Energy Levels of Light Nuclei
$A = 12$

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Abstract: An evaluation of $A = 11$–12 was published in *Nuclear Physics A*248 (1975), 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.

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^{12}Li

(Not illustrated)

^{12}Li is not observed in the 4.8 GeV proton bombardment of a uranium target: it is particle unstable (1974BO05). Its atomic mass excess is therefore > 49.0 MeV. (1974TH01) calculate the mass excess of ^{12}Li to be 52.92 MeV. ^{12}Li would then be unstable with respect to ^{11}Li + n, ^{10}Li + 2n and ^{9}Li + 3n by 3.9, 3.68 and 3.74 MeV, respectively. See also (1972TH13, 1973BO30, 1974IR04).

^{12}Be

(Figs. 5 and 8)

GENERAL: (See also (1968AJ02).)

Special reactions: (1965GI10, 1969AR13, 1971AR02, 1972VO06, 1973KO1D).

General review: (1974CE1A).

Theoretical papers: (1971DO1F, 1971ST40, 1973WI15, 1974IR04, 1974MA1E).

Mass of ^{12}Be: The Q-value of the ^{14}C(^{18}O, ^{20}Ne)^{12}Be reaction [-15.77 ± 0.05 MeV] (1974BA15) leads to an atomic mass excess of 25.05 ± 0.05 MeV; that for the ^{7}Li(^{7}Li, 2p)^{12}Be reaction [$Q = -9.71 \pm 0.10$ MeV] (1971HO26) leads to an A.M.E. of 24.95 ± 0.10 MeV. We adopt an atomic mass excess of 25.030 ± 0.045 MeV for ^{12}Be. The binding energies of (^{11}Be + n), (^{10}Be + 2n) and (^{9}Be + 3n) are then 3.22, 3.72 and 10.53 MeV, respectively. See also (1972CE1A, 1972WA07, 1974TH01).

1. ^{12}Be(β^-)^{12}B $\qquad Q_m = 11.66$

An activity of $\tau_{1/2} = 11.4 \pm 0.5$ msec, observed in the GeV proton bombardment of various targets, is ascribed to ^{12}Be. $\log ft = 3.5$ if the transition is to the ground state of ^{12}B (1965PO03).

2. ^{7}Li(^{7}Li, 2p)^{12}Be $\qquad Q_m = -9.79$

$Q_0 = -9.71 \pm 0.10$ (1971HO26).

This reaction has been studied at $E(^{7}\text{Li}) = 25.0$, 30.0 and 30.1 MeV. The ground state of ^{12}Be and an excited state with $E_x = 0.81 \pm 0.10$ MeV are populated with cross sections of 2.9 ± 1.0 μb/sr^2 and 1.1 ± 0.6 μb/sr^2, respectively (1971HO26, 1971HO1J).

Table 12.1: Energy levels of ^{12}Be

E_x (MeV ± keV)	$J^\pi; T$	$\tau_{1/2}$ (msec)	Decay	Reactions
0	$0^+; 2$	11.4 ± 0.5	β^-	1, 2, 3
(0.81 ± 100)			(γ)	2
2.09 ± 50			(γ)	3

3. ^{14}C(^{18}O, ^{20}Ne)^{12}Be $\qquad Q_m = -15.75$

$Q_0 = -15.77 \pm 0.05$ (1974BA15).

At $E(^{18}\text{O}) = 88.7$ MeV, the population of the ground state of ^{12}Be and of an excited state at $E_x = 2.09 \pm 0.05$ MeV [and of many states in ^{20}Ne: see (1978AJ03)] is reported by (1974BA15). ^{12}Be*(0.81), reported in reaction 2, was not observed by (1974BA15).

^{12}B

(Figs. 5 and 8)

GENERAL: (See also (1968AJ02).)

Model calculations: (1968FU1B, 1968GU11, 1969MO1F, 1969VA1C, 1970TA1J, 1973HA49, 1973SA30).

Special levels: (1968CE01, 1968GU11, 1970FR1C, 1973SA30).

Electromagnetic transitions: (1969VA1C, 1973HA49, 1973SA30).

Special reactions: (1969AR13, 1969GA18, 1971AR02, 1973KO1D, 1973WI15, 1974FO22).

Muon capture (See also reaction 16.): (1969VA37, 1970BU1B, 1970HI09, 1971BA96, 1971MO1Q, 1971MU20, 1972DE50, 1972MI15, 1973CH16, 1973MU04, 1973MU11, 1973MU1B, 1974DE1V, 1974IM1C, 1974PO05, 1975SU1G).

Pion capture and pion reactions: (1970HI09, 1970HI10, 1970RA39, 1971GU13, 1971SK03, 1971SK02, 1973AN1J, 1973KA1D, 1973UB01, 1974DE1U, 1974SE02).

Astrophysical questions: (1970BA1M).

Other topics: (1971BA2Y, 1972AN05, 1972GA1L, 1972OC01, 1972PN1A, 1973JU2A, 1973WI15, 1974IR04, 1975KI1M, 1975ZI1D).

Ground state:

$$\mu = +(1.003 \pm 0.001) \text{ nm (1968SU05);}$$

$$\mu = +(1.00285 \pm 0.00015) \text{ nm (1970WI17, 1970WI1L);}$$

$$Q = (+0.030 \pm 0.008) \text{ b (1970WI17);}$$

$$Q = (0.0151 \pm 0.0014) \text{ b (1970SU04);}$$

$$Q = (0.0171 \pm 0.0016) \text{ b (1971MI06).}$$

Effective μ in various hosts have been measured by (1974MC12): μ ranges from 1.00282 (2) nm in Si, 1.00291 (2) nm in Ge and 1.00287 (2) in SiC.

See also (1967SH14, 1968WE12, 1969FU11, 1969VA1C, 1969WE1G, 1971SH26, 1972VA36, 1972WI08, 1973HOYD, 1973KU1L, 1973MA1K, 1973MIYZ, 1973SA30, 1973ST1P, 1973SU1B, 1974CO1P, 1974MC07).

1. ^{12}B(β^-)^{12}C $\qquad$ $Q_m = 13.370$

The half-life of ^{12}B is 20.41 ± 0.06 msec: see Table 12.2 here and Tables 12.1 and 12.2 in

Table 12.2: Energy levels of ^{12}B

E_x in ^{12}B (MeV ± keV)	$J^\pi; T$	τ or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
g.s.	$1^+; 1$	$\tau_{1/2} = 20.41 \pm 0.06$ msec	β^-	1, 2, 3, 6, 7, 9, 10, 13, 16, 17, 19, 21, 25, 26, 27
0.95314 ± 0.60	2^+	$\tau_m = 260 \pm 40$ fsec	γ	2, 3, 7, 9, 13, 16, 19, 20, 21, 26
1.67365 ± 0.60	2^-	$\tau_m < 50$ fsec	γ	2, 3, 7, 9, 13, 16, 19
2.6208 ± 1.2	1^-	$\tau_m < 70$ fsec	γ	2, 3, 7, 9, 13, 16, 19
2.723 ± 11	0^+	$\tau_m < 140$ fsec	γ	2, 3, 7, 9, 13, 19
3.3884 ± 1.4	3^-	$\Gamma_{c.m.} = 3.1 \pm 0.6$ eV	γ, n	2, 7, 9, 10, 11, 13
3.759 ± 6	2^+	37 ± 5	γ, n	7, 9, 10, 11, 13
4.302 ± 6	1^-	9 ± 4	γ, n	7, 9, 10, 11
4.37	2^-	broad	n	11
4.521 ± 7	4^-	110 ± 20	γ, n	7, 9, 10, 11, 13
4.99 ± 15	1^+	50 ± 15	γ, n	7, 9, 10, 11
5.607 ± 7	3^+	110 ± 20	n	7, 9, 11
5.725 ± 7	3^-	60 ± 15	n	7, 9, 11
5.8	$(1)^-$	broad	n	11
6.6	$(1)^+$	140	n	7, 11
6.8	$(1)^+$	broad	n	11
7.545 ± 20	> 3	≤ 14	n	7, 11
7.836 ± 20	> 0	60 ± 30	n	7, 11, 17
7.937 ± 20	> 0	27	n	7, 11
8.1 ± 100		900 ± 200	(n)	7
8.120 ± 20			(n)	7
8.24 ± 30	> 1	65	n	7, 11
8.376 ± 20		40 ± 20	n	7, 11
8.58 ± 30	> 1	75	n	7, 11
8.707 ± 20			(n)	7
9.03 ± 20	> 1	120	n	7, 11
9.175 ± 20			(n)	7
9.43 ± 20		85 ± 30	(n)	7

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

E_x in ^{12}B (MeV ± keV)	$J^\pi; T$	τ or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
9.585 ± 20		60 ± 30	(n)	7
9.758 ± 20			(n)	7
(9.83)			(n)	7
10.00 ± 40	> 0	100	n	7, 11
10.11 ± 40				7
10.21 ± 30		50 ± 20		7
10.435 ± 20		75 ± 40		7
10.58 ± 20	> 2	50 ± 30	n	7, 11
10.887 ± 20		40 ± 20		7
(11.08)				7
11.31 ± 30		130 ± 60		7
11.59 ± 20		75 ± 25		7
12.33 ± 30	> 2	100 ± 30	n	7, 11
12.710 ± 20	$0^+; 2$	(85 ± 40)		7, 24
13.33 ± 30		50 ± 20		7
[a]				
14.7	$(2^+; 2)$	sharp		4, 24
15.5				7

[a] Thirteen resonances in ^{9}Be(t, n)^{11}B with $13.6 < E_x < 14.7$ MeV [see Table 12.3].

(1968AJ02). The decay is complex; ^{12}B decays to ^{12}C*(0, 4.4, 7.7, 10.3): see Table 12.16. The transitions to ^{12}C*(0, 4.4) are allowed: hence the J^π of ^{12}B$_{g.s.}$ is 1^+.

2. ^{6}Li(^{7}Li, p)^{12}B $\qquad Q_m = 8.337$

At $E(^7$Li$) = 2$ MeV, eleven groups of protons are reported to known states of ^{12}B (1959MO12). Angular distributions have been measured at $E(^6$Li$) = 3.5$ MeV (1967GA06: $p_0 \rightarrow p_3$) and $E(^7$Li$) = 3.78$ to 5.95 MeV (1967KI03: p_0, p_1, p_2, p_{3+4}, p_5). Except for p_2 the distributions are nearly isotropic. See also (1968AJ02).

Table 12.3: Resonances in ^{9}Be(t, n)^{11}B (1961VA1C)

E_t (MeV)	E_x in ^{12}B (MeV)	$\Gamma_{c.m.}$ (keV)	E_t (MeV)	E_x in ^{12}B (MeV)	$\Gamma_{c.m.}$ (keV)
1.00	13.677	100	1.880	14.337	45
1.130	13.775		1.932	14.375	40
1.350	13.939	60	2.045	14.460	70
1.405	13.981	50	2.130	14.524	75
1.505	14.056	70	2.210	14.584	60
1.585	14.116	65	2.325	14.670	50
1.765	14.250	110			

3. ^{7}Li(^{7}Li, d)^{12}B $\qquad Q_m = 3.311$

Angular distributions have been measured at $E(^{7}\text{Li}) = 2.10$ to 5.75 MeV (1969CA1A: d_0, d_1, d_2, d_{3+4}). The gamma decay of the first four excited states has been studied by (1963CA09): ^{12}B*(0.95) decays of course to the ground state. So, primarily, do ^{12}B*(1.67) [$> 98\%$] and ^{12}B*(2.72) [$> 80\%$], while ^{12}B*(2.62) decays [$> 90\%$] via ^{12}B*(0.95, 1.67). [See also Table 12.7.] The mean lifetimes of ^{12}B*(0.95, 2.62) are 295 ± 37 fsec and < 48 fsec, respectively (1969TH01). See also (1967CA1D, 1974CE06).

4. ^{9}Be(t, n)^{11}B $\qquad Q_m = 9.5591 \qquad E_b = 12.928$

Reported resonances in the yield of neutrons at $\theta = 0°$ are listed in Table 12.3 (1961VA1C). See also ^{11}B.

5. (a) ^{9}Be(t, d)^{10}Be $\qquad Q_m = 0.5544 \qquad E_b = 12.928$
(b) ^{9}Be(t, t)^{9}Be
(c) ^{9}Be(t, α)^{8}Li $\qquad Q_m = 2.926$

Yields of elastically scattered tritons have been measured for $E_t = 0.60$ to 1.70 MeV (1969NA04) and 1.0 to 2.1 MeV (1970CO04). The yields of α-particles [α_0, α_1] have been obtained for $E_t = 0.52$ to 1.70 MeV by (1969NA04). See also (1970CO04). There is no evidence of the resonance structure observed in reaction 4. See also ^{8}Li and ^{9}Be in (1974AJ01). For reaction (a) see (1969NA04) and ^{10}Be in (1974AJ01).

Table 12.4: Levels of ^{12}B from ^{9}Be(^{7}Li, α)^{12}B

(1961HO19) [a] E_x (MeV)	(1969GL07) [b] E_x (MeV)	(1971AJ1B) [c] E_x (MeV $\pm$ keV)	(1971AJ1B) [c] $\Gamma_{c.m.}$ (keV)
g.s.	g.s.	g.s.	
0.90	0.9	0.951 ± 15	
1.61	1.65	1.674 ± 15	
2.58	2.60	2.625 ± 15	
		2.724 ± 15	
3.27	3.30	3.390 ± 15	
3.60	3.70	3.77 ± 20	50 ± 20
4.22		4.305 ± 15	< 30
4.39	4.50	4.534 ± 15	
4.90	5.00	4.982 ± 15	40 ± 20
5.60		5.57 ± 30	
5.80	5.7	5.728 ± 15	50 ± 20
6.61			
7.00			
7.42		7.545 ± 20	< 30
7.77		7.836 ± 20	60 ± 30
		7.937 ± 20	< 40
		8.1 ± 100	900 ± 200
8.05		8.120 ± 20	
	8.25	8.24 ± 30	
8.34		8.376 ± 20	40 ± 20
		8.58 ± 30	
		8.707 ± 20	
9.06		9.03 ± 20	
		9.175 ± 20	
		9.43 ± 20	85 ± 30
	9.55	9.585 ± 20	60 ± 30
		9.758 ± 20	
		(9.83)	
		10.00 ± 40	

Table 12.4: Levels of ^{12}B from ^{9}Be(^{7}Li, α)^{12}B (continued)

(1961HO19) [a] E_x (MeV)	(1969GL07) [b] E_x (MeV)	(1971AJ1B) [c] E_x (MeV $\pm$ keV)	(1971AJ1B) [c] $\Gamma_{c.m.}$ (keV)
		10.11 ± 40	
		10.21 ± 30	50 ± 20
		10.435 ± 20	75 ± 40
	10.6	10.58 ± 20	50 ± 30
		10.887 ± 20	40 ± 20
		(11.08)	
		11.31 ± 30	130 ± 60
	11.8	11.59 ± 20	75 ± 25
	12.5	12.33 ± 30	100 ± 30
		12.77 ± 30	85 ± 40
	13.5	13.33 ± 30	50 ± 20
	15.5		

[a] $E(^{7}\mathrm{Li}) = 3.5$ MeV. Typical resolution $\Gamma_{1/2} \approx 200$ keV.
[b] $E(^{7}\mathrm{Li}) = 30.3$ MeV. No errors shown. Typical resolution ≈ 200 keV.
[c] And private communication. $E(^{7}\mathrm{Li}) = 20$ MeV. Typical resolution ≈ 40 keV.

6. ^{9}Be(α, p)^{12}B $\qquad Q_m = -6.886$

See (1968AJ02).

7. ^{9}Be(^{7}Li, α)^{12}B $\qquad Q_m = 10.462$

Observed α-particle groups are displayed in Table 12.4 (1961HO19, 1969GL07, 1971AJ1B). Angular distributions have been measured at $E(^{7}\mathrm{Li}) = 3.3$, 3.5, 3.75 MeV (1961HO19: $\alpha_0 \to \alpha_4$), 5.6 to 6.2 MeV (1969SN02: $\alpha_0 \to \alpha_4$) and 30.3 MeV (1969GL07: to most states listed in Table 12.3). See also (1970OG1A).

8. (a) ^{10}Be(d, p)^{11}Be $\qquad Q_m = -1.722 \qquad E_b = 12.374$
(b) ^{10}Be(d, α)^{8}Li $\qquad Q_m = 2.372$

Table 12.5: ^{12}B states from ^{10}B(t, p)^{12}B

E_x in ^{12}B (MeV) [a,d]	Γ (keV) [c]	L [a,b,c]	J^{π} [a,b,c]
g.s.			
0.955		0	3^+
1.673			
2.627		0	3^+
2.73		(0)	(3^+)
3.393		0	3^+
3.754	42 ± 5	1	$2^-, 3^-, 4^-$
4.297	≤ 15		
4.514	100 ± 15	1	$2^-, 3^-, 4^-$
5.00	130 ± 40		
5.612	120 ± 20	0	3^+
5.724	70 ± 20	0	3^+

[a] ±8 keV, except for the 2.73 and 5.00 MeV states.
[b] See, however, Tables 12.6 and 12.7.
[c] (1964MI04).
[d] (1960JA17).

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: the yields for both reactions vary smoothly with energy. No resonances are observed (1970GO11, 1973GO09).

9. ^{10}B(t, p)^{12}B $\qquad Q_m = 6.343$

Excited states of ^{12}B observed by (1960JA17) at $E_t = 5.5$ MeV and by (1964MI04) at $E_t = 10$ MeV are displayed in Table 12.5. See also (1968CO1H), (1967OG1A) and (1969SO02, 1970BA58, 1970KA38, 1970MA04, 1970MA38, 1970NE1F, 1974GU1D; theor.).

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

The thermal neutron capture section is 5±3 mb (1962IM01) [(1973MU14) adopt 5.5±3.3 mb]. The capture cross section shows a resonance at $E_n = 20.8 \pm 0.5$ keV (see also reaction 11) with

$\Gamma_\gamma = 0.025 \pm 0.008$ eV (1969MO10). In the range 140 to 2325 keV, resonances are observed at $E_n = 0.43$, 1.03, 1.28 and 1.78 MeV, with radiation widths of 0.3, 0.3, 0.2 and 0.9 eV, respectively ($\pm 50\%$) (1962IM01). For astrophysical implications see (1968FOZY).

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 $a = 6.1 \pm 0.1$ fm (1973MU14). See also (1969BA1P). Parameters of observed resonances in σ_{tot} are shown in Table 12.6.

Comparison of ^{11}B + n and of data from ^{11}B(d, p) shows that the $E_n = 20.8$ keV resonance is d-wave and that ^{12}B*(3.388) has $J^\pi = 3^-$. The neutron width [3.1 ± 0.6 eV] is about the Wigner limit (1969MO10). The 0.43 MeV resonance [^{12}B*(3.76)] is formed by $l = 1$; $\gamma^2_{S=1} = \gamma^2_{S=2}$; $J^\pi = 2^+$ (1955WI25, 1962EL01, 1970LA21).

The polarization and differential cross sections have been measured for $0.075 \leq E_n \leq 2.2$ MeV by (1970LA21) as has σ_t for $0.3 \leq E_n \leq 2.05$ MeV. A two-channel R-matrix analysis fits both $\sigma(\theta)$ and $P(\theta)$ assuming broad 2^- ($l = 0$) and 4^- ($l = 2$) states at $E_x = 4.37$ and 4.54 MeV [$E_n = 1.09$ and 1.28 MeV] in addition to the sharp state ^{12}B*(4.30) fitted with $J^\pi = 1^-$. The analysis also confirms $J^\pi = 1^+$ for ^{12}B*(4.99) (1970LA21). Differential cross sections have also been measured for $2.2 < E_n < 4.5$ MeV by (1973NE1F, 1973NE19) and analyzed by a three-level R-matrix calculation. The fit is quite good if assignments 1^- and (1^+) are made for broad states of ^{12}B at $E_x = 5.8$ and 6.8 MeV, respectively [$E_n = 2.7$ and 3.8 MeV]. ^{12}B*(5.61, 5.73, 6.6) are assigned $J^\pi = 3^+$, 3^- and (1^+), respectively (1973NE19). See also (1974BI07; theor.). For a study of the excitation function of ^{11}B(n, n$'\gamma_1$) see (1961LI04).

Total cross sections from $E_n = 3.4$ to 15.5 MeV have been studied by (1961FO07): see Table 12.6. There is no evidence of sharp structure in the range $9.7 < E_x < 17.3$ MeV. Limitations of statistical accuracy exclude observation of $J = 0$ levels above $E_n = 4$ MeV, and of $J = 1$ levels above $E_n = 12$ MeV in this work (1961FO07). The σ_t for natural boron has been measured for $E_n = 2.5$ to 15 MeV (1971FO1P, 1971FO24). Cross section measurements are also reported at $E_n = 7.55$ MeV (1969HO1G: elastic, and inelastic to ^{11}B*(2.12, 4.45)), 9.72 MeV (1970CO12: elastic, and inelastic to ^{11}B states below 6.8 MeV), 14.1 MeV (1970AL08: elastic, and inelastic to ^{11}B states below 8.6 MeV) and 14.5 MeV (1970AN1F: ^{nat}B). See also (1972LA1F), (1969AN1E, 1969MA39, 1969RO1F, 1970PO1E) and (1967BE1F; 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 $\qquad Q_m = -9.005$

(c) ^{11}B(n, t)^{9}Be $\qquad Q_m = -9.5591$

(d) ^{11}B(n, α)^{8}Li $\qquad Q_m = -6.633$

Table 12.6: Resonances in ^{11}B(n, n)^{11}B [a]

E_n (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	^{12}B* (MeV)	l	J^π	Comments
0.0208 ± 0.5 [b]	≪ 1.4	3.3884	2	3^- [c]	$\Gamma_n = 3.1 \pm 0.6$ eV [b]
0.43 ± 10 [g,k]	37 ± 5	3.763	1	2^+ [c]	
1.027 ± 11 [h,k]	9 ± 4	4.310	0	1^- [c]	
1.09 [c]	broad	4.37	0	2^- [c]	[i]
1.28 ± 20 [g,k]	130 ± 20	4.54	2	4^- [c]	
1.78 ± 20 [g,k]	60 ± 20	5.00	1	1^+ [c]	
2.45 ± 20 [g]	110 ± 40	5.61	1	3^+ [d]	
2.58 ± 20 [g]	55 ± 20	5.73	2	3^- [d]	
2.7 [d]	broad	5.8	2	1^- [d,j]	
3.5 [e]	140	6.6	1	$(1)^+$ [d]	
3.8 [d]	broad	6.8	1	$(1)^+$ [d]	
4.55 [f]	≤ 14	7.54	> 3		
(4.68)	45	(7.66)	> 0		
4.80	90	7.77	> 0		
(5.01)	27	(7.96)	> 0		
5.31	65	8.23	> 1		
5.49	110	8.40			
5.59	75	8.49	> 1		
6.18	120	9.03	> 1		
7.18	100	9.94	> 0		
7.82	65	10.53	> 2		
9.72	120	12.27	> 2		

[a] See also Table 12.5 in (1968AJ02).
[b] (1969MO10). Also observed in ^{11}B(n, γ): $\Gamma_\gamma = 25 \pm 8$ meV (1969MO10).
[c] (1970LA21). See also (1974BI07).
[d] (1973NE19). See also (1974BI07).
[e] (1961FO07).
[f] This resonance and all the higher energy ones have been observed by (1961FO07).
[g] (1951BO45, 1968AJ02).
[h] (1962IM01).
[i] The low penetrability for $l = 2$ neutrons means that the observed width of this level is predominantly $l = 0$. The reduced width is probably ≈ 80% $l = 2$ and 20% $l = 0$ (1970LA21).
[j] 2^- cannot be excluded (1973NE19).
[k] Also observed in ^{11}B(n, γ) (1962IM01).

The cross section for reaction (a) has been measured for $E_n = 14.7$ to 16.9 MeV (1962KA37, 1966ST17, 1967FL16, 1967NA1C). See also (1971CU1B, 1971PR09, 1972ED01). For reaction (b) see ^{10}Be in (1974AJ01). For reaction (c) see (1958WY67, 1972BI1E). See also ^{9}Be in (1974AJ01). The cross section for reaction (d) has been measured by (1956AR21, 1959SA04, 1970SC29, 1973BO26) in the range $E_n = 12.6$ to 20.0 MeV, and at $E_n = 25$ and 38 MeV (1972KI19): no resonances are observed. See also ^{8}Li in (1974AJ01) and (1968AJ02).

13. ^{11}B(d, p)^{12}B $\qquad Q_m = 1.145$

Observed proton groups and gamma rays are displayed in Table 12.7.

Angular distributions have been studied at many energies: see (1968AJ02) for earlier references and Table 12.7. Recent interest has centered on the first unbound state in ^{12}B, at $E_x = 3.39$ MeV: a DWBA analysis, when combined with information from ^{11}B + n (see reactions 10 and 11), finds $l_n = 2$ and is consistent with $J^\pi = 3^-$ for ^{12}B*(3.39) (1969FO10). See also (1971BU02; theor.). Assuming $l_n = 2$ to this state (1972DZ06, 1973DO02) analyzed the data in terms of a peripheral stripping model and calculated $\Gamma_n = (1.9^{+0.8}_{-0.6})$ eV for ^{12}B*(3.39) [see also Table 12.6]. The probability $p_{3/2}$ for transfer of a neutron with angular momentum $\frac{3}{2}$ has been determined for the p_0 and p_1 groups using vector polarized deuterons with $E_d = 10$ and 12 MeV (1970FI07).

The J^π assignments for ^{12}B*(0.95, 1.67) are derived as follows [see (1968AJ02) for detailed 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 $J \neq 0$ (1963WA20, 1968CO14). τ_m is too short for pure E2 and hence $J \neq 3$, which is confirmed by studies of the polarization of γ_1, most recently by (1968GO17: $E_d = 0.5$ to 5.5 MeV). The results are consistent with $J^\pi = 1^+$ or 2^+. The latter is fixed by γ-γ correlations in the cascade $1.67 \rightarrow 0.95 \rightarrow$ g.s. (1968CH05). The mixing ratio $\delta = -0.08 \pm 0.06$ (1968GO17). $\Gamma_\gamma = 2.2 \pm 0.25$ meV (1968OL01). See also (1968GO18, 1974KA29). *1.67 MeV:* $l_n = 0$ and therefore $J^\pi = 1^-$ or 2^-. The state decays primarily to ^{12}B$_{\text{g.s.}}$. Gamma-gamma correlations lead to $J^\pi = 2^-$ (1968CH05). An assignment of 1^- to ^{12}B*(2.62) is made in a similar manner.

