{\rm p} = 40$, 60 and 80 MeV radiative capture is observed to a state, or a narrow group of states, at $E_{\rm x} = 19.2 \pm 0.6$ MeV (1979KO05). See also (1981BL1H). (1982WE08) report the yield of γ-rays (γ_{19}) to ^{12}C*(18.43, 19.65, 20.68) [unresolved]. The angular distribution to one or more of these three states at $E_{\rm p} = 28.7$ MeV is reasonably in agreement with the predictions of an E1 + E2 direct-capture model although the analyzing powers are about a factor of two larger than the measured values at back angles (1982WE08) [yield of γ_{19} for $E_{\rm p} = 23$ to 60 MeV; γ_0 and γ_1 yields for $E_{\rm p} = 8$ to 60 MeV; angular distributions (γ_0, γ_1) at 14.5, 17.0 and 28.7 MeV]. At $E_{\vec{\rm p}} = 40$ and 50 MeV analyzing powers to ^{12}C*(0, 4.4, 9.6) and to many unresolved states with $E_{\rm x}$ to 35 MeV are reported by (1983NO1D).

(b): Excitation functions have been measured for $E_{\rm p} = 3.0$ to 18 MeV [see (1980AJ01)] as well as at $E_{\rm p} = 4.5$ to 7.5 MeV (1983BO19; $\sigma_{\rm tot}(\alpha)$), 5.4 to 7.5 MeV (1981HO13; $\sigma(150^\circ)$ for α_0) and 6 to 24 MeV (1983BU06; α_0, α_1). In the recent work resonances are observed at $E_{\rm p} = 5.10$ and 6.08 MeV (see Tables 12.11 and 12.12) (1983BO19) and some broad structures are reported by (1983BU06). See also ^{8}Be in (1984AJ01).

(c): This reaction has been studied for $E_{\rm p} = 35.4$ keV to 10.5 MeV [see (1980AJ01)] and at 20 MeV (1981LA07). The total cross section has been measured for $E_{\rm p} = 35.4$ to 1500 keV: it shows the 163 keV resonance and a broad peak centered at about 600 keV ($\sigma_{\rm max} \approx 0.9$ b). The 163 keV resonance has $\sigma_{\rm R} = 54 \pm 6$ mb and $\Gamma^{\rm R}_{\rm c.m.} = 5.2^{+0.5}_{-0.3}$ keV $E_{\rm res}$(c.m.) $= 149.8 \pm 0.2$ keV [$E_{\rm x} = 16.1059(10)$]. The astrophysical S-factor and the reaction rate $\langle\sigma\nu\rangle$ have been calculated. The values of $\langle\sigma\nu\rangle$ obtained in this work suggest that the ^{11}B(p, 3α) reaction may be a poorer candidate for CTR than previously thought (1979DA03). At higher energy the reaction proceeds predominantly by sequential two-body decays via ^{8}Be*(0, 2.9): see ^{8}Be in (1984AJ01).

Contributions from ^{12}C*(23.0, 23.6 and 25.4) are also reported: see (1980AJ01).

See also (1979RA20, 1980CO16, 1981HO1C, 1981NA06, 1983MAZI, 1983NO1G), (1979HA1G), (1980DO1C; astrophys.) and (1979TS02, 1980OH07, 1981HA01, 1981RA15, 1982DU1A, 1982LA03, 1982LO08, 1983CO1A, 1983GO1B, 1983KU06, 1983LO15, 1983LU1A, 1983RA31, 1984GO1M, 1984LU03; theor.).

The parameters of the observed resonances are displayed in Table 12.11. The following summarizes the information on the low-lying resonances: for a full list of references see (1968AJ02, 1980AJ01).

$E_p = 0.16 MeV$ [^{12}C*(16.11)]. This is the $J^\pi = 2^+$; $T = 1$ analog of the first excited states of ^{12}B and ^{12}N. The γ-decay is to ^{12}C*(0, 4.4, 9.6), and also ^{12}C*(12.71) [see Table 12.7]: the angular distribution of γ_3, together with the known α-decay of ^{12}C*(9.6), fix $J^\pi = 3^-$ for the latter.

$E_p = 0.67 MeV$ [^{12}C*(16.57)]. The proton width [$\Gamma_p \approx 150$ keV] indicates s-wave protons and therefore $J^\pi = 1^-$ or 2^-. This is supported by the near isotropy of the two resonant exit channels, α_1 and γ_1. The α_1 cross section indicates $2J + 1 \geq 5$: therefore $J^\pi = 2^-$, [This is consistent with the results of an $\alpha\alpha$ correlation study via ^{8}Be*(2.9).] The γ_1 E1 transition has $|M|^2 \approx 0.1$ W.u., suggesting $T = 1$.

$E_p = 1.4 MeV$ [^{12}C*(17.23)]. $(2J + 1)\Gamma_{\gamma_0} \geq 115$ eV. This indicates $J^\pi = 1^-$, with $T = 1$ most probable. $J^\pi = 1^-$ is also required to account for the interference at lower energies in α_0 and γ_0 and is consistent with the $\alpha\alpha$ correlation results. Two solutions for Γ_p are possible; the larger (chosen for Table 12.11) is favored by elastic scattering data.

$E_p = 2.0 MeV$ [^{12}C*(17.8)]. The resonance in the yield of α_0 requires natural parity, the small α-widths suggest $T = 1$. For $J^\pi = 1^-$ or 3^- the small γ-widths would be surprising; $J^\pi = 2^+$ would lead to a larger anomaly than is observed. J^π is then 0^+, $T = 1$. (1982HA12) [$E_p = 0.82$ to 2.83 MeV] report $E_x = 17.80$ MeV [$\Gamma_{c.m.} = 96 \pm 5$ keV] decays via a 5.10 ± 0.03 MeV γ-ray to ^{12}C*(12.71): $\Gamma_\gamma = 3.7 \pm 1.5$ eV. The angular distribution is isotropic, as expected (1982HA12).

$E_p = 2.37 MeV$ [^{12}C*(18.13)]. Seen as a resonance in the yield of 15.1 MeV γ-rays: $\sigma_R = 0.77 \pm 0.15$ μb, $\Gamma_{c.m.} = 600 \pm 100$ keV, $(2J+1)\Gamma_\gamma \geq 2.8 \pm 0.6$ eV. The results are consistent with $J^\pi = 1^+$, $T = 0$, but interference with a non-resonant background excludes a definite assignment.

$E_p = 2.62 MeV$ [^{12}C*(18.38)]. The resonance for α_0 requires natural parity; the presence of a large P_4 term in the angular distribution requires $J \geq 2$ and $l_p \geq 2$. (1982HA12) report $E_x = 18.38$ MeV, $\Gamma_{c.m.} \approx 400$ keV, Γ_γ (to ^{12}C*(9.6)) $= 5.7 \pm 2.3$ eV, consistent with $J^\pi = 3^-$; $T = 1$. The total peak cross section is 4.2 ± 1.7 μb. Transitions to ^{12}C*(0, 4.4) are also observed: $\Gamma_\gamma \approx 2 \times 10^{-3}$ eV and 3.2 ± 1.0 eV, repsectively.

$E_p = 2.66 MeV$ [^{12}C*(18.39)] is not seen here: see ^{11}B(p, p).

$E_p = 3.12 MeV$ [^{12}C*(18.81)]. The angular distribution of γ_0 indicates E2 radiation, $J^\pi = 2^+$. This assignment is supported by the angular correlation in the cascade γ_1 and by the behavior of $\sigma(\alpha_0)$; $T = 1$ is suggested by the small Γ_α. The yield of γ_3 (to ^{12}C*(9.6)) shows a peak corresponding to $E_x \approx 18.9 - 19.0$ MeV. It may be due to ^{12}C*(18.8) with an energy shift due to interference (1982WR01).

The structure near $E_p = 3.5 - 3.7$ MeV [^{12}C*(19.2, 19.4)] seems to require at least two levels. The large Γ_{γ_0} requires that one be $J^\pi = 1^-$, $T = 1$ and interference terms in $\sigma(\alpha_0)$ require another to have even spin and even parity: $J^\pi = 2^+$; $T = 0$ is favored. (1982WR01) report that they do not

Table 12.12: Anomalies and maxima in yields of ^{11}B(p, n)^{11}C and ^{11}B(p, p)^{11}B [a]

Peak no.	A			B			J^{π}	E_x (MeV)
	E_p (MeV)	Γ_{lab} [b] (keV)	Res. in	E_p (MeV)	Γ_{lab} (keV)	Res. in		
1				0.67	330	p_0	2^-	16.57
2				1.4		p_0	1^-	17.24
3				1.98		p_0	0^+	17.77
4	2.664	48		2.66	47	p_0, p_1		18.40
5	3.16 [c]	100		3.15	100	p_0, p_1		18.85
6	3.5	500		3.4	500	p_1		19.1
7	3.78 [c]	50		3.78	50	p_0, p_1		19.42
8	4.08 [c]	200	n_0					19.69
9	4.28	100		4.28	100	p_1		19.88
10	4.68 [c]	170	n_0	4.68 [f]	330 ± 40	p_0, p_1	$1^+; 1$	20.24
11	5.065 [c]	190	n_0	5.10 [f,g]	350 ± 15	p_0, p_1	$3^-; 1$	20.61
12	5.49 [c]	400 [d]	n_0					20.98
13	6.02	560	n_0, n_1	6.08 [f]	290 ± 25	p_0, p_1, p_2	3^-	21.50
14	6.4	wide	n_0	6.58 [f]	7800 ± 1100	p_0, p_2, p_3	$1^-; 1$	22.00
15	≈ 7.0 [d]	340	n_0	7.11 [f]	720 ± 90	p_0, p_2, p_3	3^-	22.47
16	7.29	360	n_0, n_1					22.63
17	7.74	65	n_0, n_1					23.04
18	8.25	380	n_0, n_1					23.51
19	8.65	180	n_0, n_2					23.88
20	9.0 [e]							24.2
21	9.25	110	n_0, n_2					24.43
22	9.79	1000	n_0, n_1					24.92
23	10.14	180	n_0, n_2					25.24
24	10.91	440	n_0					25.95
25	11.88	300						26.83

A: From the (p, n) reaction.
B: From the (p, p) reaction.
[a] See also Tables 12.11 in (1968AJ02) and 12.13 in (1980AJ01) for additional work. The earlier references are listed there.
[b] See also (1965OV01).
[c] See also (1980RA16).
[d] (1981HO13); see also for possible additional structures.
[e] Also resonance in $K_y^y(0°)$.
[f] (1983BO19). R-matrix analysis.
[g] See also α-decay in Table 12.11.

observe any evidence for an isospin mixed doublet near $E_x = 19.5$ MeV [$E_p = 2.9$ to 4.6 MeV (60° and 90°)]. Resonances at $E_p = 4.93$ and 5.11 MeV, seen in $\sigma(\gamma_1)$ also appear in $\sigma(\alpha_1)$, but not in $\sigma(\alpha_0)$. Angular distributions suggest $J^\pi = 2^+$ or 3^- for the latter [^{12}C*(20.64)]; the strength of γ_1 and absence of γ_0 favors $J^\pi = 3^-$, $T = 1$.

The first seven $T = 1$ states in ^{12}B and ^{12}C have been identified by comparing reduced proton widths obtained for this reaction and reduced widths obtained from the (d, p) and (d, n) reactions: see Table 12.12 in (1980AJ01).

22. ^{11}B(p, n)^{11}C $\quad Q_m = -2.764 \quad E_b = 15.956$

Excitation functions have been reported for $E_p = 2.6$ to 11.5 MeV [see (1980AJ01)], from threshold to 6.0 MeV (1980RA16; σ_t), 5.4 to 7.5 MeV (1981HO13; n_0 and n_1 from 6.4 MeV) and 10.87 to 27.50 MeV (1981AN16). At the higher energies the excitation function decreases essentially monotonically (1981AN16). At the lower energies many resonances are observed: see Table 12.12.

Polarization measurements have been carried out at $E_{\vec{p}} = 7.3$ to 26.5 MeV [see (1980AJ01)] and at $E_{\vec{p}} = 7.0$ to 16.3 MeV (1981MU1C, 1981MU1D). See also (1979BA68), (1981NO1G; applied), (1980WA1K) and (1979PH06, 1980DO01, 1980HA35, 1982RA07; theor.).

23. (a) ^{11}B(p, p)^{11}B $\quad E_b = 15.956$
(b) ^{11}B(p, 2p)^{10}Be $\quad Q_m = -11.229$
(c) ^{11}B(p, d)^{10}B $\quad Q_m = -9.230$

Anomalies and maxima observed in the excitation functions of p_0, p_1, p_2 and p_3 are displayed in Table 12.12. Studies of the scattering have been reported at $E_p = 1.8$ to 47.4 MeV [see (1980AJ01) but note that some of the preliminary work has not been published] and more recently at $E_p = 4.5$ to 7.5 MeV (1983BO19; p_0, p_1, p_2, p_3 [and α_0: see Table 12.11]) and 5.4 to 7.0 MeV (1981HO13; p_0, p_1). See (1983BO19) for a review of the evidence on the states with $20.2 < E_x < 22.5$ MeV. It is reported that in all the channels and throughout this energy range a strong 2^+ background is observed. It is suggested that it may be the low-energy tail of the isoscalar giant quadrupole resonance (1983BO19). For polarization measurements [$E_p = 1.9$ to 155 MeV] see (1975AJ02, 1980AJ01).

At $E_{\vec{p}} = 11.34$ to 11.94 MeV the VAP angular distributions and excitation functions of the deuterons (reaction (b)) have been studied by (1982BU03): a comparison with ^{10}B(d, $\vec{p}$) shows very good agreement between the polarization and the analyzing power (1982BU03). For reaction (c) see (1979AJ01). See also (1980DO01, 1980HA35, 1983RA05; theor.).

24. ^{11}B(p, ^{3}He)^{9}Be $\quad Q_m = -10.3227 \quad E_b = 15.956$

For studies of a possible violation of time-reversal invariance see (1981SL03, 1983RI01). See, however, reactions 4 and 23 here and reaction 13 in ^{11}B. See also (1981VI1B, 1983HA1H).

25. (a) ^{11}B(d, n)^{12}C $\quad Q_m = 13.732$
(b) ^{11}B(d, np)^{11}B $\quad Q_m = -2.22458$
(c) ^{11}B(d, nα)^{8}Be $\quad Q_m = 6.365$

Reported neutron groups are displayed in Table 12.13. Angular distributions have been studied in the range $0.5 < E_d < 11.8$ MeV: [see (1968AJ02, 1975AJ02)] and at $E_d = 12$ MeV (1983NE11). See (1983NE11), reaction 30 and Table 12.14 in (1980AJ01) for spectroscopic factors. Angular correlation studies have been carried out at many energies in the range $0.7 < E_d < 6.3$ MeV. For reactions (b) and (c) see footnotes to Table 12.13 here as well as reaction 30 in (1980AJ01). See also (1981AN16, 1983FOZW), (1984TA1N) and ^{13}C in (1986AJ01).

26. (a) ^{11}B(^{3}He, d)^{12}C $\quad Q_m = 10.463$
(b) ^{11}B(^{3}He, np)^{12}C $\quad Q_m = 8.238$

Observed deuteron groups are displayed in Table 12.13. Angular distributions have been studied at $E(^3\text{He}) = 5.1$ to 44 MeV: see (1975AJ02, 1980AJ01). At $E(^3\text{He}) = 43.6$ MeV the regions with $E_x \approx 18.4$ and ≈ 19.5 are strongly populated (1979SH1K, 1980SH1A).

27. (a) ^{11}B(α, t)^{12}C $\quad Q_m = -3.858$
(b) ^{11}B(^{7}Li, ^{6}He)^{12}C $\quad Q_m = 5.982$

Angular distributions (reaction (a)) have been studied at several energies in the range $E_\alpha = 15.1$ to 120 MeV [see (1980AJ01)] as well as at $E_\alpha = 29.5$ MeV (1982VA1F; t_0, t_1). See also (1979ZE1B, 1980ZE05, 1982BE17, 1983BE1Q, 1984ZE1B; theor.). At $E(^7\text{Li}) = 34$ MeV, angular distributions have been measured for the groups to ^{12}C*(0, 4.4, 7.7, 9.6, 10.8, 11.8, 12.7, 15.1, 16.1, 18.35) (1983NE11). It is concluded on the basis of this and other work, that the group corresponding to $E_x = 18.35 \pm 0.05$ MeV ($\Gamma = 350 \pm 50$ keV) consists of unresolved states with $J^\pi = 3^-$ ($T = 1$) and 2^- ($T = 0$ + some mixing of $T = 1$) (1983NE11; see for spectroscopic factors): no states were observed with $E_x > 18.35$ MeV.

