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Energy Levels of Light Nuclei
$A = 12$

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Abstract: An evaluation of $A = 11$–12 was published in *Nuclear Physics A*506 (1990), p. 1. This version of $A = 12$ 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 are in the NNDC/TUNL format.

(References closed June 1, 1989)

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Table of Contents for $A = 12$

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^{12}n, ^{12}He

(Not illustrated)

Neither nucleus has been observed. See (1980AJ01), (1987PE1C), (1987FL1A) and (1985PO10; theor).

^{12}Li

(Not illustrated)

^{12}Li is not observed in the 4.8 GeV proton bombardment of a uranium target: it is particle unstable. The calculated value of its mass excess is 52.93 MeV [see (1980AJ01)]: ^{12}Li would then be unstable with respect to ^{11}Li$+$n ,^{10}Li$+$2n and ^{9}Li$+$3n by 4.01, 2.96 and 3.76 MeV, respectively. The ground state of ^{12}Li is predicted to have $J^\pi = 2^-$ (1988POZS, 1985PO10; theor.). See also (1980AJ01).

^{12}Be

(Figs. 1 and 5)

GENERAL (See also (1985AJ01)).

General theoretical papers: (1984FR13, 1985AN28, 1985BA51, 1985WI1B, 1986WI04, 1987BL18, 1987GI1C, 1987SA15, 1987YA16, 1988RU01, SU88C, 1989BE03)

Hypernuclei: (1984IW1B, 1984YA04, 1985BE31, 1985GA1C, 1985IK1A, 1985WA1N, 1985YA01, 1985YA07, 1986BA1W, 1986BI1G, 1986DO1B, 1986GA33, 1986GA14, 1986GA1H, 1986HA26, 1986MA1J, 1986ME1F, 1986MI1N, 1986PO1H, 1986YA1T, 1986ZO1A, 1987DA30, 1987FA1A, 1987HA40, 1987IK1B, 1987PO1H, 1987WU1B, 1988BA24, 1988HA07, 1988MA09, 1988PO1H, 1988TA14, 1988WA1B, 1988YA05)

Other topics : (1989SU05)

Secondary beams of ^{12}Be produced in the fragmentation of ^{20}Ne accelerated to 800 MeV/A have been used to measure interaction cross sections in Be, C and Al. The interaction radius and the r.m.s. radius for the nucleon distribution in ^{12}Be have also been derived (1988TA10). See also (1989SA10, 1989TA1K).

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

The half-life of ^{12}Be is $24.4. \pm 3.0$ ms (1978AL10), 21.3 ± 2.2 ms (1986CU01), 24.0 ± 1.0 ms (1984DU15): the mean of these values is 23.6 ± 0.9 ms. Log $ft = 3.834 \pm 0.017$ (M.J. Martin, private communication), assuming the decay is to ^{12}B$_{\rm g.s.}$. The upper limit of the branching to a state which subsequently decays by neutron emission is 1% (1978AL10, 1984DU15).

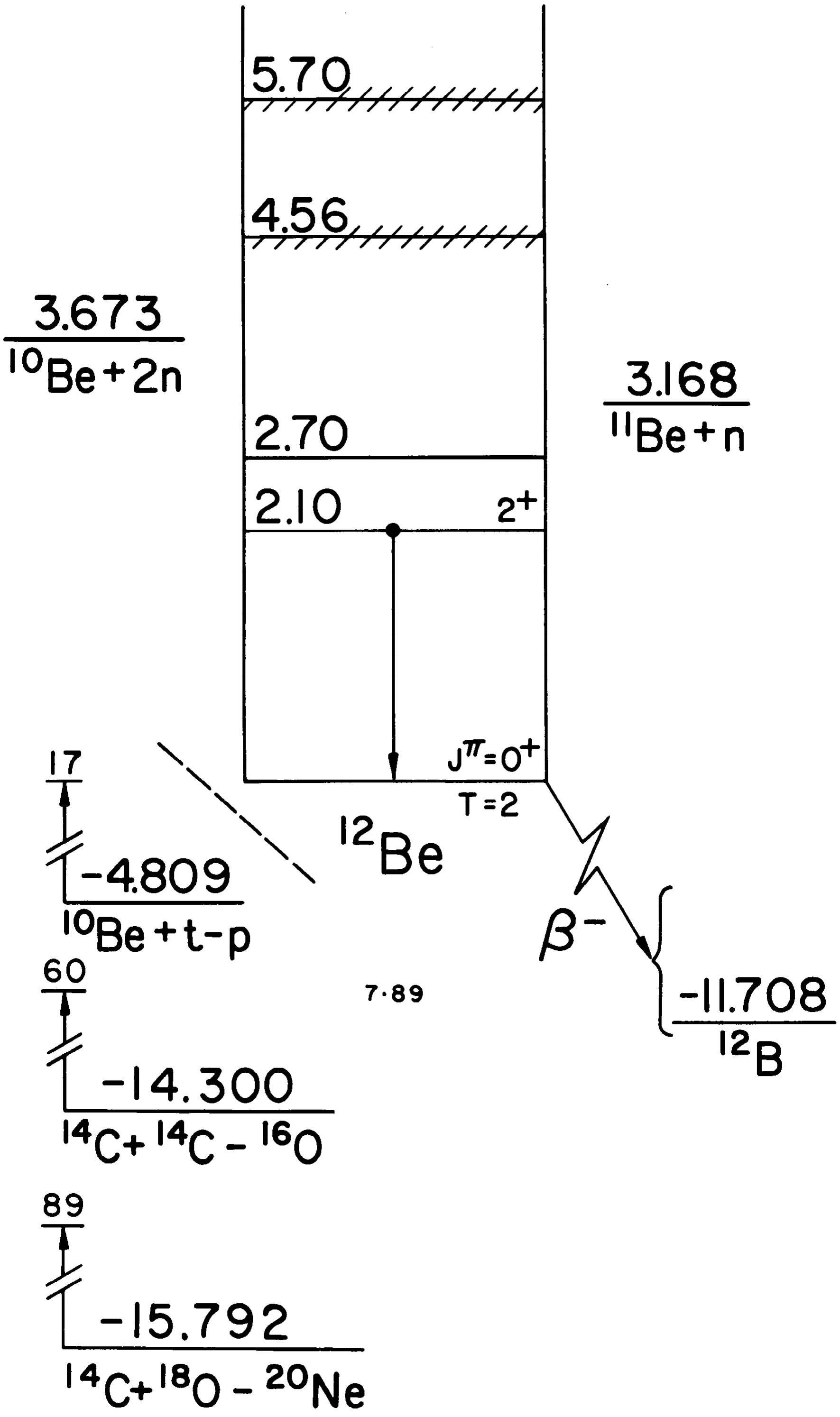

Fig. 1: Energy levels of ^{12}Be. For notation see Fig. 2.