(1971MO14) have analyzed existing ^{11}B(d, p)^{12}B and ^{11}B + p reactions and have listed the properties of the first seven $T = 1$ states in ^{12}B and ^{12}C: see Table 12.13. Neutron reduced widths $\gamma^2_{\lambda_n}$ for the first six excited states in ^{12}B were calculated from spectroscopic factors and compared with $2\gamma^2_{\lambda_p}$ for the corresponding ^{12}C states. The agreement was quite good once new values for the partial widths of ^{12}C*(16.11) [see (1974AN19)] became available (1971MO14).

See also (1967SP09, 1967TI1A, 1970WI17, 1973HOYD), (1973FI1C) and (1970VO09; theor.).

14. ^{11}B(t, d)^{12}B $\qquad Q_m = -2.888$

Not reported.

Table 12.7: ^{12}B states from ^{11}B(d, p)^{12}B [a]

^{12}B* (MeV ± keV)	l_n [g]	J^π [g]	S [i]	Gamma decay (%) [c]		τ_m (fsec)
0	1	1^+	0.69			
0.95314 ± 0.60 [b]	1	2^+	0.55	to g.s.		300 ± 33 [c]
						200 ± 40 [j]
1.67365 ± 0.60 [b]	0	2^-	0.57	(3.2 ± 0.4) [k]	[→ 0.95]	< 50 [c]
				(96.8 ± 0.4)	[→ g.s.]	
2.6208 ± 1.2 [c]	0	1^-	0.75	(14 ± 3)	[→ 1.67]	< 70 [c]
				(80 ± 3)	[→ 0.95]	
				(6 ± 1)	[→ g.s.]	
2.723 ± 11 [d,f]	1	0^+	0.21	(> 85)	[→ g.s.]	< 140 [f]
3.383 ± 9 [d]	2 [h]	3^-	0.58			
3.76 [e]	1	2^+				
4.52 [e]	2					

[a] See also Table 12.6 in (1968AJ02).

[b] (1966WI01).

[c] (1968OL01).

[d] (1950BU1A, 1953EL12).

[e] (1953HO48).

[f] 2728 ± 2 keV (1971HIZF: unpublished).

[g] See (1968AJ02) and (1971MO14). See also (1971HIZF).

[h] (1969FO10).

[i] DWBA analysis (1971MO14).

[j] (1969GA16, 1970GA09).

[k] (3.2 ± 0.5)% (1968OL01), (3.0 ± 0.6)% (1968CH05).

15. ^{11}B(α, ^{3}He)^{12}B $Q_{\rm m} = -17.209$

Not reported.

16. ^{12}C(μ^-)^{12}B $Q_{\rm m} = 92.289$

Observation of γ-transitions has led to the determination of the capture rates to ^{12}B*(0, 0.95, 1.67, 2.62) (1970BU1B, 1972MI15); those to ^{12}B*(0.95, 1.67) are consistent with zero (1972MI15). Using polarized muons, (1974PO05) have determined the average polarization of ^{12}B$_{\rm g.s.}$ to be 0.43 ± 0.10. See also (1970HI09).

17. ^{12}C(n, p)^{12}B $Q_{\rm m} = -12.588$

At $E_{\rm n} = 54$ MeV strong excitation of ^{12}B*(0, 4.4, 7.8) is reported (1973KI1K). See also (1968AJ02) and ^{13}C in (1976AJ04).

18. ^{12}C(t, ^{3}He)^{12}B $Q_{\rm m} = -13.352$

Not reported.

19. ^{12}C(^{7}Li, ^{7}Be)^{12}B $Q_{\rm m} = -14.232$

At E(^{7}Li) $= 52$ MeV the population of ^{12}B*(0, 0.95, 1.71, 2.70, 2.87) and ^{7}Be(0) [and in the case of ^{12}B(0), of ^{7}Be*(0.43)] is reported by (1973BA34).

20. ^{13}C(γ, p)^{12}B $Q_{\rm m} = -17.534$

At $E_{\rm bs} = 15$ to 40 MeV, ^{12}B*(0.95) is weakly excited (1971WI1N). See also (1973KI1J; theor.) and ^{13}C in (1976AJ04).

21. ^{13}C(d, ^{3}He)^{12}B $Q_{\rm m} = -12.041$

At $E_d = 28$ MeV angular distributions have been measured for the ^{3}He groups to ^{12}B*(0, 0.95) (1972BR27). [See reaction 66 in ^{12}C for a discussion of the population of the analog states in ^{12}C in the mirror reaction ^{13}C(d, t)^{12}C.]

22. ^{13}C(t, α)^{12}B $\qquad Q_m = 2.280$

Not reported.

23. ^{14}C(n, t)^{12}B $\qquad Q_m = -17.229$

Not reported.

24. ^{14}C(p, ^{3}He)^{12}B $\qquad Q_m = -17.993$

At $E_p = 63.4$ MeV, the excitation of the lowest $T = 2$ state in ^{12}B is stated to be at $E_x = 12.710 \pm 0.020$ MeV (1971NE1B, 1971NE1E: unpublished). This state has also been observed at $E_p = 54$ MeV as has another at $E_x = 14.7 \pm 0.1$ MeV. The angular distribution of the lower state is consistent with $L = 0$; that for the higher state is rather featureless (D. Ashery, private communication) [see also reaction 70 in ^{12}C]. See also (1970OL1B).

25. ^{14}C(d, α)^{12}B $\qquad Q_m = 0.361$

See (1968AJ02).

26. ^{14}N(^{12}C, ^{14}O)^{12}B $\qquad Q_m = -18.515$

At $E(^{14}\mathrm{N}) = 118$ MeV the excitation of ^{12}B*(0, 0.95) is reported by (1974AN36).

27. ^{15}N(n, α)^{12}B $\qquad Q_m = -7.622$

See (1948JE03).

28. ^{18}O(^{11}B, ^{17}O)^{12}B $\qquad Q_m = -4.678$

See (1974SW04).

^{12}C

(Figs. 6 and 8)

GENERAL: (See also (1968AJ02).)

Shell model: (1967SV1A, 1968BA1L, 1968DR1B, 1968FA1B, 1968FU1B, 1968GO01, 1968GU1C, 1968HA11, 1968RO1G, 1969GU1E, 1969GU03, 1969IK1A, 1969LA26, 1969MO1F, 1969SA1A, 1969SV1A, 1969WA06, 1969WO05, 1970AR21, 1970BE26, 1970BO33, 1970BO1J, 1970CO1H, 1970DE1F, 1970DO1A, 1970EI06, 1970GI11, 1970GU11, 1970KH01, 1970KO04, 1970KR1D, 1970LO1C, 1970RE1G, 1970RU1A, 1970RY1A, 1970SV1B, 1970WO12, 1971AR1R, 1971BO29, 1971GR16, 1971GU11, 1971NO02, 1971RO03, 1971ZO03, 1971ZO01, 1972AB12, 1972BE1X, 1972BO38, 1972BR1G, 1972FO1G, 1972JA18, 1972KR1D, 1972LE1L, 1972MS01, 1972RE03, 1972SA1B, 1972SU01, 1972VE01, 1973BO07, 1973EL04, 1973FR09, 1973HA05, 1973HA49, 1973KU03, 1973LO1C, 1973SA30, 1973YA1A, 1974HU1D, 1974KA11, 1974KU05).

Collective and deformed models: (1968HE1C, 1969AB05, 1969BA1R, 1969RU04, 1970DA13, 1970KH01, 1970SH1C, 1970SV1B, 1970TU01, 1970WE1B, 1971AR1R, 1971BO29, 1971CI03, 1971HO19, 1971SP11, 1971ZO03, 1971ZO01, 1972AB1C, 1972BE1X, 1972BO38, 1972FO1G, 1972HO56, 1972LE1L, 1973BO07, 1973CA16, 1973DO10, 1973FU1E, 1973KO1F, 1973LA35, 1973MS01, 1973YA1A, 1974AR04, 1974LE04, 1974TA19).

Cluster and alpha particle model: (1968FU1A, 1968HE1B, 1968PI1A, 1968TA1G, 1969AB1B, 1969BA1J, 1969BE1K, 1969BR1H, 1969HE1G, 1969HU1C, 1969IK1A, 1969KI02, 1969KO1K, 1969LE21, 1969NA1C, 1969SM1A, 1969TA1F, 1969TA1C, 1969WA06, 1969YA1A, 1970BA1Q, 1970BR35, 1970DE45, 1970EI05, 1970EI06, 1970EL01, 1970HU1F, 1970KO26, 1970LI24, 1970MC1D, 1970NE1F, 1970NO1A, 1970YU02, 1970ZI04, 1971AB07, 1971AB1B, 1971BA85, 1971BO20, 1971DA13, 1971DU06, 1971FR06, 1971FR15, 1971KH06, 1971KU1G, 1971NO03, 1971NO02, 1971OS04, 1971RA36, 1971RI1D, 1971SA1A, 1971TA13, 1971VI05, 1972AB1C, 1972AB11, 1972AB19, 1972AK10, 1972AN12, 1972AN15, 1972BA59, 1972DE03, 1972FR1B, 1972GR42, 1972HO56, 1972IK1A, 1972LE40, 1972RU13, 1972TU01, 1972VA40, 1972ZI03, 1972ZI05, 1973AB1G, 1973AB1A, 1973AN05, 1973BE1L, 1973CO13, 1973CO15, 1973FU1E, 1973HA57, 1973IK1A, 1973KH1A, 1973KU03, 1973LA35, 1973SA38, 1973YA1A, 1974AB05, 1974HO1Q, 1974JA24, 1974KA23, 1974KA11, 1974ME08, 1974SM1A, 1974SM04, 1974SU1B, 1974VA1N).

Special levels: (1966BR1D, 1967MA1B, 1968CE01, 1968LA1B, 1969GU03, 1969HA1G, 1969HA1F, 1969SO1E, 1969WO05, 1970AR21, 1970BO33, 1970BO1J, 1970DA13, 1970GO41, 1970GR27, 1970PE18, 1970RO20, 1970RU1A, 1971AR1R, 1971BE2B, 1971FA11, 1971FR15, 1971GR1V, 1971GR38, 1971GR23, 1971MC15, 1971GR49, 1971NO02, 1971RO03, 1971SE03, 1971VI05, 1971WA27, 1972AI01, 1972BE1X, 1972DE03, 1972EN05, 1972HA1R, 1972JA18, 1972SU01, 1972SU04, 1972VA40, 1973BO07, 1973CA1J, 1973IK1A, 1973KH1A, 1973KN1C, 1973MA1K, 1973MI1F, 1973SA30, 1973YA1A, 1974AR04, 1974HA1G, 1974IT1A, 1974KA11, 1975SH01).

Giant resonance: (1968BA1J, 1969DR05, 1969MA22, 1969RO26, 1969UB01, 1970FI1D, 1970FR1E, 1970GU12, 1971DU13, 1971GR23, 1971GU10, 1971SE03, 1971WA27, 1972KA33,

Table 12.8: 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	4, 10, 11, 12, 13, 20, 21, 22, 23, 24, 25, 29, 30, 31, 32, 33, 34, 35, 36, 43, 45, 46, 47, 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, 83, 84, 85, 86, 87, 88, 89, 90, 92, 93, 94, 95, 96, 97
4.4391 ± 0.3	$2^+; 0$	10.8 ± 0.6 meV	γ	3, 4, 10, 11, 12, 20, 21, 22, 23, 24, 25, 29, 30, 31, 34, 35, 36, 43, 45, 46, 47, 49, 51, 52, 53, 55, 56, 57, 58, 59, 63, 64, 65, 66, 67, 68, 70, 73, 74, 75, 76, 77, 78, 80, 81, 83, 84, 85, 86, 88, 90, 98
7.6552 ± 0.8	$0^+; 0$	8.7 ± 2.7 eV	γ, π, α	4, 10, 11, 12, 20, 22, 25, 29, 30, 31, 35, 43, 46, 47, 49, 51, 52, 53, 55, 56, 58, 63, 66, 67, 76, 80, 84, 85
9.641 ± 5	$3^-; 0$	34 ± 5 keV	γ, α	4, 10, 11, 20, 22, 25, 29, 30, 31, 34, 43, 46, 47, 49, 51, 52, 53, 55, 56, 58, 67, 76, 84, 85, 86
10.3 ± 300	$(0^+); 0$	3000 ± 700	α	10, 35, 46, 63
10.844 ± 16	$1^-; 0$	315 ± 25	α	10, 20, 29, 30, 43, 46, 47, 53, 55, 58
(11.16 ± 50)	$(2^+); 0$	430 ± 80		30
11.828 ± 16	$2^-; 0$	260 ± 25	α	20, 22, 29, 30, 46, 47, 53, 55, 58
12.710 ± 6	$1^+; 0$	14.6 ± 2.6 eV	γ, α	20, 22, 29, 30, 31, 43, 46, 47, 49, 51, 52, 53, 55, 58, 63, 65, 66, 67, 75, 76
13.352 ± 17	$(2^-); 0$	375 ± 40 keV		20, 30, 53, 55, 58
14.083 ± 15	$4^+; 0$	258 ± 15		11, 20, 43, 47, 51, 52, 53, 55, 56, 58, 75, 76, 80, 84, 86
15.110 ± 3	$1^+; 1$	42 ± 7 eV	γ, α	3, 4, 13, 20, 22, 25, 29, 30, 36, 43, 47, 49, 51, 63, 64, 65, 66, 67, 75
16.1067 ± 0.5	$2^+; 1$	6.5 ± 0.6 keV	γ, p, α	12, 20, 25, 29, 30, 36, 43, 47, 51, 65, 66, 67, 75, 80

Table 12.8: Energy levels of ^{12}C [a] (continued)

E_x in ^{12}C (MeV $\pm$ keV)	$J^\pi; T$	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
16.58	$2^-; 1$	300	γ, p, α	20, 25, 27, 29, 43, 51
17.23	$1^-; 1$	1150	γ, p, α	25, 27, 29, 36
17.76 ± 20	$0^+; 1$	80 ± 20	p, α	12, 25, 27, 38, 65, 80
18.13	$(1^+; 0)$	600 ± 100	γ, p	25, 43
(18.27 ± 50)	$(4^-; 0)$	275 ± 40		30
18.36 ± 50	$(3^-; 1)$	210 ± 40	γ, p, α	25, 30
18.40 ± 60	$0^-; (1)$	43	p	27, 51
(18.6 ± 100)	(3^-)	300		43
18.71	$\pi = +; (1)$	100	p, α	25
18.80 ± 40	$2^+; 1$	80 ± 30	γ, n, p	25, 26, 27, 29, 47, 51, 65
19.25	$(1^-; 1)$	1100	γ, n, p, α	25, 26, 27, 30, 38, 43
19.40	$(2^+; 0)$	45	γ, p, α	25, 27
19.57 ± 40	$(4^-; 1)$	400 ± 60		30, 43, 51
19.69		180	n, p	26
20.0 ± 100	(2^+)	90	p	27, 43
20.24		170	n, p	26, 27
20.5 ± 100	$(3^+; 1)$	≈ 250	γ, n, p, α	20, 25, 26, 27, 43
20.6 ± 100	$(3^-; 1)$	200 ± 40	γ, n, p, α	25, 26, 27, 30
20.98		270	n, p	26
21.60 ± 60	3^-	1200 ± 200	γ, n, p	25, 26, 43, 47, 65
21.95 ± 150	$1^-; 1$	800 ± 100		43, 47
22.50 ± 50	$1^-; 1$	275 ± 40	γ, n, p	26, 30, 37, 40, 47, 65
22.5	$1^-; 1$	3200	γ, n, p, α	25, 37, 38, 43
23.04	$(2^-; 1)$	60	n, p	26, 27, 37
23.52 ± 30	$1^-; 1$	230 ± 80	γ, n, p, α	12, 25, 26, 37, 38, 47
23.90 ± 80	$(1^-; 1)$	400 ± 100	(γ), n, p	26, 37, 43, 47
24.43		100	n, p	26
25.2 ± 150	$(1^-; 1)$	510 ± 100	γ, n, p	26, 38, 43, 47
25.24		165	n, p	26
25.5	$(1^-; 1)$	≈ 2000	γ, n, p	25, 37, 38, 43
25.9		400	γ, n, p, d, α	14, 16, 18, 26, 38, 47
26.7		270	γ, n, p, d, α	16, 25, 26, 43

Table 12.8: Energy levels of ^{12}C [a] (continued)

E_x in ^{12}C (MeV ± keV)	$J^\pi; T$	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
27.0 ± 200	$(1^-; 1)$	1400 ± 200	γ, p	25, 47
27.611 ± 20	$0^+; T = 2$			12, 70
27.8 ± 200		≈ 350	γ, n, p, ^{3}He	5, 25, 43
28.2	$1^-; 1$	1600	γ, n, p, ^{3}He	4, 25, 37
28.83 ± 40		1540 ± 90	γ, p, ^{3}He	4, 25
29.4 ± 300		1400 ± 200	γ, n, p, t, ^{3}He	5, 6, 25, 37, 38, 42, 47
29.6 ± 100	$(2^+; T = 2)$	narrow		70
30.29 ± 30		1960 ± 150	γ, n, ^{3}He	4, 37, 43
31.16 ± 30		2100 ± 150	γ, p, ^{3}He	4, 38
32.29 ± 40		1320 ± 230	γ, n, ^{3}He	4, 37, 43
33.47 ± 210		1930 ± 50	γ, ^{3}He	4
35.7 ± 700			γ, p	38

[a] See also Tables 12.9, 12.10 and 12.12.

1972KE06, 1972MS01, 1972SU01, 1972NA05, 1973BA05, 1973DE53, 1973HA1Q, 1973MA1T, 1973MS01, 1973MS02, 1973PI06, 1973SU03, 1974CA1R, 1974FA1A, 1974MU13).

Special reactions: (1968BR1E, 1969GA18, 1971AR02, 1971BA16, 1972AB11, 1973AZ1A, 1973BU12, 1973DE07, 1973KU03, 1973WI15, 1974FO22, 1974RE1B, 1975CR01, 1975KU01).

Electromagnetic transitions: (1968CA08, 1968LA1B, 1969AB05, 1969DR05, 1969HA1G, 1969HA1F, 1969LA26, 1970DO1A, 1970WE1B, 1971TA13, 1972AB12, 1972BE1X, 1972BE98, 1972BO38, 1972DE03, 1972NA05, 1973AL14, 1973BE1L, 1973BO07, 1973BO31, 1973CA16, 1973EL04, 1973HA49, 1973HA1Q, 1973KU1N, 1973LE1E, 1973SA30, 1974AB05, 1974FI03, 1974MU13).

Astrophysical questions: (1967SH1B, 1967WI1B, 1968DU1C, 1969TR1A, 1970OH1B, 1972CL1A, 1972KO1A, 1972UL1A, 1973AR1H, 1973AU1B, 1973AU1D, 1973AU1C, 1973BO1R, 1973CA1B, 1973CO1J, 1973CO1B, 1973DA1L, 1973GR1G, 1973IB1B, 1973RA1D, 1973SA1J, 1973SC1T, 1973SM1A, 1973TA1E, 1973TA1D, 1973TR1C, 1973TR1B, 1973UL1B, 1974AR1G, 1974BE1R, 1974BO2K, 1974DA1N, 1974LA1J, 1974LA1K, 1974PA1E, 1974SC1F, 1974SN1B, 1974TO1C, 1974WI1F, 1975FA1H, 1975TA1E).

Muon and neutrino capture and reactions: (1967EV1B, 1967HI1B, 1968FR1E, 1968FU1B, 1968HI1C, 1968KE1D, 1968RH1A, 1969DI1C, 1969OZ1A, 1969VA37, 1969WU1A, 1970BU1B, 1970CA1H, 1970CA1J, 1970FR1E, 1970HI09, 1970PR1H, 1971AG01, 1971BA96, 1971LA1J, 1971MO1Q, 1971MU20, 1971PI1D, 1971PL01, 1971PL1F, 1972CA08, 1972DE50, 1972KE06,

1972LO1J, 1972MI15, 1972OC01, 1972UB01, 1973BA68, 1973BE51, 1973BE38, 1973CH16, 1973DO04, 1973KI12, 1973KU1N, 1973MU04, 1973MU11, 1973SA1U, 1974DE1V, 1974DO1C, 1974DU02, 1974IM1C, 1974KA1Q, 1974KO1M, 1974PO05, 1974VO12, 1975SU1G).

Pion capture and pion reactions: (1965CH12, 1965GI10, 1967FO1A, 1967KO1B, 1967LE1D, 1967MI1B, 1968AG1A, 1968AG1C, 1968BA1M, 1968BA48, 1968BA61, 1968BE1F, 1968BI1B, 1968CH1D, 1968DA1G, 1968ER1A, 1968GO1L, 1968KE1D, 1968KO1B, 1968KO1C, 1968NO1A, 1968RH1A, 1968ST1G, 1968TA1C, 1968UB1A, 1968VA1F, 1968WI1B, 1968WI1D, 1968ZE1A, 1968ZU1A, 1969AG1A, 1969BA1L, 1969CA1B, 1969CH1C, 1969CH19, 1969GO1C, 1969HE1E, 1969KO1F, 1969MA1C, 1969MO1E, 1969MO1G, 1969UB01, 1969WE05, 1970AB1A, 1970BA44, 1970BA1E, 1970BA1F, 1970BE1J, 1970BE1L, 1970BI1A, 1970BI10, 1970BJ1A, 1970CA1J, 1970CH1F, 1970CH1C, 1970EL1E, 1970ER1A, 1970GO28, 1970GO1F, 1970HI09, 1970HI10, 1970HI11, 1970JA23, 1970JO18, 1970KA1H, 1970KA1J, 1970KO23, 1970KO26, 1970KR1F, 1970MA18, 1970SC1P, 1970RA39, 1970ST21, 1970VA18, 1970WI21, 1971AM1A, 1971BI1K, 1971CA01, 1971CA1J, 1971DE31, 1971ED02, 1971FA09, 1971GO22, 1971GO29, 1971GR1X, 1971GR34, 1971GU11, 1971GU1H, 1971GU13, 1971IN1A, 1971KO30, 1971KO40, 1971LA1P, 1971LE14, 1971LE1Q, 1971LO1H, 1971MA1C, 1971MA29, 1971MA1P, 1971MA1T, 1971MA2A, 1971MO29, 1971PE1D, 1971RO14, 1971RO1L, 1971SE02, 1971SI36, 1971SK03, 1971SK02, 1971ST10, 1971TH05, 1972AB1H, 1972AL45, 1972BA13, 1972BE34, 1972BE36, 1972BI09, 1972BU1P, 1972DE07, 1972ER02, 1972ER1A, 1972FA03, 1972FA14, 1972FU1C, 1972FU22, 1972GI04, 1972HU1A, 1972HU1F, 1972JA1H, 1972KO31, 1972LA01, 1972LA10, 1972LA24, 1972LE03, 1972LE40, 1972MA1H, 1972MA32, 1972NI13, 1972SA10, 1972SC18, 1972SC40, 1972SE13, 1972SE1F, 1972SI24, 1972ST1H, 1972SW1A, 1972VA1K, 1972YO1C, 1973AL09, 1973AL1E, 1973AL14, 1973AL1A, 1973AN18, 1973AR1B, 1973AS1A, 1973BA2G, 1973BA1E, 1973BE2C, 1973BE2B, 1973BE2D, 1973BE47, 1973BR1J, 1973BU1B, 1973BU12, 1973CA1J, 1973CA17, 1973CA1L, 1973CL1J, 1973DA1G, 1973DE1Y, 1973DI08, 1973DO1F, 1973DU1C [η], 1973EI01, 1973FA1N, 1973GA20, 1973GE11, 1973GO18, 1973GO44, 1973GO41, 1973GR1J, 1973GR1F, 1973HA34, 1973HE30, 1973HO43, 1973HS1A, 1973HS1B, 1973HU1E, 1973JA1K, 1973KA1D, 1973KI03, 1973LA1N, 1973LA30, 1973LE1F, 1973LE22, 1973LI18, 1973LU1A, 1973MA10, 1973MA11, 1973MO1H, 1973MO20, 1973MO26, 1973NY04, 1973PE1E, 1973RO10, 1973RO1Q, 1973SE1E, 1973SH1E, 1973SI1N, 1973ST1K, 1973UB01, 1973WA1J, 1973WI1A, 1973YE02, 1973ZI1A, 1974AM01, 1974AZ02, 1974BA2E, 1974BO27, 1974BU1H, 1974CA21, 1974CA1P, 1974CA1G, 1974CA1Q, 1974CA25, 1974CL04, 1974CU1A, 1974DE1U, 1974EP02, 1974GA08, 1974GI08, 1974HA61, 1974HE1F, 1974HO29, 1974HU14, 1974KI01, 1974KO14, 1974KO07, 1974KU1K, 1974KU02, 1974LA12, 1974LA22, 1974LE1L, 1974LE1M, 1974LI1H, 1974LI08, 1974LI15, 1974MA37, 1974MI07, 1974MI06, 1974MI11, 1974MI12, 1974MU03, 1974NE18, 1974NI08, 1974OH01, 1974PI02, 1974ST1G, 1974TA18, 1974UL02, 1974VO12, 1974WI1P, 1975AR02, 1975GE02, 1975HE1M, 1975PI1E, 1975YA02).

Kaon capture and kaon reactions: (1968CH1F, 1969KU1B, 1971MA1T, 1972BA09, 1972BL10, 1972JU1A, 1972WA1F, 1973BA1Y, 1973BO1W, 1973BO1X, 1973BU1H, 1973CH1M, 1973FA1P, 1973GO41, 1974AL1J, 1974CA1H, 1974DE41, 1974HU1D, 1974HU1E, 1974MO1H, 1975KI1M).