28. (a) ^{11}B(^{14}N, ^{13}C)^{12}C $\quad Q_m = 8.406$
(b) ^{11}B(^{16}O, ^{15}N)^{12}C $\quad Q_m = 3.829$

Table 12.13: States in ^{12}C from ^{11}B(d, n)^{12}C and ^{11}B(^{3}He, d)^{12}C [a]

Peak no.	E_x (MeV ± keV)	Γ_{lab} (keV)	l_p [b]	l [c]	$J^\pi; T$
1	g.s.		1	1	$0^+; 0$
2	4.44		1	1	$2^+; 0$
3	7.65			1	$0^+; 0$
4	9.629 ± 10 [a]		2	2	$3^-; 0$
5	10.84 ± 20 [d]	330 ± 30	$0 + 2$	0	$1^-; 0$
6	11.16 ± 50	550 ± 100		(1)	$(2^+); 0$
7	11.82 ± 20 [e]	300 ± 30	$0 + 2$	2	$2^-; 0$
8	12.70 ± 10 [f]		1	1	$1^+; 0$
9	13.38 ± 20	500 ± 80		((0))	$(2^-); 0$
10	(14.71 ± 10) [g]	< 15		0	
11	15.110 ± 3 [h]		1	1	$1^+; 1$
12	16.11		1	1	$2^+; 1$
13	17.23 [h,i]	broad	> 1		$1^-; 1$
14	18.27 ± 50 [g]	350 ± 50		(2)	$(4^-; 0)$
15	18.35 ± 50 [j,k,l]	350 ± 50		(2)	$3^-; 1 + 2^-; 0 + 1$
16	19.25 [g]			(2)	$(1^-; 1)$
17	19.55 ± 50 [j]	575 ± 60		(2)	$(4^-; 1)$
18	20.62 ± 60 [j]	525 ± 60		(2)	$(3^-; 0)$
19	22.40 ± 80	350 ± 50		(2)	$(1^-; 1)$

[a] See Table 12.14 in (1980AJ01) for the earlier references. Please note that the 1980 table also displays the S_{rel} obtianed in several studies. See also the newer review by (1983NE11).
[b] (d, n): see also Table 12.12 in (1968AJ02).
[c] (^{3}He, d): see also Table 12.13 in (1968AJ02).
[d] There is some evidence that this state decays primarily by α_0 (1965OL01).
[e] This state decays by α-emission to ^{8}Be*(2.91) [90%] and to ^{8}Be$_{g.s.}$ [10%] (1965OL01).
[f] Decays via α_1 to ^{8}Be*(2.9) (1965OL01).
[g] Not reported in (d, n): see Table 12.14 in (1980AJ01).
[h] From a study of slow neutron thresholds at $E_d = 1.627 \pm 0.004$ and ≈ 4.1 MeV [$E_x = 15.107$ and 17.2 MeV (broad)]. In another study at the lower threshold [$E_d = 1.633 \pm 0.003$ MeV, $E_x = 15.112$ MeV, $\Gamma < 2$ keV] 15.1 MeV γ-rays are observed: see (1980AJ01) for references.
[i] Not reported in (^{3}He, d): see Table 12.14 in (1980AJ01).
[j] Strong and broad neutron groups to ^{12}C*(18.35, 19.55, 20.62) have been reported by (1983NEZZ, 1983NE11): these states decay by p_0 (to ^{11}B$_{g.s.}$) and by α_1 decay (to ^{8}Be*(2.9)). ^{12}C*(18.35) also decays by α_0: see reaction 27.
[k] Decays primarily via p_0 and α_1 (1982KA1M).
[l] (1983NE11) find that this group is due to unresolved states with $J^\pi; T = 3^-; 1$ and $2^-; T = 0 + 1$.

Table 12.14: Branching in ^{12}B(β^-)^{12}C [a]

Decay to ^{12}C (MeV $\pm$ keV)	Branch (%)	Log ft [f]
g.s.	97.22 ± 0.30	4.067 ± 0.002
4.43891 ± 0.31	1.283 ± 0.04 [d]	5.110 ± 0.014
	1.182 ± 0.019 [e]	5.144 ± 0.007
7.6543 ± 2.1 [b]	1.5 ± 0.3	4.14 ± 0.10
10.3 ± 300 [c]	0.08 ± 0.02	4.2 ± 0.2

[a] For the earlier references see (1980AJ01).

[b] Based on the atomic mass of ^{4}He (A.H. Wapstra, private communication) and the decay energy for the breakup of this state into 3α, 379.6 ± 2.0 keV: see (1980AJ01).

[c] $\Gamma = 3.0 \pm 0.7$ MeV.

[d] Mean calculated by (1978AL01), including (1.276 ± 0.05)% measured by these authors.

[e] (1981KA31).

[f] Based on Q_m and $\tau_{1/2} = 20.20$ msec.

Angular distributions (reaction (b)) have been measured at $E(^{16}\text{O}) = 27$ to 60 MeV, involving ^{12}C*(0, 4.4, 9.6): see (1980AJ01). See also (1979ZE1B, 1983EL01; theor.). For reaction (a) see (1980AJ01) and (1978DZ1A; theor.).

29. ^{12}B(β^-)^{12}C $\qquad Q_m = 13.369$

The decay is mainly to ^{12}C$_{\text{g.s.}}$; branching ratios to ^{12}C*(0, 4.4, 7.7, 10.3) are displayed in Table 12.14. All the observed transitions are allowed. The half-life is 20.20 ± 0.02 msec (1978AL01).

^{12}C*(7.7) [$J^\pi = 0^+$] is of particular interest for helium burning processes in stars: $\Gamma_{\text{rad}} = 3.41 \pm 1.12$ meV. A search for transitions to ^{12}C*(12.7) has been unsuccessful: see (1968AJ02, 1975AJ02). The shapes of the β-spectra of ^{12}B and ^{12}N have been analyzed. The results are in agreement with CVC and with the absence of second-class induced tensor currents. See also reaction 63, (1981KA31, 1982PRZZ), (1980AJ01) and (1980OK01, 1981KO27, 1984BO03; theor.).

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

(b) ^{12}C(γ, 2n)^{10}C $\qquad Q_m = -31.8415$

The total absorption, mainly (γ, n) + (γ, p), is dominated by the giant resonance peak at 23.2 MeV, $\Gamma = 3.2$ MeV [$\sigma_{\rm max} = 21$ mb (1975AH06)] and by a smaller structure at 25.6 MeV, $\Gamma \approx 2$ MeV [$\sigma_{\rm max} \approx 13$ mb (1975AH06)]: see (1968AJ02, 1975AJ02) for a detailed listing of the earlier references and results.

The (γ, n) cross section shows a giant resonance centered at about 22.5 MeV, $\Gamma \approx 3$ MeV ($\sigma_{\rm max} \approx 8$ mb), a secondary maximum at 25.5 MeV, $\Gamma \approx 2$ MeV, and a long tail: see (1980AJ01). The (γ, n_0) cross section has been measured at $90°$ for $21 < E_{\rm x} < 40$ MeV and compared with the (γ, p_0) cross section: the isospin mixing averages about 2% in intensity and shows structure at the giant resonance. Angular distributions of n_0 measured over the giant-resonance region indicate that the main excitation mechanism is of a $1p_{3/2} \rightarrow 1d_{5/2}$ E1 single-particle character. No significant E2 strength is observed: see (1980AJ01) and (1980GO13; $E_\gamma = 60$ MeV).

The cross section for reaction (b) has been measured for $E_\gamma = 35$ to 130 MeV. The (γ, 2n) cross section is very much smaller than that for (γ, n): the highest value is 0.15% of the maximum value for reaction (a) in the energy range $E_\gamma = 20$ to 140 MeV. Reaction (b) has been studied for $E_{\rm bs} = 100$ to 800 MeV: see (1980AJ01). For work at high energies see (1979DU1C, 1980GA29). See also (1980AR1G), (1981SC1G), (1982VI07; applied) and (1980DU21, 1980TA1D, 1981BE2M, 1981DE18, 1981KO1G, 1981RO1N, 1982CA01, 1982LO08, 1983BE1U, 1983BE45, 1983BO1G, 1983BO1B, 1983CA22, 1983GI02, 1984CO07, 1984KO33; theor.).

31. (a) ^{12}C(γ, p)^{11}B	$Q_{\rm m} = -15.956$
(b) ^{12}C(γ, π^0)^{12}C	$Q_{\rm m} = -134.963$
(c) ^{12}C(γ, π^+)^{12}B	$Q_{\rm m} = -152.937$
(d) ^{12}C(γ, π^-)^{12}N	$Q_{\rm m} = -156.905$

The photoproduction cross section exhibits two broad peaks, the giant resonance peak at 22.5 MeV, $\Gamma = 3.2$ MeV, $\sigma_{\rm max} = 13.1 \pm 0.8$ mb and a 2 MeV broad peak at 25.2 MeV, $\sigma_{\rm max} = 5.6 \pm 0.3$ mb: see (1976CA21) and Table 12.19 in (1968AJ02). For a recent study of the absolute (γ, p_0) cross section at $90°$ see (1984KE05). While the E1 component dominates in the GDR, a 2% E2 contribution may possibly be present (1976CA21). In contrast with the giant resonance peak in the (γ, n) cross section, the (γ, p) cross section shows a strong peak in the center of the broad giant-resonance peak. Above 24.5 MeV the ground state (γ, p) and (γ, n) excitation functions have the same shape up to at least 36 MeV (E.G. Fuller, private communication). There is agreement between the (γ, p) results and those from the inverse reaction ^{11}B(p, γ_0)^{12}C [see reaction 21] when the population of ^{11}B*(4.4, 5.0) is taken into account. [See also (1984KE05)]. The fraction of transitions to ^{11}B*(0, 2.1, 4.7) have been determined at energies in the range $E_{\rm bs} = 21.7$ to 42 MeV: most of the transitions are to ^{11}B$_{\rm g.s.}$ and the excited-state transitions appear to orginate from localized $E_{\rm x}$ regions (1970ME17, 1980IS1F). For (γ, pX) momentum spectra using tagged photons, see (1983HO01; $E_\gamma = 357$ to 557 MeV) and (1984BA09; $E_\gamma = 360$ to 600 MeV). See also (1982BA32, 1983DO09), ^{11}B and (1980AJ01).

The photoproduction of neutral pions (reaction (b)) has been studied at $E_{\rm bs} = 145$ MeV (1982DO12) and from threshold to 450 MeV (1983AR08; total σ). See also (1978EP03, 1981RO1E, 1982COZY, 1983TI1B). (1980AR16) have obtained the total inclusive cross section and the total (γ, p) cross section [with, and without, a pion in the final state] for $E_\gamma = 210$ to 381 MeV. (1982AR06) have studied the production of charged pions for the same energy range. (1978AR08) have measured the cross section for π^- production in the range 510 to 750 MeV. See also (1979EP02, 1979GL05, 1980AN1H, 1981AL1E, 1981MC02, 1983SH1W), (1980AJ01) and ^{12}B and ^{12}N.

See also (1979EG02, 1980KI1E, 1981AK1A, 1981AL18, 1981AL1L, 1981AV01, 1981TA1T, 1983ST1G), (1979DE2A, 1979MA1G, 1980GO13, 1981SC1G, 1982DE1H, 1982IN1A), (1982SC1E; astrophys.) and (1978EP01, 1980DU21, 1980MO1M, 1980NA1B, 1980RA05, 1981BO14, 1981RA16, 1982DU1A, 1982GL04, 1982GO01, 1982LO08, 1983CA22, 1983OR03, 1983YU1A, 1984ST1F; theor.).

32. (a) ^{12}C(γ, d)^{10}B $\quad Q_m = -25.1858$
(b) ^{12}C(γ, pn)^{10}B $\quad Q_m = -27.4104$
(c) ^{12}C(γ, t)^{9}B $\quad Q_m = -27.366$

Cross sections and angular distributions of the deuterons corresponding to transitions to ^{10}B$_{\rm g.s.}$ and/or low excited states have been measured at $E_\gamma \approx 40$ MeV: the results are consistent with E2. There is some evidence also for the excitation of higher states of ^{10}B via non-E2 transitions. For $E_{\rm bs} = 90$ MeV, the ratio of the yields of deuterons to protons is $\approx 2\%$, for particle energies 15 to 30 MeV. For higher particle energies, the ratio decreases: see (1980AJ01) for references. See also (1981AL1E). For reaction (b) see (1975AJ02), (1980KH08, 1981DO1D, 1981KH08, 1982DO08) and (1984CH1A; theor.). The yield of tritons has been measured for $E_\gamma = 35$ to 50 MeV: see (1980AJ01).

33. (a) ^{12}C(γ, α)^{8}Be $\quad Q_m = -7.3665$
(b) ^{12}C(γ, pα)^{7}Li $\quad Q_m = -24.6206$
(c) ^{12}C(γ, nα)^{7}Be $\quad Q_m = -26.2649$
(d) ^{12}C(γ, pnα)^{6}Li $\quad Q_m = -31.8707$

The cross section for reaction (a) exhibits broad peaks at about 18 MeV and ≈ 29 MeV; a pronounced minimum occurs at 20.5 MeV: to what extent the peaks have fine structure is not clear. For $E_\gamma < 22$ MeV, transitions are mainly to ^{8}Be$_{\rm g.s.}$ and ^{8}Be*(2.9) with the g.s. transition dominating for $E_\gamma \lesssim 14$ MeV. For $E_\gamma > 26.4$ MeV, ^{8}Be $(T = 1)$ levels near 17 MeV are strongly excited. Alpha energy distributions show surprisingly strong E1 contributions below $E_\gamma \approx 17$ MeV: see (1980AJ01) for references. See also (1983LI1J), (1981CH28), (1982SA1A; astrophys.) and (1979KA21, 1982DU1A; theor.).

The yield of 0.48 MeV γ-rays from the decay of ^{7}Be, formed in reaction (c), shows a resonance at $E_\gamma \approx 29.5$ MeV, $\sigma = 0.9 \pm 0.2$ mb: see (1975AJ02). For reactions (b) and (c) see (1979KI04, 1980KI1E). For reaction (d) see (1982DO1G, 1982DO14).

34. ^{12}C(γ, γ)^{12}C

Resonance scattering and absorption by ^{12}C*(15.11) have been studied by many groups: see (1980AJ01) and Table 12.7 here. Inelastic scattering has also been reported to ^{12}C*(4.4, 9.6 ± 0.2, 11.8 ± 0.2, 12.7, 13.3 ± 0.2, 17.2 ± 0.2, 18.3 ± 0.2, 20.5 ± 0.2, 22–24 (giant resonance), 26.5 ± 0.4, 29.5 ± 0.3): see (1980AJ01) and (1980IS1C, 1980IS1D, 1982NO1B). See also (1982PI1D). Measurements of the cross section at $90°$ and $135°$ for $E_\gamma = 23.5$ to 39 MeV indicate a significant E2 strength [$1.9^{+0.8}_{-0.7}$ total isoscalar + isovector energy weighted sum rule], in addition to the dominant E1 strength (1980DO04, 1983DO05). However, the data of (1984WR01; $E_\gamma = 20$ to 50 MeV) are inconsistent with these results: there is no "compact" E2 strength in that energy interval. The data taken at 23.5 MeV, the peak of the giant resonance, were combined to determine the total photonuclear absorption cross section at that energy, 19.7 ± 0.4 mb. $\Gamma_{4.4}/\Gamma_0$ at 23.5 MeV $= 0.23 \pm 0.07$ (1983DO05). The scattering cross section has been measured for $E_\gamma = 150$ to 400 MeV by (1984HA08). For pair-production measurements at $E_{\rm bs} = 4.2$ to 31.1 MeV see (1983NO06). See also (1980HA1W) and (1981KE16, 1981KO1F; theor.).

35. ^{12}C(e, e)^{12}C

The nuclear charge radius is $\langle r^2 \rangle^{1/2} = 2.472 \pm 0.015$ fm (1980CA07), 2.464 ± 0.012 fm [2.468 ± 0.012 when the dispersion correction is made] (1982RE12). A value obtained from muonic X-rays is displayed in the "GENERAL" section here. See also (1979BA72). For earlier results see (1980AJ01). Elastic scattering has been studied up to 4 GeV [see (1968AJ02, 1975AJ02)] and at 25 to 115 MeV (1980CA07) and 100 to 300 MeV (1982RE12).