Table 12.1: Energy levels of ^{12}Be

E_x (MeV $\pm$ keV)	$J^\pi; T$	$\tau_{1/2}$	Decay	Reactions
0	$0^+; 2$	$\tau_{1/2} = 23.6 \pm 0.9$ ms	β^-	1, 2, 3
2.102 ± 12	$2^+; 2$	[a]	γ	2, 3
2.702 ± 17		[a]		2, 3
4.56 ± 25		[b]		2
5.70 ± 25		[b]		2

[a] See discussion in (1982BE42).

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

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

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

3. ^{14}C(^{14}C, ^{16}O)^{12}Be $\quad Q_m = -14.300$

At $E(^{14}\mathrm{C}) = 60$ MeV ^{12}Be*(0, 2.10, 2.68 ± 0.03) have been populated, the latter weakly. Angular distributions are poorly fitted by DWBA. An assignment of 0^+ is plausible but not proven for ^{12}Be*(2.70) (1982BE42).

^{12}B

(Figs. 2 and 5)

GENERAL (See also (1985AJ01)).

Model calculations: (1988WO04)

Special states: (1984KA1H, 1986XU02)

Astrophysical questions: (1988AP1A)

Applications: (1988NO1C)

Complex reactions involving ^{12}B: (1984HO23, 1984TA1K, 1985JA18, 1985NO1E, 1985PO11, 1985TA09, 1986AV1B, 1986BI1A, 1986CS1A, 1986GA1P, 1986ME06, 1986PO06, 1986UT01, 1986WE1C, 1986XU02, 1987AN1A, 1987BA38, 1987BA1T, 1987EL14, 1987GE1B, 1987JA06, 1987LY04, 1987PE1B, 1987PO23, 1987SA25, 1987VI02, 1987YA16, 1988AU1A, 1988CA06, 1988FO03, 1988KI05, 1988KI06, 1988RU01, 1988SA19, 1988TA1N, 1989DE05, 1989SA10, 1989SE03, 1989ST1G, 1989YO02)

Polarization of ^{12}B: (1984KO1A, 1984KU11, 1984TA1M, 1985TA09, 1986AU1E, 1986KU05, 1986NO1C, 1986TA13, 1987AU1D, 1987CO1L, 1987FU13, 1988NO1C)

Muon and neutrino capture and reactions (See also reaction 19.): (1984KU11, 1985GR1A, 1986KU05, 1987BR1L, 1987FU13, 1987MI17, 1988BR24, 1988FU08, 1988MI11, 1988MI20, 1989GM1A)

Pion and kaon capture and reactions (See also reactions 18, 20, and 21.): (1983AS01, 1984AS05, 1984ER06, 1984KA31, 1984MA1U, 1985DO1G, 1985SA06, 1986DI07, 1986SU18, 1988HA12, 1989MR01)

Hypernuclei: (1983SH1E, 1984CH1G, 1984CO1L, 1984MA1U, 1984SH1J, 1984ZH1B, 1985AH1A, 1985CO1H, 1985CO14, 1985DO1G, 1985YA1F, 1986AN1R, 1986BE1P, 1986CO1U, 1986DA1B, 1986FE1A, 1986HA39, 1986KO1A, 1986MA1C, 1986RO25, 1987BE1S, 1987MA08, 1987MA2A, 1987MI38, 1987PO1H, 1988MO1L, 1988RO11, 1988TA29, 1989MR01)

Antinucleon interactions: (1986AU1D)

Other topics: (1984KA1H, 1985AN28, 1986YA1F)

Ground-state properties of ^{12}B: (1985AN28, 1986GL1A, 1987VA26, 1988VA03, 1988WO04)

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

$$Q = 1.34 \pm 0.14\ \mathrm{fm}^2\ [(1978MI19);\ \text{see also}\ (1978LEZA, 1985NA1A).]$$

Interaction cross sections at 790 MeV/A by ^{12}B ions with Be, C, and Al are reported by (1988TA10). The interaction radius and the r.m.s. radius for the nucleon distribution in ^{12}B have also been derived (1988TA10). See also (1989SA10).

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

E_x in ^{12}B (MeV $\pm$ keV)	$J^\pi; T$	τ or $\Gamma_{\rm c.m.}$ (keV)	Decay	Reactions
0	$1^+; 1$	$\tau_{1/2} = 20.20 \pm 0.02$ ms	β^-	1, 2, 5, 6, 8, 9, 12, 13, 14, 15, 16, 17, 18, 19, 20, 22, 23, 24, 25, 26, 27, 28
0.95314 ± 0.60	2^+	$\tau_{\rm m} = 260 \pm 40$ fs	γ	2, 5, 6, 8, 12, 13, 15, 18, 19, 23, 24, 25, 26, 27, 28
1.67365 ± 0.60	2^-	< 50 fs	γ	2, 5, 6, 8, 12, 13, 15, 18, 19, 23, 24, 25, 26
2.6208 ± 1.2	1^-	< 70 fs	γ	2, 6, 8, 12, 13, 15, 19, 24, 26
2.723 ± 11	0^+		γ	2, 6, 8, 13, 15, 24, 27
3.3891 ± 1.5	3^-	$\Gamma = 3.1 \pm 0.6$ eV	γ, n	2, 5, 6, 8, 9, 10, 12, 13, 15, 26
3.759 ± 6	2^+	40 ± 4 keV	γ, n	5, 6, 8, 9, 10, 12, 13, 27
4.301 ± 7	1^-	9 ± 4	γ, n	6, 8, 9, 10, 12
4.46	2^-	broad	n	10, 18, 23, 25, 26
4.518 ± 8	4^-	110 ± 20	γ, n	6, 8, 9, 10, 12, 13, 15, 18, 23, 25, 26
5.00 ± 20	1^+	50 ± 15	γ, n	6, 8, 9, 10, 12, 27
5.612 ± 8	3^+	110 ± 40	n	6, 8, 10, 12, 15, 23, 28
5.726 ± 8	3^-	50 ± 20	n	6, 8, 10, 15
6.0	1^-	broad	n	10
6.6	1^+	140	n	10
7.06	1^-	broad	n	10
7.545 ± 20		≤ 14	n	6, 8, 10
(7.67)	2^-	45	n	10
7.7 ± 100	1^-	1900 ± 100	n	26
7.836 ± 20	1^-	60 ± 40	n	6, 10
7.937 ± 20	(1^-)	27	n	6
8.1 ± 100		900 ± 200	(n)	6