Other topics: (1966BR1D, 1967KU1D, 1968BA1L, 1968BA1J, 1968BO1H, 1968FA1B, 1968GU1C, 1968IR1A, 1968LA1B, 1968LE1F, 1968NE1C, 1968RO1G, 1968TK1A, 1969AB05, 1969CH1A, 1969DR05, 1969GU03, 1969GR1A, 1969HO1M, 1969IR1A, 1969KE1B, 1969LA26, 1969LE21, 1969LO06, 1969MC1C, 1969NA1E, 1969RU04, 1969SH1A, 1969SO08, 1969SO1E, 1969VI1C, 1969VO1E, 1970BE26, 1970BO1M, 1970BO1J, 1970DR07, 1970EF01, 1970GR44, 1970HO1J, 1970JA02, 1970KA30, 1970KA1K, 1970PE18, 1970RE1G, 1970RU1A, 1970RY03, 1970SU1B, 1970VA07, 1971BA85, 1971BE2B, 1971BO1F, 1971FA11, 1971GR1V, 1971GR2C, 1971GR35, 1971GR49, 1971HO19, 1971KA14, 1971KU1G, 1971MC15, 1971NG01, 1971OS04, 1971SO11, 1971ST40, 1971TU04, 1971VO1E, 1971ZO03, 1972AB12, 1972AI01, 1972AN05, 1972AR13, 1972BR1G, 1972EL1E, 1972FO1G, 1972FR1B, 1972FR09, 1972HA57, 1972KO01, 1972KR11, 1972KR1D, 1972LE1L, 1972OC01, 1972PA32, 1972PN1A, 1972RE03, 1972SA1B, 1972ST02, 1972SU04, 1972TU01, 1972VE01, 1972ZI03, 1973AN05, 1973AV1C, 1973BA1Y, 1973BO31, 1973CL09, 1973DE07, 1973DZ1A, 1973ED1A, 1973EL04, 1973ER1C, 1973ER10, 1973FA1P, 1973FO1F, 1973FR09, 1973GR36, 1973HA05, 1973HA57, 1973KO26, 1973KU03, 1973KU1G, 1973LA35, 1973LO1C, 1973MA48, 1973MI1F, 1973PE05, 1973PO1D, 1973RA1E, 1973RO1R, 1973SA1T, 1973SI21, 1973UL01, 1973VA01, 1974AB05, 1974AR04, 1974AU1E, 1974CA1H, 1974DU11, 1974DZ03, 1974FA1A, 1974FI03, 1974HO1J, 1974HU1D, 1974HU1E, 1974IR04, 1974ME08, 1974MU13, 1974SI1F, 1974ZA01, 1975GR03, 1975KI1M, 1975KU01, 1975SH01, 1975ZI1D).

Ground state: (1968BA1L, 1968BO1H, 1968FA1B, 1969AB05, 1969AG03, 1969GU03, 1969KE1B, 1969LA26, 1969LE21, 1970EL01, 1970GR44, 1970ST19, 1971BO20, 1971BO29, 1971GR16, 1971GR2C, 1971RU14, 1971ZO03, 1972AB12, 1972AV1D, 1972BE1X, 1972BR1G, 1972DE03, 1972FR09, 1971GR38, 1972GR42, 1972KR11, 1972KR1D, 1972LE1L, 1972SI24, 1972VA40, 1972VE01, 1973AB1A, 1973AR1C, 1973BU12, 1973CA16, 1973DO1F, 1973EN1E, 1973ER1C, 1973ER10, 1973FE13, 1973FO1F, 1973GR36, 1973HA57, 1973KO26, 1973KU1L, 1973LE1E, 1973LO1C, 1973PE05, 1973SA38, 1973SA30, 1973VA01, 1974AB05, 1974AD1C, 1974AR04, 1974BA1Z, 1974DU02, 1974DZ03, 1974JA24, 1974KA23, 1974MU13, 1974SI03, 1974VA1N, 1974ZA01).

1. (a) ^{6}Li(^{6}Li, n)^{11}C	$Q_{\rm m} = 9.453$	$E_{\rm b} = 28.175$
(b) ^{6}Li(^{6}Li, p)^{11}B	$Q_{\rm m} = 12.218$	
(c) ^{6}Li(^{6}Li, d)^{10}B	$Q_{\rm m} = 2.987$	
(d) ^{6}Li(^{6}Li, α)^{8}Be	$Q_{\rm m} = 20.808$	
(e) ^{6}Li(^{6}Li, nα)^{7}Be	$Q_{\rm m} = 1.908$	
(f) ^{6}Li(^{6}Li, pα)^{7}Li	$Q_{\rm m} = 3.552$	
(g) ^{6}Li(^{6}Li, 2α)^{4}He	$Q_{\rm m} = 20.900$	

For $E(^{6}\text{Li}) = 1.2$ to 2.8 MeV, population ratios of ^{7}Be*(0.43), ^{7}Li*(0.48) and ^{10}B*(0.72) (reactions (c), (e) and (f)) remain approximately constant. Simple tunneling or compound nucleus models are not compatible with the data and a direct interaction through long-range tails is suggested (1962MC12). Absolute reaction cross sections at $E(^6\text{Li}) = 2.1$ MeV are in reasonable agreement with estimates based on barrier penetration. A strong preference for α-emission suggests that the favored mechanism involves interacting clusters (1963HU02). The α_0 yield (0°) (reaction (d)) shows two broad peaks at $E(^6\text{Li}) = 4$ and 9 MeV (1967CA1D: prelim. results; $E(^6\text{Li}) = 2$ to 14.5 MeV) while (1970FR06: $E(^6\text{Li}) = 4$ to 24 MeV) report a broad peak at $E(^6\text{Li}) \approx 10$ MeV. The yield of $^6\text{Li} + {}^6\text{Li} \rightarrow 3\alpha$ (reaction (g)) for $E(^6\text{Li}) = 4$ to 20 MeV is dominated by a broad resonance ($\Gamma = 5$ MeV) at the Coulomb barrier, which is consistent with the formation of a quasi-molecular state $^6\text{Li} + {}^6\text{Li}$ with $\tau \approx 10^{-21}$ sec (1970FR06). A multiparameter coincidence study of reaction (g) for $E(^6\text{Li}) = 2$ to 13 MeV shows the importance of direct interactions: the data were fitted assuming an (α + d) cluster structure for ^{6}Li and an interaction potential acting only between the two deuterons (1971GA1N, 1971GA21, 1972GA32). See also (1971WY01), (1968AJ02) for the earlier work, ^{8}Be and ^{10}B in (1974AJ01) and ^{11}B and ^{11}C for reactions (a) and (b).

2. (a) $^6\text{Li}(^6\text{Li}, {}^6\text{He})^6\text{Be}$ $\quad Q_\text{m} = -7.797$ $\quad E_\text{b} = 28.175$
   (b) $^6\text{Li}(^6\text{Li}, {}^6\text{Li})^6\text{Li}$

The elastic scattering (reaction (b)) follows the Mott formula at low energies [$\lesssim 4.0$ MeV] (1966PI02: $E(^6\text{Li}) = 3.2$ to 7.0 MeV). A broad structure is observed in the excitation functions [$\theta_\text{c.m.} = 60°$ and 90°] at $E(^6\text{Li}) \approx 13$ MeV (1973GR34) and ≈ 26 MeV [$\Gamma \approx 7$ MeV] (1971FO08: $\theta_\text{c.m.} = 90°$; $E(^6\text{Li})$ to 34 MeV). The elastic scattering appears to be dominated by absorption (1971FO08). See also (1973GO01). Excitation functions for the transitions to $^6\text{Li}^*_{3.56} + {}^6\text{Li}^*_{3.56}$ have been measured for $E(^6\text{Li}) = 28.0$ to 33.0 MeV (1970NA02: $\theta_\text{c.m.} = 90°$) and 28.0 to 36.0 MeV (1973WH02: $\theta_\text{c.m.} = 88°$). See also ^{6}Li in (1974AJ01). For reaction (a) see ^{6}He in (1974AJ01).

3. $^6\text{Li}(^7\text{Li}, \text{n})^{12}\text{C}$ $\quad Q_\text{m} = 20.924$

At $E(^7\text{Li}) = 2.6$ MeV, population of ^{12}C*(4.44, 15.11) is reported (1962BE24).

4. $^9\text{Be}(^3\text{He}, \gamma)^{12}\text{C}$ $\quad Q_\text{m} = 26.2801$

(1970BL09) had reported the observation of a capture resonance at $E(^3\text{He}) = 1.74$ MeV which subsequently decayed via ^{12}C*(15.11) and which was assumed to correspond to the first $J^\pi = 0^+$; $T = 2$ state in ^{12}C [$E_\text{x} = 27.585 \pm 0.005$ MeV]. However, neither (1972HA63) nor (1972WA18) have been able to repeat this measurement: $\Gamma_{^3\text{He}}\Gamma_\gamma/\Gamma < 1.5$ meV (1972WA18), < 2 meV (1972HA63). See also (1974HA1G). Excitation functions and angular distribution studies

Table 12.9: Electromagnetic decay of ^{12}C levels [a]

Level (MeV)	Width or τ_m			Refs.
4.44	$\Gamma_\gamma = 10.6 \pm 1.1$ meV			(1967CR01)
	$\Gamma_\gamma = 10.1 \pm 2$ meV			(1958RA14)
	$\tau_m = 55 \pm 7$ fsec			(1968RI16)
	$\Gamma_\gamma = 12.0 \pm 1.5$ meV			
	$\tau_m = 65 \pm 9$ fsec			(1970CO09)
	$\Gamma_\gamma = 10.1 \pm 1.5$ meV			
	$\Gamma_\gamma = 11.0 \pm 1.0$ meV			(1970ST10)
	$\Gamma_\gamma = 10.8 \pm 0.6$ meV			mean
7.66	$\Gamma_\pi/\Gamma = (6.9 \pm 2.1) \times 10^{-6}$			(1960AL04, 1972OB01)
	$\Gamma_\pi = 62 \pm 6$ μeV			(1967CR01)
	$\Gamma_\pi = 59 \pm 5$ μeV			(1970ST10)
	$\Gamma_\pi = 60 \pm 4$ μeV			mean
	$\Gamma_{rad}/\Gamma = (4.2 \pm 0.2) \times 10^{-4}$ [f]			(1974CH03)
	$\Gamma = (8.7 \pm 2.7)$ eV			from above values
	$\Gamma_{rad} = (3.7 \pm 1.2)$ meV [b]			from above values
	$\Gamma_{rad} = (3.4 \pm 1.1)$ meV			(1973BA73)
9.64	$\Gamma_{rad}/\Gamma < 4.1 \times 10^{-7}$			(1974CH32)
	$\Gamma_{rad} < 14$ meV [c]			(1974CH32)
12.71	$\Gamma = 14.6 \pm 2.6$ eV			(1974CE01)
	$\Gamma_{\gamma_0} = 0.35 \pm 0.05$ eV			(1974CE01)
	$\Gamma_{\gamma_0}/\Gamma_\gamma = 0.83 \pm 0.03$			(1970RE09)
	$\Gamma_\alpha/\Gamma = 0.971 \pm 0.003$			(1970RE09)
	$\Gamma_\alpha = 14.2 \pm 2.5$ eV			from above
	Branching ratio (%) to			
$E_f \rightarrow$	0	4.4	7.7	
	83 ± 3	17 ± 3	< 10	(1970RE09)
	85 ± 4	15 ± 4		(1972AL03)
15.11	$\Gamma_{\gamma_0} = 37.0 \pm 1.1$ eV			(1973CH16)
	($\Gamma_{\gamma_0} = 39.4 \pm 1.5$ eV)			Table 12.8 (1968AJ02)

Table 12.9: Electromagnetic decay of ^{12}C levels [a] (continued)

Level (MeV)	Width or τ_m					Refs.
	$\Gamma_{\gamma 0}/\Gamma_\gamma = 0.92 \pm 0.02$					(1972AL03)
	$\Gamma_\alpha/\Gamma = 0.041 \pm 0.009$					(1974BA42)
	$\Gamma_\alpha = 1.8 \pm 0.3$ eV					(1974BA42)
	$\Gamma = 42 \pm 7$ eV					from above
	Branching ratio (%) to					
$E_f \rightarrow$	0	4.4	7.7	10.3	12.7	
	96 ± 1	1.5 ± 0.3	1.5 ± 0.2		0.7 ± 0.3	(1970RE09)
	92 ± 2	2.3 ± 0.9	2.6 ± 0.7	(1.6) [d]	1.4 ± 0.4	(1972AL03)
		2.32 ± 0.25 [e]				(1973HA1Y)

[a] See also Tables 12.10, 12.12, 12.20 and 12.23.

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

[c] Based on $\Gamma = 34 \pm 5$ keV: see Table 12.8.

[d] Undetected: branching ratio shown is derived from β-decay work (1972AL03).

[e] 3.6 ± 0.7% (1970AH02).

[f] $\Gamma_{rad}/\Gamma = (4.30 \pm 0.20) \times 10^{-4}$ (1975MA2J: preliminary value and C.N. Davids, private communication).

have been carried out by (1972BL17: $E(^3\text{He}) = 1.0$ to 6.0 MeV; γ_0, γ_1, γ_2), (1972LI29: 1.5 to 11 MeV; γ_0, γ_1, γ_2, γ_3), (1964BL12: 2 to 4.5 MeV; γ_0, γ_1) and (1974SH01: 3 to 21 MeV (γ_2), to 24 MeV (γ_0), to 26 MeV (γ_1, γ_3)). Observed resonances are shown in Table 12.10.

^{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 (1972BL17). The resonance structure reported by (1974SH01) appears to confirm the role of 3p-3h configurations for ^{12}C excitations somewhat above the giant resonance region. The γ_3 yield is relatively unstructured (1972LI29, 1974SH01: to $E(^3\text{He}) = 26$ MeV).

5. (a) ^{9}Be(^{3}He, n)^{11}C $\quad Q_m = 7.558 \quad E_b = 26.2801$
   (b) ^{9}Be(^{3}He, p)^{11}B $\quad Q_m = 10.3229$
   (c) ^{9}Be(^{3}He, 2n)^{10}C $\quad Q_m = -5.566$

Excitation functions for neutrons have been measured for $E(^3\text{He}) = 1.2$ to 9.9 MeV for several neutron groups: see (1968AJ02) for a listing of the earlier references. No sharp structure is

Table 12.10: Resonances in ^{9}Be(^{3}He, γ)^{12}C

$E(^3$He) (MeV $\pm$ keV)	Res. in	E_x (MeV)	$\Gamma_{c.m.}$ (MeV)	$J^\pi; T$	Refs.
2.55 [a]	γ_0, γ_2	28.2	1.6	$1^-; 1$	(1972BL17)
3.40 ± 40	γ_0, γ_2	28.83	1.54 ± 0.09		(1972LI29, 1974SH01)
5.35 ± 30	γ_1	30.29	1.96 ± 0.15		(1972LI29, 1974SH01)
6.51 ± 30	γ_0	31.16	2.10 ± 0.15		(1972LI29, 1974SH01)
8.02 ± 40	γ_1, γ_2	32.29	1.32 ± 0.23		(1974SH01)
9.60 ± 210	γ_1, γ_2	33.47	1.93 ± 0.05		(1974SH01)

[a] $\Gamma_\gamma \geq 11.8$ eV [γ_0], ≥ 4.6 eV [γ_1], ≥ 11.3 eV [γ_2], assuming $J = 1$, $\Gamma(^3$He) $= \Gamma$.

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 $E(^3$He) ≈ 2 MeV: $E_x = 27.8$ MeV (1965DI06, 1963DU12). The total cross section for ^{11}C production rises monotonically for $E(^3$He) $= 0.60$ to 1.15 MeV (1973SU07) and then shows a broad maximum, $\sigma = 113$ mb, at $E(^3$He) $= 4.3$ MeV (1966HA21: $E(^3$He) $= 3.2$ to 10 MeV). Polarization measurements have been carried out for $E(^3$He) $= 2.1$ to 3.9 MeV (1971TH15: n_0, n_1, n_{2+3}): the shapes of the measured angular distributions for n_0 and n_1 show very gradual changes with energy. It is suggested that a significant direct interaction contribution is present (1971TH15). See also (1970KR09) and ^{11}C.

Excitation functions and angular distributions for protons (reaction (b)) have been measured for $E(^3$He) $= 1.0$ to 10.2 MeV for a number of proton groups: see (1968AJ02) for a listing of the earlier references. The yields of ten proton groups have been determined for $E(^3$He) $= 0.50$ to 1.10 MeV ($\theta = 110°$): the yields increase monotonically (1971ST1H, 1973SU07). The excitation curves at higher energies show only a slow and smooth increase: see, e.g. (1960HI08). See also ^{11}B. The excitation function for reaction (c) has been measured from threshold to $E(^3$He) $= 31$ MeV (1974MO23).

6. (a) ^{9}Be(^{3}He, d)^{10}B — $Q_m = 1.0916$ — $E_b = 26.2801$
(b) ^{9}Be(^{3}He, t)^{9}B — $Q_m = -1.0860$

The cross section for ground state tritons (reaction (b)) increases monotonically for $E(^3$He) $=$ 2.5 to 4.2 MeV (1969OR01: $\theta = 40°$) and then shows a broad maximum at $E(^3$He) ≈ 4.5 MeV (1967EA01: $\theta = 20°$). For reaction (a) see (1967CR04). See also ^{9}B and ^{10}B in (1974AJ01).

7. ^{9}Be(^{3}He, ^{3}He)^{9}Be — $E_b = 26.2801$

The elastic scattering excitation function decreases monotonically for $E(^3\text{He}) = 4.0$ to 9.0 MeV (1967EA01: $\theta = 45°$) and 15.0 to 21.0 MeV (1972MC01: $\theta_{\text{c.m.}} = 90°$). At $\theta_{\text{c.m.}} = 111°$ a slight rise is observed for $E(^3\text{He}) = 19$ to 21 MeV (1972MC01). See also (1974BO38: $E(^3\text{He}) =$ 1.2 to 2.5 MeV). Polarization measurements are reported at $E(^3\text{He}) = 18$ MeV (1972MC01) and 31.4 MeV (1971EN03). See also ^{9}Be in (1974AJ01).

8. (a) ^{9}Be(^{3}He, α)^{8}Be $\quad Q_m = 18.9134 \quad E_b = 26.2801$
(b) ^{9}Be(^{3}He, 2α)^{4}He $\quad Q_m = 19.005$

Excitation functions at $\theta = 140°$ (reaction (a)) do not show resonant behavior for $E(^3\text{He}) = 1.0$ to 1.9 MeV (1970EH1A: α_0, α_1; unpublished work). For reaction (b) see ^{8}Be in (1974AJ01) and (1972TA04). See also (1971OS05; theor.).

9. ^{9}Be(^{3}He, ^{6}Li)^{6}Li $\quad Q_m = -1.895 \quad E_b = 26.2801$

The excitation functions for $E(^3\text{He}) = 4$ to 10 MeV (1969TA05: $\theta = 50°$; 1972YO02: $\theta_{\text{c.m.}} =$ 32°, 90°) show some fluctuations. See also ^{6}Li in (1974AJ01).

10. ^{9}Be(α, n)^{12}C $\quad Q_m = 5.702$

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 $E_\alpha = 1.9$ to 23 MeV: see (1968AJ02) for earlier references and (1969KL09: $E_\alpha = 1.75$ and 1.96 MeV; n_0), (1970VA23: $E_\alpha = 2.55$ to 7.87 MeV (n_0); 2.55 to 7.47 MeV (n_1); 4.36 to 7.47 MeV (n_2)), (1972OB01: 3.21 to 6.44 MeV (n_0, n_1, n_2); 6.24 and 6.44 MeV (n_3)) and (1968VE06: 6.79, 7.96, 8.91, 9.92 MeV; n_0, n_1, n_2).

The mean life of ^{12}C*(4.4) [$J^\pi = 2^+$] is 57^{+23}_{-17} fsec, $\Gamma_\gamma = (11.5^{+5}_{-3.2})$ meV (1966WA10): see Table 12.9. ^{12}C*(7.7) decays predominantly into ^{8}Be + α (see reactions 20 and 35), $J^\pi = 0^+$, $\Gamma_\pi/\Gamma = (6.9 \pm 2.1) \times 10^{-6}$ (1960AL04, 1972OB01).

See (1959AJ76, 1968AJ02) for surveys of the earlier work. See also ^{13}C in (1976AJ04) and (1968LE24, 1969KL1C, 1969NO01, 1969ZI1A, 1970FO1C, 1970GE1A, 1972DA32, 1972DE10, 1973TY1A, 1973VI1C, 1973WE03) and (1968VA1E, 1969HO34; theor.).

11. ^{9}Be(^{6}Li, t)^{12}C $\quad Q_m = 10.486$

At $E(^6\text{Li}) = 23.8$ MeV strong transitions are observed to ^{12}C*(0, 4.4, 7.7, 9.6, 14.1) (1970OG1A; unpublished). See also (1968JA08) and (1972RI1C; theor.).

12. ^{10}Be(^{3}He, n)^{12}C $\quad Q_{\rm m} = 19.468$

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).

13. ^{10}B(d, γ)^{12}C $\quad Q_{\rm m} = 25.1885$

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 direct capture process or to a very broad resonance: no sharp resonances are observed corresponding to the $T = 2$ state reported in reaction 4 [$\Gamma_{\rm d_0}\Gamma_\gamma/\Gamma \lesssim 0.2$ eV] (1970BL09, 1974HA1G). Upper limits to the differential cross sections for γ_0 and γ_1 are 5 nb/sr and 50 nb/sr, respectively for $E_{\rm d} = 4.0$ to 20.2 MeV (1971SH1E; prelim. results).

14. ^{10}B(d, n)^{11}C $\quad Q_{\rm m} = 6.467 \quad E_{\rm b} = 25.1885$

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 (1954BU06, 1955MA76). The 0° excitation function for ground state neutrons shows no structure for $E_{\rm d} = 3.2$ to 9.0 MeV (1967DI01). The excitation function for the neutrons to ^{11}C*(6.48) increases monotonically for $E_{\rm d} = 4.0$ to 4.8 MeV (1972TH14). The branching ratios at 90° for the transitions to the ground states of ^{11}C and ^{11}B [$\rm n_0/p_0$] have been measured for $E_{\rm d} = 1.0$ to 2.0 MeV by (1973BR24).

Polarization measurements have been carried out for $E_{\rm d} = 1.20$ to 2.90 MeV (1968BR26: $\rm n_0$) and 2.4 to 4.0 MeV (1972ME06: $\rm n_0$, $\rm n_1$, $\rm n_{2+3}$). The transitions to ^{11}C*(0, $4.32 + 4.80$) appear to involve a direct reaction mechanism (1972ME06). See also (1969DI08) and ^{11}C.

15. ^{10}B(d, p)^{11}B $\quad Q_{\rm m} = 9.2314 \quad E_{\rm b} = 25.1885$

Absolute yields have been measured for various proton groups for $E_{\rm d} = 0.14$ to 12 MeV: see (1968AJ02) and (1972AR31: $E_{\rm d} = 0.7$ to 2.5 MeV; $\rm p_0 \rightarrow p_3$) and (1970BL09: $E_{\rm d} = 2.605$ to 2.960 MeV; $\rm p_0 \rightarrow p_3$). See also (1970PO03). No clear resonance structure is observed. There is some indication that a broad resonance, corresponding to ^{12}C*(27.1) affects the $\rm p_1$ and $\rm p_3$ yields (1964BR1A). Upper limits for the partial widths ($\rm p_0 \rightarrow p_3$) of the $T = 2$ state reported in reaction

4 are given by (1970BL09). See also (1972AH1A). For a study of the branching ratio n_0/p_0 see reaction 14 (1973BR24).

Polarization measurements have been carried out recently for $E_d = 1.15$, 1.40 and 1.85 MeV (1969DI08; p_0), 10 MeV (1969CU10: p_0) and 10 and 12 MeV (1970FI07, 1972FI1E: p_0) and 13.6 MeV (1967GO27: p_0). For earlier polarization studies [$E_d = 6.9$ to 21 MeV] see (1968AJ02). See also (1967GO27, 1967SA06), (1970DE35, 1973CO18; theor.) and ^{11}B.

16. ^{10}B(d, d)^{10}B $\qquad E_b = 25.1885$

The yield of elastically scattered deuterons has been measured for $E_d = 1.0$ to 2.0 MeV: resonances at $E_d = 1.0$ and 1.9 MeV are suggested by (1969LO01). Excitation functions for the deuterons to ^{10}B*(1.74, 2.16) [$J^\pi = 0^+$; $T = 1$ and $J^\pi = 1^+$; $T = 0$, respectively] have been measured at several angles for $E_d = 4.2$ to 16 MeV: they are characterized by rather broad, slowly varying structures. The ratio $\sigma_{1.74}/\sigma_{2.15}$ varies from $0.69 \pm 0.04\%$ at $E_d = 6.5$ MeV to $0.16 \pm 0.04\%$ at $E_d = 12.0$ MeV corresponding, respectively, to isospin impurities of $\approx 2\%$ and $\approx 0.5\%$ (1974ST01). No resonance structure is observed in the elastic yield for $E_d = 14.0$ to 15.5 MeV (1974BU06). Polarization measurements are reported at $E_d = 9$, 10 and 11 MeV (1972FI1E, 1973FI1C) and at 15 MeV (1974BU06). See also ^{10}B in (1974AJ01).

17. (a) ^{10}B(d, t)^{9}B $\qquad Q_m = -2.178 \qquad E_b = 25.1885$

(b) ^{10}B(d, ^{3}He)^{9}Be $\qquad Q_m = -1.0916$

For polarization measurements at $E_d = 15$ MeV involving ^{9}Be*(0, 2.43) and ^{9}B*(0, 2.36) see (1974LU06). See also ^{9}Be and ^{9}B in (1974AJ01).

18. (a) ^{10}B(d, α)^{8}Be $\qquad Q_m = 17.822 \qquad E_b = 25.1885$

(b) ^{10}B(d, 2α)^{4}He $\qquad Q_m = 17.9138$

Excitation functions have been measured for the α_0 and α_1 groups for $E_d = 0.4$ to 3.3 MeV: see (1968AJ02) for earlier references and (1968FR07: 0.5 to 2.0 MeV), (1968CO31: 0.8 to 2.5 MeV) and (1970BL09: 2.605 to 2.960 MeV). The α_0 yield has also been measured for $E_\alpha = 4$ to 12 MeV by (1971RE1D) and the yields to ^{8}Be*(16.6, 16.9) have been determined for $E_d = 2.856$ to 2.906 MeV by (1972AH1A; in 2 keV steps; unpublished). A number of broad maxima are observed in the excitation curves above $E_d = 1$ MeV. The α_0 yield shows such a maximum at $E_d = 1$ MeV which (1968FR07) attribute to an s-wave resonance corresponding to a state with $E_x \approx 26.0$ MeV, $\Gamma \approx 0.5$ MeV. No evidence for the $T = 2$ state reported in reaction 4 was found in the α_0 and α_1 yield curves taken in 2 keV steps for $27.35 < E_x < 27.65$ MeV

(1970BL09). See also (1972AH1A). The relative populations of ^{8}Be*(17.6, 18.1) have been determined for $E_{\rm d} = 4$ to 12 MeV (1970CA12): see ^{8}Be, reaction 38 (1974AJ01). For reaction (b) see (1968AS01, 1973RO28) and ^{8}Be in (1974AJ01). See also (1967LE1C, 1967NA11) and (1970KO01, 1970KO27, 1971LA25; theor.).

19. ^{10}B(d, ^{6}Li)^{6}Li $\quad Q_{\rm m} = -2.987 \quad E_{\rm b} = 25.1885$

This reaction has been studied for $E_{\rm d} = 8$ to 13.5 MeV (1964GE10).