^{12}C states observed in inelastic scattering are displayed in Table 12.15. The variation of the form factor with momentum transfer yields unambiguous assignments of $J^\pi = 2^+$, 0^+ and 3^- for ^{12}C*(4.4, 7.7, 9.6). Longitudinal form factors show ^{12}C*(16.1, 18.6, 20.0, 21.6, 22.0, 23.8, 25.5) while the transverse form factors show ^{12}C*(15.1, 16.1, 16.6, 18.1, 19.3, 19.6, 20.6, 22.7, (25.5)). ^{12}C*(19.3) may be the expected giant magnetic quadrupole state, $J^\pi = 2^-$: see (1975AJ02, 1980AJ01) for references and additional information. At $E_{\rm e} = 150.6$ MeV ($\theta = 180°$) two peaks are observed at 16.1 and at 19.6 MeV corresponding to E2 and M2–M4 excitations (1984RY01). There are no further peaks at higher $E_{\rm x}$ (1984RY01) in contradiction to the predictions of (1983CA17). Deep-inelastic scattering up to and including the Δ-region has been studied by (1983BA28, 1983BA54). For an attempt to observe axions see (1979BE1U) and reaction 40.

See also (1977CR02, 1979HA14, 1979HU1C, 1981CA05, 1981LO02, 1982BU1E, 1982PAZT, 1983BU20, 1983NI1B, 1983PA1D), (1979CA1E, 1979FR1J, 1979PE1F, 1980CA1H, 1980DR1B, 1980SI1B, 1981CA1D, 1981HA1T, 1981SI1B, 1982BE1J, 1982DE1H, 1982DE1J, 1982MO1X, 1983BE1A, 1983HE1E, 1983SI11, 1984OC1B) and (1978HA43, 1979AR1F, 1979BE1G, 1979BU1A, 1979GL10, 1979IN05, 1979KI1G, 1979UE03, 1979WA1G, 1980BA2E, 1980BE58, 1980CH11, 1980DE14, 1980ER1B, 1980HA18, 1980KO1W, 1980PE05, 1980TO04, 1981AM08, 1981BA2T, 1981BU04, 1981DE1T, 1981DE1U, 1981DU16, 1981FI05, 1981KA03, 1981KL1B, 1981KO41,

Table 12.15: States of ^{12}C from ^{12}C(e, e′)^{12}C* [a]

E_x (MeV)	$J^\pi; T$	Γ_{γ_0} (eV)	E_x (MeV)	$J^\pi; T$
4.44	$2^+; 0$	$(10.8 \pm 0.6) \times 10^{-3}$	19.6 ± 0.1	(4^-)
7.66 [b]	$0^+; 0$	$(6.0 \pm 0.4) \times 10^{-5}$	20.0 ± 0.1	(2^+)
9.64	$3^-; 0$	$(3.1 \pm 0.4) \times 10^{-4}$	20.6 ± 0.1	(3^+)
10.84	$1^-; 0$		21.6 ± 0.1	(3^-)
12.71 [c,d]	$1^+; 0$	0.35 ± 0.05 (M1)	22.0 ± 0.1	(1^-)
14.08 [e]	$4^+; 0$		22.7 ± 0.1 [h]	(1^-)
15.11 [d,f]	$1^+; 1$	38.5 ± 0.8	23.8 ± 0.1	(1^-) [i]
15.44 ± 0.04 [g]			24.9 ± 0.2	
16.11	$2^+; 1$	0.35 ± 0.04	25.5	(1^-)
16.57 [f]	2^-	$(48 \pm 8) \times 10^{-3}$	25.5	(3^-)
17.6 ± 0.2			26.4 ± 0.3	
18.1	(1^-)		27.8 ± 0.2	
18.6 ± 0.1	(3^-)		30.2 ± 0.4	
19.3	2^-		32.3 ± 0.3	

[a] See also Tables 12.18 in (1975AJ02) and 12.16 in (1980AJ01) for additional information and for the earlier references.

[b] The matrix element is 5.48 ± 0.22 fm^2 for the E0 decay by π emission to ^{12}C$_{\rm g.s.}$: see (1980AJ01). The other value has not been published.

[c] $\Gamma_{\rm tot} = 14.6 \pm 2.6$ eV.

[d] Form factors have been obtained at $180°$. See also Table 12.10 (1979FL08). For cross sections at $E_e = 37.0$, 50.5 and 60.5 MeV, see (1977CR02). See also (1983DE53).

[e] $\Gamma \approx 0.3$ MeV.

[f] See (1983DE53) for form factors for $q = 0.4 - 3.0$ fm^{-1}. The Γ_{γ_0} shown are also from (1983DE53); that for ^{12}C*(15.11) improves the agreement with the CVC predictions.

[g] (1983DE53): $\Gamma = 1.5 \pm 0.2$ MeV. See also (1979FL08).

[h] The giant dipole resonance has an average $E_x = 23.0 \pm 0.7$ MeV and $\Gamma = 5.7 \pm 0.7$ MeV. It may involve fine structure at $E_x = 22.2$, 22.8, 23.4 and 23.8 MeV.

[i] See (1972AN03). Widths for these states have also been calculated.

1981LA1E, 1981LI1X, 1981SI09, 1981SP1A, 1981SU03, 1981SU04, 1981SU08, 1981TO04, 1981VA08, 1981WE1G, 1982BA37, 1982CE03, 1982GU09, 1982IN03, 1982KO21, 1982LE1M, 1982MA38, 1982OS1C, 1982WE1J, 1983BO26, 1983KO32, 1983OC01, 1983PO03, 1984CO1U, 1984DE02, 1984FI06, 1984RO05, 1984ST03; theor.).

36. (a) ^{12}C(e, ep)^{11}B $\quad Q_{\rm m} = -15.9561$

(b) ^{12}C(e, en)^{11}C $\quad Q_{\rm m} = -18.721$

(c) ^{12}C(e, eπ^+)^{12}B $\quad Q_{\rm m} = -152.937$

(d) ^{12}C(e, eπ^-)^{12}N $\quad Q_{\rm m} = -156.905$

Electron spectra in the region of large energy loss show a broad peak which is ascribed to quasi-elastic processes involving ejection of single nucleons from bound shells: see (1968AJ02). Studies of e′–p coincidences for $E_{\rm e} = 497$ to 700 MeV reveal peaks corresponding to ejection of 1p and 1s protons: the energy of the two peaks [$\Gamma = 6.9 \pm 0.1$ and 19.8 ± 0.5 MeV] are 15.5 ± 0.1 and 36.9 ± 0.3 MeV (1976NA17: 700 MeV; DWIA). By studying the missing energy spectrum at $E_{\rm e} = 497$ MeV the population of ^{11}B*(0, 2.14, 5.0) is reported: see (1980AJ01) for references. At $E_{\rm e} = 500$ MeV momentum distributions for the transition to ^{11}B$_{\rm g.s.}$ have been studied by (1982BE02): measurements have been made for both perpendicular and parallel kinematics with -150 MeV/c $\leq$ p $\leq$ 150 MeV/c. (1980CA1L; prelim) have extracted the yield for the proton decay of the giant resonance to various states of ^{11}B for $E_{\rm e} = 86$ and 126 MeV (see ^{11}B): the results indicate that more than one $J^\pi = 1^-$ doorway state is important in the ^{12}C giant resonance.

The π^-/π^+ ratios have been measured at $E_\pi = 10$ MeV (1979JE04), 15.8 and 17.9 MeV (1982LO07; $E_{\rm e} = 200$ MeV). Pion production has also been studied by (1981SE05, 1983SC11): see ^{12}B and ^{12}N. See also (1980AJ01) and the "GENERAL" section here.

See also (1978DE32, 1980GA29, 1982LI1C, 1984LOZY), (1979CA1E, 1979MA1G, 1979MO1G, 1980MO1C, 1980SI1B, 1981HA1T, 1981HU1E, 1981MO1H, 1982DE1W, 1983MO1F) and (1979BE67, 1979KU25, 1980BA2E, 1980BO08, 1980GI1D, 1980HO26, 1980NA13, 1980RO17, 1980SA1E, 1981BO1M, 1981DE07, 1981DE1Q, 1981EI01, 1981KL1A, 1981KL1C, 1981RO1N, 1981TO1N, 1982AL12, 1982CI1D, 1982LO1B, 1982ZI1A, 1983AN1C, 1983BE29, 1983CO18, 1983KL04, 1983NA07, 1984CO07, 1984KL04; theor.).

37. (a) ^{12}C($\pi^\pm$, $\pi^\pm$)^{12}C

(b) ^{12}C($\pi^\pm$, $\pi^\pm$p)^{11}B $\quad Q_{\rm m} = -15.9561$

(c) ^{12}C($\pi^\pm$, $\pi^\pm$n)^{11}C $\quad Q_{\rm m} = -18.721$

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

(e) ^{12}C(π^-, p)^{11}Be $\quad Q_{\rm m} = 112.103$

Angular distributions of the elastic and inelastically scattered pions have been measured at many energies: see Table 12.16. (1980BA45) have compared the elastic cross sections of π^+

on ^{12}C and on ^{11}B at $E_{\pi^+} = 38.6$ and 47.7 MeV. The difference in the charge radius $\langle r^2 \rangle^{1/2}$ is 0.072 ± 0.021 fm for ^{12}C and ^{11}B. See also (1984DU01; theor.).

At $E_{\pi^+} = 162$ MeV $\pi^+ - \gamma$ angular correlations via ^{12}C*(4.4) have been studied by (1984VO04): the results support use of the isobar-hole formalism. At $E_{\pi^\pm} = 100$ to 130 MeV the charge-dependent matrix element between ^{12}C*(12.71, 15.11) has been studied by (1981MO07): see Table 12.10. ^{12}C*(14.1, (15.4), 16.1) are also populated. The possible group to ^{12}C*(15.4) has a width of $\approx$ 2 MeV (1981MO07). A strong energy-dependent enhancement in the pion scattering to ^{12}C*(15.1) but not to ^{12}C*(12.7) is observed at $E_{\pi^\pm} = 100$, 180 and 230 MeV: this is interpreted as possible evidence for direct (Δ–h) components in the wave function of the $T = 1$ state (1982MO01). Multiple scattering is a very important feature in the quasielastic region (1980BU07; $E_{\pi^\pm} = 180$ and 291 MeV). However (1983LE12) have studied inclusive pion scattering at $E_{\pi^+} = 100$, 160, 220 and 300 MeV: a peak is observed near that expected from single-step quasifree scattering. The ratio of π^+/π^- inelastic yields has been measured at $E_{\pi^\pm} = 100$, 160 and 220 MeV (1981MC09). The cross section for absorption of pions in ^{12}C has been obtained at $E_{\pi^\pm} = 50$, 85 to 315 MeV and $E_{\pi^-} = 125$ and 165 MeV. A strong energy dependence is observed in the π^+ absorption (1981AS07, 1983NA18). At $E_{\pi^\pm} = 50$ MeV the absorption of π^- is about twice that of π^+ (1983NA18).

(1981PI05, 1982PI03, 1982PI04) have studied reaction (b) at $E_{\pi^+} = 165$ MeV and $E_{\pi^\pm} = 245$ MeV. See also (1979FR1K, 1983LIZS). For reaction (c) see (1979FR1K, 1981PI05, 1982PI04). For reactions (d) and (e) see (1981MC09). See also (1980AJ01) for additional studies, as well as (1979DA16), (1980DE1V, 1983TR1J) and (1980NA06, 1980PE01, 1981TO17, 1982OS01, 1983AM03, 1983BA62, 1983RA31; theor.) and the "GENERAL" section here.

38. ^{12}C($K^\pm$, $K^\pm$)^{12}C

At $E_{\mathrm{K}^\pm} = 442$ MeV angular distributions have been obtained for ^{12}C*(0, 4.4, 9.6) (1982MA16). See also (1979CH34).

39. (a) ^{12}C(n, n)^{12}C

(b) ^{12}C(n, nα)^{8}Be $\qquad Q_{\mathrm{m}} = -7.3665$

Angular distributions of elastic and inelastically scattered neutrons have been studied at many energies up to 350 MeV: see (1980AJ01) and (1983WO02; n$_0$; $8.9 \to 14.9$ MeV), (1983DA22; n$_0$; $9.6 \to 15$ MeV), (1983ANZY; n$_0$, n$_1$; 10 MeV; small angles), (1982HAZK; n$_0$; 14.6 MeV), (1981GU12; n$_0$, n$_1$, n$_2$, n$_3$; 14.7 MeV), (1980TH07; n$_0$, n$_1$; $15.0 \to 18.25$ MeV), (1979BE50; n$_0$; 16.1 MeV), (1981ME1G, 1982MEZZ, 1983MEZY, 1983MEZS, 1983PEZY; neutrons to ^{12}C*(0, 4.4, 7.7, 9.6, 10.8, 11.8, 12.7, 13.4, 14.1, 15.1, 16.1); $E_{\mathrm{n}} = 20.7$ to 26 MeV) and (1979DEZK; n$_0$; 30.3, 40 MeV). Angular correlations (n$_1$, $\gamma_{4.4}$) have been studied at $E_{\mathrm{n}} = 13.9$ to 15 MeV: see (1975AJ02). For discussions of the spin-flip probability involving the transition to ^{12}C*(4.4),

Table 12.16: Summary of recent ^{12}C(π, π) angular distributions

E_{π^+} (MeV)	E_{π^-} (MeV)	Angular distributions to ^{12}C	References
13.9		g.s.	(1982GI08)
20		g.s.	(1983OB02)
	29	g.s.	(1978JO09)
$29 \rightarrow 56$		g.s.	(1982GU08)
	29.2, 49.5	g.s.	(1979JO08)
30.3, 50		g.s.	(1981PR03)
34.7, 67.5		g.s., 4.4, 7.7, 9.6	(1981AM02)
40.0		g.s.	(1979BL07)
50		g.s., 4.4, 9.6	(1977DY02, 1978MO25, 1979DY02)
50		g.s.	(1983MIZY) [a]
65, 80	65, 80	g.s., 4.4	(1982BL09, 1983BL11)
80	80	g.s.	(1981DE1R)
80	80	g.s.	(1984LE01)
100	100	g.s., 4.4, 7.7, 9.6, 12.7	(1984AN11)
	$120 \rightarrow 280$	g.s., 4.4, 9.6, 15.1	(1970BI1A)
125		g.s.	(1979NA04)
125, 162, 200		7.7	(1983MOZX) [a]
$150 \rightarrow 226$	$150 \rightarrow 226$	g.s., 4.4, 7.7, 9.6	(1977PI02, 1977PI09, 1979CH05)
162		g.s., 19.3	(1978MO23)
162		g,s,	(1984BUZZ) [a,c]
180	180	4.4, 7.7, 9.6	(1981MO17)
180	180	[b]	(1982MO25)

[a] Preliminary work.

[b] To gross structures of the giant resonance: $E_x \approx 18.3$, 19.3, 22.1, 23.7, 25.6. The pion scattering is dominated by the isovector giant dipole resonance.

[c] Large-angle scattering.

see (1975AJ02) and (1980TH07). The quadrupole deformation parameter $\beta_2 = -0.67 \pm 0.04$ (1983WO02). For polarization studies see (1980TH07, 1983WO02) and (1986AJ01).

For a kinematically complete study of reaction (b) at $E_n = 11$ to 35 MeV see (1983AN02): the sequential decay via ^{12}C*(9.64) and ^{8}Be$_{\rm g.s.}$ is clearly observed at the higher energies. For the earlier work see (1980AJ01). See also (1979SM08, 1982KN02, 1983SH2K), (1979SO1B, 1980JA1G; applied) and (1980AK01, 1980SH01, 1982FI1L, 1982OL1C, 1983BA1T, 1983GU1F; theor.).

40. ^{12}C(p, p)^{12}C

Angular distributions od elastically and inelastically scattered protons have been measured at many energies up to $E_p = 1040$ MeV: see Tables 12.22 in (1968AJ02), 12.20 in (1975AJ02), 12.17 in (1980AJ01) and 12.17 here.

Table 12.18 displays the information on excited states of ^{12}C. A summary of the decay of some excited states is shown in Table 12.7. The angular distributions have been analyzed by DWBA (and CCBA), DWIA (including microscopic calculations) and DWTA (DW t-matrix approximation with density-dependent interactions). Microscopic DWIA calculations give good results for transitions which take place through the $S = T = 1$ part of the effective interaction and also gives a reasonable description of the $S = T = 0$ transition. However the mechanism for the excitation of ^{12}C*(12.71) $(S = 1, T = 0)$ remains a puzzle (1980CO05; $E_p = 122$ MeV). The angular distributions of the inelastically scattered protons to ^{12}C*(12.71) are usually poorly fitted: see e.g. (1983BA57).

At $E_p = 402$ MeV the differential cross sections for ^{12}C*(12.7, 15.1) $(J^\pi = 1^+)$ are very similar for large q. This may be due to the smallness of precursor effects [precursor to a pion condensate] (1981ES04). See also (1981SU04; theor.).