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

E_x in ^{12}B (MeV $\pm$ keV)	$J^\pi; T$	τ or $\Gamma_{\rm c.m.}$ (keV)	Decay	Reactions
8.120 ± 20	(3^-)		n	6, 8, 10
8.24 ± 30	3^-	65	n	6, 10
8.376 ± 20		40 ± 20		6, 8
8.58 ± 30	(3^-)	75	n	6, 8, 10
8.707 ± 20	(3^-)		n	6, 10
9.04 ± 20	1^-	95 ± 20	n	6, 8, 10
9.175 ± 20	(2^-)		n	6, 10
9.43 ± 20		85 ± 30		6, 8
9.585 ± 5	3^-	34 ± 5	n	6, 8, 10
9.758 ± 20				6
(9.83)				6
10.00 ± 40		100	n	6, 10
10.11 ± 40				6
10.220 ± 20		< 25		6, 8
10.435 ± 20		75 ± 40		6
10.59 ± 20		< 30		6, 8
10.90 ± 20		30 ± 10		6, 8
(11.08)				6
11.31 ± 30		130 ± 60		6
11.59 ± 20		75 ± 25		6
12.345 ± 25		100 ± 30	n	6, 8, 10
12.75 ± 50	$0^+; T = 2$	85 ± 40		6, 28
13.33 ± 30		50 ± 20		6
(13.4 ± 100)		broad		8
14.82 ± 100	$(2^+; T = 2)$	≤ 200		28
15.5				6
(21.8 ± 400)	(3^-)	(1300 ± 400)		24
(23.9 ± 1000)	(1^-)	(6000 ± 1000)		24

[a] See also Table 12.5.

^{12}B*(3.39) has been produced in the interaction of a 490 MeV ^{14}N beam with Ag: its 19 keV neutron decay to ^{11}B$_{\text{g.s.}}$ has been observed (1989DE05).

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

The half-life of ^{12}B is 20.20 ± 0.02 ms (1978AL01). See also (1988SA04). The decay is complex. ^{12}B decays to ^{12}C*(0, 4.4, 7.7, 10.3): see Table 12.14. The transitions to ^{12}C*(0, 4.4) are allowed; hence the J^π of ^{12}B(g.s.) is 1^+. The β-momentum spectrum has recently been measured by (1987NA08). For measurements of the angular distribution functions from oriented ^{12}B nuclei see, for instance (1986MI1P, 1986MI1T, 1987MI1P). See also the “Polarization” section in (1985AJ01), (1986CU01, 1986RO27, 1987MI20), (1985GR1A, 1985MI1A), (1985BA2L, 1987RO03; applied) and (1984DU1E, 1984TA1M, 1985MO13, 1986KE1A, 1986KO2C, 1986TO1A, 1987DR1A, 1987KE1B, 1987SA1N, 1988AL1E, 1988SA12, 1989SA1H; theor.).

2. (a) ^{6}Li(^{7}Li, p)^{12}B $\qquad Q_\text{m} = 8.334$
(b) ^{7}Li(^{7}Li, d)^{12}B $\qquad Q_\text{m} = 3.309$

Eleven groups of protons (reaction (a)) are reported to known states of ^{12}B. Angular distributions have been measured at $E(^{6}\text{Li}) = 3.5$ to 5.95 MeV. The distributions are generally featureless. Angular distributions for d_0, d_1, d_2, d_{3+4} have been measured at $E(^{7}\text{Li}) = 2.10$ to 5.75 MeV. See (1975AJ02) for references. See also (1984KO25).

3. (a) ^{9}Be(t, n)^{11}B $\qquad Q_\text{m} = 9.5580 \qquad E_\text{b} = 12.928$
(b) ^{9}Be(t, p) ^{11}Be $\qquad Q_\text{m} = -1.165$

Figure 2: Energy levels of ^{12}B. In these diagrams, energy values are plotted vertically in MeV, based on the ground state as zero. Uncertain levels or transitions are indicated by dashed lines; levels which are known to be particularly broad are cross-hatched. Values of total angular momentum J, parity, and isobaric spin T which appear to be reasonably well established are indicated on the levels; less certain assignments are enclosed in parentheses. For reactions in which ^{12}B is the compound nucleus, some typical thin-target excitation functions are shown schematically, with the yield plotted horizontally and the bombarding energy vertically. Bombarding energies are indicated in laboratory coordinates and plotted to scale in cm coordinates. Excited states of the residual nuclei involved in these reactions have generally not been shown; where transitions to such excited states are known to occur, a brace is sometimes used to suggest reference to another diagram. For reactions in which the present nucleus occurs as a residual product, excitation functions have not been shown; a vertical arrow with a number indicating some bombarding energy, usually the highest, at which the reaction has been studied, is used instead. Further information on the levels illustrated, including a listing of the reactions in which each has been observed, is contained in the master table, entitled “Energy levels of ^{12}B”.