20. (a) ^{10}B(^{3}He, p)^{12}C $\quad Q_{\rm m} = 19.6948$
(b) ^{10}B(^{3}He, pα)^{8}Be $\quad Q_{\rm m} = 12.328$
(c) ^{10}B(^{3}He, 2p)^{11}B $\quad Q_{\rm m} = 3.738$
(d) ^{10}B(^{3}He, pn)^{11}C $\quad Q_{\rm m} = 0.973$

Proton groups observed by (1958MO99, 1959AL96, 1962BR10) are displayed in Table 12.11. Angular distributions of many of these groups have been measured for $E(^{3}{\rm He}) = 1.4$ to 14 MeV: see (1968AJ02) for the earlier references and (1970BE1F).

From studies of ^{10}B(^{3}He, pα)^{8}Be it is determined that ^{12}C*(7.7, 9.6, 10.8, 14.1, 16.1) have natural parity $\pi = (-1)^{J}$, and that ^{12}C*(11.8, 12.7, 13.3), which decay only to ^{8}Be*(2.9) and not to the ground state, have unnatural parity: see Tables 12.8 and 12.11, and (1968AJ02). ^{12}C*(12.7) decays also by γ-emission: the cascade via ^{12}C*(4.4) is $15 \pm 4\%$, the crossover transition is $85 \pm 4\%$ (1972AL03); $\Gamma_{\gamma}/\Gamma_{\alpha} = 2.5 \pm 1\%$ (1958MO99, 1959AL96). ^{12}C*(15.11) [$J^{\pi} = 1^{+}$; $T = 1$] decays by γ-emission to ^{12}C*(0, 4.4, 7.7, (10.3), 12.7): see Table 12.9 (1972AL03). It is suggested by (1972AL03) that an isospin-forbidden α-decay branch from ^{12}C*(15.11) to ^{8}Be*(2.9), which had been reported with an intensity of $(1.2 \pm 0.7)\%$ in reaction 67, does not exist: the problem might have been an inaccurate determination of the intensity of the γ-branch to ^{12}C*(12.7) by (1970RE09): see, however, (1974BA42) in reaction 67.

^{12}C*(16.11, 16.58) show decay to both ^{8}Be*(0, 2.9). The consequent assignment of natural parity is consistent with $J^{\pi} = 2^{+}$ for the former but not with $J^{\pi} = 2^{-}$ for the latter. For ^{12}C*(16.11) observed values of Γ_{α_0}/Γ are $0.05 - 0.12$; the decay to 3α occurs rarely if at all (1966WA16).

Reactions (c) and (d) have been studied by (1970BO39). The latter, at $E(^{3}{\rm He}) = 11$ MeV, appears to proceed via a state in ^{12}C at $E_{\rm x} = 20.5 \pm 0.1$ MeV, which is suggested to be $J^{\pi} = 3^{+}$; $T = 1$. The relative intensities of the decays of ^{12}C states with $20 < E_{\rm x} < 25$ MeV via channels (c) and (d) is estimated. The α_0 decay is very small, consistent with the expected population of $T = 1$ states (1970BO39).

See also ^{8}Be in (1974AJ01), ^{13}N in (1976AJ04) and (1968KR02, 1970BE1F, 1972BE05, 1974AN19), (1967HO1C) and (1967PR1B; theor.).

Table 12.11: ^{12}C states from ^{10}B(^{3}He, p)^{12}C

E_x [a] (MeV ± keV)	$\Gamma_{c.m.}$ [c] (keV)	Γ_γ/Γ	Alpha decay [d,j]		Parity [d,k]	$J^\pi; T$
			^{8}Be$_{g.s.}$	^{8}Be*(2.9)		
4.44						
7.655 ± 6		3×10^{-4} [e]	yes		natural	0^+
9.645 ± 6	36 ± 6		yes	yes	natural	
10.849 ± 25	320 ± 30		strong	yes	natural	
11.841 ± 25	245 ± 30		no	yes	unnatural	
12.713 ± 6		0.025 ± 0.01 [f]	no	yes	unnatural	1^+
13.29 ± 30	430 ± 100		no	yes	unnatural	≥ 1 [d]
	290 ± 70 [d]					
14.083 ± 15	252 ± 15		yes	yes	natural	(2^-) [g]
	320 ± 50 [d]					
15.108 ± 6		> 0.95 [h,i]				$1^+; 1$
16.108 ± 6			weak	strong	natural	(2^-)
16.58			yes	yes	natural	
20.5 ± 100 [b]						

[a] (1962BR10). Excitation energies based on $Q_0 = 19.693$ MeV and Po $\alpha = 5.3056$ MeV: see also (1958MO99, 1959AL96).
[b] (1970BO39). Previous work by (1967CO1F) is unpublished.
[c] (1962BR10).
[d] (1966WA16).
[e] (1961AL23): The cascade decay (via 4.44) is $(3.3 \pm 0.9) \times 10^{-4}$ of the total decay. This is 50 times stronger than the direct g.s. decay (via pairs). $\Gamma_{rad}/\Gamma = (3.5 \pm 1.2) \times 10^{-4}$ (1964HA23): see Table 12.9.
[f] Branching ratios to ^{12}C*(0, 4.4) are $85 \pm 4\%$ and $15 \pm 4\%$, respectively (1972AL03): see Table 12.9.
[g] Proton-α correlations require $J \geq 2$ (1966WA16).
[h] (1965AL1B): $\Gamma_\alpha/\Gamma < 0.05$.
[i] Branching ratios to ^{12}C*(0, 4.4, 7.7, 12.7) are, respectively, $92 \pm 2\%$, $2.3 \pm 0.9\%$, $2.6 \pm 0.7\%$, $1.4 \pm 0.4\%$ (1972AL03): see Table 12.9. Gamma rays are observed with energies $E_\gamma = 15.11, 10.71 \pm 0.05, 7.48 \pm 0.03, 4.44$ and 2.38 ± 0.02 MeV (1972AL03).
[j] (1968KR02).
[k] (1965AL1B).

Table 12.12: Resonances in ^{11}B(p, γ)^{12}C and ^{11}B(p, α)^{8}Be

Peak number	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)	$J^\pi; T$	Refs.
1	0.163 [a]	6.5 [a]	5.5	152	res.	res.	0.65	21.0 ± 3.3 [b]	0.290 ± 0.045	6.3 ± 0.5	0.0217 ± 0.0018	16.1067	$2^+; 1$	(1953HU29, 1961SE10, 1974AN19)
2	0.675	300	non-res.	48 [f]	non-res.	600 [f]	< 0.4	8.0	< 0.27	150	150	16.58	$2^-; 1$	(1953BE61, 1953HU29, 1965SE06)
3	1.388	1150	[27] [c]	3	3.3	≈ 180	44	5	10	140	1000	17.23	$1^-; 1$	(1953HU29, 1963SY01, 1965SE06)
4	1.98	100	non-res.	non-res.	9.0	(25)	< 0.5	< 0.5	4.6	11.4	76	17.77	$0^+; 1$	(1955HO48, 1963SY01, (1965SE06)
5	2.37	600 ± 100		0.77 [h]								18.13	$(1^+; 0)$	(1972SU08)
6	2.62	310	weak?	res.	32.4 ± 4.8	270 ± 40	< 1.5	3.2	65	177	68	18.36	$(3^-; 1)$	(1955BA22, 1963SY01, 1965SE06, 1974GO21)
7	2.66	43	non-res.	non-res.	non-res.	non-res.	< 0.5	< 0.5	< 1	< 5	33	18.39	0^-	(1965SE06)
8	3.01	100	non-res.	non-res.	3.4						< 10	18.71	n.π. [g]; (1)	(1965SE06)
9	3.12	100	weak	[20] [c]	non-res.	non-res.	(0.4)	2.0	< 0.2	< 1.5	97	18.82	$2^+; 1$	(1955BA22, 1965SE06)
10	3.5	1100	[20] [c]	res.	5.2	res.	25	10	50	200	300	19.2	$(1^-; 1)$	(1955BA22, 1965SE06)
11	3.75	(1100)	non-res.	res.	7.4 ± 1.1	300 ± 40	< 3	3	20	450	450	19.39	$(2^+; 0)$	(1963SY01, 1965SE06)
12	4.93	180	non-res.	res.	non-res.	170 ± 40						20.47		(1955BA22, 1963SY01, 1964AL20)
13	5.11	275	non-res.	[35] [c]	6.0 ± 0.9	non-res.						20.64	$(3^-; 1)$	(1955BA22, 1963SY01, 1964AL20)
14	6.0		res.	non-res.								21.5		(1964AL20)
15	6.7		res.	[35] [c]	res.							22.1		(1963BE18, 1964AL20)
16	7.2	3200	120	non-res.		(res.)	≥ 2500 [e]					22.6	$(1^-; 1)$	(1961GO13, 1963BE18, 1964AL20)
17	8.3		res.	res.	res.							23.6		(1963BE18, 1964AL20)
18	10.3	≈ 6500	[60] [c]	83					[k]			25.4	[i]	(1961GO13, 1963BE18, 1964AL20, 1967FE04, 1972GL01)
19	11.76		non-res.	45 [d]	res.				[k]			26.73	(1^-) [l]	(1963BE18, 1964AL20, 1967FE04)
20	12.55 [j]		21 [d]	non-res.								27.45		(1967FE04)
21	13.09		19 [d]	38 [d]								27.94		(1964AL20, 1967FE04)

Table 12.12: Resonances in ^{11}B(p, γ)^{12}C and ^{11}B(p, α)^{8}Be (continued)

Peak number	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)	$J^\pi; T$	Refs.
22	[13.6] [j]		non-res.	25 [d]					[k]			28.4		(1967FE04)
23	14.19 [j]		16 [d]	non-res.								28.95		(1967FE04)
24	14.8	broad	res.						[k]			29.5		(1969KE02)

[a] 163.1 ± 0.2 keV, $\Gamma_{c.m.} = 6.5 \pm 0.6$ keV: see (1955AJ61) and see footnote 7 in (1961SE10).

[b] 97% of the value for Γ_γ reported by (1974AN19) [21.7 ± 3.3 eV] to take into account the branching ratios.

[c] Estimated from graph (1964AL20).

[d] $4\pi \times \sigma$ (90°).

[e] Assuming a single resonance (1961GO13).

[f] (1953HU29, 1953BE61).

[g] n.π. = natural parity.

[h] Resonance in yield of 15.1 MeV γ-rays; $(2J + 1)\,\Gamma_\gamma \geq 2.8 \pm 0.6$ eV (1972SU08).

[i] See text (1972GL01).

[j] See also (1971SN1A).

[k] See (1972TH1C).

[l] See (1970KO27).

21. ^{10}B(α, d)^{12}C $\quad Q_m = 1.3409$

$Q_0 = 1340.6 \pm 1.5$ keV (1967BR1B).

At $E_\alpha = 21.2$, 23.0 and 25.0 MeV angular distributions of the deuterons to ^{12}C*(0, 4.4) have been measured (1967AL16). The (d$\gamma_{4.4}$) angular correlations have been measured for $E_\alpha = 19$ to 25 MeV (1972EL09). See also (1967SP09, 1973HA1Y, 1973SP1D), (1971BU1K, 1973ZE03; theor.) and ^{14}N in (1976AJ04).

22. ^{10}B(^{6}Li, α)^{12}C $\quad Q_m = 23.715$

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 (1966MC05), as is that of ^{12}C*(15.11) [$T = 1$] (1964CA18: $E(^6\text{Li}) = 3.8$ MeV): the intensity ratio $\alpha_{15.1}/\alpha_{12.7} = 3 \pm 2\%$. See also (1969CO1D, 1970GI05).

23. ^{10}B(^{14}N, ^{12}C)^{12}C $\quad Q_m = 14.916$

Angular distributions involving $^{12}\text{C}^*_{4.4} + {}^{12}\text{C}_{\text{g.s.}}$ and $^{12}\text{C}^*_{4.4} + {}^{12}\text{C}^*_{4.4}$ have been measured at $E(^{14}\text{N}) = 22.5$ and 30 MeV (1969IS01). See also (1972VO02).

24. ^{10}B(^{16}O, ^{14}N)^{12}C $\quad Q_m = 4.452$

Angular distributions involving $^{14}\text{N}_{\text{g.s.}} + {}^{12}\text{C}_{\text{g.s.}}$ and $^{14}\text{N}_{\text{g.s.}} + {}^{12}\text{C}^*_{4.4}$ have been measured at $E(^{16}\text{O}) = 30$ and 32.5 MeV and also at 26 MeV for the double ground state transition (1969IS01). See also (1968OK06).

25. (a) ^{11}B(p, γ)^{12}C $\quad Q_m = 15.9572$

(b) ^{11}B(p, α)^{8}Be $\quad Q_m = 8.591$ $\quad E_b = 15.9572$

(c) ^{11}B(p, α)^{4}He^{4}He $\quad Q_m = 8.6824$

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.

(a) In the range 4 MeV $< E_p <$ 14.5 MeV $\sigma(\gamma_0)$ is dominated by the giant dipole resonance at $E_p = 7.2$ MeV ($E_x = 22.6$ MeV, $\Gamma_{\text{c.m.}} = 3.2$ MeV), while the giant resonance in γ_1 occurs at $E_p \approx 10.3$ MeV ($E_x = 25.4$ MeV, $\Gamma_{c.m.} \approx 6.5$ MeV): see (1964AL20). A study of the giant dipole resonance region with polarized protons ($E_p = 6$ 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 consistent either with a single $J^\pi = 2^-$ state or with interference of pairs of states such as $(1^-, 3^-)$, $(2^-, 3^-)$ and $(1^-, 2^-)$ (1972GL01). Measurements of differential cross sections at 90° ($E_p = 13$ to 22 MeV), of angular distributions ($E_p = 7$ and 14 to 21 MeV), and of total cross sections ($E_p = 14$ to 21 MeV) have been reported by (1970BR1J, 1972BR26) for γ_0, γ_1 and γ_3 [to ^{12}C*(0, 4.4, 9.6)]: disagreement is reported with the cross section values reported by (1964AL20). The γ_2 yield to ^{12}C*(7.7) exhibits a peak at $E_p \approx 14.3$ MeV with a cross section $\approx 2.3\%$ that of γ_0. The γ_3 yield shows two large asymmetric peaks at $E_p = 12.5$ and 13.8 MeV with $\Gamma \approx 0.7$ and 2.5 MeV, respectively, as well as a weaker structure near $E_p = 9.8$ MeV (1971SN1A: $E_p = 6$ to 18 MeV; abstracts). (1969KE02: $E_p = 13$ to 21 MeV) report a broad peak in the γ_0 cross section at $E_p = 14.8$ MeV [$E_x = 29.5$ MeV]. The previously reported resonance in γ_0 at $E_p = 20.1$ MeV [see (1968AJ02)] does not exist: see (1969KE02, 1972BR26). No evidence is seen in this reaction for the $J^\pi = 0^+$; $T = 2$ state reported in reactions 4 and 12 (1974HA1G: search for $\gamma_{12.5} + \gamma_{15.1}$, that is $(0^+; 2) \to (1^+; 1) \to (0^+; 0)$). Work on other resonances is discussed below. See also the reviews by (1968BR1D, 1968SC1B, 1972HA1Y, 1973GL1C, 1973HA1Q, 1973SU1E, 1974HA1N), (1972CA1H) and (1969MA22, 1970GO41, 1973BA05, 1973HA1X, 1973SU03; theor.).

(b) Excitation functions for α_0 have been measured recently for $7.50 < E_p < 18.9$ MeV: no marked structure is observed above $E_x = 28$ MeV (1972TH1C: Ph.D. thesis; (1969TH1B, 1971TH1F); abstracts). See also ^{8}Be in (1974AJ01) and (1968CH01, 1971GU23).

(c) This reaction has been studied for $E_p = 0.15$ to 9.5 MeV. It proceeds predominantly by sequential two-body decay via ^{8}Be*(0, 2.9): see ^{8}Be in (1974AJ01) and (1968CH01, 1968GI03, 1969QU01, 1970CO03, 1971KO22, 1971YA13, 1972CH35, 1972DZ10, 1972HU04, 1972MI1J, 1972TR07, 1972VO01, 1973PR1C). See also (1969PH1B), (1967CO29, 1967EN1A, 1967FL12, 1968LA1C, 1969LA1B, 1970PA10), (1969GO13, 1969SA1B, 1970GI1C, 1970GO1J, 1970GO33, 1970GO49, 1970KO01, 1970KO1K, 1970KO27, 1970MC25, 1970MC1T, 1970SC01, 1971GO20, 1971LA25, 1972GO1N, 1972KO1J, 1973GO35, 1973KO11, 1973KO38; theor.) and (1974LI1M; applied).

The parameters of the observed resonances are displayed in Table 12.12. The following summarizes the information on the low-lying resonances: for a full list of references see (1968AJ02).

$E_p = 0.16\ MeV$ [^{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): the angular distribution of γ_3, together with the known α-decay of ^{12}C*(9.6), fix $J^\pi = 3^-$ for the latter (1961CA13). A new measurement of the (p, γ) and (p, α) resonant cross sections yields 125 ± 16 μb and 38.5 ± 3.2 mb, respectively, based on $\Gamma_{c.m.} = 6.7$ keV. Γ_γ and Γ_p for ^{12}C*(16.11) are then 21.7 ± 3.3 eV and 21.7 ± 1.8 eV, respectively (1974AN19). See also Table 12.9.

$E_p = 0.67\ MeV$ [^{12}C*(16.58)]. 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 α-α correlation study via ^{8}Be*(2.9) (1972TR07)]. The γ_1 E1 transition has $|\mathrm{M}|^2 \approx 0.01$ W.u., suggesting $T = 1$ (1957DE11, 1965SE06). (1962BL10) report a γ branch to ^{12}C*(12.71) ($\approx$ 6% of the intensity of the γ_1 transition). Such a branch may also be present for ^{12}C*(17.23). See also (1973PR1C).

$E_\mathrm{p} = 1.4$ *MeV* [^{12}C*(17.23)]. $(2J + 1)\,\Gamma_{\gamma_0} \geq 115$ eV. This indicates $J^\pi = 1^-$, with $T = 1$ most probable (1965SE06). $J^\pi = 1^-$ is also required to account for the interference at lower energies in α_0 and γ_0: see (1957DE11) and is consistent with the α-α correlation results of (1972TR07). Two solutions for Γ_p are possible; the larger (chosen for Table 12.12) is favored by elastic scattering data (1965SE06).

$E_\mathrm{p} = 2.0$ *MeV* [^{12}C*(17.76)]. 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^+; $T = 1$ (1965SE06).

$E_\mathrm{p} = 2.37$ *MeV* [^{12}C*(18.13)]. Seen as a resonance in the yield of 15.1 MeV γ-rays: $\sigma_\mathrm{R} = 0.77 \pm 0.15$ μb, $\Gamma_\mathrm{c.m.} = 600 \pm 100$ 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 (1972SU08).

$E_\mathrm{p} = 2.62$ *MeV* [^{12}C*(18.36)]. 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 $l_\mathrm{p} \geq 2$. The assignment $J^\pi = 3^-$ is consistent with the data (1965SE06, 1972CH35, 1972VO01, 1974GO21).

$E_\mathrm{p} = 2.66$ *MeV* [^{12}C*(18.40)] is not seen here: see ^{11}B(p, p).

$E_\mathrm{p} = 3.12$ *MeV* [^{12}C*(18.80)]. 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 (1965SE06).

The structure near $E_\mathrm{p} = 3.5 - 3.7$ 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 the other to have even spin and even parity: $J^\pi = 2^+$; $T = 0$ is favored (1963SY01, 1965SE06).

Levels at $E_\mathrm{p} = 4.93$ and 5.11 MeV, seen in $\sigma(\gamma_1)$ (1955BA22) 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 $J^\pi = 3^-$; $T = 1$ (1963SY01).

The first seven $T = 1$ states in ^{12}B and ^{12}C have been identified by comparing reduced proton widths obtained from this reaction and reduced widths obtained from the (d, p) and (d, n) reactions: see Table 12.13 (1971MO14, 1974AN19).

26. ^{11}B(p, n)^{11}C　　$Q_\mathrm{m} = -2.765$　　$E_\mathrm{b} = 15.9572$

Excitation functions have been reported for $E_\mathrm{p} = 2.6$ to 11.5 MeV. They are characterized by numerous peaks: see Table 12.14. The positions of these appear to correspond with ^{11}B(p, α)^{8}Be and with some of the (γ, n) and (γ, p) structure, suggesting that resonances, and not fluctuations, are involved. Angular distributions do not change as rapidly as might be expected from the pronounced structure in the excitation function (1965OV01). The strength of the pronounced peak at $E_\mathrm{p} = 6.03$ MeV ($E_\mathrm{x} = 21.49$) appears to demand $J \geq 4$ (1961LE11).

Table 12.13: Properties of $T = 1$ analogs in ^{12}B and ^{12}C

$E_x(^{12}B)$ (MeV)	$E_x(^{12}C)$ (MeV)	J^π	S(d, p) [a]	S(d, p) [b]	S(d, n) [c]	Γ_p [d] (keV)	$\frac{\gamma^2_{\lambda n}}{2\gamma^2_{\lambda p}}$
0	15.11	1^+	0.69	0.50	0.77		0.59 [e]
0.95	16.11	2^+	0.55	0.35	0.74	$(21.7 \pm 1.8) \times 10^{-3}$	0.47 [e]
1.67	16.58	2^-	0.57	0.26	0.54	150	0.76 [e]
							0.68 [a]
2.62	17.23	1^-	0.75			1000	0.70 [a]
2.72	17.76	0^+	0.21			76	0.93 [a]
3.39	18.36	3^-	0.58			68	0.99 [a]
3.76	18.80	2^+				33	0.93 [f]

[a] (1971MO14).
[b] $E_d = 5.5$ MeV (1965GA02): see (1974AN19).
[c] $E_d = 6.0$ MeV (1974AN19).
[d] See Table 12.12.
[e] (1974AN19): $\pm 30\%$.
[f] See discussion on p. 2196 of (1971MO14).

The polarization transfer coefficient has been measured for $E_p = 7$ to 15 MeV: the strong influence of resonances is apparent (1974LI1J). See also (1974MA07; theor.). Polarization measurements have been carried out for $E_p = 7$ to 11 MeV (1965WA04) and at 24.5 MeV (1972MO41). See also (1973BA05; theor.), ^{11}C and (1968AJ02).

27. (a) ^{11}B(p, p)^{11}B $\qquad E_b = 15.9572$
(b) ^{11}B(p, p$'$)^{11}B*
(c) ^{11}B(p, 2p)^{10}Be $\qquad Q_m = -11.2294$

A pronounced anomaly in the elastic scattering is observed near $E_p = 0.67$ MeV at all angles; the level is therefore formed by s-waves. The 0.3 to 1.0 MeV results are well accounted for by two resonances: $E_p = 0.67$ MeV, s-wave, $J^\pi = 2^-$, $\Gamma = 0.33$ MeV, $\Gamma_p/\Gamma = 0.5$, and $E_p = 1.4$ MeV, $J^\pi = 1^-$ (1957DE11). Higher energy structure in the yields of reactions (a) and (b) are displayed in Table 12.14 (1955BA22, 1965SE06, 1971SA1H). Excitation functions for p_0 and p_1 have been measured for $E_p = 7.5$ to 21.5 MeV: no pronounced structure is observed above $E_x = 28$ MeV (1972TH1C: Ph.D. thesis; (1969TH1B, 1971TH1F); abstracts).

Table 12.14: Maxima in yields of ^{11}B(p, n)^{11}C and ^{11}B(p, p′)^{11}B*

Peak number	A		(1965OV01) [a,b]		(1955BA22) [c]		(1965SE06) [e]		E_x (MeV)
	E_p (MeV)	Γ_{lab} (keV)	E_p (MeV)	res. in group(s)	E_p (MeV)	Γ_{lab} (keV)	E_p (MeV)	Γ_{lab} (keV)	
1							1.98 [d]		17.77
2					2.664	48	2.66 [c,d]	46	18.40
3	3.16	100			3.15	100	3.15 [c,d]	100	18.84
4	3.66	500			3.4	500	3.5 [c]	broad	19.3
5					3.78	50			19.42
6	4.05	200	4.10	n_0					19.69
7					4.28	100			19.88
8	4.70	150	4.62	n_0	4.68	200			20.24
9	5.065	180	5.07	n_0	5.13	200			20.60
10	5.48	300	5.50	n_0					20.98
11	6.04	560	6.01	n_0, n_1					21.47
12			6.4	n_0					21.8
13	7.29	360	7.3	n_0, n_1					22.63
14	7.74	65	7.73	n_0, n_1			7.73 [f]		23.04
15	8.25	380	8.25	n_0, n_1					23.51
16	(8.30)	($\leq$ 50)							(23.56)
17	8.65	180	8.6	n_0, n_2					23.88
18	9.0								24.2
19	9.25	110	9.25	n_0, n_2					24.43
20	9.79	1000	9.79	n_0, n_1					24.92
21	10.14	180	10.1	n_0, n_2					25.24
22	10.91	440	10.9	n_0					25.95
23	11.88	300							26.84

A: (1955BA22, 1959GI47, 1961LE11, 1964BA16, 1965SE06): see (1968AJ02).

[a] Widths $\approx$ 200 keV, except $E_p = 6.4$ and ≥ 9.25 MeV which are wider.

[b] (p, n).

[c] (p, p′).

[d] (p, p).

[e] See also Table 12.12.

[f] Observed in (p, p) and (p, p′) with polarized protons: $J^\pi = 2^-$; $T = 1$ is consistent with the data (1971SA1H: conf. proceedings).