The spin-flip probability (SFP) for the transition to ^{12}C*(4.4) has been measured for $E_p = 15.9$ to 41.1 MeV: two bumps appear at ≈ 20 and ≈ 29 MeV. It is suggested that the lower one is due to a substructure of the E1 giant dipole resonance while the upper one results from the E2 giant quadrupole resonance (1975DE32, 1982DE02). The SFP has also been studied at $E_{\vec{p}} = 24.1, 26.2$, 28.7 MeV (1981FU12; to ^{12}C*(4.4)), at $E_p = 42$ MeV (1981CO08; to ^{12}C*(12.7)), at $E_{\vec{p}} = 397$ MeV (1982SE12; to ^{12}C*(9.6, 12.7, 15.1, 16.1)) [the SFP to ^{12}C*(9.6) is consistent with zero; the others exhibit large SFP at forward angles] and at $E_p = 398$, 597 and 698 MeV (1983JO08; to ^{12}C*(18.3, 19.4)). At $E_{\vec{p}} = 23$ to 27 MeV (1980HO06) have tried to study out-of-plane (p, p$'\gamma$) angular correlations to determine the SF M1 contribution to the cross section for ^{12}C*(12.7, 15.1): the study was not successful. See also (1979PR04).

(1980HO07) have measured the angular distribution of γ-rays from the decay of ^{12}C*(12.7, 15.1) at $E_p = 21.5$ to 27 MeV. Microscopic DW calculations were performed for the A_0 and a_2 coefficients from these and earlier data. The theoretical calculations underestimate A_0 for energies below 35 MeV and are in agreement with the experimental A_0 for higher energies. The calculations also predict significant differences in the a_2 values for the transitions from ^{12}C*(12.7, 15.1), and these are observed (1980HO07). $\beta_2 = -0.663$, $\beta_4 \approx 0$ for ^{12}C$_{\rm g.s.}$ (1983DE36).

Table 12.17: Recent work on ^{12}C(p, p), ^{12}C(d, d), ^{12}C(t, t), ^{12}C(^{3}He, ^{3}He) and ^{12}C(α, α) angular distributions [a]

E_p (MeV)	To states in ^{12}C at E_x (MeV)	References
6.6	0, 4.4	(1979PR04)
$19.15 \rightarrow 23.34$ [b]	0, 4.4, 12.7	(1979GA13)
$19 \rightarrow 27$ [b]	0	(1984BAZZ)
24.1, 26.2, 28.7 [b]	4.4	(1981FU12)
30.0, 35.2, 39.9	0, 4.4, 7.7, 9.6, 14.1	(1983DE36)
35.2	0	(1980FA07)
48.5	0	(1983GR14)
60.0, 64.5 [b]	0	(1980KA02)
61.8	15.1, 16.1	(1979GO16)
72	0	(1982AU1B) [f]
80	0, 4.4, 7.7, 9.6, 12.7, 15.1	(1980BE1T)
120 [b]	0, 4.4, 11.8, 12.7, 15.1, 16.1, 16.6	(1981CO20, 1981CO21)
121.9, 159.6, 200.0 [b]	4.4	(1983HU06)
122, 160 [b]	0	(1983ME02)
122	0, 4.4, 11.8, 12.7, 13.4, 14.1, 15.1, 15.3, 16.1, 16.6	(1980CO05)
135	0, 4.4, 7.7, 9.6, 12.7, 14.1, 15.1, 16.1, 16.6, 18.3	(1983BA57)
155, 200 [c]	12.7, 15.1, 16.1, 16.6	(1981CO10)
159.4 [b]	0, 4.4	(1983TA12)
200 [b]	0	(1981ME02)
200	0	(1981ME11)
200 [b]	4.4, 7.7, 9.6, 10.8, 11.8, 12.7, 13.4, 14.1, 15.1, 15.3, 16.1, 16.6, 18.4, 19.2, 20.5	(1982CO21)
398, 597, 698 [b]	18.30, 19.40	(1983JO08)
400, 600, 700 [b]	12.7	(1983JO1J)
402	12.7, 15.1	(1981ES04)
800 [d]	0, 4.4, 7.7, 9.6, 14.1	(1981BL07)
800 [e]	4.4, 12.7, 15.1, 16.1, 16.6	(1982HA26)
800	12.7, 15.1	(1980GL1B)

Table 12.17: Recent work on ^{12}C(p, p), ^{12}C(d, d), ^{12}C(t, t), ^{12}C(^{3}He, ^{3}He) and ^{12}C(α, α) angular distributions (continued) [a]

800	15.1	(1980HA30)
800 [b]	12.7, 15.1, 18.3, 19.4	(1980MO06)
1 GeV	0	(1979AL26)
46.8 MeV [g]	0, 4.4	(1984GA04)
E_d (MeV)	To states in ^{12}C at E_x (MeV)	References
$0.556 \rightarrow 2.050$	0	(1980HA1X)
52 [b]	0	(1980MA10)
650	0 [g]	(1980DU12)
E_t (MeV)	To states in ^{12}C at E_x (MeV)	References
9.0, 11.0 [b]	0	(1984FI01)
15.0, 17.0 [b]	0	(1978SC02)
E(^{3}He) (MeV)	To states in ^{12}C at E_x (MeV)	References
$1.0 \rightarrow 2.7$	0	(1980VO1C)
40.9	0	(1982AL14)
41	0	(1980TR02)
108.5	9.2, 20.3 [h,i]	(1980LE25)
119	0	(1980HY02)
132	0	(1981CH1C)
E_α (MeV)	To states in ^{12}C at E_x (MeV)	References
5, 6	0	(1982WA23)
$10.5 \rightarrow 20$	0, 4.4, 7.7	(1982AM02)
$17.4 \rightarrow 20.5$	7.7	(1981FR11)
$18.3 \rightarrow 21.5$	7.7 [j]	(1982KA30)
18.5, 21.7, 25.4	0	(1981BE19)
$19.3 \rightarrow 30.7$	0, 4.4	(1981BU21)
25.3	4.4	(1978AL20)
28.1, 29.1, 35.8	0	(1983AR12)
35.8	7.7	(1983AR12)
65	0, 4.4, 14.1	(1983YA01)
97	0	(1984ON1A)
98	4.4, 7.7, 9.7 [g]	(1981YO04)

Table 12.17: Recent work on ^{12}C(p, p), ^{12}C(d, d), ^{12}C(t, t), ^{12}C(^{3}He, ^{3}He) and ^{12}C(α, α) angular distributions (continued) [a]

120, 145, 172.5	0	(1981WI16)

[a] See Table 12.17 in (1980AJ01) for the earlier work. See also (1983MC02).

[b] Polarized.

[c] Only the 200 MeV protons were polarized.

[d] ^{12}C*(0, 4.4, 14.1) [$J^\pi = 0^+, 2^+, 4^+$] are part of the ground-state rotational band. The angular distributions have been analyzed using CCBA (for $q < 4$ fm^{-1}). DWBA fits the distributions to ^{12}C*(7.7, 9.6).

[e] ^{12}C*(14.1) is also populated.

[f] See also (1982KO1J).

[g] Energy of antiprotons: see reaction 41.

[h] See, however, reaction 46.

[i] Small angles only.

[j] Back angles only.

For polarization studies see (1979GA13, 1980KA02, 1980MO06, 1981CO10, 1981CO20, 1981CO21, 1981FU12, 1981ME02, 1982CA08, 1982CO21, 1982SE12, 1983FU1J, 1983HO1L, 1983HU06, 1983JO1J, 1983JO08, 1983MC02, 1983ME02, 1983TA12, 1984BAZZ, 1984KOZZ, 1984MC1A, 1984MC04) and ^{13}N in (1981AJ01, 1986AJ01).

A study of inclusive reactions in the region dominated by the Δ-isobar ($E_x \approx 300$ MeV) is reported by (1984MC04: $E_p = 800$ MeV). See also (1984SEZZ). For spallation see (1979KO21; $E_p = 640$ MeV) and (1983AN13; $E_p = 1.05$ and 2.1 GeV). See also (1980CH05). For π^- production see (1983MO14). (1979CA1F) have studied the decay of ^{12}C*(12.7, 15.1) looking for axions ($m \approx 12$ MeV): the results were negative. The e^+e^- pair decay of ^{12}C*(15.1) has been observed (1982EN01; $E_p = 22$ MeV).

See also (1980PI1A, 1981BR1L, 1981JO1C, 1981MO1B, 1981SA1T, 1982GU03, 1983CE1A, 1983KA2C), (1978AL36, 1979DE1P, 1979GL1H, 1980CA1H, 1980DE33, 1980DE1V, 1980KE14, 1980MO01, 1980WH1A, 1981BA1F, 1982IG2A, 1982MO1F, 1982WA1H, 1982WE1J, 1983HA1H, 1983MO1K, 1983SC1G), (1979RA1C, 1982RA1M; astrophys.) and (1978CH28, 1979AB13, 1979FO18, 1979MA48, 1979PH05, 1979YU02, 1980AB02, 1980AL12, 1980BA2E, 1980CO07, 1980CO06, 1980CR01, 1980JA05, 1980KO1V, 1980MA06, 1980TO04, 1980WU02, 1981AB1D, 1981BE1Y, 1981BL1C, 1981DY1D, 1981GA1G, 1981GA1J, 1981KA04, 1981KH07, 1981LO11, 1981NO13, 1981PE06, 1981PO1E, 1981TO04, 1981VA1L, 1981WA20, 1981WE1G, 1981YA08, 1982BIZZ, 1982BL22, 1982CH15, 1982DY02, 1982FA03, 1982FI1L, 1982HE1E, 1982MO18, 1982MO24, 1982NA13, 1982OL1C, 1982OS1C, 1982VOZZ, 1982YE01, 1983BA25, 1983DI1B, 1983DI09, 1983FA04, 1983LI1N, 1983NE1F, 1983PH1A, 1983PI1C, 1983TZ01, 1983WA10, 1983ZA1E, 1984BE01, 1984GO04, 1984HW1A, 1984PEZV, 1984PI05, 1984RI03; theor.).

41. ^{12}C($\bar{p}$, $\bar{p}'$)^{12}C

Table 12.18: ^{12}C levels from ^{12}C(p, p′)^{12}C* [a]

E_x (MeV ± keV)	Γ (MeV)	$J^\pi; T$	E_x (MeV ± keV)	Γ (MeV)	$J^\pi; T$
4.4390 ± 1.1 [b]	[a]	2^+; 0	19.40 ± 30 [d]	0.48 ± 0.04	$2^-; T = 1$
7.65400 ± 0.13	[g]	0^+; 0	20.27 ± 50 [e]	0.14 ± 0.05	
9.64	[g]	3^-; 0	20.57 ± 50	0.35 ± 0.1	3^-; 1
10.84		1^-; 0	21.65 ± 100	1.20 ± 0.15	3^-; 0
11.83	[h]		(21.95 ± 150)	0.8 ± 0.1	1^-; 1
12.71 [b]	[g]	1^+; 0	(22.36 ± 50) [e]	0.3 ± 0.05	
13.35	[h]		(22.6 ± 100)	0.9 ± 0.1	1^-; 1
14.08		4^+; 0	23.50 ± 50	0.23 ± 0.1	1^-; 1
15.11 [b]	[g]	1^+; 1	23.92 ± 80	0.4 ± 0.1	1^-; 1
15.4 ± 100 [c]	1.41 ± 0.15	2^+; 0	(25.3 ± 150)	0.51 ± 0.1	1^-; 1
16.11	[h]		$((25.8 \pm 300))$	0.75 ± 0.15	(1^-; 1)
16.57	[h]		(27.0 ± 300)	1.4 ± 0.2	1^-; 1
18.30 ± 30 [d]	0.38 ± 0.03	$(2^-; T = 0)$	(29.4 ± 300) [f]		(2^+; 1)

[a] See Table 12.18 in (1980AJ01) for the earlier references.

[b] On the basis of angular distributions to ^{12}C*(4.4, 12.7, 15.1) for $E_p = 22.2$ to 45 MeV, it is suggested that the E2 strength is fragmented with the major concentration, corresponding to the isoscalar E2 resonance, near 28 MeV, and subsidiary strength near 32 and 42 MeV, the latter possibly a part of the isovector quadrupole resonance (1975GE15). See also the structures reported in this table (1977BU19).

[c] (1979GO16). See also (1980CO05, 1982CO21).

[d] (1983JO08). Γ are in c.m. system. See also (1980MO06).

[e] Only observed at $E_p = 45$ MeV.

[f] Only observed at $E_p = 155$ MeV.

[g] See Table 12.7.

[h] This footnote has not been defined - unknown footnote.

Antiproton scattering angular distributions have been measured at an antiproton energy of 46.8 MeV to ^{12}C*(0, 4.4) and compared with proton scattering work at about the same energy. Limits have been deduced for the strengths of the real and imaginary parts of the antiproton-carbon optical potential. There is some evidence for the excitation of ^{12}C*(9.6, 15.1). The continuum cross section is smaller than for the corresponding proton data (1984GA04). Differential cross sections for the elastic scattering of antiprotons with momenta in the range 470 to 880 MeV/c have been measured by (1984NA03). See also (1984PEZY) and (1984KA14, 1984LO04, 1984SAZT; theor.).

42. (a) ^{12}C(p, 2p)^{11}B $\quad Q_{\rm m} = -15.9561$
(b) ^{12}C(p, pn)^{11}C $\quad Q_{\rm m} = -18.721$
(c) ^{12}C(p, pd)^{10}B $\quad Q_{\rm m} = -25.1858$
(d) ^{12}C(p, pα)^{8}Be $\quad Q_{\rm m} = -7.3665$
(e) ^{12}C(p, 3p)^{10}Be $\quad Q_{\rm m} = -27.1849$

The (p, 2p) reaction has been studied at energies up to 1 GeV: see (1975AJ02) for the earlier work, and ^{11}B here. See also (1979DE35, 1980TA1F). Although the shapes of the momentum distributions in the (p, pn) reaction (reaction (b)) at 400 MeV are consistent with quasifree knockout from distinct shells, the magnitude of the cross section relative to that for the (p, 2p) process is inconsistent with the PWIA model (1979JA20). See aslo (1982REZZ).

At $E_{\rm p} = 670$ MeV the missing energy spectrum in the (p, pd) reaction (reaction (c)) shows a strong bump at $E_{\rm miss.} = 25$ MeV and another weaker one at $E_{\rm miss.} = 45$ MeV corresponding, respectively, to the ^{10}B ground-state region and ^{10}B*(20) (1981ER10).

At $E_{\rm p} = 56.5$ MeV reaction (d) proceeds primarily by sequential α-decay. ^{12}C*(22.2 ± 0.5, 26.3 ± 0.5) which subsequently decay to ^{8}Be$_{\rm g.s.}$ must therefore have natural parity and a significant $T = 0$ admixture. ^{12}C*(19.7, 21.1, 26.3) decay to ^{8}Be*(2.9). These states must also have a $T = 0$ component. It is suggested that ^{12}C*(21.1) has unnatural parity (1969EP01). In recent work at $E_{\rm p} = 44.2$ MeV ^{12}C*(12.7, 14.1, 21.6, 26.6) are observed in the angular correlation involving α_0 and ^{12}C*(21.6, 24.1, 26.6) decay via α_1 to ^{8}Be*(2.9) [suggesting 2^+ for these states, assuming that only resolved states are involved (1981DE08)].

For reaction (e) see (1979KO36, 1979NA14, 1980KO40, 1981KO1H). For backward scattering at 400 GeV see (1979BA28). For other reactions see reaction 49 in (1980AJ01). See also (1981TA1E, 1983AN18, 1983BE1R), (1979RA1C; astrophys.), (1980AJ01, 1983CH1B) and (1978UC1A, 1979AB13, 1979KI10, 1979KN03, 1979MA24, 1979MA1M, 1980BA2E, 1980SM03, 1981AM01, 1981IL1A, 1981IS11, 1981SA37, 1981ZH1E, 1981ZH1F, 1982CH1P, 1982JA02, 1982KA1L, 1982KI1G, 1982ZH02, 1982ZH06, 1983IK03, 1983IS1C, 1983LI18, 1983LU1C, 1983TA1H, 1983VD1B; theor.).

43. (a) ^{12}C(d, d)^{12}C
(b) ^{12}C(d, pn)^{12}C $\quad Q_{\rm m} = -2.2246$

(c) ^{12}C(d, dα)^{8}Be $\qquad Q_m = -7.3665$

The angular distribution of elastically and inelastically scattered deuterons has been studied at many energies: see (1968AJ02), Tables 12.22 in (1975AJ02), 12.17 in (1980AJ01) and 12.17 here. In addition to well-known states in ^{12}C such as ^{12}C*(4.4) [$E_x = 4440.5 \pm 1.1$ keV] and ^{12}C*(12.7, 15.1) [see Table 12.10 for charge-dependent matrix element], the population of ^{12}C*((10.8 ± 0.2), (11.8 ± 0.2), 18.3 ± 0.3, 20.6 ± 0.3, 21.9 ± 0.3 (broad), $\approx$ 27 (broad)) is also reported. See (1980AJ01) for references and for additional structures which have not been published. Calculated deformation parameters listed in (1980AJ01) are $\beta_2 = -0.48 \pm 0.02$ and 0.47 ± 0.05, and $\beta_3 = 0.35 \pm 0.06$.