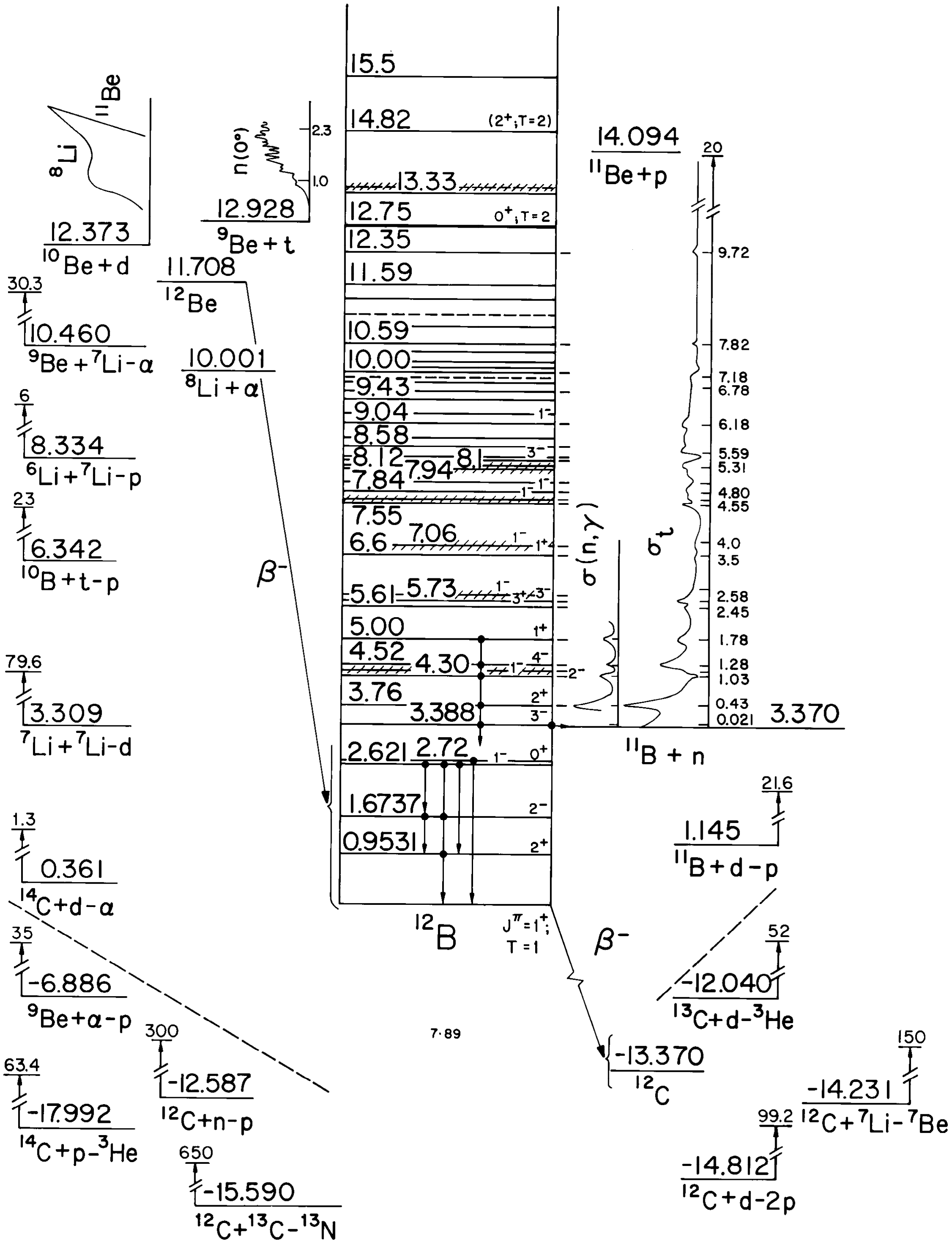

Fig. 2: Energy levels of ^{12}B. For notation see Fig. 2.

(c) ^{9}Be(t, d)^{10}Be $Q_m = 0.5547$ (d) ^{9}Be(t, t)^{9}Be
(e) ^{9}Be(t, α)^{8}Li $Q_m = 2.9271$
(f) ^{9}Be(t, ^{6}He)^{6}Li $Q_m = -5.3807$

Thirteen resonances have been reported in reaction (a) corresponding to $13.6 < E_x < 14.7$ MeV: see Table 12.3 in (1975AJ02). The yield of 2.12 MeV γ-rays has been measured for $E_t = 1.5$ to 3.3 MeV and $E(^9\text{Be}) = 10$ to 16 MeV: no resonances are observed. This is also the case for the yields of 0.32 MeV (reaction (b)), 0.98 MeV (reaction (e)) and 0.48 MeV γ-rays (from the (t, αn) reaction). Elastically scattered tritons have been studied for $E_t = 0.60$ to 2.1 MeV and $E_{\vec{t}} = 15$ and 17 MeV (also A_y). The yields of α_0 and α_1 have also been reported for $E_t = 0.52$ to 1.70 MeV: see (1975AJ02). The analyzing powers of the reactions leading to ^{6}He$_{\text{g.s.}}$ and ^{6}Li*(0, 3.56) have been measured at $E_{\vec{t}} = 17$ MeV. For references see (1985AJ01). See also (1988AJ01).

4. ^{9}Be(α, p)^{12}B $Q_m = -6.886$

See unpublished work in (1985AJ01). See also (1986AU1E).

5. ^{9}Be(^{6}Li, ^{3}He)^{12}B $Q_m = -2.8674$

At $E(^6\text{Li}) = 32$ MeV ^{12}B*(0, 0.95, 1.67, 3.38, 3.76) and some unresolved states are populated (1986AS02).

6. ^{9}Be(^{7}Li, α)^{12}B $Q_m = 10.460$

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

7. (a) ^{10}Be(d, p)^{11}Be $Q_m = -1.720$ $E_b = 12.373$
(b) ^{10}Be(d, α)^{8}Li $Q_m = 2.3724$

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

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

E_x [b] (MeV ± keV)	$\Gamma_{c.m.}$ [b] (keV)	E_x [c] (MeV ± keV)	$\Gamma_{c.m.}$ [c] (keV)	L [c]	J^π [c]
0		0		2	$(1, 2, 4, 5)^+$
0.951 ± 15		0.955 ± 8		2	$(1, 2, 4, 5)^+$
1.674 ± 15		1.673 ± 8		1	$(2, 3, 4)^-$
2.625 ± 15		2.627 ± 8		3	$(0, 1, 5, 6)^-$
2.724 ± 15		2.72 [f]		4	$(0, 6, 7)^+$
3.390 ± 15		3.393 ± 8			
3.77 ± 20 [d]	40 ± 20	3.754 ± 8	42 ± 5	2	$(1, 2, 4, 5)^+$
4.305 ± 15	< 30	4.297 ± 8	≤ 15		
4.534 ± 15		4.514 ± 8	95 ± 15		
4.982 ± 15 [d]	40 ± 20	5.00 [g]	130 ± 40		
5.57 ± 30 [d]		5.612 ± 8	120 ± 20		
5.728 ± 15	50 ± 20	5.724 ± 8	70 ± 20		
7.545 ± 20	< 30	7.55 [f]			
7.836 ± 20	60 ± 40				
7.937 ± 20	< 40				
8.1 ± 100	900 ± 200				
8.120 ± 20		8.16 ± 30			
8.24 ± 30					
8.376 ± 20	40 ± 20	8.38 [f]			
8.58 ± 30		8.58 [f]			
8.707 ± 20					
9.03 ± 20		9.07 ± 30	95 ± 20		
9.175 ± 20					
9.43 ± 20 [e]	85 ± 30	9.44 ± 30			
9.585 ± 20	60 ± 30	9.626 ± 20	34 ± 10		
9.758 ± 20					
(9.83)					
10.00 ± 40					
10.11 ± 40					
10.21 ± 30	50 ± 20	10.227 ± 20	< 25		

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

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

[a] For references see Tables 12.3 and 12.4 in (1980AJ01).