Table 12.15: States in ^{12}C from ^{11}B(d, n) and ^{11}B(^{3}He, d)

Peak number	E_x (MeV ± keV)	$J^\pi; T$	Γ_{lab} [a] (keV)	l_p [b]	l [c]	S_{rel} [d]	S_{rel} [e]	S_{rel} [f]	S_{rel} [g]	S_{rel} [h]	S_{rel} [i]	S_{rel} [j]	S_{rel} [k]
1	g.s.	$0^+; 0$		1	1	8.0 ± 2.6	3.30	5.4		5.8 ± 0.6	7.1 ± 1.5		
2	4.44	$2^+; 0$		1	1	3.1 ± 0.7	1.53	0.78	1.23 ± 0.20	2.2 ± 0.3	1.64 ± 0.17		
3	7.66	$0^+; 0$			1	< 0.5		0.078	0.08 ± 0.02				
4	9.629 ± 10 [l]	$3^-; 0$		2	2	0.73 ± 0.09	0.29	0.28	0.45 ± 0.08	0.35 ± 0.1	0.35	0.155 ± 0.01	0.191 ± 0.01
5	10.84 ± 20 [m]	$1^-; 0$	330 ± 30	0	0	0.13 ± 0.03		1.1	0.13 ± 0.02	0.17 ± 0.08	0.22 ± 0.10	0.038 ± 0.01	0.047 ± 0.01
				2		0.5 ± 0.2			$\leq 0.14 \pm 0.10$				
6	11.16 ± 50 [n]	$(2^+); 0$	550 ± 100		(1)			0.14					
7	11.82 ± 20 [m]	$2^-; 0$	300 ± 30	0	2	0.13 ± 0.03		0.17	0.11 ± 0.02	0.11 ± 0.04	0.20 ± 0.1	0.11 ± 0.01	0.073 ± 0.03
				2		0.5 ± 0.2			$\leq 0.28 \pm 0.10$				
8	12.70 ± 10 [m]	$1^+; 0$		1	1	$\equiv 1$	$\equiv 1$	$\equiv 1$	$\equiv 1$	$\equiv 1$	$\equiv 1$	$\equiv 1$	$\equiv 1$
9	13.38 ± 20 [m]	$(2^-); 0$	500 ± 80		(0)								
10	(14.71 ± 10) [m,o]		< 15		0 [g,o]				0.02 ± 0.01 [o,r]				
11	15.11	$1^+; 1$		1	1	0.63 ± 0.04 [p]	1.58	0.92	1.50 ± 0.20			0.87 ± 0.05	0.89 ± 0.05
12	16.11	$2^+; 1$		1	1	0.27 ± 0.05 [p] [q]		1.1	1.55 ± 0.50			0.58 ± 0.04	0.65 ± 0.04
13	16.58	$2^-; 1$											
14	17.23	$1^-; 1$		> 1									
15	18.27 ± 50 [n]	$(4^-; 0)$	350 ± 50		(2)								
16	18.36	$(3^-; 1)$	270 ± 50		(2)								
17	19.25	$(1^-; 1)$			(2)								
18	19.56 ± 50 [n]	$(4^-; 1)$	500 ± 80		(2)								
19	20.6	$(3^-; 0)$	250 ± 50		(2)								
20	22.40 ± 80 [n]	$(1^-; 1)$	350 ± 50		(2)								

[a] (1961HI08, 1971RE03).
[b] (d, n): see Table 12.12 in (1968AJ02).
[c] (^{3}He, d): see Table 12.13 in (1968AJ02) and (1971RE03).
[d] All S_{rel} are relative to ^{12}C*(12.71). $E_d = 6$ MeV (1967FU07).
[e] $E_d = 11.8$ MeV (1971MU18).
[f] $E(^3\text{He}) = 44$ MeV (1971RE03): values recomputed so that they are relative to ^{12}C*(12.71).
[g] $E(^3\text{He}) = 11.8$ MeV (1968BO26). Values shown are average when r (cutoff) is varied between 0 and 4 fm.
[h] $E(^3\text{He}) = 10 - 12$ MeV: deep potential, zero range, no cutoff (1969MI15).
[i] $E(^3\text{He}) = 10 - 12$ MeV: deep potential, finite range, no cutoff (1969MI15).
[j] $E(^3\text{He}) = 18$ MeV: deep potential, zero range, no cutoff (1969MI15).
[k] $E(^3\text{He}) = 18$ MeV: deep potential, finite range, no cutoff (1969MI15).
[l] Based on 7656 ± 7 keV for next lower level (1960FO01).
[m] (1961HI08).
[n] (1971RE03): (^{3}He, d).
[o] This state, reported by (1961HI08), is not seen by (1971RE03). At $E(^3\text{He}) = 44$ MeV, $\theta = 12.5^\circ$, its yield is $< 2\%$ that of ^{12}C*(15.11). (1968BO26) report an angular distribution for ^{12}C*(14.71) but their paper does not give enough information to determine whether the group was a clearly resolved one.
[p] See also Table 12.13 (1974AN19).
[q] See (1974AN19).
[r] Assuming $J^\pi = (1)^-$.

Polarization measurements have been reported at $E_p = 1.9$ to 3.0 MeV (1974DE45: p_0), 3.5 to 10.5 MeV (1971SA1H; prelim. report; p_0, p_1), 30.3 MeV (1969KA15, 1971LO05; p_0, p_1, p_2) and 155 MeV (1968GE04; p_0, p_1, p_2, p_4). See also (1965HU10, 1968RI1J, 1972RE06) and (1969WA11, 1971BL1E; theor.). For reaction (c) see (1971RA26). See also ^{11}B and ^{10}Be in (1974AJ01).

28. ^{11}B(p, d)^{10}B $\quad Q_m = -9.2314 \quad E_b = 15.9572$

See ^{10}B in (1974AJ01).

29. ^{11}B(d, n)^{12}C $\quad Q_m = 13.7325$

Reported neutron groups are displayed in Table 12.15. Angular distributions have been reported for many energies in the range $0.5 < E_d < 11.8$ MeV: see (1968AJ02) for a listing of the earlier references and (1970BU15: 5.5 MeV; n_0, n_1), (1967FU07: 6 MeV; see Table 12.15), (1974AN19: 6 MeV; n to ^{12}C*(15.1, 16.1); see Table 12.13), (1971MU18: 11.8 MeV; see Table 12.15). See (1971MU18) for a discussion of the problems involved in comparing spectroscopic factors obtained in this reaction and in the (^{3}He, d) reaction [reaction 30].

Angular correlations of neutrons and γ-rays have been studied at many energies: see (1968AJ02) for the earlier references and (1968TE03: 1.6 to 3.3 MeV for $\gamma_{4.4}$; 2.9 and 3.3 MeV for $\gamma_{15.1}$) and (1972TH14: 4.0 to 4.8 MeV; $\gamma_{4.4}$, $\gamma_{15.1}$).

In the range $E_d = 1.0$ to 5.5 MeV, two slow neutron thresholds are observed at 1.627 ± 0.004 MeV ($E_x = 15.109 \pm 0.005$ MeV) and near 4.1 MeV (broad; $E_x = 17.2$ MeV) (1955MA76). At the lower threshold, 15.1 MeV γ-rays are observed: $E_d = 1.633 \pm 0.003$ MeV, $\Gamma < 2$ keV (1958KA31) [$E_x = 15.110 \pm 0.003$ MeV].

A study of the angular distributions and energy spectra of α-particles from the decay of ^{12}C states shows that the 12.71 and 11.83 MeV states decay sequentially via ^{8}Be; the former via ^{8}Be*(2.9), the latter 90% via ^{8}Be*(2.9) and 10% via ^{8}Be(0). There is some evidence that the 10.84 MeV state decays primarily to ^{8}Be(0). $J^\pi = 3^-$ for the 9.64 MeV state is favored on the basis of the angular distribution of the α-particles to ^{8}Be(0). There is no evidence for direct 3α decay of ^{12}C levels in the range $E_x = 9$ to 13 MeV, nor does ^{12}C*(10.3) appear to participate in this reaction (1965OL01).

See also ^{13}C in (1976AJ04) and (1970MI1G, 1970YA11; theor.).

30. (a) ^{11}B(^{3}He, d)^{12}C $\quad Q_m = 10.4634$
(b) ^{11}B(^{3}He, np)^{12}C $\quad Q_m = 8.2388$

Observed deuteron groups are displayed in Table 12.15. Angular distributions have been measured at $E(^3\text{He}) = 5.1$ to 44 MeV: see (1968AJ02) for the earlier references and (1969MI15: $E(^3\text{He}) = 10$, 12 and 18 MeV), (1968BO26: 11 MeV), (1971RE03: 44 MeV). ^{13}N*(15.1) $[T = \frac{3}{2}]$ has been observed to decay to ^{12}C*(9.6, 10.8) with branching ratios of $9.6 \pm 1.4\%$ and $16.4 \pm 3.6\%$, respectively. The upper limit to ^{12}C*(12.7) is $\approx 5\%$ (1974AD1D).

31. ^{11}B(α, t)^{12}C $\qquad Q_{\text{m}} = -3.8574$

Angular distributions have been measured at $E_\alpha = 15.1$, 18.3 and 24.9 MeV (1972VA34: t_0; and t_1 at 24.9 MeV), 27 MeV (1969TE1B: t_0, t_1; unpublished) and 46 MeV (1969FO1C: $\text{t}_0 \rightarrow \text{t}_3$ and t to ^{12}C*(12.7); abstracts). See also (1968AJ02). The (t_1, γ) angular correlations have been measured for $E_\alpha = 21.2$ to 25.0 MeV (1972EL09). See also (1973ZE03; theor.).

32. ^{11}B(^{7}Li, ^{6}He)^{12}C $\qquad Q_{\text{m}} = 5.979$

See (1968ST12).

33. ^{11}B(^{14}N, ^{13}C)^{12}C $\qquad Q_{\text{m}} = 8.407$

Angular distributions have been measured for the ground state transition at $E(^{14}\text{N}) = 41$, 77 and 113 MeV: they show damping of the oscillations with increasing energy (1971LI11). See also (1973DE35; theor.).

34. ^{11}B(^{16}O, ^{15}N)^{12}C $\qquad Q_{\text{m}} = 3.829$

Angular distributions have been measured at $E(^{16}\text{O}) = 27$, 30, 32.5, 35 and 60 MeV for the transitions $^{15}\text{N}_{\text{g.s.}} + {}^{12}\text{C}_{\text{g.s.}}$, $^{15}\text{N}^*_{6.3} + {}^{12}\text{C}_{\text{g.s.}}$, $^{15}\text{N}_{\text{g.s.}} + {}^{12}\text{C}^*_{4.4}$ and $^{15}\text{N}_{\text{g.s.}} + {}^{12}\text{C}^*_{9.6}$ (the latter at $E = 60$ MeV only) (1972SC03): at the highest energy the ratio $\theta^2/\theta^2_{\text{g.s.}}$ for the transition $^{11}\text{B}_{\text{g.s.}} + \text{p} \rightarrow {}^{12}\text{C}$ is 0.12 and 0.05, respectively for ^{12}C*(4.4, 9.6). See also (1968OK06), (1969BR1D, 1972MO1E) and (1968VA1D, 1969KA1G, 1970AN1D, 1970SC1G, 1972BO21, 1973DE1W, 1973DE35, 1973OS03, 1974OS1A; theor.).

35. ^{12}B(β^-)^{12}C $\qquad Q_{\text{m}} = 13.370$

Table 12.16: Branching in ^{12}B(β^-)^{12}C

Decay to ^{12}C* (MeV)	Branch (%)	log ft	Refs.
g.s.	97.13 ± 0.31	4.072 ± 0.002	(1974MC11)
4.43891 ± 0.00031 [a]	1.33 ± 0.09 [b]		
	1.27 ± 0.06		(1972AL31)
	1.29 ± 0.05	5.11 ± 0.02 [c]	mean
7.6544 ± 0.0021 [d]	1.5 ± 0.3 [e]	4.14 ± 0.10 [f]	
10.3 ± 0.3 [g]	0.08 ± 0.02 [h]	4.2 ± 0.2 [f]	

[a] (1967CH19).

[b] Mean of values obtained by (1956TA07, 1958KA31, 1963PE10).

[c] (1974MC11).

[d] Based on Wapstra-Gove value for the atomic mass excess of ^{4}He, and the decay energy for the breakup of this state into 3α measured by (1973BA73) [$Q = 379.6 \pm 2.0$ keV]. See also footnote [n] of Table 12.21.

[e] Mean of values obtained by (1957CO59, 1963AL15).

[f] See (1966BA1A).

[g] $\Gamma = 3.0 \pm 0.7$ MeV, $\theta^2_\alpha = 1.5$ (1966SC23).

[h] Mean of values obtained by (1958CO66, 1963WI05).

The decay is mainly to ^{12}C$_{\rm g.s.}$; branching ratios to ^{12}C*(4.4, 7.7, 10.3) are shown in Table 12.16. All the observed transitions are allowed. The half-life is 20.41 ± 0.06 msec [see Table 12.2 of (1968AJ02)].

^{12}C*(7.7) is of particular interest for helium burning processes in stars [see (1968AJ02)]. The fact that the β-decay is allowed indicates $J^\pi = 0^+$, 1^+ or 2^+; it decays primarily by α-emission eliminating $J^\pi = 1^+$, and requiring 0^+ (1957CO59). (1973BA73) have measured the Q of the α-decay of ^{12}C*(7.7) to be 379.6 ± 2.0 keV. When this result is combined with the Q determined from accurate measurements of the $E_{\rm x}$ of ^{12}C*(7.7), the "best" value is $Q = 380.1 \pm 1.1$ keV. This value, together with previously measured values of Γ_π, Γ_π/Γ and $\Gamma_{\rm rad}/\Gamma$ [see Table 12.9] lead to $\Gamma_{\rm rad} = 3.41 \pm 1.12$ meV and to a mean lifetime for the destruction of helium by the [$\alpha\alpha\alpha$] process of $2.59 \times 10^{-8} \rho^2 T_9^{-3} \exp(-4.411/T^9)$ sec^{-1} (1973BA73).

A search for transitions to ^{12}C*(12.7) has been unsuccessful (1967AL03). See also reaction 63. For asymmetry measurements see (1967PF02, 1973ST1P, 1974PO05). See also ^{12}C, reaction 28 in (1968AJ02), and (1971MI06, 1973CH16, 1973MIYZ, 1974PO05).

See also (1974AL11), (1968DA1J) and (1969BL1D, 1969CH1A, 1969CH1F, 1969MO1F, 1970ST04, 1971BL06, 1971KI04, 1971KI11, 1971LA21, 1971LI1F, 1971LI1H, 1971WI18, 1971WI1C, 1972AR04, 1972EM02, 1972OC01, 1972WI28, 1972WI1C, 1973BO09, 1973EM1B, 1973HA49, 1973KU1D, 1973KU1N, 1973TO14, 1973WI11, 1973YO04, 1974BO18, 1974HO1D, 1974WI1L, 1975GR03; theor.).

36. ^{12}C(γ, γ)^{12}C

Resonance scattering and absorption by ^{12}C*(15.11) have been studied by many groups: see Table 12.15 in (1968AJ02). The partial widths are displayed in Table 12.9. The scattering angular distribution indicates dipole radiation (1959GA09), the azimuthal distribution of scattered polarized radiation indicates M1 (1960JA01) and the large Γ_γ indicates $T = 1$. The branching ratio for the cascade decay via ^{12}C*(4.4) is 3.6 ± 0.7% (1970AH02). Elastic scattering to ^{12}C*(4.4, 16.1, 17.2) has also been observed. See also (1968AJ02) and Table 12.20.

At higher energies, elastic scattering studies show the giant resonance peak at ≈ 24 MeV. A considerable tail is visible, extending to > 40 MeV (1959PE32). See also reaction 37, (1969MO1H, 1971ME1B) and (1968SI1A; theor.).

37. (a) ^{12}C(γ, n)^{11}C $\qquad Q_{\rm m} = -18.722$
(b) ^{12}C(γ, 2n)^{10}C $\qquad Q_{\rm m} = -31.846$

The total absorption, mainly (γ, n) + (γ, p), is dominated by the giant resonance peak at 23.2 MeV, $\Gamma = 3.2$ MeV [$\sigma_{\rm max} = 19.8$ mb (1965WY02)] and by a smaller structure at 25.6 MeV, $\Gamma \approx 2$ MeV ($\sigma_{\rm max} \approx 8$ mb): see (1968AJ02) [Tables 12.16, 12.17] for a detailed listing of the earlier references and results, and see (1973AH1A, 1974BE2B). See also (1967DO1A, 1969BE92). Total absorption cross sections have also been measured at $E_\gamma = 84$ to 662 keV by (1968RA1D), at 7.28 and 7.65 MeV by (1969MO1H), at 10 to 140 MeV by (1970AH02, 1972AH1B, 1973AH1A) and at 250 to 1000 MeV by (1972MI1K, 1974HO15). See also Table 12.16 in (1968AJ02).

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 (1968AJ02). The giant resonance peak is rather flat-topped with several small fine structure bumps across the top (E.G. Fuller, private communication): see (1966CO09, 1966FU02, 1966LO04, 1971IS09, 1972VA32, 1973BE2F, 1973IS1A, 1974BE2B). 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 (1968WU01): the isospin mixing averages about 2% in intensity and shows structure at the giant resonance. [See the reviews by (1970HA1F, 1973HA1Q).] 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 (1968RA21, 1970JU1C, 1973JU1C). The fraction of transitions to the ground state and to excited states of ^{11}C has been measured at $E_{\rm bs} = 24.5$ to 42 MeV: see ^{11}C (1970ME17), reaction 38 and the discussion in (1973DI1C). For polarization measurements see (1973NA1K) and (1968AJ02). For a listing of recent cross section measurements see Table 12.17.

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 (1970KA37).

See also (1967AN11, 1969DE12, 1971JO1E, 1973MO1G, 1973VA12), (1972BU1J, 1973CO1N, 1973HA1Q) and (1968PA1H, 1969ER1A, 1969GA1J, 1969GO1D, 1969MA22, 1969UB01, 1970GO41,

Table 12.17: Recent cross section measurements: $^{12}C(\gamma, n)^{11}C$ and $^{12}C(\gamma, p)^{11}B$ [a]

Range in E_γ (MeV)	Reaction	Refs.
19.0 – 19.7	(γ, n)	(1968JO08)
19.0 – 24.0	(γ, n)	(1971IS09, 1973IS1A)
19 – 25	(γ, n)	(1969BA35, 1971BA2W)
19 – 33	(γ, n)	(1972VA32)
19 – 37	(γ, n)	(1974BA1Z)
20 – 140	(γ, n)	(1970KA37)
21 – 40	(γ, n)	(1968WU01)
55, 85	(γ, n)	(1968KA38, 1971KA70)
64 – 123	(γ, n)	(1973EY1A)
64 – 128	(γ, n)	(1971MI04, 1970MI1H)
100 – 1050	(γ, n)	(1970HY01)
30 – 1000	(γ, n)	(1968DI1B)
1 – 5.5 GeV	(γ, n)	(1969DE34)
1 – 7 GeV	(γ, n)	(1972AN19)
20 – 29	(γ, p)	(1969CA22, 1974WI12)
21 – 37.5	(γ, p)	(1968FR12, 1968FR14)
24 – 70	(γ, p)	(1969TA11)
400 – 1400	(γ, p)	(1969AN1F, 1969AN10)

[a] See Table 12.16 in (1968AJ02) for earlier measurements. See also the text of reactions 37 and 38.

1970MU1D, 1971AN08, 1971BA97, 1971BI01, 1971WA27, 1972BI11, 1973BA05, 1973BE1W, 1973BI1K, 1973MA1T, 1973MS01, 1973MS02, 1973SR1B, 1973SU03, 1973WE1U, 1974CA1R, 1974FI03, 1974GI1A; theor.). For applied work see (1973AL1G).

38. (a) ^{12}C(γ, p)^{11}B $\qquad Q_{\rm m} = -15.9572$
(b) ^{12}C(γ, π^+)^{12}B $\qquad Q_{\rm m} = -152.939$
(c) ^{12}C(γ, π^-)^{12}N $\qquad Q_{\rm m} = -156.913$

The photo-proton cross section exhibits two broad peaks, the giant resonance peak at 22.4 MeV, $\Gamma = 3.2$ MeV, $\sigma_{\rm max} = 13$ mb [see Table 12.19 in (1968AJ02)], and a second broad peak at 25.1 MeV, in addition to some fine structure. In contrast with the giant resonance peak in the (γ, n) cross section, the (γ, p) cross section shows a sharp 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). The (γ, p) results of (1968FR12, 1968FR14, 1969CA22) are in good agreement with those of (1964AL20) for the inverse reaction, ^{11}B(p, γ_0)^{12}C [see reaction 25], when the population of ^{11}B*(4.4, 5.0) is taken into account: the required cross sections for the (γ, p$_2$) and (γ, p$_3$) processes peak at 1.5 mb at 29 and 30 MeV, respectively (1973DI1C, 1974DI17). The fraction of transitions to the ground and excited states of ^{11}B at several energies in the range $E_{\rm bs} = 24.5$ to 42 MeV has been measured by (1970ME17): most of the transitions are to ^{11}B$_{\rm g.s.}$ and the excited state transitions appear to originate from localized $E_{\rm x}$ regions. See ^{11}B and the discussions in (1970HA1F, 1973DI1C). Proton spectra and angular distributions have also been measured at $E_{\rm bs} = 50$ to 80 MeV (1968MA32, 1969MA23), 98.5 MeV (1968MA19) and 80, 120, 285 and 1140 MeV (1970AN34). The ratio of deuterons to protons has been determined at 1140 MeV by (1972AN1M). For polarization measurements see (1970TO09). See also (1968AJ02) for the earlier measurements and reaction 44.

For reactions (b) and (c) see (1971GR1X, 1972AB1H, 1974BO47, 1974DE1U, 1974EP02) and the "*Pion capture and pion reactions*" section here.

See also (1970WO1E, 1971AN04, 1971EG03, 1971EG02, 1971GO32, 1971IR1C, 1972TO22, 1973DO13, 1974BO47, 1974DO08, 1974DO07), (1972BU1J, 1973CO1N, 1973HA1Q) and (1969GA1J, 1969GO1D, 1969MA22, 1969UB01, 1970GO41, 1970MU1D, 1971BA97, 1971BI01, 1971GI1D, 1972AK02, 1972BI11, 1972WE1G, 1973BA05, 1973BE1W, 1973DE1Y, 1973LA1M, 1973MS01, 1973MS02, 1974SE02; theor.)

39. (a) ^{12}C(γ, d)^{10}B $\qquad Q_{\rm m} = -25.1885$
(b) ^{12}C(γ, pn)^{10}B $\qquad Q_{\rm m} = -27.4132$

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 (1972SK08). The high apparent threshold for reaction (a) is thought to reflect the presence of continuum states of ^{10}B with a high parentage in ^{12}C (1964SH1B). For $E_{\rm bs} = 90$ MeV, the ratio of yields of deuterons to protons is $\approx 2\%$, for particle energies 15 to 30 MeV. For higher particle energies, the ratio decreases (1962CH26). See also (1969AN1F, 1969AN10, 1971AN04, 1971AN15, 1972AN09, 1972AN1M) for excitation functions to 1400 MeV, and (1968AJ02). For reaction (b) see (1968TA10, 1969TA11) and (1973KO1H; theor.).

40. (a) ^{12}C(γ, t)^{9}B $\qquad Q_{\rm m} = -27.366$

(b) ^{12}C(γ, ^{3}He)^{9}Be $\qquad Q_{\rm m} = -26.2801$

The yield of tritons has been measured for $E_\gamma = 35$ to 50 MeV by (1967KR05). See also (1969AN1F, 1972AN09). For reaction (b) see (1969TA11).

41. ^{12}C(γ, α)^{8}Be $\qquad Q_{\rm m} = -7.367$

The cross section 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: see (1964TO1A) and (1968AJ02). 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 (1955GO59). Alpha energy distributions show surprisingly strong E1 contributions below $E_\gamma \approx 17$ MeV (1955GO59, 1964TO1A).

42. (a) ^{12}C(γ, pα)^{7}Li $\qquad Q_{\rm m} = -24.623$

(b) ^{12}C(γ, nα)^{7}Be $\qquad Q_{\rm m} = -26.267$

The yield of 0.48 MeV γ-rays from the decay of ^{7}Be, formed in reaction (b), shows a resonance at $E_\gamma \approx 29.5$ MeV, $\sigma = 0.9 \pm 0.2$ mb. It is assumed to be the dipole state with a 5p-5h character ($J^\pi = 0^+$) based on ^{12}C*(7.66) considered to be relatively pure 4p-4h (1969OW01). For work on the γ-induced spallation of ^{12}C see (1968TA10, 1969TA11). See also (1968DI1B, 1969DI18, 1971DI1F) and (1969ER1A; theor.). For older work on these reactions see (1968AJ02).

43. ^{12}C(e, e)^{12}C

The nuclear charge radius of ^{12}C, $R_{\rm rms} = 2.462 \pm 0.022$ fm (1973FE13). Other values include $R_{\rm rms} = 2.445 \pm 0.015$ fm (Fermi model), 2.453 ± 0.008 fm (shell model) (1972JA10). See also (1969BE21, 1970BR1C, 1970SI08, 1971BE25, 1973EN1E, 1973KL12, 1973TH1B) and (1968AJ02). Elastic scattering has been studied up to 4 GeV: see (1968AJ02) for the earlier references and (1972JA10: $E_{\rm e} = 20 \rightarrow 80$ MeV), (1973KL12: $E_{\rm e} = 374.6$ MeV), (1970SI08: $E_{\rm e} = 374.5$ and 747.4 MeV) and (1971ST10: $E_{\rm e} = 1$ to 4 GeV).

Table 12.18: States of ^{12}C from ^{12}C(e, e′)^{12}C [a]

$E_{\rm x}$ (MeV)	$J^\pi; T$	Γ_{γ_0} (eV)	Refs.
4.44	$2^+; 0$	$(10.6 \pm 1.1) \times 10^{-3}$	(1967CR01)
		$(11.0 \pm 1.0) \times 10^{-3}$	(1970ST10)
7.66 [b]	$0^+; 0$	$(6.2 \pm 0.6) \times 10^{-5}$	(1967CR01)
		$(5.9 \pm 0.5) \times 10^{-5}$	(1970ST10)
9.64	$3^-; 0$	$(3.1 \pm 0.4) \times 10^{-4}$	(1967CR01)
10.84	$1^-; 0$		(1969TO01, 1971NA14)
12.71 [c]	$1^+; 0$	0.35 ± 0.05 (M1)	(1974CE01)
14.08 [d]	$4^+; 0$		(1971NA14)
15.11 [g]	$1^+; 1$	35.74 ± 0.86	(1972SP1C)
		37.0 ± 1.1	(1973CH16)
16.11 [g]	$2^+; 1$	0.83 ± 0.06	(1969GU05)
		1.8 ± 0.5 [k]	(1963BO36, 1965BI1B)
16.58	2^- [l]		(1970AN1C, 1971YA03)
17.6 ± 0.2	[l]		(1969GU05)
18.1	(1^-)		(1968BE1H, 1970AN1C, 1971BE51, 1971YA03)
18.6 ± 0.1	(3^-) [l]		(1970TO13, 1971YA03)
19.3	2^- [l]		(1968BE1H, 1968DR01, 1969GU05, 1970AN1C, 1971YA03)
19.6 ± 0.1 [g]	(4^-)		(1970TO13, 1971BE51, 1971YA03)
20.0 ± 0.1 [g]	(2^+)		(1968BE1H, 1969GU05, 1970TO13, 1971YA03)
20.6 ± 0.1 [g]	(3^+)		(1968BE1H, 1969GU05, 1970TO13, 1971YA03)
21.6 ± 0.1 [h,i]	(3^-)		(1969GU05, 1970TO13, 1971YA03)
22.0 ± 0.1 [h,i]	(1^-) [l]		(1970TO13, 1971YA03)
22.7 ± 0.1 [e,f,h,i]	(1^-)		(1969GU05, 1970TO13, 1971BE51, 1971YA03)
23.8 ± 0.1 [h]	(1^-) [l]		(1969GU05, 1970TO13, 1971YA03)
24.9 ± 0.2 [j]			(1969GU05)
25.5 [h,i,j]	(1^-)		(1971BE51, 1971YA03)
25.5 [h,i]	(3^-)		(1971YA03)
26.4 ± 0.3 [h,i]			(1969GU05)
27.8 ± 0.2 [i]			(1969GU05)
30.2 ± 0.4 [i]			(1969GU05)
32.3 ± 0.3			(1969GU05)

[a] See also Table 12.20 and reaction 36 in (1968AJ02) and Table 12.9.
[b] The matrix element is 5.48 ± 0.22 fm^2 for the E0 decay by π to $^{12}C_{g.s.}$ (1968ST20).
[c] $\Gamma_{tot} = 14.6 \pm 2.6$ eV (1974CE01).
[d] $\Gamma \approx 0.3$ MeV (1971NA14).
[e] The giant dipole resonance has an average $E_x = 23.0 \pm 0.7$ MeV and $\Gamma = 5.7 \pm 0.7$ MeV (1969GU05).
[f] May involve fine structure at E_x = 22.2, 22.8, 23.4 and 23.8 MeV.
[g] See also (1968DO08).
[h] See also (1970LI02).
[i] See also (1968RI06).
[j] See also (1970AN1C).
[k] (1969GU05) have recalculated this value and suggest that it should be 1.0 eV.
[l] See (1972AN03). Widths for these states have also been calculated.