Reaction (b) has been studied at $E_d = 5.0$ to 9.85 MeV [see (1980AJ01)] and at 56 MeV (1983BA37). See also (1983WI1D). For spallation studies see (1983AN13; 2.1 and 4.2 GeV). For reaction (c) see (1979HE06). For π^- production see (1983MO14). See also ^{14}N in (1981AJ01, 1986AJ01), (1976ZA1B, 1983AB1E, 1983JI04, 1984GR1F), (1979DE1P, 1981DA1B) and (1977MA44, 1980LE14, 1982EV1A, 1982NI1B, 1982TA19, 1983GA14, 1983MA1U, 1984EV1C, 1984KH01; theor.).

44. ^{12}C(t, t)^{12}C

Angular distributions of elastically scattered tritons have been determined at $E_t = 1.0$ to 20.04 MeV: see (1975AJ02) and Table 12.17 here. See also ^{15}N in (1981AJ01) and (1980KH09, 1982GU1E; theor.).

45. (a) ^{12}C(^{3}He, ^{3}He)^{12}C
(b) ^{12}C(^{3}He, pd)^{12}C $\qquad Q_m = -5.4936$

Angular distributions of ^{3}He ions have been measured in the range $E(^{3}\text{He}) = 2$ to 217 MeV: see (1968AJ02), Tables 12.22 in (1975AJ02), 12.17 in (1980AJ01) and 12.17 here. Parameters of observed ^{3}He groups are displayed in Table 12.19.

Angular distributions of the ^{3}He groups to ^{12}C*(15.11, 16.11, 16.58, 19.56) have been compared with those for the tritons to ^{12}N*(0, 0.96, 1.19, 4.25) in the analog (^{3}He, t) reaction: the correspondence is excellent and suggests strongly that these are $T = 1$ isobaric analog states. See also Tables 12.12 in (1980AJ01) and 12.19 here. ^{12}C*(4.4, 15.2, 18.4, 18.9, 21.3, 23.5, 25.9, 28.8) all appear to correspond to E2 transitions: their strengths add up to 46% of the EWSR (energy-weighted sum rule). See (1980AJ01) for references. (1980LE25) have reported states at $E_x = 9.15 \pm 0.2$ and 20.3 ± 0.2 MeV [$\Gamma = 1.8 \pm 0.2$ and 1.1 ± 0.2 MeV, respectively]: it is suggested that both are E0 states whose intensities are (2.1 ± 0.4) and (2.6 ± 0.2)% of the EWSR: see, however, (1981EY02) in reaction 46.

Table 12.19: States of ^{12}C from ^{12}C(^{3}He, ^{3}He), ^{12}C(α, α) and ^{14}N(d, α) [a]

E_x (MeV ± keV)	L [b]	Γ (MeV)	J^π; T
0	0		0^+; 0
4.4422 ± 1.5	2		2^+; 0
7.65			0^+; 0
9.64	3	0.030 ± 0.008	3^-; 0
10.84			1^-; 0
11.83			2^-; 0
12.71	0		1^+; 0
13.35 [c]		0.355 ± 0.050	
14.08 ± 30 [d]			4^+; 0
15.11	0		1^+; 1
15.5 ± 100	2	2.0 ± 0.3	(2^+; 0)
16.11	2		2^+; 1
16.57			2^-; 1
18.40 ± 60	2	0.4 ± 0.1	(2^+); 1
18.9 ± 150 [e]	2	0.7 ± 0.15	(2^+); 1
19.56 ± 50 [f]		≈ 0.25	$(1, 2, 3)^+$
20.55 ± 100 [c,f]		≈ 0.2	$(2, 3)^+$
21.54 ± 110 [g]	2		2^+
22.4 ± 100 [e]		≈ 0.25	$(2)^+$
23.82 ± 110	2	0.6 ± 0.2	
25.9 ± 300	2	2.2 ± 0.3	(2^+)
28.8 ± 400 [d]	2	2.7 ± 0.4	(2^+)

[a] See also Table 12.23 in (1975AJ02). For references see Table 12.19 in (1980AJ01). Energies listed without uncertainties are from Table 12.6.

[b] From (^{3}He, ^{3}He).

[c] Not reported in (^{3}He, ^{3}He).

[d] See also (1983YA01).

[e] Reported in (^{3}He, ^{3}He) only.

[f] See also (1982KA1M).

[g] May be unresolved states: if so, $\Gamma = 1.4 \pm 0.2$ MeV and $\Gamma = 0.43 \pm 0.08$ MeV are reported.

For reaction (b) see (1983DR06; $E(^3\text{He}) = 33$ MeV) and (1980MA07; $E(^3\text{He}) = 90$ MeV). See also (1983CA07). See also ^{15}O in (1981AJ01), (1979KA1G), (1982TA05) and (1977MA44, 1979BE1Q, 1982GU1J, 1984EV1C; theor.).

46. (a) ^{12}C(α, α)^{12}C
(b) ^{12}C(α, 2α)^{8}Be $\quad Q_{\rm m} = -7.3665$
(c) ^{12}C(α, ^{8}Be)^{8}Be $\quad Q_{\rm m} = -7.4583$

Angular distributions have been measured at many energies up to 1.37 GeV: see Tables 12.24 in (1968AJ02), 12.22 in (1975AJ02), 12.17 in (1980AJ01) and 12.17 here. Parameters of observed states of ^{12}C are displayed in Table 12.19. The quadrupole deformation parameter β_2 is -0.29 ± 0.02, -0.30 ± 0.02 [see (1980AJ01)], -0.40 ± 0.02 (1983YA01), while $\beta_3 \approx 0.23$ [see (1980AJ01)] and $\beta_4 = +0.16 \pm 0.03$ (1983YA01; see also for a review of deformation parameters).

Angular correlation measurements (α_1, $\gamma_{4.4}$) have been carried out for $E_\alpha = 10.2$ to 104 MeV [see (1980AJ01)] and at 14 to 19 MeV and at 25.3 MeV (1978AL20), as well as at 19.3 to 30.7 MeV (1981BU21). At $E_\alpha = 104$ MeV, the sum of the E2 strength in the dominant decay channels [$\alpha_0 + \alpha_1 + \text{p}_0$] for $20 < E_{\rm x} < 30$ MeV exhausts less than 15% of the EWSR (1978RI03). At $E_\alpha = 150$ MeV, the observed isoscalar E2 strength is (6 ± 2)% of the EWSR (1976KN05).

At $E_\alpha = 104$ MeV (1981EY02) report no evidence for E0 strength in the region of a state at $E_{\rm x} = 9.15$ MeV (1980LE25) reported in reaction 45. There is no evidence for concentrated E0 strength above $E_{\rm x} = 7.7$ MeV (1981EY02). See also (1981YO04).

Reaction (b) has been studied for E_α up to 700 MeV [see (1975AJ02)] and at $E_\alpha = 65$ MeV (1983YA01) and 140 MeV (1980WA07). For cross-section measurements (reaction (a)) of the transitions to ^{12}C*(0, 4.4, 7.7, 9.6) at $E_\alpha = 24$ MeV see (1983SA1R). For spallation work at 1.6, 4.2 and 8.4 GeV see (1983AN13). For pion production see (1981AB04, 1982AN1H, 1983MO14). For reaction (c) see (1981RU10) and (1980AJ01). See also ^{16}O in (1982AJ01, 1986AJ04), (1982AB1K, 1983GU1E, 1983ZH09, 1984GU1E, 1984LE1E), (1978BE1G, 1979DE1P, 1979MA1V, 1979PA21), (1979RA1C; astrophys.) and (1977MA44, 1978GU23, 1979GH01, 1979GO24, 1979KR08, 1979PA18, 1979ZE06, 1980IH01, 1980AM1C, 1980BA1Z, 1980KH09, 1980LI09, 1980LI1K, 1980NI11, 1980VI01, 1980WA1G, 1980WO1D, 1981BA20, 1981DA1H, 1981DY02, 1981DY1C, 1981DY1D, 1981GR17, 1981GU1B, 1981KA04, 1981LA13, 1981LI1V, 1981MA1L, 1981MA42, 1981SU05, 1981WA1M, 1981WO1D, 1981ZE01, 1982BU1D, 1982CA1B, 1982GE1A, 1982GU1E, 1982IN03, 1982JA07, 1982NI1B, 1983AH04, 1983BU15, 1983LI1P, 1983SM1B, 1984BA30, 1984BU1M, 1984BU1R, 1984GO04, 1984KH01, 1984NA11, 1984SA1T; theor.).

47. (a) ^{12}C(^{6}Li, ^{6}Li)^{12}C
(b) ^{12}C(^{6}Li, αd)^{12}C $\quad Q_{\rm m} = -1.4753$
(c) ^{12}C(^{7}Li, ^{7}Li)^{12}C

Table 12.20: Recent work on ^{12}C(^{6}Li, ^{6}Li), ^{12}C(^{7}Li, ^{7}Li), ^{12}C(^{9}Be, ^{9}Be), ^{12}C(^{10}B, ^{10}B), ^{12}C(^{11}B, ^{11}B), ^{12}C(^{12}C, ^{12}C) and ^{12}C(^{16}O, ^{16}O) angular distributions [a]

E(Li) (MeV)	To states in ^{12}C at E_x (MeV)	References
$E(^6\text{Li}) = 9$, 19.2 [j]	0	(1983RU09)
$20 \rightarrow 36$	0, 4.4	(1980FU06) [b]
24, 30	0	(1983VIZW)
36	0, 4.4	(1982WO09)
40	0	(1979ZE01)
42.1	0, 4.4	(1978BE43)
90	0, 4.4, 9.6	(1981GL03)
99	0	(1981SC16)
156	0	(1982CO19) [c]
$E(^7\text{Li}) = 34$	0	(1983STZS)
48	0, 4.4, 7.7, 9.6 [d]	(1979ZE01)
63, 78.7	0, 4.4	(1980ZE03)
70	0 [e]	(1981SH01)
$E(^9$Be) (MeV)	To states in ^{12}C at E_x (MeV)	References
20	0	(1979BO1K)
27, 40	0	see (1978GR22)
50	0	(1977ST20)
140	0	(1984FUZZ)
158.3	0, 4.4	(1983FUZY, 1983SA20)
E(B) (MeV)	To states in ^{12}C at E_x (MeV)	References
$E(^{10}\text{B}) = 18 \rightarrow 46$	0	(1982MA20)
$E(^{11}\text{B}) = 25 \rightarrow 50$	0	(1982MA20)
28	0, 4.4 [f]	(1983SR01)
$E(^{12}$C) (MeV) [g]	To states in ^{12}C at E_x (MeV)	References
$12 \rightarrow 20$	0	(1980TR07)
$12.9 \rightarrow 14.0$	0	(1979KO19)
$23.30 \rightarrow 25.50$	0	see (1983TA1J)
$29.2 \rightarrow 62.6$	0	(1983LE05)
30, 34, 40, 50	0	(1978CO20)

Table 12.20: Recent work on ^{12}C(^{6}Li, ^{6}Li), ^{12}C(^{7}Li, ^{7}Li), ^{12}C(^{9}Be, ^{9}Be), ^{12}C(^{10}B, ^{10}B), ^{12}C(^{11}B, ^{11}B), ^{12}C(^{12}C, ^{12}C) and ^{12}C(^{16}O, ^{16}O) angular distributions (continued) [a]

40	4.4	(1981HE08)
45, 55, 65, 68	9.6, 14.1, 18.5	(1979TR1C)
49, 60, 72.5	0, 4.4, 9 [h]	(1981CH1R)
$52 \rightarrow 64$	7.7	(1984FU02)
57	$7.7 + 7.7$	(1982ZUZZ)
$70.7 \rightarrow 126.7$	0, 4.4, 9 [h]	(1979ST10)
93.8	0, 4.4, 9 [h]	(1979FU04)
$134.2 \rightarrow 288.6$	0	(1981CO22)
139.5, 158.8	0	(1983KU07)
300	0, 4.4	(1982BO32)
360	0	(1983LO1K)
1.02 GeV	0, 4.4	(1981BU08, 1982BU17)
E(^{16}O) (MeV) [i]	To states in ^{12}C at E_x (MeV)	References
$21 \rightarrow 35$	0	(1983FR02)
33	0	(1980FR05)
$45.5 \rightarrow 49.0$	0	(1982WI04)
140, 218, 315	0	(1981BR05)
$E(^{12}\text{C}) = 77$ [i]	0	(1979MO14)

[a] See (1980AJ01) for the earlier work.
[b] Used ^{12}C beams to obtain back angles.
[c] See also (1982MA21, 1982MI1D; theor.).
[d] Also ^{7}Li*(0.48) + ^{12}C*(0, 4.4).
[e] Via t + α breakup of ^{7}Li projectile.
[f] And ^{11}B*(0, 2.1, 4.4).
[g] Reaction 50.
[h] Sum of excitation of both ^{12}C ions to ^{12}C*(4.4) plus excitation to ^{12}C*(9.6).
[i] Reaction 53.
[j] Polarized.

The elastic scattering in reaction (a) has been studied at $E(^{6}\text{Li}) = 4.5$ to 100 MeV [see (1975AJ02, 1980AJ01)] and 20 to 156 MeV [see Table 12.20 here]. At $E(^{6}\text{Li}) = 36.4$ and 40 MeV (1974BI04) have studied the inelastic angular distributions to ^{12}C*(4.4, 7.7, 9.6, 10.8, 11.8, 12.7, 13.4, 14.1) and have calculated deformation parameters under various assumptions. Reaction

(b) at $E(^6\text{Li}) = 60$ MeV takes place via ^{12}C*(0, 4.4, 7.7) (1982AR20). See also ^{16}O in (1982AJ01, 1986AJ04).

The elastic scattering in reaction (c) has been studied at $E(^7\text{Li}) = 4.5$ to 89 MeV [see (1975AJ02, 1980AJ01)] and 34 to 78.7 MeV [see Table 12.20 here]. For fusion and yield measurements see (1980FU06, 1982DE30, 1982TA23). For pion production see (1982AS1B). For a polarization study see (1984MO06). See also ^{18}F, ^{19}F in (1983AJ01), (1981BY1D, 1983KA1T), (1979MA1T, 1979KN1A, 1983BI1A) and (1979SU1F, 1980KH09, 1980ST22, 1981DY02, 1981GR17, 1981ME1E, 1981ME1F, 1981OS1D, 1981TH07, 1982CO16, 1982DE28, 1982DR1D, 1982GU21, 1982MA35, 1982RA22, 1983BU15, 1983KH1A, 1983OS03, 1983SH24, 1984BR08, 1984GR05, 1984SA1B; theor.).

48. ^{12}C(^{9}Be, ^{9}Be)^{12}C

Angular distributions have been obtained at $E(^9\text{Be}) = 14$ to 43.8 MeV, $E(^{12}\text{C}) = 12$ to 21 MeV [see (1980AJ01)] and at $E(^9\text{Be}) = 20$ to 158.3 MeV: see Table 12.20. For fusion and yield measurements see (1981JA09, 1982DEZL, 1982HU06, 1983JA09). See also (1982JA1E, 1983DU13) and (1980BR05, 1980OH1B, 1981GR17, 1981HU07, 1982GU21, 1982LO13, 1983DE1U, 1983KA17, 1983OH04; theor.).

49. (a) ^{12}C(^{10}B, ^{10}B)^{12}C
(b) ^{12}C(^{11}B, ^{11}B)^{12}C

Angular distributions for reaction (a) have been measured at $E(^{10}\text{B}) = 18$ and 100 MeV. Elastic angular distributions in reaction (b) have been studied at $E(^{12}\text{C}) = 15$ to 87 MeV. See (1980AJ01) and Table 12.20 here. For fusion cross-section and excitation-function studies see (1979FR05, 1981MA18, 1982MA20, 1983MA53, 1984MAZZ). See also (1979SH22), (1978BE1G, 1982FR1T, 1983BI1A, 1983DU13) and (1978DZ1A, 1979IS07, 1979ZE1B, 1981DE13, 1981YO05, 1982FR1T, 1982HA42, 1983HA1E; theor.).