[b] ^{9}Be(^{7}Li, α)^{12}B.

[c] ^{10}B(t, p)^{12}B.

[d] $\theta_n^2 = 0.46 \pm 0.06, 0.08 \pm 0.03$ and 0.10 ± 0.02 for ^{12}B*(3.76, 5.00, 5.61).

[e] Probably unresolved.

[f] Observed but E_x not determined.

[g] Not observed at $E_t = 23$ MeV.

8. ^{10}B(t, p)^{12}B $\qquad Q_m = 6.342$

Observed excited states are displayed in Table 12.3. Angular distributions have been studied at $E_t = 10$ and 23 MeV: see (1980AJ01). See also (1982CI1B; theor.)

9. ^{11}B(n, γ)^{12}B $\qquad Q_m = 3.370$

The thermal-neutron capture cross section is 5.5 ± 3.3 mb [see (1981MUZQ)]. The capture cross section shows resonances at $E_n = 20.8 \pm 0.5$ keV and at 0.43, 1.03, 1.28 and 1.78 MeV, with $\Gamma_\gamma = 25 \pm 8$ meV and 0.3, 0.3, 0.2 and 0.9 eV (± 50%): see Table 12.4 and (1968AJ02). For a summary and the ENDF projections see (1988MCZT). See also (1985BA2L; applied) and (1988MA1U; astrophysics).

10. ^{11}B(n, n) ^{11}B $E_\mathrm{b} = 3.370$

The thermal (bound) scattering cross section is 3.9 ± 0.2 b. The scatttering amplitude (bound) is $a = 6.65 \pm 0.04$ fm, σ(free) $= 4.84 \pm 0.04$ b (1983KO17). Parameters of observed resonances are shown in Table 12.4. See also (1981MUZQ). For a summary and the ENDF projections see (1988MCZT). See also (1982GL02). For differential cross sections see ^{11}B. Total cross-section measurements have been reported for $E_\mathrm{n} = 0.3$ to 18.0 MeV: see (1968AJ02, 1980AJ01, 1985AJ01). Polarization measurements have been studied at $E_\mathrm{n} = 75$ keV to 2.2 MeV [see (1980AJ01)] and at $E_{\vec{\mathrm{n}}} = 10$ to 17 MeV (1985WA1P, 1986MU08; n_0; prelim.).

Results from the most recent R-matrix analysis are displayed in Table 12.4 (1983KO03). For a discussion of the earlier work see (1980AJ01). See also (1986BAYL, 1986DR10), (1985BO1C) and (1988HAZT; theor.).

11. (a) ^{11}B(n, p)^{11}Be $Q_\mathrm{m} = -10.7234$ $E_\mathrm{b} = 3.370$
(b) ^{11}B(n, d)^{10}Be $Q_\mathrm{m} = -9.0033$
(c) ^{11}B(n, t)^{9}Be $Q_\mathrm{m} = -9.5580$
(d) ^{11}B(n, α)^{8}Li $Q_\mathrm{m} = -6.6309$

The cross section for reaction (a) has been measured for $E_\mathrm{n} = 14.7$ to 16.9 MeV and that for reaction (b) has been investigated for E_n=12.6 to 20.0 MeV and at 25 and 38 MeV: see (1975AJ02). A study of reaction (d) is reported at $E_\mathrm{n} = 14.4$ MeV: see (1985AJ01). For a summary and the ENDF projections see (1988MCZT). See also (1985FO1D), (1986WI1B; applied) and (1985BO1D).

12. ^{11}B(p, π^+)^{12}B $Q_\mathrm{m} = -136.981$

The cross section for π^+ production near threshold has been measured. At $E_\mathrm{p} = 200$ MeV ^{12}B*(0, 0.95, 1.67, 2.62, 3.39, 3.76, $4.30 + 4.52$, 5.00, 5.61) are reported: see (1985AJ01). See also the "General" section here.

13. ^{11}B(d, p)^{12}B $Q_\mathrm{m} = 1.145$

Observed proton groups and γ-rays are displayed in Table 12.5. The J^π assignments for ^{12}B*(0.95, 1.67) are derived as follows [see (1968AJ02) for a listing of earlier references]: *0.95 MeV*: $l_\mathrm{n} = 1$ leads to $J^\pi = 0^+, 1^+, 2^+$ or 3^+. The γ-radiation is anisotropic and therefore $J \neq 0$. τ_m is too short for pure E2 and hence $J \neq 3$, which is confirmed by studies of the polarization of

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

E_n (MeV ± keV)	$\Gamma_{\mathrm{c.m.}}$ (keV)	^{12}B* (MeV)	l [a, e]	J^π [a, e]
0.0208 ± 0.5 [b, d]	$\ll 1.4$	3.3891 [f]	2	3^-
0.43 ± 10 [c, d]	37 ± 5	3.763	1	2^+
1.027 ± 11 [c, d]	9 ± 4	4.310	0	1^-
1.19 [e]	broad	4.46	0, 2	2^-
1.28 ± 20 [c, e]	130 ± 20	4.54	2	4^-
1.78 ± 20 [c, e]	60 ± 20	5.00	1	1^+
2.45 ± 20 [e]	110 ± 40	5.61	1	3^+
2.58 ± 20 [e]	55 ± 20	5.74	2	3^-
2.9 [e]	broad	6.0	0, 2	1^-
3.5 [e]	140	6.6	1	1^+
4.03 [e]	broad	7.06	0, 2	1^-
4.55	≤ 14	7.54	> 3	
4.70 [e]	45	7.67	0, 2	2^-
4.80 [e]	90	7.77	0, 2	1^-
4.93 [e]		(7.88)	0, 2	1^-
5.19 [e]		(8.12)	2	3^-
5.31 [e]	65	8.23	2	3^-
5.59 [e]	75	8.49	2	3^-
5.82 [e]		(8.70)	2	3^-
6.18 [e]	120	9.03	0, 2	1^-
6.25 [e]		(9.09)	0, 2	2^-
6.78 [e]	34 ± 5	9.578 [g]	2	3^-
7.18	100	9.94	> 0	
7.82	65	10.53	> 2	
9.72	120	12.27	> 2	

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

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

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

[d] See also (1983KO03).