^{12}C states observed in the inelastic scattering are displayed in Table 12.18 (1963BO36, 1965BI1B, 1967CR01, 1968BE1H, 1968DO08, 1968ST20, 1969GU05, 1969TO01, 1970AN1C, 1970LI02, 1970ST10, 1970TO13, 1971BE51, 1971NA14, 1972SP1C, 1973CH16, 1974CE01). See also (1968PR01, 1969VA10). The variation of the form factor $F(q^2)$ with momentum transfer yields unambiguous assignments of $J^\pi = 2^+, 0^+$ and 3^-, respectively for ^{12}C*(4.4, 7.7, 9.6) (1960BA38, 1964CR11, 1967HA1F). Form factors for ^{12}C*(0, 4.4, 14.1) have been measured by (1971NA14). The isospin mixing between ^{12}C*(12.71) and (15.11) [both $J^\pi = 1^+$; $T = 0$ and 1, respectively] has been measured by (1974CE01): $\beta = 0.19 \pm 0.01$ or 0.05 ± 0.01.

Inelastic scattering of the giant resonance has been studied by many groups: see (1968AJ02) for the earlier work and Table 12.18. The 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)) (1970AN1C, 1970TO13, 1971YA03, 1972AN03). See also (1969TO10). ^{12}C*(19.3) may be the expected giant magnetic quadrupole state, $J^\pi = 2^-$: see (1968AJ02) and (1968BE1H, 1968DR01). See also (1970GR27; theor.).

(1974OB01) has measured the most probable energy loss for $E_e = 50$ and 100 MeV. See also (1968DE25, 1969CA1C, 1970AN1G, 1970DE04, 1971TI03, 1973ME1K), (1968GO1J, 1972THZF, 1973BI1A, 1973TH1B), reaction 44 and (1968AN1B, 1968BO1J, 1968CI1C, 1968FR1E, 1968HE1C, 1968HO1B, 1968KE10, 1968MA1N, 1968RA1B, 1969CH01, 1969CH1A, 1969CI1A, 1969DE14, 1969DO1D, 1969FU1F, 1969HE1F, 1969KA1H, 1969KU1C, 1969UB01, 1969VI02, 1970CH1H, 1970CH1J, 1970CI1B, 1970DO1F, 1970DO1G, 1970DO1H, 1970DO1A, 1970FR1E, 1970GO41, 1970GU12, 1970HI1C, 1970JA08, 1970LI18, 1970LI1P, 1970MC1D, 1970ON1B, 1970SA1B, 1970SP1C, 1971CI03, 1971DE1T,1971DU06, 1971FR13, 1971MO1Q, 1971TA13, 1972AB19, 1972AN03, 1972AN15, 1972BE1X, 1972BO01, 1972EL11,1972FR06, 1972GU25, 1972LE45, 1972OC01, 1972PA32, 1972ST35, 1972SU01, 1972UB01, 1973AL14, 1973BA05, 1973BO1Q, 1973DO1H, 1973FO1G, 1973FO1F, 1973GA19, 1973KU1N, 1973MA07, 1973MU04, 1973RI1A, 1973ROYN, 1973SI13, 1973SI1P, 1973SU03, 1973TA1F, 1974AB05, 1974BA1Z, 1974DZ06, 1974DZ05, 1974FR12, 1974IN05, 1974SI03; theor.).

44. (a) ^{12}C(e, e′p)^{11}B $\qquad Q_m = -15.9572$

(b) ^{12}C(e, e′n)^{11}C $Q_{\rm m} = -18.722$

(c) ^{12}C(e, e′α)^{8}Be $Q_{\rm m} = -7.367$

(d) ^{12}C(e, eπ^+)^{12}B $Q_{\rm m} = -152.939$

(e) ^{12}C(e, eπ^-)^{12}N $Q_{\rm m} = -156.913$

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). A study of e′-p coincidences for $E_{\rm e} = 550 - 600$ MeV reveals peaks corresponding to ejection of 1p and 1s protons: the results are consistent with observations in (p, 2p) (1964AM1C, 1967AM03). At $E_{\rm e} = 497$ MeV, the proton spectrum is dominated by an $l = 1$ transition to ^{11}B$_{\rm g.s.}$ (1974BE12). See also (1971BU26). The data obtained by (1974BE12) do not satisfy the sum rule of (1972KO01). The quasi-elastic scattering cross section has also been measured at $E_{\rm e} = 199.5$ MeV (1969GU05), 500 MeV (1971MO06, 1974WH05) [the Fermi momentum is 221 ± 5 MeV/c (1971MO06)], 1 to 4 GeV (1971ST10) and 2.5 and 2.7 GeV (1974HE20, 1974KO21). See also (1967AM1A, 1968BO46, 1968DE25, 1969BE1L, 1969DE20, 1970DE04, 1970HI1F, 1970VY01, 1970WO1E, 1971EG03, 1971EG02, 1971SH09, 1972BE1U, 1972VL1A, 1973HE1H, 1974BA70, 1974SI1G) and (1967AM1C, 1972RA1E).

Absolute cross sections for reaction (b) have been measured for $E_{\rm e} = 20$ to 30 MeV, using both electrons and positrons (1972KU27). See also (1973MO1G, 1973VO09). For reaction (c) see (1970EN1A). For reactions (d) and (e) see (1969TI04, 1970TI03, 1971TI03, 1971ST10, 1973HE1H) and the "*Pion capture and pion reactions*" section here. See also (1968BO1J, 1968BO1D, 1968CI1B, 1968DE1F, 1968MA1M, 1968WA1D, 1969DR05, 1969MO1G, 1969ST1E, 1969VY1A, 1969WA1E, 1970CI1C, 1970EP1A, 1970PA1H, 1970SI23, 1971BO1M, 1971CI1A, 1971PA42, 1971SH18, 1972AM1C, 1972AN03, 1972RA20, 1972RA18, 1972WE14, 1973BA2M, 1973BA71, 1973CI1A, 1973HI03, 1973JO1H, 1973SH02, 1974HA14, 1974KN1C, 1974ME24; theor.).

45. (a) ^{12}C(π^-, π^-)^{12}C

(b) ^{12}C(π^+, π^+)^{12}C

(c) ^{12}C(π^-, $\pi^+\pi^-\pi^-$)^{12}C

Angular distributions of the elastic scattering and for the inelastic scattering to ^{12}C*(4.4, 9.6, 15.0) have been measured at $E_{\pi^-} = 120$ to 280 MeV (1970BI1A). [Not all groups were measured at the seven energies in the above interval. ^{12}C*(9.6) represents the group of levels with $9.6 \le E_{\rm x} \le 10.8$ and ^{12}C*(15.0) those with $15.1 \le E_{\rm x} \le 17.2$ (1970BI1A).] Observation of 4.4 MeV γ-rays at $E_\pi = 73$ MeV leads to a cross section ratio (π^-/π^+) of 1.23 ± 0.22. The cross section is 14.5 ± 3.0 mb for π^+. The population of ^{12}C*(15.11) was not observed in either reaction (1970HI10). The involvement of ^{12}C*(4.4) in reaction (c) has been studied by (1973AS1A). See also the "GENERAL" section here, (1971TH05, 1975PI1E) and (1971RO14, 1974JA1F, 1974NI08; theor.).

Table 12.19: Summary of ^{12}C(n, n) angular distribution studies [a]

E_n (MeV)	^{12}C states	Refs.
$0.50 - 2.00$	g.s.	(1970AH1B)
$1.8 - 4.0$	g.s.	(1975HO1N)
$1.98 - 4.64$	g.s.	(1973AB07)
$2.15 - 4.72$	g.s.	(1973FA06)
2.63	g.s.	(1973KN06)
$3.0 - 6.94$	g.s.	(1972GA13)
4.0, 5.1, 5.6	g.s.	(1971BO07)
$4.7 - 5.2$	g.s.	(1972DR03)
$5.8 - 7.5$	4.4	(1970DR11)
$7 - 14$ [b]	g.s.	(1974HO1E)
$7.20 - 9.00$	g.s.	(1973VE03)
7.48	g.s., 4.4	(1972MC20)
$7.73 - 9.00$	4.4	(1973VE03)
14.1	g.s., 4.4	(1972BO03)
14.1	g.s., 4.4, 7.7, 9.6	(1967JO13, 1969GR30)
15.0	g.s., 4.4	(1971SP01)
17.3, 18.3, 19.9	g.s., 4.4	(1970DE14)

[a] See Table 12.21 in (1968AJ02) for a listing of the earlier references.
[b] Forward angles only.

46. (a) ^{12}C(n, n)^{12}C
(b) ^{12}C(n, n$'$)^{4}He^{4}He^{4}He $\qquad Q_m = -7.2748$

Elastic and inelastic scattering to ^{12}C*(4.4, 7.7, 9.6, 10.3, 10.8, 11.8) have been studied at many energies up to 350 MeV: see (1968AJ02) and Table 12.19. Angular correlations of (n_1, $\gamma_{4.4}$) have been studied at $E_n = 13.9$ MeV (1973DE45) and 15.0 MeV (1971SP01), and at $14-14.7$ MeV [see (1968AJ02)]. The spin-flip probability for the transition to ^{12}C*(4.4) has been studied at $E_n = 7.48$ MeV (1971MC1K, 1972MC20) and at 15.0 and 16.9 MeV (1973TH08, 1974ME29). The shape of the angular distribution of the probability at $E_n = 7.48$ MeV is similar to that measured by (1964SC07) in the (p, p$'$) reaction at $E_p = 10$ MeV (1972MC20); while that at $E_n = 16.9$ MeV is similar to that measured by (1969KO07) at $E_p = 20$ MeV (1974ME29).

At $E_n = 14.4$ MeV reaction (b) involves ^{12}C*(9.6, 10.8, 11.8, 12.7). The decay of ^{12}C*(11.8) leads to an assignment of $J^\pi = 1^-$ (1964BR25, 1971DO1K, 1975AN01, 1975AN02). [See,

Table 12.20: ^{12}C(p, p)^{12}C angular distribution studies [a]

E_p (MeV)	Angular distributions to ^{12}C*	Refs.
5.9	g.s.	(1968AN27)
7.0	g.s., 4.4	(1969GU02)
7.999, 8.175	4.4	(1972BE15)
$9.95 - 10.90$	g.s.	(1972WI26)
$12.3 - 13.2$	g.s., 4.4	(1970KO15)
12.74, 13.60, 16.19, 19.46	g.s.	(1974JA25)
$19.9 - 28.9$	g.s.	(1970GI04)
≈ 20	7.7	(1974PL02)
20	g.s., 4.4	(1972TE01)
22.3, 26.7, 30.5, 61.9	12.7, 15.1	(1974AM05)
$22 - 45$	12.7, 15.1	(1973GE1F)
40	4.4	(1974IN02)
45, 155	see Table 12.21	(1974BU17)
46	g.s.	(1972WI24)
49.5	g.s., 4.4	(1970CL10, 1971RU04)
61.4	g.s.	(1969FU07)
100	g.s.	(1968LI1C)
100	see Table 12.21	(1969HO1J, 1970HO03)
144	g.s.	(1972JA07)
156	g.s.	(1974CO09)
185	see Table 12.21	(1969SU03)
1000	g.s., 4.4	(1972AL58)
1040	g.s., 4.4, 7.7, 9.6	(1973BE29)
2.1 GeV/c	g.s.	(1974ZH1B)

[a] See Table 12.22 in (1968AJ02) for a listing of the earlier experiments and ^{13}N in (1976AJ04).

however, Table 12.8]. See also (1966MO05, 1968BE1J).

See also ^{13}C in (1976AJ04), (1968BR05, 1968KO1A, 1969PE1C, 1969RO1F, 1970BR1K, 1970MA1J, 1972DE31, 1974DR1C), (1968CA1A, 1968CH35, 1968TI1B, 1969AL1C, 1969DU1B, 1969OL03, 1970CA13, 1970SH14, 1971CH01, 1971MI07, 1972IK01, 1972JO11, 1972MO45, 1974CH1X; theor.) and (1969TR1A; astrophys. problems).

47. ^{12}C(p, p)^{12}C

Angular distributions of elastically and inelastically scattered protons have been measured at many energies up to $E_{\mathrm{p}} = 1040$ MeV: see Table 12.22 in (1968AJ02) for the earlier work and Table 12.20 here. Angular distributions at $E_{\mathrm{p}} = 20$ MeV (1963DI16, 1970BL03) and 46 MeV (1967PE05) show that a large quadrupole deformation exists: $\beta_2 = -0.72$ (1972DE13) and 0.6 (1967SA13), respectively.

Table 12.21 shows the information on excited states of ^{12}C. The angular distribution for ^{12}C*(7.7) is best described by double quadrupole excitation via ^{12}C*(4.4). ^{12}C*(14.1) is identified as the 4^+ rotational state (1967SA13). The values $E_{\mathrm{x}} = 7656.2 \pm 2.1$ keV (1971AU16), 7655.9 ± 2.5 keV (1971ST22) obtained for the 0^+ second excited state of ^{12}C lead to a substantial change in the reaction rate for helium-burning nucleosynthesis: see (1971AU16).

The in-plane and spin-flip p$\gamma_{4.4}$ angular correlations have been measured at 20 MeV. The sub-state cross sections were determined: these show a more pronounced structure than does the total inelastic cross section to ^{12}C*(4.4). The $M = 0$ cross section is the most diffraction like. Agreement with the compound nucleus DWBA predictions is poor (1972TE01). The spin-flip probability in the scattering to ^{12}C*(4.4) has been studied at $E_{\mathrm{p}} = 8.00$ to 8.30 MeV (1972BE15), 12 to 14 MeV (1970KO15), 12, 13, 14, 15 and 20 MeV (1969KO07), 15.9 and 17.35 MeV (1971WI16) and 26.2 and 40 MeV (1969KO13). See also (1973SA1N). (1972BE15) find that the interference between the resonant and the background spin-flip is large: see ^{13}N in (1976AJ04). At $E_{\mathrm{p}} = 26.2$ and 40 MeV the observed spin-flip is almost entirely accounted for by distortions in the entrance and exit elastic channels, due to the spin-orbit term in the optical model potential (1969KO13).

For polarization measurements see (1970LI19, 1975GL1C) and ^{13}N in (1976AJ04). See also (1971GA42, 1973TH1A, 1974AL1G, 1974BR1J, 1974DA1Q, 1974GA30, 1974OB1C, 1975PI1E), (1964KA1A, 1967LE13, 1968BA1K, 1968CH35, 1968GL1A, 1968KO26, 1968LE1D, 1968LI1B, 1968NE1B, 1968TA1D, 1968TA1E, 1968TI1B, 1969BA06, 1969BY1A, 1969HA07, 1969KO1H, 1969LE03, 1969MA1G, 1969NE1A, 1969OL03, 1969PE1E, 1969TA1D, 1969TI02, 1969WA11, 1970BA1F, 1970CA13, 1970CZ1A, 1970DA17, 1970GU15, 1970HA1J, 1970KO1L, 1970KR1E, 1970KU1C, 1970SA06, 1970SH01, 1970SH14, 1971AH03, 1971CH01, 1971FR1L, 1971HA31, 1971IN05, 1971JA16, 1971LE01, 1971MI07, 1971MO18, 1971RA36, 1971SH18, 1971SI11, 1971SI37, 1972AN12, 1972AU1A, 1972BA2E, 1972JO11, 1972IK01, 1972SI19, 1972SO03, 1972ST35, 1973AL14, 1973AU05, 1973DO10, 1973FR08, 1973GE1E, 1973KA04, 1973MA2B, 1973MI19, 1973SI37, 1973VA18, 1974AL1H, 1974BE22, 1974BR06, 1974IN04, 1974IN06, 1974IN07, 1974JA1F, 1974KU20, 1974SC1K, 1974ST02, 1973TE1B; theor.) and (1969TR1A; astrophys. questions).

Table 12.21: ^{12}C levels from ^{12}C(p, p′)^{12}C* [a]

^{12}C* [b] (MeV)	^{12}C* [g] (MeV)	Multipolarity [g,i]	Γ [b,g] (MeV)
4.43 ± 0.03 [c]	4.4390 ± 0.0011 [m]	E2	[j]
7.67 ± 0.05 [d]	7.6552 ± 0.0011 [n]		
9.63 ± 0.04		E3	
10.78 ± 0.10		E3	
(11.8 ± 0.2) [e]			
12.70 ± 0.08		(M1)	[k]
14.05 ± 0.10		E4	
15.11 ± 0.05 [f]		M1	[l]
16.05 ± 0.10			
18.20 ± 0.10	18.35 ± 0.05		$0.5 - 0.8$
	18.8		
19.35 ± 0.10	[h]	M2	$0.5 - 0.8$
20.40 ± 0.15	[h]		$0.5 - 0.8$
21.4 ± 0.3	21.65 ± 0.08	E3 [o]	1.2 ± 0.2
22.1 ± 0.3	21.95 ± 0.15	E1	0.8 ± 0.1
	(22.4)	not E1	
	22.6 ± 0.1	E1	0.45 ± 0.2
23.4 ± 0.4	23.50 ± 0.05	E1	0.23 ± 0.08
	23.92 ± 0.08	(E1)	0.4 ± 0.1
	25.3 ± 0.15	(E1)	0.51 ± 0.1
	(25.8 ± 0.3)	(E1)	(0.75 ± 0.15)
	27.0 ± 0.2	(E1)	(1.4 ± 0.2)
	29.4 ± 0.3		≈ 2

[a] See also Table 12.23 in (1968AJ02).
[b] $E_p = 185$ MeV (1965HA17, 1969SU03). See also (1969HO1J, 1970HO03: 100 MeV).
[c] $E_x = 4442.2 \pm 1.5$ keV (1971ST22), 4439.2 ± 0.5 keV (1974NO07).
[d] $E_x = 7655.9 \pm 2.5$ keV (1971ST22), 7656.2 ± 2.1 keV (1971AU16).
[e] (1970HO03).
[f] The branching ratio for the decay to ^{12}C*(4.4) is $2.32 \pm 0.25\%$ (1973HA1Y): see also Table 12.9.
[g] $E_p = 45$ and 155 MeV (1974BU17) and M. Buenerd, private communication.
[h] Observed but unresolved.
[i] (1964JA03, 1969SU03).
[j] $\tau_m = 55 \pm 7$ fsec (1968RI16): $\Gamma_\gamma = 12.0 \pm 1.5$ eV.
[k] $\Gamma_\gamma/\Gamma = 0.027 \pm 0.007$ (1962WA31).
[l] $\Gamma_\gamma/\Gamma = 1.15 \pm 0.3$ (1962WA31).
[m] (1974JO14).
[n] (1974JO15). The best value of E_x is 7655.2 ± 0.8 keV, based on this and other measurements. This sets the Q-value for the decay into 3α as 380.3 ± 1.1 keV. When this value is combined with that of (1973BA73) [379.6 ± 2.0 keV] the value 380.1 ± 1.0 keV is suggested (1974JO15).
[o] $\beta_3^2 = 0.125$ (M. Buenerd, private communication).

48. (a) ^{12}C(p, 2p)^{11}B $\quad Q_m = -15.9572$
(b) ^{12}C(p, pn)^{11}C $\quad Q_m = -18.722$
(c) ^{12}C(p, pd)^{10}B $\quad Q_m = -25.1885$
(d) ^{12}C(p, pα)^{8}Be $\quad Q_m = -7.367$

At $E_p = 56.5$ MeV, ^{12}C*(20.3 ± 0.5) is excited and then decays to $^{11}B_{g.s.}$ (1969EP01). At $E_p = 385$ MeV and estimate of the momentum distribution of the protons bound in ^{12}C has been obtained. The results are consistent with a model in which the nuclear core is essentially a spectator. Distortion effects are mainly of an absorptive nature (1969JA05). At $E_p = 1.0$ GeV, the process is essentially quasifree (1970SI01, 1972CO11). See also (1971PA1H). Small angle multiple scattering of 600 MeV protons has been measured by (1972HU12). The angular correlation to ^{11}B(0) has been measured at $E_p = 49.5$ MeV by (1971HA61).

See also (1968AJ02) for earlier references, ^{11}B, (1968PE1A, 1971LA16, 1971LO25), (1969JA1F, 1969VO1E, 1972RA1E) and (1968DE1G, 1968JA1E, 1969GU1G, 1969JA1D, 1969KO1J, 1969MC13, 1970FL1B, 1970KR1E, 1971JA11, 1971JA16, 1971MC26, 1971SH18, 1971WI15, 1971YO1E, 1972AB1G, 1972CH1L, 1972JA1C, 1972PE04, 1972PI11, 1972ST29, 1972WI16, 1973ER19, 1973FR09, 1973GU1D, 1973JA01, 1973JO1H, 1973SH02, 1974BH1B, 1974PI01; theor.).

Table 12.22: Summary of recent ^{12}C(d, d), (^{3}He, ^{3}He) and (α, α) angular distributions [a]

(a) ^{12}*C(d, d) measurements*

E_d (MeV)	^{12}C states	Refs.
1.39 – 2.16	g.s.	(1970AL26)
4.66 – 5.27	g.s.	(1968CO04)
5.00 – 8.40	g.s.	(1969CO02)
9.2 – 13.9	g.s.	(1966BA60)
10.03, 12.01	g.s.	(1974JA25)
10.6 – 13.9	g.s.	(1970GU01)
13.6	g.s.	(1970VE06, 1972MA47)
13.7	4.4	(1970GU01)
24.1, 26.2, 27.5, 28.8	12.7, 15.1	(1975LI1K)
28	g.s.	(1968GA13, 1968LE1G, 1970BU1G)
41, 46, 51	g.s.	(1971FE1C)
52	g.s., 4.4, 7.7, 9.6	(1968HI09, 1968HI14)
80	g.s., 4.4, 9.6	(1971DU09)

(b) ^{12}*C(^{3}He, ^{3}He) measurements*

E(^{3}He) (MeV)	^{12}C states	Refs.
3.6 – 3.8	g.s.	(1967SC27)
5.29 – 5.50	g.s.	(1968LA19)
6, 7, 8	g.s.	(1968WE15, 1968WE1C)
9.5, 10.5, 11.5	g.s., 4.4	(1970BO34)
11	g.s.	(1970SC23)
15	g.s.	(1969ZU02)
16, 17, 18	g.s., 4.4	(1968FO06)
18.6, 20.0, 22.2, 23.9	g.s.	(1968WA1E, 1970BA1P)
24.0, 29.2, 34.7, 39.6	g.s., 4.4, 7.7, 9.6	(1973FU03)
25.3	g.s.	(1968MA46)
34.7, 39.6	14.1	(1973FU03)
36	g.s., 4.4, 12.7, 14.1, 15.1, 16.1	(1969AR08, 1969AR10, 1970AR05)
36, 42	g.s.	(1968HU1A, 1969HU1B)
42	g.s., 4.4, 7.7, 12.7, 14.1, 16.1	(1973SI11)
49.8	see Table 12.23	(1968BA1E, 1969BA06)
65	g.s., 4.4, 7.7, 9.6, 12.7, 14.1, 15.1, 16.1	(1973CE1C)
217	g.s.	(1973WI07, 1974WI16)

(c) ^{12}*C(α, α) measurements*

E_α (MeV)	^{12}C states	Refs.
12.5 – 16.9	7.7	(1970MO22)
15.3 – 17.0	9.6	(1970MO22)
18.0 – 26.6	g.s.	(1972KU19, 1973KU18)

Table 12.22: Summary of recent ^{12}C(d, d), (^{3}He, ^{3}He) and (α, α) angular distributions [a] (continued)

19.4 – 26.6	g.s., 4.4	(1970MO06)
20.1 – 24.0	g.s., 4.4, 9.6	(1968AG03, 1969AG06, 1970AG08, 1970FE07, 1970FE09, 1971FE1F)
22, 24, 28, 29	g.s.	(1972OE01, 1973OE01)
28.4	g.s., 4.4	(1965KO1A)
32.5	g.s., 4.4	(1972BU09)
33.4	g.s., 4.4	(1967AR17)
36	12.7	(1975CE1E)
41	g.s., 4.4	(1971BA64)
44	g.s.	(1968FA1A)
56	g.s.	(1968GA1C, 1969GA11)
56	g.s., 4.4	(1968LE1G)
90	see Table 12.23	(1972FA07)
104	g.s.	(1968HA1D, 1969HA14)
104	g.s., 4.4, 7.7	(1970SP01, 1971SP08)
139	g.s., 4.4, 7.7, 9.6	(1973SM03)
155	4.4, 9.6	(1970TA12)
166	g.s., 4.4, 7.7, 9.6	(1969BR19, 1970TA12, 1972BR30, 1973BI12)

[a] See (1968AJ02) for the older measurements, in particular Table 12.24 for (α, α).

For reaction (b) see (1968PA05: $E_{\rm p} = 450$ MeV). See also (1971TH05: $\bar{\rm p}$, $\bar{\rm p}$n), (1970TH1F) and (1972AB1G; theor.). For reaction (c) see (1970BA1T, 1971AZ01, 1972AZ03, 1972BO17, 1973KO1M) and (1968RO1F, 1974ZH01; theor.).