50. ^{12}C(^{12}C, ^{12}C)^{12}C

Angular distributions have been measured at $E(^{12}\text{C}) = 10$ to 174 MeV [see (1980AJ01)] and at 12 MeV to 1.02 GeV (see Table 12.20). Single and mutual inelastic scattering to ^{12}C*(4.4) have been studied by the angular correlation method by (1979CA13, 1981BA21; $E(^{12}\text{C}) = 29$ to 64 MeV). For pion production see (1980BA1V, 1981AL1K, 1981AN1D, 1981GA1F, 1981NA1E, 1982AS1B, 1982BO1L, 1982GRZW, 1982JO1A, 1983AG1D, 1983MO14, 1984BR01, 1984NO02). For fusion, yields and cross-section measurements, see (1978CO05, 1978CO20, 1978HA1F, 1978TR08,

1979KO19, 1979KO20, 1979LE14, 1979TR1C, 1979UZ1A, 1980BE1U, 1980BE1V, 1980CH1K, 1980CO03, 1980DE28, 1980FU01, 1980KE15, 1980KO02, 1980KO03, 1980PA19, 1980SK1A, 1980TR07, 1980TR06, 1980WI1F, 1980ZY1A, 1981BR03, 1981HE08, 1981MC13, 1981MO20, 1981NA1E, 1981PE01, 1982BE54, 1982BR20, 1982DA16, 1982DE48, 1982HO1F, 1982KA1W, 1982ME05, 1982PE11, 1982SA27, 1982ZUZZ, 1983AN13, 1983BR1N, 1983DE1Y, 1983HAZI, 1983LE05, 1983ME22, 1983NO1E, 1983SH26, 1983SIZY, 1983TR07, 1983WI11, 1984FU02, 1984TR01).

See also (1979SA29, 1980TA1B, 1981PL1C, 1983DA10, 1983ME1Q, 1983SH1Z, 1984HA1U), (1980HE1F, 1982SA1A, 1984FO1A; astrophys.), (1978ER1B, 1978HO1C, 1979CO1F, 1979DE1P, 1979GO1C, 1979SC1D, 1980DE1Z, 1980ER1D, 1980SI1A, 1981BA21, 1981BR1M, 1981BR1P, 1981ER02, 1981SC1N, 1981SC1P, 1981ST1P, 1982CO1X, 1982ER1F, 1982EV1B, 1982FR1G, 1982FR1T, 1982KO1C, 1982MO1N, 1983BI1A, 1983BO1M, 1983BR31, 1983GR1M, 1983JA13, 1983NA1K) and (1978AB1A, 1978BH1B, 1978BR1D, 1978DZ1A, 1978FI1D, 1978KO1E, 1978WI05, 1979CU03, 1979DA1F, 1979FR11, 1979HA42, 1979KN03, 1979MO1J, 1979SA1E, 1979SC1F, 1979VA15, 1979YA12, 1980AB1D, 1980BE01, 1980CE1C, 1980CU1D, 1980DR08, 1980FA1D, 1980FL02, 1980FO1D, 1980FU1H, 1980GA1E, 1980HE1F, 1980HE01, 1980KO27, 1980LA09, 1980LA10, 1980LE01, 1980MU02, 1980OH05, 1980SC1D, 1980SI1J, 1980TA01, 1980VA1G, 1980WO01, 1981AB1A, 1981AS1F, 1981BR01, 1981CA09, 1981CH23, 1981CH26, 1981CU03, 1981DA1E, 1981DA1F, 1981DA12, 1981DE2D, 1981DY02, 1981FA1D, 1981FU1F, 1981GA1E, 1981GI10, 1981HA1E, 1981HA18, 1981HA47, 1981HE01, 1981HE02, 1981HE13, 1981IC01, 1981JE1B, 1981LE20, 1981MA1G, 1981PI1D, 1981SC05, 1981SI1F, 1981SU1J, 1981TA20, 1981UB01, 1981XU1A, 1981YA1D, 1982AB1F, 1982AH02, 1982AH03, 1982BA22, 1982BA37, 1982DE19, 1982HA1R, 1982HA1W, 1982HA56, 1982KO01, 1982KO09, 1982LE09, 1982LE1W, 1982LO13, 1982MA1J, 1982MO1U, 1982MO1V, 1982OH01, 1982SU06, 1982TA13, 1982VO04, 1982WO02, 1983BI01, 1983BI12, 1983BR01, 1983BU15, 1983CH1L, 1983CH38, 1983CI08, 1983CI09, 1983CS01, 1983DE1U, 1983DU13, 1983FA12, 1983FA08, 1983FA14, 1983FO1E, 1983GO25, 1983GU1A, 1983GY1A, 1983HA1E, 1983KA1N, 1983KA1V, 1983KH02, 1983LA09, 1983LA14, 1983MA29, 1983MA1U, 1983SA1D, 1983SM1B, 1983TA01, 1983TA1J, 1983TA13, 1983TA15, 1983TO11, 1984AI01, 1984BA26, 1984CH04, 1984FA02, 1984HU01, 1984LA08, 1984MC06, 1984NY02, 1984OR1B, 1984SH02, 1984TO03; theor.).

51. (a) ^{12}C(^{13}C, ^{13}C)^{12}C
(b) ^{12}C(^{14}C, ^{14}C)^{12}C

Angular distributions for reaction (a) have been studied at $E(^{12}\mathrm{C}) = 15$ to 87 MeV and $E(^{13}\mathrm{C}) = 12$ and 36 MeV [see (1975AJ02)] and at $E(^{12}\mathrm{C}) = 15$ MeV [elastic; see (1980VO05)] and $E(^{13}\mathrm{C}) = 87$ MeV (1981TA21; to ^{12}C*(4.4)). Elastic angular distributions in reaction (b) are reported at $E(^{12}\mathrm{C}) = 12$ to 20 MeV: see (1980AJ01). For a study of the spin-flip probability to ^{12}C*(4.4) see (1981TA21). See also (1984BYZZ). For fusion, yield and cross-section measurements see (1979KO20, 1980FR03, 1981HE08, 1982DA16, 1983FR04, 1983HAZI). See also (1981PL1C, 1982KO2B), (1981ST1P, 1982FR1U, 1983BI1A, 1983DU13, 1983VO1J) and

(1979GR20, 1979IM02, 1979ZE1B, 1980BA54, 1981HA18, 1982LO13, 1982OH05, 1982VO1F, 1983CI08, 1983DE1U, 1983FR23, 1983HU1C, 1983LA1E; theor.).

52. (a) ^{12}C(^{14}N, ^{14}N)^{12}C
(b) ^{12}C(^{15}N, ^{15}N)^{12}C

Angular distributions (reaction (a)) have been measured at $E(^{14}\text{N}) = 21$ to 155 MeV (at certain energies involving ^{12}C*(4.4, 9.6) as well as the elastic scattering) [see (1975AJ02, 1980AJ01)] and at 37, 47 and 58.3 MeV (1978CO20) and 48 MeV (1983QU02; g.s., 4.4) and 78.8 MeV (1979MO14; g.s.).

Angular distributions (reaction (b)) are reported at $E(^{15}\text{N}) = 31.5$ to 47 MeV [see (1980AJ01)] and at 31.5, 36.5, 39.5 and 47 MeV (1978CO20) as well as at 94 MeV (1981TA21; ^{12}C*(4.4)). The SFP (transition to ^{12}C*(4.4)) has been studied by (1981TA21). For fusion, yields and cross sections see (1978CO20, 1979KO20, 1980TA1B, 1980WI09, 1981CO11, 1981DIZW, 1982NO12, 1983CA1N, 1983DA10). See also (1978HA1F), (1979NA1G, 1981ST1P, 1983BI1A, 1983DU13, 1984GO1C) and (1979MO1J, 1980LE11, 1980LO02, 1980VA03, 1981CH23, 1981CU06, 1981DE13, 1981VA1E, 1981VA1H, 1982BL12, 1982HA42, 1982HA56, 1982HU1G, 1982LO13, 1983CI08, 1983GO13; theor.).

53. (a) ^{12}C(^{16}O, ^{16}O)^{12}C
(b) ^{12}C(^{16}O, α)^{12}C^{12}C $\qquad Q_{\text{m}} = -7.1620$

Angular distributions have been measured at $E(^{16}\text{O}) = 17.3$ to 315 MeV and at $E(^{12}\text{C}) = 65$ to 76.8 MeV [see (1975AJ02, 1980AJ01)] and at $E(^{16}\text{O}) = 21$ to 315 MeV [see Table 12.20]. The excitation of ^{12}C*(0, 4.4, 14.1, 26) has been reported.

(1979DO01) present evidence for the excitation of giant resonances in a number of nuclei including ^{12}C: ^{12}C*(25.3–26.7) ($\Gamma \approx 4$ MeV) contain (25^{+15}_{-10})% of the E2 strength. The m-state populations in the transition to ^{12}C*(4.4) have been studied at $E_{\text{c.m.}} = 19$ to 22.6 MeV (1980BE02) and 19.7 and 23.6 MeV (1983KA01). Angular correlation measurements involving ^{16}O*(6.13) are reported by (1979JA25, 1980JA06). See also (1984PO01) and ^{16}O in (1986AJ04). Reaction (b) has been studied at $E(^{16}\text{O}) = 25.96$ MeV (1983GE09), 140 MeV (1980RA12, 1981RA20) and 142.4 MeV (1983SH26): ^{12}C*(0, 4.4) are involved, as are a number of ^{16}O states. See also (1983KA10, 1984MU04).

For fusion, yield and cross-section measurements see (1979JA25, 1979KO03, 1979KO20, 1979LU1B, 1980BE02, 1980FR10, 1980FR05, 1980JA06, 1980TA1B, 1981BR05, 1981FU05, 1981SC1C, 1981TA24, 1982BR1P, 1982CO22, 1982FR04, 1982HUZV, 1982PR1A, 1982SAZL, 1982ST11, 1982WI04, 1983CA1N, 1983CHZX, 1983FR02, 1983GE09, 1983GO1X, 1983KA01, 1983KL1A, 1983LA07, 1983ME04, 1983ME10, 1983RE1C, 1983SAZQ, 1983SC29, 1983VO1A, 1984BE22, 1984HU02, 1984MU04). For pion production see (1983NO1E).

See also (1979SA1L, 1979UZ1A, 1980CO08, 1981CO1W, 1983AZ1A), (1977GA1B, 1978GA1B, 1979GA1F, 1979GO1C, 1980ER1D, 1980GA1E, 1980GA1J, 1980VO1D, 1981BR1P, 1981GA1D, 1981ST1P, 1982EV1B, 1982FR1T, 1982KO1C, 1982LE1N, 1982MA2B, 1983BI1A, 1983BR1R, 1983DU13, 1983HE1B) and (1978BH1B, 1978MA1G, 1979GO24, 1979TE1A, 1979VE1C, 1980AB1D, 1980DE2A, 1980DR08, 1980FU1F, 1980HU02, 1980KO27, 1980LA16, 1980TA1E, 1980TA1G, 1980VA03, 1981CA09, 1981DY02, 1981GU1B, 1981HA18, 1981HU1D, 1981HU07, 1981SC05, 1981TA01, 1981TO1F, 1981UB01, 1981WI01, 1982AB1F, 1982BA22, 1982BR1T, 1982FL1B, 1982GE1B, 1982HA42, 1982HA56, 1982HU1G, 1982KA35, 1982LO13, 1982ME12, 1983AD1E, 1983AU04, 1983BU15, 1983CI08, 1983CI09, 1983DE1U, 1983DE21, 1983DE1Y, 1983DE2G, 1983FR23, 1983KA30, 1983LI1L, 1983MA29, 1983SM1B, 1983TA07, 1984BA26, 1984KA1T; theor.)

54. (a) ^{12}C(^{17}O, ^{17}O)^{12}C
(b) ^{12}C(^{18}O, ^{18}O)^{12}C

The elastic scattering angular distributions have been measured at $E(^{17}\text{O}) = 30.5$ to 35 MeV and at $E(^{18}\text{O}) = 32.3$ to 57.5 MeV [see (1980AJ01)] and at $E(^{18}\text{O}) = 32.0$ to 140 MeV (1982HE07). For reaction (b) see also (1984BH01) in ^{18}O in (1987AJ02). For fusion, yields and cross-section measurements see (1979DAZK, 1979KO20, 1980WI09, 1982BA49, 1982HE07, 1983CA1N, 1983VO1B). See also (1980HE11, 1983BI1A) and (1980CH1J, 1980LE11, 1980LO02, 1980VA03, 1981HA18, 1982GI1C, 1982LO13, 1983CI08, 1983MA29, 1984AB1F; theor.).

55. ^{12}C(^{19}F, ^{19}F)^{12}C

Elastic angular distributions have been measured at $E(^{19}\text{F}) = 40$, 60 and 68.8 MeV [see (1980AJ01)], at 18.0, 20.7, 21.5 and 22.3 MeV (1981MA1Q) and at $E(^{12}\text{C}) = 30.0$, 40.3, 50.0 and 60.1 MeV (1984TA08). See also ^{19}F in (1983AJ01). For fusion and yield measurements see (1979KO20, 1981MA1Q). See also (1980CO08, 1982MA2E), (1983BI1A) and (1980LO02, 1982GI1C, 1982LO13, 1983CI08; theor.).

56. (a) ^{12}C(^{20}Ne, ^{20}Ne)^{12}C
(b) ^{12}C(^{22}Ne, ^{22}Ne)^{12}C

Elastic angular distributions (reaction (a)) have been measured at $E(^{12}\text{C}) = 37$ MeV and $E(^{20}\text{Ne}) = 65.7$ MeV [see (1980AJ01)] as well as at $E(^{12}\text{C}) = 20$ to 34.4 MeV (1983RI13), 60.7 and 72.6 to 75.2 MeV (1982SH29; also ^{20}Ne*(0, 1.6)) and 77.4 MeV (1979MO14). See also (1979FO22). For fusion, yields and breakup measurements see (1978TR08, 1979FO22,

1979SA26, 1979SH18, 1980HU12, 1980SK1A, 1980TS03, 1981DE20, 1981OS07, 1981ST20, 1982DE10, 1982KO29, 1982MO15, 1982SH29, 1983RI13). For pion production see (1979NA12, 1982AN1H, 1982RA1D). See also ^{20}Ne in (1983AJ01), (1980CO08, 1980MA1T, 1983OS1J), (1979GO1C, 1981SC1J, 1983BI1A, 1983DU13 [also on ^{23}Na], 1983HE1B), (1981RO1W; astrophys.) and (1978VO13, 1980OH05, 1981AB1A, 1981AN1D, 1981VA1E, 1982LO13, 1983CI08, 1983TO1L; theor.).

57. (a) ^{12}C(^{24}Mg, ^{24}Mg)^{12}C
(b) ^{12}C(^{26}Mg, ^{26}Mg)^{12}C

Elastic angular distributions (reaction (a)) have been measured at $E(^{12}\text{C}) = 20$ to 36 MeV (1979CH24), 20 to 60 MeV (1982DA09), 24.8, 27.7 to 34.8 MeV (1981ME10) and 40 MeV (1982LI16). In reaction (b) these have been studied at $E(^{12}\text{C}) = 20$ to 56 MeV (1982DA09). For fusion, yields and breakup measurements see (1979CH24, 1979FO22, 1981ME10, 1982DA09, 1982GA09, 1982ME06, 1983GL1E, 1983ROZZ). See also (1982FR1T, 1983BI1A, 1983BR1R, 1983DU13) and (1980TA1E, 1983HU1C, 1984HU05; theor.).

58. ^{12}C(^{27}Al, ^{27}Al)^{12}C

Elastic angular distributions have been measured at $E(^{12}\text{C}) = 30.0$ to 39.9 MeV (1979RO11), while that of the transition to ^{12}C*(4.4) has been studied at $E(^{12}\text{C}) = 82$ MeV (1977BE42). For fusion, yield and breakup measurements see (1979RO11, 1979WU1A, 1980WU1C, 1981WU1B, 1983ROZZ). For pion production see (1982AS1B). See also (1980TA1B, 1983BI1A, 1983DU13) and (1981CH23, 1982BL12, 1982GI1C, 1983FR08, 1983SH1V, 1983XI1A; theor.).

59. (a) ^{12}C(^{28}Si, ^{28}Si)^{12}C
(b) ^{12}C(^{29}Si, ^{29}Si)^{12}C
(c) ^{12}C(^{30}Si, ^{30}Si)^{12}C

Elastic angular distributions have been studied for reaction (a) at $E(^{12}\text{C}) = 19$ to 186.4 MeV and at $E(^{28}\text{Si}) = 58.3$ to 116.7 MeV [see (1980AJ01)] as well as at $E(^{12}\text{C}) = 19$ to 48 MeV (1979CH25), 41.3 MeV (1979BA32), 56.0 to 69.5 MeV (1983SH1Y) and 131.5 MeV (1980SA25). For fusion, yield and breakup measurements see (1979BA49, 1979CH25, 1979JO07, 1979KU09, 1980SK1A, 1981BR13, 1981VA01, 1982CH02, 1982GA09, 1982LE04, 1982NA21, 1982SH16, 1983RA26, 1983ROZZ, 1983ZH1E). See also (1979RO11, 1983SC1H, 1983SC1J), (1978ST1F, 1979DE1N, 1980ER1D, 1980SA25, 1982BR1T, 1982ER1F, 1983BI1A, 1983BR1R, 1983DU13) and (1978FI1D, 1978FR1B, 1980BA44, 1980FR1F, 1980HU09, 1980TA1E, 1981FR12, 1981HU07,

1981VA1H, 1982BR1E, 1982HA29, 1982HU04, 1982HU1G, 1982KH04, 1982SM1D, 1983HA39, 1983SA1D, 1983SI07; theor.).