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

[f] ±1.6 keV.

[g] ±5 keV.

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

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

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

γ_1. The results are consistent with $J^\pi = 1^+$ or 2^+. The latter is fixed by $\gamma\gamma$-correlations in the cascade $1.67 \rightarrow 0.95$ →g.s. The mixing ratio $\delta = -0.08 \pm 0.06$. *1.67 MeV*: $l_n = 0$ and therefore $J^\pi = 1^-$ or 2^-. The state decays primarily to ^{12}B(g.s.). Gamma-gamma correlations lead to $J^\pi = 2^-$. An assignment of 1^- to ^{12}B*(2.62) is made in a similar manner.

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

14. ^{11}B(^{6}Li, ^{5}Li)^{12}B $\qquad Q_m = -2.30$

See (1984KO25).

15. ^{11}B(^{7}Li, ^{6}Li)^{12}B $\qquad Q_m = -3.880$

At $E(^7$Li$) = 34$ MeV angular distributions have been studied to ^{12}B*(0, 0.95, 1.67, $2.62+2.72$, 3.39, 4.52, $5.61 + 5.73$) (1987CO16) [see for spectroscopic factors].

16. ^{11}B(^{9}Be, ^{8}Be)^{12}B $\qquad Q_m = 1.705$

See (1984DA17, 1986CU02).

17. ^{12}Be(β^-)^{12}B $\qquad$ $Q_{\rm m} = 11.708$

See ^{12}Be.

18. (a) ^{12}C $(\gamma, \pi^+)^{12}$B $\qquad$ $Q_{\rm m} = -152.938$
(b) ^{12}C(e, eπ^+)^{12}B $\qquad$ $Q_{\rm m} = -152.938$

Using monoenergetic photons with $E_\gamma = 210$ to 381 MeV (1982AR06) have measured the total cross section for π^+ emission and the spectra of the positive pions. The latter show the influence of quasi-free pion production and FSI processes. At $E_{\rm e} = 195$ to 205 MeV the π^+ energy distributions show contributions from ^{12}B*(0, 0.95, ≈ 4.5, 7.0): see (1986SH14, 1988SH36) and (1985AJ01). The 2^- and 4^- states at $E_{\rm x} \approx 4.5$ MeV have been compared with their isobaric analogs in ^{12}C at $E_{\rm x} \approx 19.5$ MeV. At $E_{\rm e} = 400$ MeV π^+ with $E_\pi = 32$ MeV have been studied: double differential cross sections are obtained for the transitions to ^{12}B*(0, 0.95, 1.67), and single differential cross sections to ^{12}B*(0, 0.95). The cross section (at $\theta = 54°$) is the same whether virtual or real photons are used in producing the pions. At $E_\gamma = 176 - 187$ MeV the giant resonance region as well as some lower groups have been studied by (1987MIZZ, 1987MI1O; prelim.). See also (1988ADZN).

19. ^{12}C(μ^-, ν)^{12}B $\qquad$ $Q_{\rm m} = 92.290$

Observations of γ-transitions have led to the determination of the capture rates to ^{12}B*(0, 0.95, 1.67, 2.62) [$J^\pi = 1^+$, 2^+, 2^-, 1^-]: see (1985AJ01). The ratio of the polarization of ^{12}B$_{\rm g.s.}$, $P_{\rm av}$, and of the longitudinal polarization leads to a neutrino helicity $h_\nu = -1.08 \pm 0.11$, in agreement with the partial conservation of axial-vector current (PCAC) hypothesis: see (1985AJ01). The polarization of ^{12}B has also been studied recently by (1984KU20): $P_{\rm av}$ is deduced to be 0.462 ± 0.053 which yields a ratio of the induced pseudoscalar to the axial vector coupling constant in the hadronic weak current, ${\rm g_p/g_a} = 10.1^{+2.4}_{-2.6}$ which is consistent with the prediction of ≈ 7 from PCAC (1984KU20). See also the "General" section here and (1988DO05).

20. ^{12}C(π^-, γ)^{12}B $\qquad$ $Q_{\rm m} = 126.199$

The photon spectrum from stopped pions is dominated by peaks corresponding to ^{12}B*(0, 4.4, 7.9), and branching ratios have been obtained for these and other transitions. That to ^{12}B$_{\rm g.s.}$ is (6.22 ± 0.35)% (absolute branching ratio per stopped pion) (1986PE05). For the earlier work see (1980AJ01).

21. ^{12}C(π^-, π^0)^{12}B $Q_{\rm m} = -8.765$

See (1987CL02) for a study of delta production at $E_{\pi^-} = 475$ MeV. See also (1989BRZX).

22. ^{12}C(n, p)^{12}B $Q_{\rm m} = -12.587$

At $E_{\rm n} = 59.6$ MeV the angular distribution of the $\rm p_0$ group is reported. Broad (unresolved) structures are also observed with $E_{\rm x} < 10$ MeV: see (1985AJ01). The $0°$ differential cross section to ^{12}B$_{\rm g.s.}$ at $E_{\rm n} = 198$ MeV has been measured. Its ratio to that for the H(n, p) reaction, R, is 0.180 ± 0.006 (1988JA01). The angular distribution to ^{12}B*(4.52) [u?] is reported at $E_{\rm n} = 300$ MeV (1987WAZY, 1989POZY; prelim.). See also (1985FO1C, 1985FR07, 1985SOZX, 1986DO12, 1986SOZY, 1987FR16, 1987HE24, 1987VE08, 1988RAZX, 1989SOZY) and (1985BR1G, 1986ALZJ, 1986FO1E, 1986VO1G, 1987BR32, 1987HE22, 1988HA1K).

23. ^{12}C(d, 2p)^{12}B $Q_{\rm m} = -14.812$

Angular distributions are reported at $E_{\rm d} = 55$ and 99.2 MeV to ^{12}B*(0, 4.5(u)) [and, at the lower energy to ^{12}B*(0.95)] [see (1985AJ01)] and at $E_{\vec{\rm d}} = 70$ MeV (1986MO27, 1988MO11; to ^{12}B*(0, 4.5(u)); also VAP, TAP) [^{12}B*(0.95, 8.2) are also populated]. See also (1986EL1C, 1987EL14).