At $E_{\rm p} = 56.5$ MeV, reaction (d) proceeds primarily by sequential α-decay: initially ^{12}C*(19.7± 0.5, 21.1 ± 0.3, 22.2 ± 0.5 and 26.3 ± 0.5 MeV) are formed. The states, which therefore must have natural parity and a significant $T = 0$ admixture, subsequently decay to ^{8}Be$_{\rm g.s.}$ [^{12}C*(22.2, 26.0)] or ^{8}Be*(2.9) [^{12}C*(19.7, 21.1, 26.3)] (1969EP01). At $E_{\rm p} = 160$ MeV, knock-out, sequential decay and spallation processes are observed (1970GO12). See also (1969HO1K, 1971GA1J, 1972MA62, 1972YA1B, 1973HO1R, 1973TH1A) and ^{8}Be and ^{9}B in (1974AJ01). For spallation studies see (1968KO1E, 1969DA1D, 1969ED01, 1969KO1G) and ^{13}N in (1976AJ04). See also (1968ED1A). For pion production see (1970DO04), (1971IN1A, 1971RE12, 1972KE1F, 1973DI1G, 1974MI11; theor.), the "*Pion capture and pion reactions*" section here and ^{13}C in (1976AJ04).

49. (a) ^{12}C(d, d)^{12}C

(b) ^{12}C(d, pn)^{12}C $\qquad Q_{\rm m} = -2.2246$

The angular distribution of elastically and inelastically scattered deuterons has been studied at many energies to $E_{\rm d} = 650$ MeV: see (1968AJ02) for the older references and Table 12.22 here.

DWBA analysis of the distributions at $E_\mathrm{d} = 80$ MeV leads to $\beta_l = 0.47 \pm 0.05$ and 0.35 ± 0.06 for ^{12}C*(4.4, 9.6), respectively (1971DU09). E_x of ^{12}C*(4.4) is 4440.5 ± 1.1 keV: the average of this value and of the one determined in (p, p′) (Table 12.21) gives 4439.5 ± 1.0 keV (1974JO14). The isospin mixing of ^{12}C*(12.71, 15.11) [both $J^\pi = 1^+$; $T = 0$ and 1, respectively] has been measured for $E_\mathrm{d} = 27.2$ and 28.0 MeV. The ratio of the cross sections for the population of the $T = 1$ and 0 states is $(7.0 \pm 1.2) \times 10^{-3}$. [In a remeasurement of this quantity (1975LI1K) find $\approx (1.1 \times 10^{-2})$. Angular distributions for the two states were obtained at $E_\mathrm{d} = 24.1$, 26.2, 27.5 and 28.8 MeV (1975LI1K).] This leads to $\beta^2 = 0.011 \pm 0.003$ (1972BR27: see also reactions 66, 67, 76). For a study of the distribution of ionic charge when ^{12}C recoils in elastic scattering at $E_\mathrm{p} = 10$ MeV, see (1971WO10).

Reaction (b) has been studied, in a kinematically complete experiment, at $E_\mathrm{d} = 5.00$ to 5.50, 9.20 and 9.85 MeV by (1970SA1K, 1973SA03). An increase in yield is observed for all spectra in the region of low relative proton-neutron energy where both rescattering and sequential decay leading to the $^1\mathrm{S}_0$ final state interaction are possible. Due to the probable superposition and interference of different reaction mechanisms, it is apparently not possible to evaluate how much spin singlet and spin triplet interaction is involved (1973SA03). See, however, (1973SH04). Studies of reaction (b) are also reported at $E_\mathrm{d} = 5.1$ to 6.25 MeV (1973SH04), 5.4 and 6.0 MeV (1968BO02) and 5.5 to 6.5 MeV (1970VA1K, 1972VA10). See also ^{13}C and ^{13}N in (1976AJ04) and (1972GE1G).

See also ^{14}N in (1976AJ04), (1968VA12, 1968VE11, 1968VE1C, 1969KO1B, 1969PH1B, 1971PU01, 1972HE1E) and (1968DU01, 1968LY1A, 1968ME1E, 1968NO1C, 1969OL03, 1969TA1D, 1969VE09, 1970EL16, 1970OH1C, 1971GR54, 1971KO42, 1971KO43, 1971SI24, 1972BE54, 1972DM01, 1972ST1J, 1973HE1J, 1974AS1D, 1974IA02, 1974IN07; theor.).

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

Angular distributions of elastically scattered tritons have been determined at $E_\mathrm{t} = 1.0$ to 1.75 MeV (1962GU01, 1969HE08), 1.11 to 3.40 MeV (1969ET01 and Private Communication), 1.75 and 2.10 MeV (1969SI12), 6.4, 6.8 and 7.2 MeV (1964PU01), 12 MeV (1965GL04, 1966GL1B), 16 and 20 MeV (1972KE02) and 20.04 MeV (1974JA25). See also (1968HO1C) and (1971KA04; theor.).

51. ^{12}C(^{3}He, ^{3}He)^{12}C

Angular distributions of ^{3}He ions have been measured at many energies in the range $E(^3\mathrm{He}) =$ 2 to 217 MeV: see reaction 43 in (1968AJ02) for the older measurements and Table 12.22, here, for the newer ones. DWBA analyses seem to be inadequate: complete coupled channels analyses appear to be necessary to explain the data; see, e.g., (1972AS03, 1973SI11).

Angular distributions of the ^{3}He groups to ^{12}C*(15.11, 16.11, 16.58, 19.57) have been compared with those for the tritons to ^{12}N*(0, 0.96, 1.19, 4.25) in the analogue reaction ^{12}C(^{3}He, t)^{12}N: the correspondence is excellent and suggests strongly that these are $T = 1$ isobaric analogue states (1968BA1E, 1969BA06: $E(^3\text{He}) = 49.8$ MeV). See also Tables 12.13 and 12.23, ^{12}N and (1970AR05, 1974WI16). The (^{3}He$'$, γ_1) reaction plane angular correlation has been measured at $E(^3\text{He}) = 17$ MeV as a function of gamma-ray angle for 43 ^{3}He scattering angles. The spin-flip probability was also determined, and the quadrupole deformation was found to be $\beta_2 = -0.60$ (1968AS03, 1972AS03). See also (1971PA1K, 1974YA10). For polarization measurements see ^{15}O in (1976AJ04).

See also (1967AR17, 1967BA1D, 1970JA1E, 1970KA1D) and (1968LE1G, 1968PA1F, 1969RA1B, 1970CA1G, 1973BR1L; theor.).

52. (a) ^{12}C(α, α)^{12}C
(b) ^{12}C(α, 2α)^{8}Be $\qquad Q_m = -7.367$

Angular distributions have been measured at many energies to $E_\alpha = 166$ MeV: see Table 12.24 in (1968AJ02) and Table 12.22 here. Alpha-particle groups have been observed to many ^{12}C states: see Tables 12.22 and 12.23 (1972FA07). J^π assignments have also been suggested for ^{12}C states with $9.6 \le E_x \le 39.3$ MeV on the basis of their decay into 3 α-particles: see (1973JA02; $E_\alpha = 90$ MeV). See also (1969BA06).

Angular correlation measurements ($\alpha_1\gamma_{4.4}$) have been carried out at $E_\alpha = 10.2$ to 10.5 MeV (1972KE18), 18.0 to 24.0 MeV (1968KL07), 19 MeV (1972AS03), 19.3 to 25.3 MeV (1972EL09), 22.75 MeV (1970HA15), 32.5 MeV (1972BU09) and 41 MeV (1971BA64): the relative population of magnetic substates has been studied by (1970HA15, 1972BU09). See also (1968AJ02). The quadrupole deformation, β_2, is -0.29 ± 0.02 (1971SP08), 0.46 (1973SM03); $\beta_3 = 0.24$ (1973SM03). See also (1971BE60, 1972EE1A).

Measurements of the radiative widths yield $\Gamma_{\text{rad}}/\Gamma = (4.2 \pm 0.2) \times 10^{-4}$ [$\Gamma_{\text{rad}} \equiv \Gamma_\gamma + \Gamma_{e^\pm}$ is then 3.7 ± 1.2 meV] for ^{12}C*(7.7) (1974CH03) and $\Gamma_{\text{rad}}/\Gamma < 4.1 \times 10^{-7}$ [$\Gamma_{\text{rad}} < 14$ meV] for ^{12}C*(9.6) (1974CH32): see also Table 12.9. The value for Γ_{rad} for ^{12}C*(7.7) implies a 45% faster rate for the ($\alpha\alpha\alpha$) astrophysical process (1974CH03). See also (1973HA1Y, 1974MA2C). For total cross sections for formation of various ^{12}C states, see ^{16}O in (1971AJ02, 1977AJ02) and (1973SP1D).

For polarization measurements, see ^{16}O in (1977AJ02). See also (1967HA1G, 1968CA11, 1968ED1B, 1968GA1D, 1968RA1C, 1968SH1D, 1968SH1E, 1968TO1D, 1969BU1D, 1969PI02, 1971MU1H, 1971TA30, 1971TE10, 1972DM01, 1973AL14, 1973BR1K, 1973BU1G, 1973DM01, 1973KU08, 1973SI1M, 1974PI11, 1974GO1U, 1974HO19, 1974WA02; theor.) and (1969TR1A; astrophys. questions).

Reaction (b) at $E_\alpha = 25$ MeV appears to involve ^{12}C*(7.66, 9.64) (1969DO02, 1969DO03). See also (1974RU06). See (1968YA02, 1969PI1B, 1970KE1B, 1970EI05, 1970PI1D, 1973RU09, 1974DO1G) for other studies of the (α, 2α) reaction with E_α up to 700 MeV. See also ^{8}Be in (1974AJ01), (1971GA1J) and (1968BA1H, 1970BU1C, 1970MI12, 1972AV04, 1972MI05; theor.).

Table 12.23: Energy levels of ^{12}C from ^{12}C(^{3}He, ^{3}He)^{12}C, ^{12}C(α, α)^{12}C and ^{14}N(d, α)^{12}C

E_x [a,b] (MeV ± keV)	L [b]	E_x [a,c] (MeV ± keV)	Γ [c] (MeV)	$J^\pi; T$ [d]
0	0	0		$0^+; 0$
4.4422 ± 1.5 [e]	2	4.44		$2^+; 0$
7.67		7.67		$0^+; 0$
9.64	3	9.642 ± 14 [j]	0.030 ± 0.008 [j]	$3^-; 0$
10.84	[f]	10.84 [f]		$1^-; 0$
11.83	[f]	11.83 [f]		$2^-; 0$
12.71	0	12.71 ± 130 [f,k]		$1^+; 0$
		13.29 [l]	0.355 ± 0.050 [l]	
14.08		14.08 ± 30 [h]		$4^+; 0$
15.11	0			$1^+; 1$
		15.62 ± 120 [h]	1.2 ± 0.3	
16.11	2			$2^+; 1$
16.58 [g]				$2^-; 1$
18.40 ± 60 [g]	[f]	18.39 ± 80 [f]		0^-
18.80 [g]	[f]			2^+
		19.20 ± 130 [f,i]	0.39 ± 0.10	
19.58 ± 60 [g]				
		20.3 ± 300 [f,i]	0.45 ± 0.15	
		21.81 ± 80 [f,i]	0.43 ± 0.08	
		22.70 ± 80 [f,i]		
		24.24 ± 80 [f,i]	0.18 ± 0.08	

[a] When no errors are shown, values are from Table 12.8.

[b] $E(^{3}\text{He}) = 49.8$ MeV (1968BA1E, 1969BA06).

[c] $E_\alpha = 90$ MeV and $E_d = 52$ MeV (1972FA07).

[d] Best values.

[e] (1971ST22).

[f] Angular distribution not obtained.

[g] ($T = 1$) (1969BA06).

[h] (1972FA07) suggests $J^\pi = 3^-$ for ^{12}C*(14.08) and 4^+ for ^{12}C*(15.6).

[i] Decays predominantly by α-emission.

[j] (1956DO41): ^{14}N(d, α)^{12}C.

[k] 12.7 ± 0.07 MeV (1965PE17): ^{14}N(d, α)^{12}C.

[l] (1965SC12): ^{14}N(d, α)^{12}C.

53. (a) ^{12}C(^{6}Li, ^{6}Li)^{12}C

(b) ^{12}C(^{7}Li, ^{7}Li)^{12}C

The elastic scattering in reaction (a) has been studied at $E(^{6}\mathrm{Li}) = 4.5$ to 13 MeV (1972PO07), 20 MeV (1968BE1K, 1972WA31), 24.5 MeV (1968DA20), 28 MeV (1972BA52), 30 MeV (1971CH1P, 1971DA33), 34 and 36 MeV (1973SC26; also ^{12}C*(4.4)) and 36.4 and 40 MeV (1974BI04). See also (1964OL1A). (1974BI04) have also measured 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. Two step processes are important in the excitation of ^{12}C*(7.7, 14.1) (1974BI1H). See also (1971DA1J) and (1968NO1C, 1971OS02, 1974AS1D; theor.).

The elastic scattering in reaction (b) has been studied at $E(^{7}\mathrm{Li}) = 4.5$, 5.8, 9.0, 11.0 and 13.0 MeV (1972PO07), 15 and 21.1 MeV (1972WE08) and at 36 MeV (1973SC26). At 36 MeV the angular distributions corresponding to $^{12}\mathrm{C}_{\mathrm{g.s.}} + {}^{7}\mathrm{Li}^{*}_{0.48}$, $^{12}\mathrm{C}^{*}_{4.4} + {}^{7}\mathrm{Li}_{\mathrm{g.s.}}$ and $^{12}\mathrm{C}^{*}_{4.4} + {}^{7}\mathrm{Li}^{*}_{0.48}$ have also been studied (1973SC26).

54. ^{12}C(^{9}Be, ^{9}Be)^{12}C

Elastic scattering angular distributions have been obtained at $E(^{12}\mathrm{C}) = 12$, 15, 18 and 21 MeV (1970BA49).

55. (a) ^{12}C(^{10}B, ^{10}B)^{12}C

(b) ^{12}C(^{11}B, ^{11}B)^{12}C

Angular distributions have been measured for reaction (a) at $E(^{10}\mathrm{B}) = 18$ MeV (1968VO1A, 1969VO10: to g.s.) and 100 MeV (1973BI1J, 1974BI1E: to ^{12}C*(0, 4.4, 7.7, 9.6, 10.8, 11.8, 12.7, 13.4, 14.1, 14.8). Two-step processes appear to be involved in the excitation of ^{12}C*(7.7, 14.1) (1974BI1E). See also (1974AS1D; theor.).

Angular distributions for reaction (b) have been studied at $E(^{12}\mathrm{C}) = 15$, 17, 20 and 24 MeV (1974BO15: to g.s.) and 87 MeV (1971LI11: to g.s.), and at $E(^{11}\mathrm{B}) = 28$ MeV (1968VO1A, 1969VO07, 1969VO10: to g.s., 4.4; and to several ^{11}B states). A consistent description of the elastic data at $E(^{12}\mathrm{C}) = 15$ to 24 MeV is obtained by including the elastic transfer of a $1\mathrm{p}_{1/2}$ hole (1974BO15). See also (1972SC1Q) and (1970AN1D, 1973DE35; theor.).

For yield measurements see ^{22}Na and ^{23}Na in (1973ENVA) and (1974DA1P).

56. ^{12}C(^{12}C, ^{12}C)^{12}C

Angular distributions have been measured at $E(^{12}C) = 18.8$ to 37.6 MeV (1973EM03: g.s. + g.s., g.s. + 4.4, 4.4 + 4.4), 40 to 60 MeV (1973WI09: g.s. + g.s., g.s. + 4.4, 4.4 + 4.4), 70 MeV (1971KO11: g.s.) and at 87 MeV (1971LI11: g.s.). At $E(^{12}C) = 114$ and 174 MeV differential cross sections have been measured for the population of $^{12}C^*$(0, 4.4, 7.7, 9.6, 14.1, 19.6). The population of $^{12}C^*_{4.4} + {}^{12}C^*_{4.4}$ is also reported (1973AN22).

The relative population of elastic and inelastic channels is very energy dependent: see ^{24}Mg in (1973ENVA) and (1968WI1C, 1973EM03, 1973GO01, 1973RE13, 1973RE12, 1973WI09, 1974RA1J, 1974RA1K, 1974SH16, 1974SP06, 1974VO09, 1975OB1B).

See also (1969BR1D, 1969BR1G, 1969HE06, 1970BR1G, 1973BR1C, 1973PE1D, 1973ST1A, 1974ST1L), (1968IM1A, 1969IM1A, 1969MI1B, 1969VO1E, 1970AN1D, 1970MI1D, 1970MO35, 1970PR12, 1971MC1J, 1971RI1F, 1971RI1G, 1972AR11, 1972FI11, 1972GO1G, 1972MA74, 1972MI1H, 1972RE1K, 1972RI19, 1973BO06, 1973CO1X, 1973FI07, 1973JA22, 1973MO1J, 1973SC1K, 1974FI1G, 1974GA1L, 1974KO1N, 1974PA08, 1974WA02; theor.) and (1968AR1C, 1970NA1F, 1971BA1A, 1972MI1H, 1973AR1E, 1973CL1E, 1973GR1G, 1974AR2B, 1974CO1L, 1975SW1A; astrophys. questions).

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

Elastic angular distributions in reaction (a) have been studied at $E(^{12}C) = 15$ and 19 MeV (1971BO52, 1971BO1U, 1972BO68), at 20 to 36 MeV (1972CH1H, 1973CH1L; and also to $^{12}C^*$(4.4) and various states in ^{13}C) and at 87 MeV (1971LI11). See also (1970GO1B, 1971WI1J, 1973BR1C, 1973GO01, 1973SC1B) and ^{13}C in (1976AJ04). Elastic angular distributions in reaction (b) are reported at $E(^{12}C) = 12$ to 20 MeV (1972BO68).

For yield measurements, see (1972BO68, 1973FE03, 1974CR03) and ^{24}Mg and ^{25}Mg in (1973ENVA). See also (1970VO1D, 1973BA2K, 1973DE35, 1973MC1J, 1973SA1K, 1973VO04, 1974GA1L, 1974IM1B; theor.).

58. $^{12}C(^{14}N, {}^{14}N)^{12}C$

Angular distributions have been measured at $E(^{14}N) = 21$ MeV (1971BO1U, 1971VO01: to g.s.), 22.5 MeV (1969HE06: to g.s.), 65, 84 and 88 MeV (1971KO11: to g.s.), 78 MeV (1970VO02: to g.s., 4.4) and 155 MeV (1974BI1E: to g.s., 4.4, 7.7, 9.6, 10.8, 11.8, 12.7, 13.4, 14.1; see also reaction 54). See (1968AJ02) for earlier measurements. See also ^{14}N in (1976AJ04), (1974AN36) and (1974NA1G). For yield measurements see ^{26}Al in (1973ENVA) and (1974JO1J, 1974ST1N). See also (1969BR1D) and (1972MA74, 1974GA1L; theor.).

59. (a) $^{12}C(^{16}O, {}^{16}O)^{12}C$
(b) $^{12}C(^{16}O, \alpha)^{12}C^{12}C$ $\qquad Q_m = -7.1616$

Elastic angular distributions have been measured at $E(^{16}\mathrm{O}) = 20$, 24, 35 and 42 MeV (1968VO1A, 1969VO10), 26, 30 and 32.5 MeV (1969KR03), 27 to 53 MeV (1972MA29, 1972MA1P), 36 MeV (1971OR02) and 65 and 80 MeV (1973GU12). At $E(^{16}\mathrm{O}) = 65$ and 80 MeV, angular distributions involving ^{12}C*(0, 4.4) and various states of ^{16}O have been studied by (1973GU12): see ^{16}O in (1977AJ02).

A kinematically complete study of reaction (b) has been carried out at $E(^{16}\mathrm{O}) = 58.3$ MeV. The main process appears to involve (^{12}C $+\alpha$) corresponding to an excited state of ^{16}O with $E_\mathrm{x} \approx 10$ MeV. Formation and decay of compound states in ^{24}Mg are also involved (1974WI05). See also (1973ENVA).

For studies of the yields of these reactions see (1968MA1J, 1969VO10, 1972MA29, 1972ST09, 1973CH1N, 1973MA1N, 1974MA1L, 1974WI05). See also ^{28}Si in (1973ENVA).

See also (1970JA1B), (1969BR1D, 1969BR1G, 1969HE06, 1970BL1E, 1970BR1G, 1971GA1P, 1972GA1E, 1973PA1J, 1973PE1D, 1973ST1A), (1969KA1G, 1969RO1G, 1969VO1E, 1970AN1D, 1970CL1E, 1971DA30, 1972BA73, 1972CH1E, 1972GO1G, 1972MA1U, 1972RI03, 1973DE40, 1973FE1G, 1973LO02, 1973SA1K, 1974GA1L, 1974WA02, 1975KI01; theor.) and (1970NA1F, 1971WO1E, 1973AR1E, 1973CL1E, 1974CO1L, 1975SW1A; astrophys. questions).

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

The elastic scattering angular distributions in both (a) and (b) have been measured at $E = 35$ MeV (1967GO1A). See also ^{18}O in (1978AJ03) and (1971BE60, 1974CH1Q).

61. ^{12}C(^{19}F, ^{19}F)^{12}C

Elastic scattering angular distributions have been measured at $E(^{19}\mathrm{F}) = 40$, 60 and 68.8 MeV (1968VO1A, 1969VO10, 1972SC03). See also (1970AN1D, 1970BL1E; theor.).

62. ^{12}C(^{20}Ne, ^{20}Ne)^{12}C

The elastic scattering angular distribution has been measured at $E(^{12}\mathrm{C}) = 37$ MeV (1974VA18). See also ^{32}S in (1973ENVA).

63. ^{12}N(β^+)^{12}C $\qquad Q_\mathrm{m} = 17.344$

Table 12.24: Branching in ^{12}N(β^+)^{12}C

Decay to ^{12}C*	Branch (%)	log ft [c]	Refs.
g.s. [a]	94.25	4.119 ± 0.003	
4.44	2.4 ± 0.2		(1963PE10)
	2.2 ± 0.25		(1963WI05)
	2.10 ± 0.16	5.11 ± 0.03	[d]
7.66	2.2 ± 0.6		(1963GL04)
	3.0 ± 0.5		(1962MA22)
	2.7 ± 0.4	4.34 ± 0.06	mean
10.3	0.85 ± 0.6		(1963GL04)
	0.44 ± 0.15		(1963WI05)
	0.46 ± 0.15	4.36 ± 0.17	mean
12.71 [b]	0.29 ± 0.13	3.55 ± 0.16	(1967AL03)
15.11	$(4.4 \pm 1.5) \times 10^{-3}$	3.30 ± 0.13	(1967AL03)

[a] E_β(max) $= 16.384 \pm 0.015$ MeV (1963GL04, 1963PE10).
[b] See also (1963GL04, 1963WI05, 1966SC23).
[c] Based on $\tau_{1/2} = 10.97 \pm 0.04$ msec and on $Q_{\rm m}$: see (1974MC11) and (1966BA1A).
[d] Based on adopted branching ratio 1.29 ± 0.05% for ^{11}B(β^-) $\rightarrow$ ^{12}C*(4.4) (1972AL31, 1974MC11) and "best" value of the ^{12}N/^{12}B ratio for this decay, $R = 1.63 \pm 0.11$ (1974MC11).

The decay is mainly to the ground state via an allowed transition. Branching ratios to other states of ^{12}C are displayed in Table 12.24. The half-life is 10.97 ± 0.04 msec: see Table 12.28 in (1968AJ02). Since transitions to ^{12}C*(g.s., 4.4) are allowed $J^\pi(^{12}\text{N}) = 1^+$.

Recent measurements of the ratios of the branching ratios, ^{12}N/^{12}B, for the decays to ^{12}C*(4.4) is 1.52 ± 0.06 (1972AL31), 1.74 ± 0.08 (1974MC11). Using $R = 1.63 \pm 0.11$, and other data, (1974MC11) find that the asymmetry in the decay to the excited state is $\delta_{4.44} = -0.013 \pm 0.066$ and that $\delta_{\rm g.s.} = 0.1155 \pm 0.0085$. See also (1973KU1D; theor.).

^{12}C*(12.7), populated in an allowed transition, decays primarily to ^{8}Be*(2.9) [$J^\pi = 2^+$]; the absence of decay to ^{8}Be$_{\rm g.s.}$ is in agreement with the assignment $J^\pi = 1^+$ (1966SC23). The ft values for the β-transitions to ^{12}C*(12.7, 15.1) agree well with shell-model calculations of (1965CO25). The agreement strongly suggests a close relation between ^{12}C*(12.7) [$J^\pi = 1^+$; $T = 0$] and ^{12}C*(15.1) [$J^\pi = 1^+$; $T = 1$]. See also (1971MI06, 1973CH16, 1973MIYZ).

See also (1968DA1J) and (1969BL1D, 1969CH1A, 1969CH1F, 1970JA1K, 1970ST04, 1971BL06, 1971KI04, 1971KI11, 1971LA21, 1971LI1F, 1971LI1H, 1971WI18, 1971WI1C, 1972EM02, 1972OC01, 1972WI28, 1972WI1C, 1973EM1B, 1973HA49, 1973TO14, 1973YO04, 1974HO1D, 1974WI1L, 1974WI1Q, 1975GR03; theor.).

64. ^{13}C(γ, n)^{12}C $\qquad Q_{\rm m} = -4.9464$

At $E_{\rm bs} = 28$ MeV, 4.4 and 15.1 MeV γ-rays have been observed corresponding to the population of ^{12}C*(4.4, 15.1), while at $E_{\rm bs} = 21$ MeV only ^{12}C*(4.4) is excited (1971MU11). See also (1971WI1N), (1973KI1J; theor.) and ^{13}C in (1976AJ04).