60. $^{12}C(^{32}S, ^{32}S)^{12}C$

Elastic angular distributions are reported at $E(^{12}C) = 35.8$ MeV and $E(^{32}S) = 73.3$ to 128.3 MeV [see (1980AJ01)] and at $E(^{32}S) = 60$ to 99 MeV (1982CH02) and 160 MeV (1983GI12). For fusion and yield measurements see (1982CH02, 1983RAZY). See also (1979DE1N, 1982BR1T, 1983DU13 [also on ^{31}P, ^{34}S, ^{35}S, ^{35}Cl, ^{37}Cl, ^{36}Ar, ^{38}Ar], 1983GI12) and (1982BR1E; theor.).

61. $^{12}C(^{39}K, ^{39}K)^{12}C$

Elastic angular distributions have been studied at $E(^{12}C) = 54$ and 63 MeV (1980GL03). See also (1983DU13; also on ^{40}K).

62. (a) $^{12}C(^{40}Ca, ^{40}Ca)^{12}C$
(b) $^{12}C(^{42}Ca, ^{42}Ca)^{12}C$
(c) $^{12}C(^{48}Ca, ^{48}Ca)^{12}C$

The elastic scattering in reactions (a), (b) and (c) has been studied at $E(^{12}C) = 51.0$, 49.9 and 49.9 MeV, respectively (1979RE03). For fusion, yield and cross section measurements see (1980KU03, 1983RAZY, 1983ROZZ) and (1980AJ01). See also (1980PE1D), (1979DE1N, 1981SC1N, 1983DU13 [also on ^{43}Ca, ^{46}Ca]) and (1979SA27, 1980GL03, 1982AL02, 1982BR1E, 1982KH04, 1983SH1V, 1983XI1A; theor.).

63. $^{12}N(\beta^+)^{12}C$ $Q_m = 17.338$

The decay is mainly to the ground state via an allowed transition. Branching ratios to other states of ^{12}C are displayed in Table 12.21. The half-life of ^{12}N is 11.000 ± 0.016 msec (1978AL01). See also (1968AJ02). The ratio of the branching ratios $^{12}N/^{12}B$ for the decays to ^{12}C*(4.4) is 1.607 ± 0.021 (1981KA31). This leads to the following values for the mirror asymmetries of ^{12}B and ^{12}N for decay to ^{12}C*(0, 4.4): $\delta_{g.s.} = +0.129 \pm 0.008$ (1978AL01), $\delta_{4.4} = -0.001 \pm 0.014$ (1981KA31). The results displayed here as well as in ^{12}B (see reaction 29 and Table 12.14 in ^{12}C) are consistent with the absence of SCC contributions and are in agreement with CVC: see reaction 69 in (1980AJ01). See also (1980OK01, 1980SY02, 1981HO06; theor.).

Table 12.21: Branching in ^{12}N(β^+)^{12}C

Decay to ^{12}C*	Branch (%)	Log ft [a]	References
g.s.	94.55 ± 0.60	4.120 ± 0.003	(1978AL01)
4.44	1.898 ± 0.032 [b]	5.149 ± 0.007	(1981KA31)
7.65	2.7 ± 0.4	4.34 ± 0.06	[c]
10.3	0.46 ± 0.15	4.36 ± 0.17	[c]
12.71	0.31 ± 0.12	3.52 ± 0.14	[d]
15.11	$(4.4 \pm 1.5) \times 10^{-3}$	3.30 ± 0.13	[d]

[a] Based on $\tau_{1/2} = 11.000 \pm 0.016$ msec and $Q_{\rm m}$.
[b] For other values see Table 12.20 in (1980AJ01).
[c] Mean of values quoted in (1975AJ02).
[d] See (1980AJ01) for reference.

64. ^{13}C(γ, n)^{12}C $\qquad Q_{\rm m} = -4.9463$

The decay of the giant resonance in ^{13}C takes place predominantly to ^{12}C*(15.1, 16.1) [and to their analogues in ^{12}B]. Below $E_\gamma = 21$ MeV transitions to ^{12}C*(4.4) are dominant: see (1980AJ01). See also (1979WO06, 1980HO11, 1983ZU02) and ^{13}C in (1981AJ01, 1986AJ01).

65. ^{13}C(π^+, p)^{12}C $\qquad Q_{\rm m} = 135.4033$

Angular distributions have been measured at $E_{\pi^+} = 90$ and 170 MeV to ^{12}C*(0, 4.4, 7.7, 9.6, 12.7, 14.1, 15.1, 16.1, 19.1, 20.6, 22.9, 25.3) (1981AN10): an energy-dependent ratio for the excitation of ^{12}C*(12.7, 15.1) is reported. Similarities in the population of states seen in this reaction and in the (p, d) reaction are observed (1981AN10). Angular distributions at $E_{\pi^+} = 32$ MeV are also reported (1982DO01; g.s., 4.4). See also (1982HO1C, 1982LO1B).

66. (a) ^{13}C(p, d)^{12}C $\qquad Q_{\rm m} = -2.7218$
(b) ^{13}C(p, 2pd)^{10}Be $\qquad Q_{\rm m} = -29.9066$

Angular distributions have been measured at $E_{\rm p} = 8$ to 54.9 MeV [see (1980AJ01)] and at $E_{\vec{\rm p}} = 65$ MeV (1980HO18, 1982KA01; ^{12}C*(0, 12.7, 15.1, 16.1); see also for C^2S), 200 and 400 MeV (1981LI06; ^{12}C*(0, 4.4)), and at $E_{\rm p} = 800$ MeV (1980BA02; ^{12}C*(0, 4.4, 12.7, 14.1, 15.1, 16.1)). See also (1980KA01, 1981IR1A, 1982MA1H, 1983BE1D). For yields and polarization measurements see (1980HO18, 1981LI06, 1982BU03) and ^{14}N in (1981AJ01, 1986AJ01).

At $E_p = 62$ MeV the excitation of states with $E_x = 15112 \pm 5$, 16110 ± 5 [< 20], 17760 ± 20 [80 ± 20], 18800 ± 40 [80 ± 30], 21500 ± 100 [< 200] and 22550 ± 50 [< 200] keV has been reported [the numbers shown in brackets are $\Gamma_{c.m.}$, in keV]; $l_n = 1$ for all states except ^{12}C*(21.5) and (22.55) for which $l_n = (1)$ and $\neq 1$, respectively: see (1980AJ01) for references.

At $E_p = 800$ MeV an enhancement is observed in the yield of forward emitted deuterons (reaction (b)) which correspond to an E_x of 241 MeV in ^{12}C. It is suggested that it may be due to the formation of low-spin (ΔN^{-1}) states in ^{12}C (1983MO04). See also (1980CA1A, 1982LO1B, 1982YA1A, 1984PEZW) and (1980BA54, 1980SH1J, 1983DI1C, 1983TO10; theor.).

67. ^{13}C(d, t)^{12}C $\qquad Q_m = 1.3110$

Angular distributions have been studied at $E_d = 0.41$ to 27.5 MeV [see (1975AJ02, 1980AJ01)] and at $E_{\overline{d}} = 29$ MeV (1979CO08; to ^{12}C*(0, 4.4, 12.71, 15.11, 16.11) [see also ^{13}C(d, ^{3}He) in ^{12}B]. For charge-dependent matrix elements between ^{12}C*(12.71, 15.11) see Table 12.10. See also (1979SH1K), (1983AD1B) and (1980BA54, 1980LE14; theor.).

68. (a) ^{13}C(^{3}He, α)^{12}C $\qquad Q_m = 15.6314$

(b) ^{13}C(^{3}He, 2α)^{8}Be $\qquad Q_m = 8.2649$

Angular distributions have been measured at many energies up to $E(^3\text{He}) = 45$ MeV [see (1980AJ01)] as well as at 18.3 and 23.1 MeV (1982GU12; α_0, α_1). Angular correlations involving ^{12}C*(15.1) have been studied at $E_\alpha = 24$ and 25.5 MeV: the average ratio between the $p_{1/2}$ and $p_{3/2}$ amplitudes is -0.086 ± 0.030 (1980BA1U; prelim.). For the earlier work see (1980AJ01).

A study of reaction (b) leads to Γ_α/Γ for ^{12}C*(15.11) $= (4.1 \pm 0.9)$%; together with the other parameters for the decay of the state (see Table 12.7) this leads to $\Gamma_\alpha = 1.8 \pm 0.3$ eV. If this isospin forbidden α-width is the result of the mixing between ^{12}C*(12.71, 15.11) via a charge-dependent interaction the matrix element is 340 ± 60 keV: see, however, Table 12.10. See also (1978MO1G, 1984LE1E, 1984VA1J), and (1981KA1K) in ^{16}O in (1982AJ01).

69. (a) ^{13}C(^{6}Li, ^{7}Li)^{12}C $\qquad Q_m = 2.3037$

(b) ^{13}C(^{7}Li, ^{8}Li)^{12}C $\qquad Q_m = -2.9136$

At $E(^7\text{Li}) = 34$ MeV angular distributions have been observed for the reactions to ^{12}C*(0, 4.4) + ^{7}Li*(g.s., 0.48) and ^{8}Li*(0, 0.95) in all combinations. While ^{12}C*(0, 4.4) are dominant in the two spectra, ^{12}C*(7.7, 9.6) and, in reaction (a) at $E(^6\text{Li}) = 36$ MeV, ^{12}C*(12.7) are also populated (1973SC26).

70. ^{13}C(^{13}C, ^{14}C)^{12}C $\qquad Q_m = 3.2302$

Angular distributions have been reported at $E(^{13}\text{C}) = 16.0$ to 50.0 MeV by (1983KO15) who have also studied the excitation functions over that energy range. See also (1981BR1P) and (1983KO16; theor.).

71. (a) ^{13}C(^{16}O, ^{17}O)^{12}C $\qquad Q_m = -0.8025$
(b) ^{13}C(^{17}O, ^{18}O)^{12}C $\qquad Q_m = 3.0977$
(c) ^{13}C(^{18}O, ^{19}O)^{12}C $\qquad Q_m = -0.989$

Angular distributions for reaction (a) have been measured at $E(^{16}\text{O}) = 13$ to 46.0 MeV: see (1980AJ01). See also (1980RA12) in ^{16}O in (1986AJ04), as well as (1979GO1C) and (1980GO1L, 1980PA04; theor.). For reactions (b) and (c) see (1980AJ01) and (1983OS08; theor.).

72. ^{14}C(p, t)^{12}C $\qquad Q_m = -4.6410$

Angular distributions have been measured at $E_p = 14.5$, 18.5 and 39.8 MeV: see (1975AJ02). At $E_p = 54$ MeV angular distributions are reported to two states at $E_x = 27.57 \pm 0.03$ and 29.63 ± 0.05 MeV [$\Gamma_{\text{c.m.}} \lesssim 200$ keV]: their identification as the first $T = 2$ states is supported by the similar angular distributions to the first two $T = 2$ states in ^{12}B, reached in the (p, ^{3}He) reaction [see reaction 24 in ^{12}B]. The lower $T = 2$ state is well fitted by $L = 0$; the angular distribution to ^{12}C*(29.63) is rather featureless. It is suggested that its shape is somewhat more consistent with $L = 0$ than with $L = 2$ (1976AS01): [(1976BA24) has suggested that the second $T = 2$ state in $A = 12$ may have $J^\pi = 0^+$.] It is not excluded that the group to ^{12}C*(29.63) may be due to unresolved states (1976AS01). (1976AS01) report $\Gamma_p/\Gamma \approx 0.3 \pm 0.1$ and $\Gamma_{\alpha_1}/\Gamma < 0.1$ for the first $T = 2$ state and $\Gamma_p/\Gamma = 0.8 \pm 0.2$, $\Gamma_{p_0}/\Gamma \approx 0.4$ and $\Gamma_\alpha/\Gamma \approx 0.2$ for ^{12}C*(29.63). (1978RO08) report $E_x = 27595.0 \pm 2.4$ keV, $\Gamma \leq 30$ keV for the first $T = 2$ state and calculate the decay properties for two values of total width, 0 and 30 keV. Branching ratios for the decays to ^{8}Be(0)$+\alpha$; ^{11}B*(0, 2.12, 4.45, 5.02, $6.74+6.79$)$+$p; and ^{10}B(0)$+$d are, respectively, (10.5 ± 3.0), (3.0 ± 2.2), (8.0 ± 2.3), (0 ± 3.3), (8.4 ± 3.2), (8 ± 5), and (2.8 ± 2.0)% (1979FR04).

73. ^{14}C(^{16}O, ^{18}O)^{12}C $\qquad Q_m = -0.9349$

Angular distributions to the ground states have been measured at $E(^{16}\text{O}) = 20$, 25, 30 and 32 MeV: see (1980AJ01).

74. ^{14}N(n, t)^{12}C $Q_m = -4.0151$

See (1980AJ01).

75. ^{14}N(p, ^{3}He)^{12}C $Q_m = -4.7788$

Angular distributions have been studied at $E_p = 7.5$ to 52 MeV [at the higher energies to ^{12}C*(12.7, 14.1, 15.1, 16.1) as well as to ^{12}C*(0, 4.4)]. (1979SH1K; prelim.) conclude on the basis of the results in this reaction and in the ^{14}N(d, α) reaction that ^{12}C*(19.6, 20.6, 22.7) are of mixed isospin (primarily $T = 0$) and have positive parity. See, however, Table 12.6 for the density of states. See also (1983GO10; theor.).

76. ^{14}N(d, α)^{12}C $Q_m = 13.5743$

Observed α-particle groups are shown in Table 12.19. Angular distributions have been measured at energies up to 40 MeV: see (1980AJ01). At the latter energy (1976VA07) have measured the distributions of the α-particles to ^{12}C*(0, 4.4, 12.7, 14.1, 19.5, 20.6, 22.5) and suggest $J^\pi = (1, 2, 3)^+$, (2, 3)$^+$ and (2, 3)$^+$, respectively, for ^{12}C*(19.5, 20.6, 22.5). See also (1979SH1K) in reaction 75 and Table 12.6. For recent polarization studies (1979DE45, 1981KR1A, 1982US1A) see ^{16}O in (1982AJ01, 1986AJ04).

77. ^{14}N(^{10}B, 3α)^{12}C $Q_m = 7.6387$

See (1978BE1G) and (1980SH04; theor.).

78. ^{14}N(^{12}C, p^{13}C)^{12}C $Q_m = -7.5506$

See (1982QU1B).

79. ^{14}N(^{14}N, ^{16}O)^{12}C $Q_m = 10.4639$

See (1983KL1A).

80. ^{15}N(e, t)^{12}C $\quad Q_{\rm m} = -14.8484$

See (1979UE01) in reaction 59 of ^{15}N (1981AJ01).

81. ^{15}N(p, α)^{12}C $\quad Q_{\rm m} = 4.9656$

Angular distributions of α_0 and α_1 have been measured for $E_{\rm p}$ up to 43.7 MeV: see (1980AJ01). At the highest energy the angular distributions to the 0^+ states ^{12}C*(0, 7.65, 17.76) are fitted by $L = 1$, and $L = 3$ is consistent with distributions to ^{12}C*(14.1, 16.1) [$J^\pi = 4^+$ and 2^+]. See also (1983LE25), (1983SC43; applied), (1980CA28; theor.) and ^{16}O in (1982AJ01, 1986AJ04).

82. ^{15}N(α, ^{7}Li)^{12}C $\quad Q_{\rm m} = -12.3803$

At $E_\alpha = 42$ MeV angular distributions have been obtained for all four of the transitions involving ^{12}C*(0, 4.4) and ^{7}Li*(0, 0.48): see (1980AJ01).

83. ^{16}O(γ, 2d)^{12}C $\quad Q_{\rm m} = -31.00869$

See (1984GL1H; theor.).

84. ^{16}O(e, e$'\alpha$)^{12}C $\quad Q_{\rm m} = -7.1620$

At $E_{\rm e} = 128$ MeV the α-decay is primarily to ^{12}C*(0, 4.4) (1983VO1F).