24. ^{12}C(^{7}Li, ^{7}Be)^{12}B $Q_{\rm m} = -14.231$

At E(^{7}Li) $= 150$ MeV, giant resonances at $E_{\rm x} = 21.8 \pm 0.4$ ($\Gamma = 1.3 \pm 0.4$) and 23.9 ± 1.0 ($\Gamma = 6.0 \pm 1.0$) MeV, with $J^\pi = 3^-$ and 1^-, respectively, have been reported by (1987NA16). For the earlier work see (1985AJ01). See also (1983PU01), (1987COZZ) and (1984BA53; theor.).

25. ^{12}C(^{12}C, ^{12}N)^{12}B $Q_{\rm m} = -30.708$

At E(^{12}C) $= 35$ MeV/A forward-angle differential cross sections have been measured for the groups to ^{12}B*(0, 0.95, 1.67, 4.5[u]). A broad peak $E_{\rm x} = 7.8$ MeV is also populated (1986WI05). The groups to ^{12}B*(4.5)[u] dominate the spectra at this energy (1986WI05) and at 30 MeV/A (1986VO1J). For preliminary work at 70 MeV/A see (1988BO1R, 1989ANZZ). For a recent review of the excitation of the Δ-resonance see (1988RO1H). See also (1986BA16, 1988ANZY), (1986RO1Q, 1987AU04, 1987EL14, 1988AN06, 1988RO17, 1988VO06) and (1986BA1D, 1986DE34, 1986DU1N, 1986LE1N, 1988LE12, 1989LE03; theor.).

26. ^{12}C(^{13}C, ^{13}N)^{12}B $\qquad Q_{\rm m} = -15.590$

Differential cross sections at $\theta = 1.8^\circ$ are reported at $E(^{13}\rm C) = 30$ MeV/A for the groups to ^{12}B*(0, 0.95, 4.5[u]) and to structures at $E_{\rm x} \approx 5.5$, 7.8, 10.1 and 18.2 MeV (1987AD07). See also (1988VO08). ^{12}B*(1.67, 2.62, 3.38) are also populated (1988VO06; 0°; 29.2 MeV/A). At $E(^{13}\rm C) = 50$ MeV/A the GDR peak is located at 7.7 ± 0.1 MeV ($\Gamma_{\rm c.m.} = 1.9 \pm 0.1$ MeV). Forward-angle differential cross sections have been measured also for ^{12}B*(0, 0.95) (1989BE50) [and M. Buenerd, private communication]. See also (1986VO02, 1989VO1D).

27. ^{13}C(d, ^{3}He)^{12}B $\qquad Q_{\rm m} = -12.040$

Angular distributions have been measured for the transitions to ^{12}B*(0, 0.95) at $E_{\rm d} = 24.1$ to 29 and at 52 MeV. Distributions to ^{12}B*(2.72, 3.76, 5.00) have been reported at $E_{\rm d} = 52$ MeV: see (1980AJ01). The spectroscopic factors for ^{12}B*(0, 0.95) are $S = 1.1 \pm 0.2$ and 2.0 ± 0.5. $C^2S = 1.09$ [assuming $1{\rm p}_{3/2}$], 2.17, 0.14, 0.07, 0.22 [assuming $1{\rm p}_{1/2}$] for ^{12}B*(0, 0.95, 2.72, 3.76, 5.00) [from measurements at $E_{\rm d} = 52$ MeV]. See (1980AJ01) for references. For a summary of information on analog states of ^{12}B and ^{12}C see Table 12.12 in (1980AJ01).

28. ^{14}C(p, ^{3}He)^{12}B $\qquad Q_{\rm m} = -17.992$

At $E_{\rm p} = 54$ MeV, in addition to transitions to ^{12}B*(0, 0.95, 5.61), the population of $T = 2$ states at $E_{\rm x} = 12.72 \pm 0.07$ and 14.82 ± 0.10 MeV is reported. The angular distribution of ^{3}He ions to ^{12}B*(12.75) is fittted by $L = 0$; that to ^{12}B*(14.82) is rather featureless [its $T = 2$ character is assigned from the energies of the analog states]: both states have $\Gamma_{\rm c.m.} \lesssim 200$ keV (1976AS01). See also reaction 70 in ^{12}C.

^{12}C

(Figs. 3 and 5)

GENERAL (See also (1985AJ01)).

Shell model: (1984CA1N, 1984ZW1A, 1985AN16, 1985AR07, 1985CA23, 1985KO2B, 1985MI23, 1986YO1F, 1987JI01, 1987GU1C, 1987KI1C, 1987PR01, 1987SC1J, 1988GU13, 1988JA13, 1988OR1C, 1988WO04, 1989KW1A)

Deformed Models: (1984LO05, 1984SA37, 1985RO1G, 1986KU1P, 1986LE16, 1987HO1C, 1987PR03, 1988KH07)

Cluster Model: (1983DZ1A, 1983JA09, 1984KR10, 1985DE05, 1985KO2B, 1985KW02, 1986GU1F, 1986KA51, 1986OR1C, 1986SA03, 1986SA1D, 1986SU12, 1986ZE1A, 1987JI01, 1987KU1B, 1987MI1L, 1987WA07, 1987ZE05, 1988FL1A, 1988HA39, 1988KA1Z, 1988MI26, 1988OS04, 1988OS1E, 1988RU1C, 1989KW1A, 1989OR05)

Special states: (1984BA38, 1984CA1N, 1984CO16, 1984CO21, 1984MO13, 1984SA31, 1984SA37, 1984TR1C, 1984ZW1A, 1985CA23, 1985CH27, 1985CO05, 1985GO1A, 1985HA1J, 1985KU22, 1985PA12, 1985RO1G, 1985SHZL, 1986AN10, 1986CH25, 1986DI04, 1986HU1E, 1986KA51, 1986KH1G, 1986OR1C, 1986PA06, 1986SA03, 1986SA32, 1986SU18, 1986VO07, 1987BL18, 1987BO1L, 1987CA1E, 1987JI01, 1987KA18, 1987KI1C, 1987MA08, 1987PR01, 1987PR03, 1987SC1J, 1988AJ1C, 1988AL1D, 1988BL10, 1988GU13, 1988KW02, 1988PO1C, 1988SP1A, 1989BA60, 1989KW1A, 1989OR02, 1989OR05, 1989RO03)

Electromagnetic transactions: (1984CI1B, 1984ER06, 1984LO05, 1984MO13, 1984VA06, 1985AR07, 1985CA23, 1985GR1A, 1986AN10, 1986CH25, 1986KE1P, 1986SA32, 1986VO07, 1987CA1E, 1987ER1F, 1987RA01, 1987ST1E, 1989BA60)