65. (a) ^{13}C(p, d)^{12}C $\qquad Q_{\rm m} = -2.7218$
(b) ^{13}C(p, pn)^{12}C $\qquad Q_{\rm m} = -4.9464$

Angular distributions of the d_0 and d_1 groups to ^{12}C*(0, 4.4) have been measured at $E_{\rm p} = 8$ and 12 MeV (1966GL01), 17 MeV (1961BE12), 50 MeV (1970SC02) and 54.9 MeV (1968TA08). In addition angular distributions have also been measured for the groups to ^{12}C*(12.7, 15.1, 16.1) at the two higher energies (1968TA08, 1970SC02). ^{12}C*(14.1) is not excited, consistent with $J^\pi = 4^+$ (1970SC02, 1974PA01). At $E_{\rm p} = 62$ MeV, (1974PA01) report the excitation of states with $E_{\rm x} = 15112 \pm 5$, 16110 ± 5 [< 20], 17760 ± 20 [80 ± 20], 18800 ± 40 [80 ± 30], 21500 ± 100 [< 200] and 22550 ± 50 [< 200] keV [the numbers shown in the brackets are $\Gamma_{\rm c.m.}$, in keV]: $l_{\rm n} = 1$ for all states except ^{12}C*(21.5) and (22.55) for which $l_{\rm p} = (1)$ and $\neq 1$, respectively. Spectroscopic factors are derived by (1968TA08, 1970SC02, 1974PA01). At $E_{\rm p} = 17$ MeV (1969CO06) give the ratio of σ(p, d)/σ(p, $\bar{\rm d}$) to the ground state of ^{12}C as 17. (1971OT02) suggest, however, that a part of the apparent (p, $\bar{\rm d}$) cross section may be due to ^{12}C + n final state interaction through ^{13}C*(10.75). In a kinematically complete experiment at $E_{\rm p} = 7.9$ to 12.5 MeV, it is found that sequential decay via states in ^{13}C and ^{13}N is strongly involved in reaction (b). Near $E_{\rm p} = 12.5$ MeV there is some indication of sequential decay via singlet deuteron formation (1971OT02). See also (1967SP09, 1970VA1K) and ^{13}C, ^{13}N and ^{14}N in (1976AJ04).

66. ^{13}C(d, t)^{12}C $\qquad Q_{\rm m} = 1.3112$

Angular distributions have been obtained at $E_{\rm d} = 0.41$ to 0.81 MeV (1971PU01: t_0), 1.0 to 2.7 MeV (1970LI1E, 1971LI1K: t_0), 2.2 and 3.3 MeV (1954HO48: t_0), 8 and 12 MeV (1966GL01: t_0, t_1), 12.1, 13.3 and 14.0 MeV (1968TE04: t_0, t_1), 13.6 MeV (1973ZA06: t_0, t_1), 14.8 MeV (1960MA10: t_0, t_1, t_2), 15 MeV (1974LU06) and 28 MeV (1972BR27). In the latter experiment (1972BR27) have studied the triton groups to ^{12}C*(12.7, 15.1, 16.1) [J^π; T = (1^+; 0), (1^+; 1) and (2^+; 1), respectively] and the ^{3}He groups, in the analogue reaction, to ^{12}B*(0, 0.95) [$J^\pi = 1^+$; $T = 1$ and $J^\pi = 2^+$; $T = 1$, respectively]. The relative yield to ^{12}C*(15.1) is greater than that to its analogue, ^{12}B$_{\rm g.s}$, while the yields to the 2^+ states are in good agreement. The value of β required to give the observed ratio of yields for the 1^+ states is 0.13 [in good agreement with the (d, d′) results: see reaction 49]: the charge-dependent matrix element is then 250 ± 50 keV (1972BR27). See also ^{15}N in (1976AJ04), (1967SP09, 1969DE1H) and (1969LI1D; theor.).

67. (a) ^{13}C(^{3}He, α)^{12}C $\qquad Q_{\rm m} = 15.6321$
(b) ^{13}C(^{3}He, 2α)^{8}Be $\qquad Q_{\rm m} = 8.2653$

Angular distributions have been measured at many energies up to $E(^3\text{He}) = 45$ MeV: see (1968AJ02) for the earlier references and (1971BO26: 1.5 to 5.3 MeV; α_0, α_1, α_2) and (1968AR12: 19.1, 27.3, 35.7, 36.8 MeV; α_0, α_1, α_2, α_3 and α to ^{12}C*(12.7, 15.1, 16.1)). Angular correlations of α-particles and 4.4 MeV γ-rays have been studied at $E(^3\text{He}) = 4.5$ MeV (1962HO13) and for $\alpha\gamma_{15.1}$ at 9.4 and 11.2 MeV (1969TA09). See also (1975MA2J).

Attempts have been made using this reaction (1970AR30, 1970RE09, 1974BA42) and reactions 49 and 66 to study the T mixing between the 1^+ states ^{12}C*(12.71, 15.11). Reported values for Γ_α/Γ for ^{12}C*(15.11) are $1.2 \pm 0.7\%$ (1970RE09, 1970RE1F), $6.0 \pm 2.5\%$ (1970AR30), $4.1 \pm 0.9\%$ (1974BA42). The (1974BA42) value was obtained by observing the decay α-particles in reaction (b): adopting this value, and using the other parameters for the decay of ^{12}C*(15.11) [see Table 12.9] leads to $\Gamma_\alpha = 1.8 \pm 0.3$ eV. If this isospin forbidden α-width is the result of mixing between the two 1^+ states via a charge-dependent interaction, the matrix element is 340 ± 60 keV (1974BA42). (1970RE09) have measured branching ratios for the decays of ^{12}C*(12.7, 15.1): see Table 12.9. See also ^{16}O in (1977AJ02).

68. (a) ^{13}C(^{6}Li, ^{7}Li)^{12}C $\qquad Q_{\rm m} = 2.3042$
(b) ^{13}C(^{7}Li, ^{8}Li)^{12}C $\qquad Q_{\rm m} = -2.9136$

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).

69. (a) ^{13}C(^{16}O, ^{17}O)^{12}C $\qquad Q_{\rm m} = -0.8040$
(b) ^{13}C(^{17}O, ^{18}O)^{12}C $\qquad Q_{\rm m} = 3.1004$
(c) ^{13}C(^{18}O, ^{19}O)^{12}C $\qquad Q_{\rm m} = -0.9895$

Angular distributions have been obtained for reaction (a) at $E(^{16}\text{O}) = 14$, 17 and 20 MeV (1968KN1A, 1971BA68: ^{12}C$_{\rm g.s}$+^{17}O*(g.s., 0.87)), 41.7 and 46.0 MeV (1973DE21). See also ^{28}Si in (1973ENVA) and (1974BE1J; theor.).

For reaction (b) see (1974CH1Q). Ground state angular distributions for reaction (c) have been measured at $E(^{18}O) = 15$, 20 and 24 MeV (1971BA68, 1971KN05). See also (1974CH1Q).

70. $^{14}C(p, t)^{12}C$ $Q_m = -4.6412$

Angular distributions have been measured at $E_p = 14.5$ MeV (1971CU01: t_0), 18.5 MeV (1963LE03: t_0) and 39.8 MeV (1970OL1B, 1973HO10: t_0, t_1). At $E_p = 50.5$ MeV the excitation of a $T = 2$ state with $E_x = 27.595 \pm 0.020$ MeV is reported by (1970NE1A, 1971NE1B, 1971NE1E; unpublished results). This state has also been observed at $E_p = 54$ MeV as has another narrow state at $E_x = 29.6 \pm 0.1$ MeV. The angular distribution of the tritons to the lower state is consistent with $L = 0$; that for the higher state is rather featureless (D. Ashery, private communication). [See also reaction 24 in ^{12}B.] See also (1971KA04; theor.).

71. (a) $^{14}C(^{16}O, ^{18}O)^{12}C$ $Q_m = -0.9342$
(b) $^{14}C(^{18}O, ^{20}O)^{12}C$ $Q_m = -1.563$

Angular distributions leading to the ground states in reaction (a) have been measured at $E(^{16}O) =$ 20, 25 and 30 MeV (1973SC24). For reaction (b) see (1972EY01) and ^{20}O in (1978AJ03).

72. $^{14}N(\gamma, np)^{12}C$ $Q_m = -12.4971$

See (1970TH01, 1972GE11), ^{13}C and ^{14}N in (1976AJ04), and (1973KI05; theor.).

73. $^{14}N(n, t)^{12}C$ $Q_m = -4.0149$

Angular distributions of the t_0 group have been measured at $E_n = 14-15$ MeV: see (1968AJ02). The γ-ray from $^{12}C^*(4.4)$ has been seen: $E_\gamma = 4436 \pm 5$ keV (1971NY03). See also ^{15}N in (1976AJ04) and (1971MI1H).

74. $^{14}N(p, pd)^{12}C$ $Q_m = -10.2725$

At $E_p = 46$ MeV the transitions to $^{12}C^*(0, 4.4)$ have been studied by (1970WE1J, 1971WE05). See also ^{14}N in (1976AJ04).

75. ^{14}N(p, ^{3}He)^{12}C $\qquad Q_m = -4.7787$

Angular distributions have been studied at $E_p = 7.53$, 8.03, 9.54 and 10.54 MeV (1970ME30: g.s.), 20.5, 24.3, 29.4, 34.6, 40.1 and 44.6 MeV (1974PI05: g.s., 4.4), 39.8 MeV (1973HO10: g.s., 4.4) and 50 MeV (1970SC02: g.s., 4.4, 12.7, 14.1, 15.1, 16.1). The results of (1970SC02) strongly indicate $J^\pi = 4^+$ for ^{12}C*(14.1). See also ^{15}O in (1970AJ04, 1976AJ04), (1968SH11, 1968TO1E) and (1970CH1E; theor.).

76. (a) ^{14}N(d, α)^{12}C $\qquad Q_m = 13.5751$

(b) ^{14}N(d, 2α)^{8}Be $\qquad Q_m = 6.2084$

Observed α-particle groups are shown in Table 12.23 (1956DO41, 1965PE17, 1965SC12, 1972FA07). Angular distributions have been measured at many energies up to $E_d = 28.5$ MeV: see (1968AJ02) for the earlier work and (1969GO14: $1.0 - 3.1$ MeV; $\alpha_0 \rightarrow \alpha_3$), (1971AR41: 1.70, 2.30, 2.90 MeV; α_0, α_1, α_2), (1967BO37: $2.29 - 5.76$ MeV; α_0, α_1), (1969CU08: 10.5 MeV; $\alpha_0 \rightarrow \alpha_3$), (1970SC02: 15 to 20 MeV; α_0, α_1 and α to ^{12}C*(12.7, 14.1)), (1968SC1C: 17 MeV; $\alpha_1 \rightarrow \alpha_3$ and α to ^{12}C*(12.7, 14.1)), (1968MA1K: 20 MeV; $\alpha_0 \rightarrow \alpha_3$ and α to ^{12}C*(12.7, 14.1)) and (1967VI03: 28.5 MeV; α_0, α_1. At $E_d = 40$ MeV the upper limits for the ratio of the cross sections to ^{12}C*(15.11) and ^{12}C*(12.71) are $\approx 0.3\%$ for $\theta_{lab} = 6°$ to $10°$ and 0.5% at $40°$ and $50°$: these results by (1974VA15) imply a lower isospin mixing between these two 1^+ states than suggested by the work of (1972BR27): see reactions 49, 66 and 67. For reaction (b) see (1972FA07). See also ^{16}O in (1977AJ02), (1967SP09) and (1968DA1K, 1968ZE1B, 1969JO23, 1970JA1J; theor.).

77. ^{14}N(^{3}He, pα)^{12}C $\qquad Q_m = 8.0814$

See (1969HO13), ^{13}N in (1970AJ04, 1976AJ04) and ^{16}O in (1971AJ02, 1977AJ02).

78. (a) ^{14}N(α, ^{6}Li)^{12}C $\qquad Q_m = -8.7987$

(b) ^{14}N(α, αd)^{12}C $\qquad Q_m = -10.2725$

At $E_\alpha = 42$ MeV, angular distributions of ^{6}Li ions corresponding to transitions to ^{12}C*(0, 4.4) have been measured by (1964ZA1A). Reaction (b) at $E_\alpha = 22.9$ MeV proceeds by sequential decay via states in ^{14}N, ^{16}O or ^{6}Li to ^{12}C$_{g.s.}$ (1969BA17): see also ^{6}Li in (1974AJ01), ^{14}N in (1970AJ04) and ^{16}O in (1971AJ02).

79. (a) ^{14}N(^{10}B, 3α)^{12}C $\quad Q_m = 7.6413$

(b) ^{14}N(^{10}B, ^{12}C)^{12}C $\quad Q_m = 14.9161$

See (1965SH1A) (reaction (a)) and (1973ST1A) (reaction (b)).

80. ^{15}N(p, α)^{12}C $\quad Q_m = 4.9661$

Angular distributions of α_0 and α_1 have been measured for E_p up to 18.6 MeV (see (1968AJ02)) and at six energies in the range $E_p = 19.85$ to 43.35 MeV (1971GU23). At $E_p = 43.7$ MeV the angular distributions to the 0^+ states ^{12}C*(0, 7.66, 17.76) are fitted by $L = 1$, and $L = 3$ is consistent with the distributions to ^{12}C*(14.1, 16.1) [$J^\pi = 4^+$ and 2^+, respectively] (1972MA21). The lifetime of ^{12}C*(4.4) $\tau_m = 65 \pm 9$ fsec (1970CO09). The energy of the second excited state of ^{12}C is 7654.2 ± 1.6 keV. The weighted average of this and previous values leads to $E_x = 7654.6 \pm 1.1$ keV, a value which leads to a sharply reduced rate for the ($\alpha\alpha\alpha$) process (1973MC01). See also (1972CA1N, 1973CL1E; astrophys. questions) and (1967SP09).

81. ^{15}N(α, ^{7}Li)^{12}C $\quad Q_m = -12.382$

At $E_\alpha = 42$ MeV angular distributions have been obtained for all four of the transitions ^{12}C$_{\rm g.s.}$ + ^{7}Li*(g.s., 0.48) and ^{12}C$^*_{4.4}$ + ^{7}Li*(g.s., 0.48) (1968MI05).

82. (a) ^{16}O(γ, α)^{12}C $\quad Q_m = -7.1616$

(b) ^{16}O(γ, 3α)^{4}He $\quad Q_m = -14.4364$

There is evidence for the involvement of many ^{12}C states: see (1965RO05, 1967CA1C). See also (1973CL1E; astrophys. questions).

83. (a) ^{16}O(n, nα)^{12}C $\quad Q_m = -7.1616$

(b) ^{16}O(p, pα)^{12}C $\quad Q_m = -7.1616$

For reaction (a) see (1968AJ02). Reaction (b) appears to proceed primarily via excited states of ^{13}N and ^{16}O to ^{12}C*(0, 4.4): see (1971EP03: $E_p = 46.8$ MeV) and (1972BO71: $E_p = 50$ MeV), ^{13}N in (1976AJ04) and ^{16}O in (1971AJ02, 1977AJ02). At $E_p = 160$ MeV, unpublished measurements by S.L. Kannenberg quoted by (1971EP03) show that reaction (b) proceeds in part by quasi-elastic scattering to ^{12}C$_{\rm g.s.}$. See also (1970GO12).

84. ^{16}O(d, ^{6}Li)^{12}C $Q_{\rm m} = -5.6879$

Angular distributions have been determined at $E_{\rm d} = 13.6$ and 14.6 MeV (1974GA30: g.s.), 14.6 MeV (1964DA1B: g.s.), 19.5 MeV (1971GU07: g.s., 4.4), 28 MeV (1972BE29, 1972BE1T: g.s., 4.4), 35 MeV (1975BE01: g.s.) and 55 MeV (1971MC04: g.s., 4.4, 7.7, 9.6, 14.1). See also (1969KE1C, 1972CO23), (1967OG1A, 1972GA1E) and (1971DR02, 1972RO1L, 1974DO03, 1974KU05; theor.).

85. ^{16}O(^{3}He, ^{7}Be)^{12}C $Q_{\rm m} = -5.575$

Angular distributions have been measured at $E(^{3}\text{He}) = 25.5$ to 29 MeV (1972PI1A: ^{12}C*(0, 4.4)+^{7}Be*(0, 0.4)) and 30 MeV (1970DE12: ^{12}C*(0, 4.4, 9.6)+^{7}Be*(0, 0.4), ^{12}C*(7.6)+^{7}Be(0)). See also (1971DE37, 1973PI1B, 1973ST1N) and (1972RO1L, 1973KL1B; theor.). (1975AU01) report the extraction of the α-particle pickup spectroscopic factor S_α using a finite range DWBA analysis ($E(^{3}\text{He}) = 26$ MeV).

86. (a) ^{16}O(α, 2α)^{12}C $Q_{\rm m} = -7.1616$
(b) ^{16}O(α, ^{8}Be)^{12}C $Q_{\rm m} = -7.2535$

Reaction (a) at $E_\alpha = 25$ MeV proceeds in part by sequential decay via states in ^{16}O and ^{20}Ne (1968PA12): see (1971AJ02, 1972AJ02). See also (1971BR1G, 1972SH1J). Angular distributions for the transitions to ^{12}C*(0, 4.4) in reaction (b) have been studied at $E_\alpha = 35.5$ to 41.9 MeV (1965BR13) and 65 MeV (1973WO06). The excitation of ^{12}C*(9.6, 14.1) is also reported (1973WO06, 1974WO1D). See also (1972SH10; theor.) and (1973SC1B).

87. ^{16}O(^{14}N, ^{18}F)^{12}C $Q_{\rm m} = -2.746$

See (1966GA10). See also (1969BR1D) and (1970AN1D; theor.).

88. ^{16}O(^{16}O, ^{20}Ne)^{12}C $Q_{\rm m} = -2.432$

Angular distributions have been measured at $E(^{16}\text{O}) = 23.9$ MeV (1974SP06: g.s. + g.s.) and 51.5 MeV (1974RO04: ^{12}C*(0, 4.4) and various ^{20}Ne states). See also (1971SI1F, 1973PE1D, 1974ER1A), ^{20}Ne in (1978AJ03) and ^{32}S in (1973ENVA).

89. ^{17}O(d, ^{7}Li)^{12}C $\quad Q_{\rm m} = -2.580$

See (1967DE03).

90. ^{18}O(p, tα)^{12}C $\quad Q_{\rm m} = -10.869$

The decay of the lowest $T = 2$ state of ^{16}O to ^{12}C*(0, 4.4) has been studied by (1973KO02). See also ^{16}O in (1977AJ02).

91. ^{18}O(d, ^{8}Li)^{12}C $\quad Q_{\rm m} = -8.594$

See (1963DE02; unpublished).

92. ^{19}F(p, ^{8}Be)^{12}C $\quad Q_{\rm m} = 0.861$

See (1969GO1B, 1971GO1R). See also ^{20}Ne in (1972AJ02).

93. ^{19}F(d, ^{9}Be)^{12}C $\quad Q_{\rm m} = 0.302$

Ground state angular distributions have been measured at $E_{\rm d} = 9$ to 14.5 MeV (1964DA1B, 1967DE03, 1967DE14).

94. ^{19}F(^{3}He, ^{10}B)^{12}C $\quad Q_{\rm m} = 1.393$

See (1967DE14).

95. ^{19}F(^{13}C, ^{20}F)^{12}C $\quad Q_{\rm m} = 1.655$

See (1972SE1J).

96. ^{19}F(^{15}N, ^{22}Ne)^{12}C $\quad Q_{\rm m} = 6.641$

See (1973GA14).

97. ^{20}Ne(α, ^{12}C)^{12}C $\qquad Q_m = -4.6168$

The α-induced fission of ^{20}Ne has been studied by (1962LA05, 1962LA03, 1962LA15, 1963LA08). See also (1974VO09, 1974WI05).

98. ^{24}Mg(^{16}O, ^{28}Si)^{12}C $\qquad Q_m = 2.823$

At $E(^{16}\text{O}) = 42$ MeV (1972MA36) and 56 MeV (1974GR1R) angular distributions involving ^{12}C*(4.4) and several ^{28}Si states have been measured.

^{12}N

(Figs. 7 and 8)

GENERAL: (See also (1968AJ02).)

Model calculations: (1973HA49, 1973KU1L, 1973SA30).

Muon and neutrino interactions: (1972KE06, 1972UB01).

Pion reactions: (1970HI10, 1970RA39, 1973BE1X, 1973UB01, 1974BO27, 1974EP02, 1974SE02).

Other topics: (1969GA1G, 1972AN05, 1972JA14, 1972OC01, 1973HA77, 1973RO1R, 1974IR04).

$$\mu = +(0.4571 \pm 0.0005) \text{ nm (1968SU05).}$$

See also (1971SH26, 1972VA36, 1973KU1L, 1973MA1K, 1973SU1B, 1974HA2C).

1. ^{12}N(β^+)^{12}C $\qquad Q_m = 17.344$

The half-life of ^{12}N is 10.97 ± 0.04 msec: see Table 12.28 in (1968AJ02). ^{12}N decays to ^{12}C*(0, 4.44, 7.65, 10.3, 12.71, 15.11): see Table 12.24.

2. ^{10}B(^{3}He, n)^{12}N $\qquad Q_m = 1.569$

Observed neutron groups are displayed in Table 12.26 (1966ZA01, 1968AD03, 1970BO39, 1971ADZZ, 1974FU11). Angular distributions have been studied at $E(^3\text{He}) = 2.5$ to 5.8 MeV (see (1968AJ02)), at 11 MeV (1970BO39: n_0 and n to ^{12}N*(5.3)) and at 12.5 and 13 MeV (1974FU11: to states shown in Table 12.26 except ^{12}N*(2.4)). See also (1970CH1G).

3. ^{12}C(p, n)^{12}N $\qquad Q_m = -18.126$

$$E_{\text{thresh.}} = 19.658 \pm 0.005 \text{ (1969OV01).}$$

At $E_p = 50$ MeV neutron groups are reported to ^{12}N states at $E_x = 0$, 1.0 ± 0.1, 3.7 ± 0.2, 4.2 ± 0.2, 5.3 ± 0.2 and 7.5 ± 0.3 MeV [compare with Table 12.25]. Angular measurements have been measured at $E_p = 30.5$ and 49.5 MeV for the two most energetic groups (1970CL01). See also (1969JU1A, 1970AM1A, 1970WI1B, 1973WA1K, 1975CA1W) and (1968AJ02).

4. ^{12}C(^{3}He, t)^{12}N $\qquad Q_m = -17.362$

Table 12.25: Energy levels of ^{12}N

E_x (MeV ± keV)	$J^\pi; T$	$\tau_{1/2}$ or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
g.s.	$1^+; 1$	$\tau_{1/2} = 10.97 \pm 0.4$ msec	β^+	1, 2, 3, 4, 5, 6
0.964 ± 8	$2^+; 1$	$\Gamma < 35$ keV	(p)	2, 3, 4, 5
1.192 ± 9	$(2)^-; 1$	140 ± 30	(p)	2, 3, 4
(1.72 ± 0.08)			(p)	2
2.43 ± 40			(p)	2, 4, 5
3.114 ± 15	$\pi = +$	210 ± 50	(p)	2, 4
3.533 ± 15	$(2)^+; 1$	170 ± 50	(p)	2, 3, 4, 5
4.25 ± 30		290 ± 70	(p)	2, 3, 4
5.320 ± 12		180 ± 20	(p)	2, 3, 4
(6.4)			(p)	2
(6.9)			(p)	2, 5
7.629 ± 20		200 ± 40	(p)	2, 3
8.446 ± 17		90 ± 30		2
9.035 ± 12		< 35		2

Triton groups observed at $E(^3\text{He}) = 49.8$ MeV are shown in Table 12.27 (1968BA1E, 1969BA06). Angular distributions of inelastically scattered ^{3}He to ^{12}C*(15.11, 16.11, 16.58, 19.57) have been compared with those of the tritons to ^{12}N*(0, 0.96, 1.19, 4.25). When the ^{3}He cross sections are corrected for phase-space and isospin factors, the angular distributions are closely similar (to within 10%) to those for the triton groups, strongly suggesting isobaric analogues (1969BA06). Angular distributions have also been studied at $E(^3\text{He}) = 217$ MeV (1974WI16: 0, 0.96, 3.53; partly resolved). See also (1970AR05, 1973PA1C).

5. ^{14}N(p, t)^{12}N $\qquad Q_m = -22.141$

At $E_p = 46$ MeV triton groups are reported to ^{12}N*(0, 0.97, 2.41, 3.50, 4.51, 5.13, 6.12, 7.13) (1968FO1C, 1968TO1E, 1969KI1C; abstracts). See also (1971KA04; theor.).

6. ^{16}O(^{3}He, ^{7}Li)^{12}N $\qquad Q_m = -22.058$

See (1971DE37).

Table 12.26: Neutron groups from ^{10}B(^{3}He, n)^{12}N [a]

E_x (MeV ± keV)				L	$\Gamma_{c.m.}$ (keV)	
(1966ZA01)	(1968AD03, 1971ADZZ) [b]	(1970BO39)	(1974FU11)	(1974FU11)	(1966ZA01)	(1974FU11) [h]
g.s.	g.s.	g.s. [c]	g.s.	2	sharp	20 ± 20
0.959 ± 20	0.972 ± 13		0.960 ± 12	2	< 50	16 ± 20
1.24 ± 30	1.195 ± 13		1.189 ± 12	1	140 ± 40	140 ± 30
(1.72 ± 0.08)	(1.75)					
2.4 ± 100	(2.44)		(2.40 ± 60)			
3.14 ± 80			3.114 ± 15	2	280 ± 80	180 ± 40
3.57 ± 80			3.533 ± 15	2	270 ± 80	120 ± 40
		4.3	4.250 ± 30 [f]			290 ± 70 [f]
		5.3 [d]	5.320 ± 12	(0)		180 ± 20
		6.4 [e]				
		6.9 [e]				
		7.7 [e]	7.629 ± 20			200 ± 40
			8.446 ± 17			90 ± 30
		9.2 [e]	9.035 ± 12 [g]			16 ± 20

[a] See also Table 12.29 in (1968AJ02).
[b] Values shown are from the unpublished report (1971ADZZ). (1968AD03) reported $E_x = 969 \pm 10$, 1191 ± 10 keV.
[c] $L = 2$.
[d] $L = 0$ assignment is made by authors who suggest $J^\pi = 3^+$ for ^{12}N*(5.3).
[e] Reported to be involved in the sequential decay at $E(^3\text{He}) = 11$ MeV. These E_x are given to ±50 keV.
[f] May be due to unresolved states.
[g] (1970CH1G; unpublished) also reports the excitation of states at $E_x = 9.6$, 10.2, 11.0 and 11.6 MeV.
[h] T.G. Masterson, private communication.

Table 12.27: States of ^{12}N from ^{12}C(^{3}He, t)^{12}N

(1969BA06)		(1969BA06)
E_x (MeV ± keV)	J^π [a]	E_x (MeV ± keV)
g.s.		3.10 ± 30
0.96 ± 20	2^+	3.50 ± 40 [b]
1.20 ± 30	(2^-)	4.24 ± 50 [c]
2.43 ± 40 [b]		5.27 ± 40

[a] Determined in this study.
[b] Angular distributions were not measured.
[c] Broad or unresolved.

^{12}O

(Not illustrated)

This nucleus has not been observed: see (1968AJ02, 1972WA07, 1973SP1A, 1974IR04).

^{12}F

(Not illustrated)

This nucleus has not been observed: see (1974IR04).

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(Closed 31 January 1975)

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

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