85. ^{16}O(p, pα)^{12}C $\quad Q_{\rm m} = -7.1620$

This reaction appears to proceed primarily via excited states of ^{13}N and ^{16}O to ^{12}C*(4.4) [$E_{\rm p} = 46.8$ and 50 MeV]: see (1980AJ01). The reaction has also been studied at $E_{\rm p} = 101.5$ MeV (1981CA02; S_α relative to the (p, p, α) reaction on other nuclei).

86. ^{16}O(d, ^{6}Li)^{12}C $\quad Q_{\rm m} = -5.6866$

Angular distributions have been measured at $E_d = 12.7$ to 35 MeV [see (1980AJ01)], at $E_d = 50$, 60, 65 and 80 MeV (1979OE04; g.s., 4.4, 14.1) and at 54.25 MeV (1980YA02; g.s., 4.4, 7.7, 9.6, 14.1). Both of the latter groups performed a FRDWBA analysis of their data. (1980YA02) derive $S_\alpha = 0.57$, 1.50, 0.09, 0.05, 0.83 for ^{12}C*(0, 4.4, 7.7, 9.6, 14.1). See also (1979OE04, 1984NE1A) and (1980AJ01).

87. ^{16}O(^{3}He, ^{7}Be)^{12}C $\quad Q_m = -5.5744$

Angular distributions have been studied at $E(^3\text{He}) = 30$ MeV (^{12}C*(0, 4.4, 7.7, 9.6) and ^{7}Be*(0, 0.4)) and 70 MeV (^{12}C*(0, 4.4) and ^{7}Be*(0, 0.4)) [see for S_α] [see (1980AJ01)], as well as at 41 MeV [see (1981LE01)].

88. (a) ^{16}O(α, 2α)^{12}C $\quad Q_m = -7.1620$
(b) ^{16}O(α, ^{8}Be)^{12}C $\quad Q_m = -7.2537$

At $E_\alpha = 90$ MeV angular distributions involving ^{12}C*(0, 4.4) (reaction (a)) have been analyzed by PWIA and DWBA by (1976SH02): $S_\alpha = 2.9 \pm 0.5$ and 0.70 ± 0.23, respectively. At $E_\alpha = 65$ MeV angular distributions involving $^8\text{Be}_{\text{g.s.}}$ (reaction (b)) and ^{12}C*(0, 4.4, 7.7, 9.6, 14.1) have been measured by (1976WO11) [the ground-state distributions have also been studied for $E_\alpha = 55$ to 72.5 MeV]: $S_\alpha = 0.25$, 1.07, 0.05, 1.40 for ^{12}C*(0, 4.4, 7.7, 14.1). See also (1980BE04), (1980WE1D), (1983FR14) in ^{16}O (1986AJ04), and (1981BA20; theor.).

89. (a) ^{16}O(^{16}O, ^{20}Ne)^{12}C $\quad Q_m = -2.428$
(b) ^{16}O(^{16}O, 2α^{12}C)^{12}C $\quad Q_m = -14.3239$

For reaction (a) see ^{20}Ne in (1983AJ01). See also (1981PO1A) and (1981KR09; theor.). For reaction (b) see (1982PE08).

90. ^{19}F(d, ^{9}Be)^{12}C $\quad Q_m = 0.3009$

At $E_d = 13.6$ MeV angular distributions have been obtained for the ^{9}Be groups to ^{12}C*(0, 4.4) (1981GO16). See (1980AJ01) for the earlier work.

91. ^{20}Ne(α, ^{12}C)^{12}C $\quad Q_m = -4.6213$

Angular distributions have been measured in the range $E_\alpha = 13.4$ to 20.8 MeV (1981DA1G). See also ^{20}Ne in (1987AJ02).

92. ^{23}Na(d, ^{13}C)^{12}C $\qquad Q_{\rm m} = 0.479$

See (1984GO1H; $E_{\rm d} = 13.6$ MeV).

93. ^{24}Mg(α, ^{16}O)^{12}C $\qquad Q_{\rm m} = -6.7710$

Angular distributions have been reported at $E_\alpha = 22.8$ to 25.4 MeV and at 90 MeV: see (1980AJ01).

94. (a) ^{24}Mg(e, e$'$^{12}C)^{12}C $\qquad Q_{\rm m} = -13.933$
(b) ^{28}Si(e, e$'$^{16}O)^{12}C $\qquad Q_{\rm m} = -16.755$

For (a) see (1979CA1E); for (b) see (1980SC1F; theor.).

^{12}N
(Figs. 8 and 9)

GENERAL: (See also (1980AJ01).)

Model calculations: (1980OK01).

Muon and neutrino capture and reactions: (1979MA1U, 1982MI05).

Pion capture and reactions (See also reactions 2, 4 and 5.): (1979BU1C, 1979NA1J, 1979RA1G, 1979SI16, 1980KE13, 1980KL03, 1980NA11, 1980RA05, 1980SI07, 1980TR1A, 1981DU1H, 1981SI09, 1981RA16, 1982BE1D, 1982RA28, 1982SC1L, 1983DE2G, 1983GI08).

Hypernuclei: (1979BU1C, 1981WA1J, 1982KA1D).

Other topics: (1981GR08, 1981NO1D, 1982DE42, 1982NG01, 1983AN25, 1983FR1A, 1983OL1A, 1984SA1V).

Ground-state properties of ^{12}N: (1982NG01, 1983ANZQ, 1984SA1V).

$$\mu = +0.4573\ (5)\ \text{nm (1978LEZA).}$$

1. ^{12}N(β^+)^{12}C $\qquad Q_{\rm m} = 17.338$

The half-life of ^{12}N is 11.000 ± 0.016 msec: ^{12}N decays to ^{12}C*(0, 4.44, 7.65, 10.3, 12.71, 15.11): see Table 12.21. Since the transitions to ^{12}C*(0, 4.4) are allowed J^π (^{12}N) $= 1^+$. Measurements on $\beta\gamma$ correlations in aligned ^{12}N (and ^{12}B) nuclei are consistent with strong conservation of vector currents without second-class currents (1979MA31). See also (1983AD1B) and (1979HW03, 1979KI1G, 1979MA1U, 1979NO01, 1979RH1A, 1980OK01, 1981CH1B, 1981KO27, 1982GU09, 1983MO1N; theor.).

2. ^{10}B(d, π^-)^{12}N $\qquad Q_{\rm m} = -131.719$

See (1982AS01).

3. ^{10}B(^{3}He, n)^{12}N $\qquad Q_{\rm m} = 1.572$

Observed neutron groups are displayed in Table 12.23.

Table 12.22: Energy levels of ^{12}N

E_x (MeV $\pm$ keV)	$J^\pi; T$	$\tau_{1/2}$ or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
0	$1^+; 1$	$\tau_{1/2} = 11.000 \pm 0.016$ msec	β^+	1, 2, 3, 4, 5, 6, 7, 8, 9
0.960 ± 12	2^+	$\Gamma < 20$ keV		3, 6, 7, 9
1.191 ± 8	2^-	118 ± 14	(p)	3, 6, 7
1.80 ± 30	1^-	750 ± 250	(p)	7
2.439 ± 9	0^+	68 ± 21	(p)	3, 7, 9
3.132 ± 8	$2^+, 3^-$	220 ± 20	(p)	3, 7
3.558 ± 9	$(1)^+$	220 ± 25	(p)	3, 6, 7
4.140 ± 10 [a]	$2^- + 4^-$	825 ± 25	(p)	3, 6, 7
5.348 ± 13	3^-	180 ± 23	(p)	3, 6, 7
(5.60 ± 11)		120 ± 50	(p)	7
6.40 ± 30 [a]	(1^-)	1200 ± 30	(p)	7
7.40 ± 50 [a]	(1^-)	1200 ± 30	(p)	7
7.684 ± 21 [a]		200 ± 32	(p)	3, 6, 7
8.446 ± 17 [a]		90 ± 30		3
9.035 ± 12		< 35		3
(9.42 ± 100)		≈ 200		7
9.80 ± 20		450 ± 100		7
10.30 ± 20		450 ± 100		7
11.00 ± 20		350 ± 100		7

[a] Probably corresponds to unresolved states. See Table 12.23 and reaction 7.

Table 12.23: States of ^{12}N from ^{10}B(^{3}He, n) and ^{12}C(^{3}He, t)

E_x [a] (MeV ± keV)	$\Gamma_{c.m.}$ [a,c] (keV)	L [a]	E_x [b] (MeV ± keV)	$\Gamma_{c.m.}$ [b] (keV)	E_x [d] (MeV ± keV)	$\Gamma_{c.m.}$ [d] (keV)	J^π [e]
0	20 ± 20	2	0		0		(1^+)
0.960 ± 12	16 ± 20	2	≡ 0.964	< 20 [h]	0.960		(2^+)
1.189 ± 12	140 ± 25	1	1.190 ± 20	80 ± 30 [h]	1.193 ± 10	120 ± 20	2^-
(1.72 ± 0.08)					1.80 ± 30	750 ± 250	1^-
2.4 ± 100			2.415 ± 20	45 ± 15 [h]	2.445 ± 10	110 ± 20	0^+
3.114 ± 15	200 ± 36	2	3.136 ± 30	240 ± 40	3.14 ± 10	220 ± 25	$2^+, 3^-$
3.533 ± 15	150 ± 40	2	3.55 ± 50	150 ± 100	3.57 ± 10	260 ± 30	1^+
4.250 ± 30 [f]	290 ± 70		4.15 ± 80 [f]	650 ± 100	4.14 ± 10 [f]	830 ± 20	$2^- + 4^-$
5.320 ± 12	180 ± 20	(0)	5.23 ± 80 [f]	400 ± 80	5.37 ± 10	150 ± 30	3^-
			6.10 ± 80 [f]	300 ± 100	(5.60 ± 11)	120 ± 50	
			7.13 ± 100 [f]	500 ± 100	6.40 ± 30	1200 ± 300	(1^-)
7.629 ± 20	200 ± 40		7.48 ± 100 [f]	180 ± 80	7.40 ± 50	1200 ± 500	(1^-)
8.446 ± 17	90 ± 30				7.70 ± 11	200 ± 50	
			(8.86 ± 100)	≈ 100			
9.035 ± 12	16 ± 20						
			9.42 ± 100	≈ 200			
			9.90 ± 100	100 ± 50			
			[g]		9.80 ± 20	450 ± 100	
					10.30 ± 20	450 ± 100	
					11.00 ± 20	350 ± 100	

[a] ^{10}B(^{3}He, n)^{12}N: see Table 12.22 in (1975AJ02) for references.
[b] ^{12}C(^{3}He, t)^{12}N: see Table 12.23 in (1980AJ01) for references.
[c] Weighted means of values shown in Table 12.23 in (1980AJ01).
[d] ^{12}C(^{3}He, t)^{12}N: (1983ST10: $E(^{3}\text{He}) = 75$ and 81 MeV), and M.N. Harakeh, private communication.
[e] DWBA calculations (1983ST10). Some of the J^π assignments also reflect knowledge of the analog region in ^{12}B.
[f] May be due to unresolved states.
[g] No other states observed with $E_x < 13$ MeV.
[h] $J^\pi = 2^+$, (2^-) and (0^+) for ^{12}N*(0.96, 1.19, 2.42), respectively: see Table 12.23 in (1980AJ01).

4. ^{12}C(γ, π^-)^{12}N $\qquad Q_m = -156.905$

The total cross section (measured from threshold to $E_e = 360$ MeV) has been measured by (1979BO23). See also (1983SC11), (1980AJ01) and the "GENERAL" section here.

5. ^{12}C(π^+, γ)^{12}N $\qquad Q_m = 122.229$

See (1980MA1R).

6. ^{12}C(p, n)^{12}N $\qquad Q_m = -18.120$

Angular distributions have been reported at $E_p = 30.5$ and 49.5 MeV [see (1980AJ01)] and at $E_p = 61.8$ and 119.8 MeV (1979GO16, 1980AN05; n_0, n_1) [compared with (p, p′) to analog states at 15.1 and 16.1 MeV in ^{12}C], 99.1 MeV (1980KN02; n_0, n_1), 120, 160 and 200 MeV (1981RA12; n_0, n_1) [the spin-isospin term of the effective interaction appears to be almost energy independent over the latter energy interval], and at 144 MeV (1980MO10; n_0; forward angles). The $0°$ differential cross section for populating $^{12}N_{g.s.}$ for $E_p = 62$ to 160 MeV has been compared by (1982AN08) with the B(M1↑) to the analog state ^{12}C*(15.1). The transverse spin-transfer coefficient, for the n_0 group, consistent with a GT-type transition has been measured at $E_p = 160$ MeV (1984TA07). See also (1980GO07).

See also (1980GO1J, 1982TAZQ, 1983KI1B, 1983OR1D, 1984JEZZ), (1980AJ01) and (1980DU16, 1981BA50, 1981OL02; theor.).

7. ^{12}C(^{3}He, t)^{12}N $\qquad Q_m = -17.357$

Observed triton groups are displayed in Table 12.23. Angular distributions of inelastically scattered ^{3}He to ^{12}C*(15.11, 16.11, 16.58, 17.77, 19.57) have been compared with those of tritons to ^{12}N*(0, 0.96, 1.19, 2.42, 4.25). When the ^{3}He cross sections are corrected for phase-space and isospin factors the angular distributions are closely similar to those for the triton groups, strongly suggesting isobaric analogs: see (1980AJ01) for references. [If ^{12}C*(17.77) and ^{12}N*(2.42) are analogs, then the latter is a 0^+ state]. Angular distributions have been reported recently at $E(^3\mathrm{He}) = 0.6$, 1.2 and 2 GeV (1983EL05; t_{0+1}) [^{12}N*(4, 7.1) reached via an $l = 1$ transfer are also populated] and at 81 MeV (1983ST10) [to many of the states shown in Table 12.23]. [Compare the ^{12}B and the ^{12}N level structure: it is clear that not all the analog states have been observed in ^{12}N]. The spectra of inelastically scattered ^{3}He ions (see ^{12}C) and of tritons have been studied at $E(^3\mathrm{He}) = 170$ MeV. The triton spectrum has been compared with photoabsorption results. (1982TA05) conclude that the isovector GDR is preferentially excited in the (^{3}He, t) process while the (^{3}He, ^{3}He) process preferentially excites the isoscalar giant multipole resonances. See also (1981AA01) adn (1982BR1H; theor.).

8. ^{12}C(^{6}Li, ^{6}He)^{12}N $\qquad Q_{\rm m} = -20.845$

See (1984GL1G; $E(^{6}{\rm Li}) = 93$ MeV).

9. ^{14}N(p, t)^{12}N $\qquad Q_{\rm m} = -22.135$

At $E_{\rm p} = 51.9$ MeV angular distributions of the tritons to ^{12}N*(0, 0.96) and of the ^{3}He ions to the analog $T = 1$ states [^{12}C*(15.11, 16.11)] have been measured. At $E_{\rm p} = 52.5$ MeV the angular distribution to ^{12}N*(2.42) has been studied. See (1980AJ01) for references. See also (1979SH1K).

^{12}O
(Fig. 9)

^{12}O has been observed in the ^{16}O(α, ^{8}He) reaction at $E_{\alpha} = 117.4$ MeV (1978KE06) and in the ^{12}C(π^{+}, π^{-}) reaction at $E_{\pi} = 164$ MeV (1983BL08; see for angular distribution) and 180 MeV (1980BU15). The mass excess of ^{12}O is 32.10 ± 0.12 MeV (1978KE06), 32.059 ± 0.048 MeV (1980BU15): we adopt 32.065 ± 0.045 MeV. ^{12}O is thus unstable to decay into ^{10}C + 2p by 1.79 MeV and into ^{11}N* + p by 0.45 MeV [note that ^{11}N* is probably not the ground state of ^{11}N and that is very broad: see ^{11}N].

The width of the ground state is $\approx 400 \pm 250$ keV. The diproton branching ratio of $^{12}{\rm O}_{\rm g.s.}$ is estimated to be 60 ± 30% (1978KE06). The d-coefficient in the IMME for $A = 12$ is calculated to be 0 ± 11 keV (1978KE06), 4.4 ± 7.2 keV (1980BU15). The first $T = 2$ state in ^{12}N should occur at $E_{\rm x} = 12.29 \pm 0.02$ MeV (1978KE06). There is some indication of an excited state of ^{12}O at $E_{\rm x} = 1.0 \pm 0.1$ MeV, which would imply an appreciable downward shift from the position of the analog first excited state in ^{12}Be (1978KE06). See also (1980TR1E, 1981SE1B) and (1981WA1J, 1982NG01, 1983ANZQ; theor.).

^{12}F, ^{12}Ne
(Not illustrated)

These nuclei have not been observed: see (1980AJ01) and (1983ANZQ; theor.).

References

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