Giant resonances: (1984BA38, 1984RA1H, 1985GI1G, 1985GO1A, 1985OR1F, 1986ER1A, 1986NA1H, 1987FE05, 1987GOZK, 1987KI1C, 1987MI1L, 1988CO1G, 1988HO10, 1988MI26, 1989LH02)

Astrophysical questions: (1982BA1D, 1982BU1A, 1982CA1A, 1982GR1A, 1982WO1A, 1984CO1H, 1984HA1R, 1984LA1J, 1984LI1L, 1984RA1E, 1984TR1C, 1984WE1C, 1985AR1A, 1985BR1E, 1985DW1A, 1985GU1A, 1985HA1R, 1985HE1F, 1985KH1D, 1985KO2A, 1985MI1E, 1985NO1B, 1985TA1A, 1985YO1A, 1986CH1H, 1986CO1R, 1986DO1L, 1986GO1Q, 1986KH1G, 1986LA16, 1986LA1C, 1986MA1E, 1986MA2E, 1986SM1A, 1986SN1C, 1986SN1D, 1986TH1E, 1986TR1C, 1986WI1L, 1986WO1A, 1987AL1B, 1987AR1C, 1987AU1A, 1987BE1H, 1987BO1B, 1987BR1P, 1987CU1A, 1987DO1A, 1987DW1A, 1987FU04, 1987HA1C, 1987HA1U, 1987HA1E, 1987KR1M, 1987LA1C, 1987MA2C, 1987ME1B, 1987MU1B, 1987PI1E, 1987PR1A, 1987RA1D, 1987RI1B, 1987SA1D, 1987SO1F, 1987WA1L, 1987WA1F, 1988AP1A, 1988AR1H, 1988AS1D, 1988BA86, 1988CA26, 1988CO1D, 1988CR1A, 1988CUZX, 1988DE1I, 1988DU1G, 1988FE1A, 1988FO1E, 1988JU1C, 1988KA1G, 1988MI1A, 1988PA1H, 1988RE1F, 1988SC1A, 1988TR1H, 1989BO1M, 1989CU1F, 1989DE1J, 1989GU1Q, 1989HA1O, 1989JI1A, 1989KA1K, 1989ME1C, 1989NO1A, 1989TH1C, 1989WE1G, 1989WY1A)

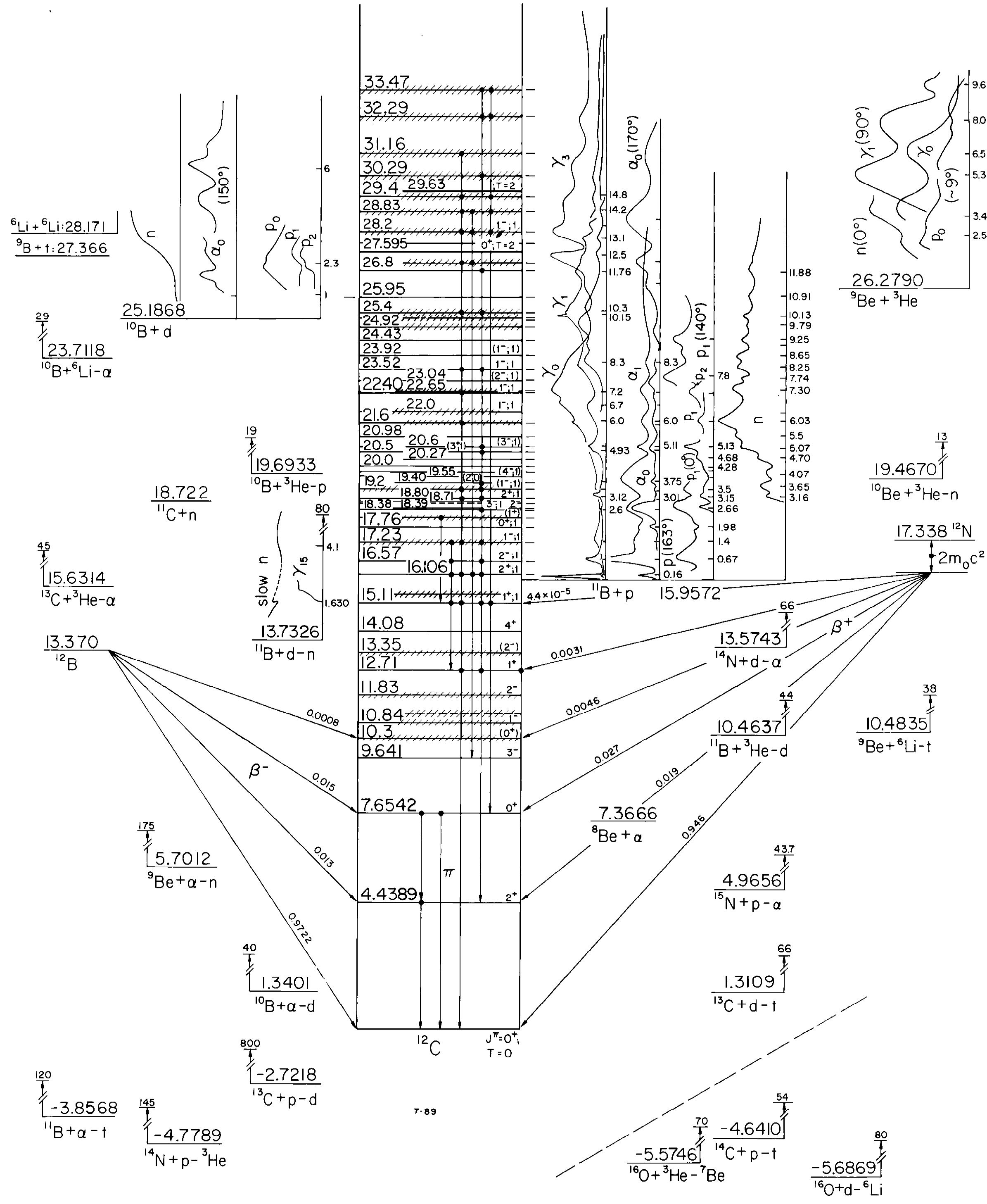

Fig. 3: Energy levels of ^{12}C. For notation see Fig. 2.

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

E_x in ^{12}C (MeV $\pm$ keV)	J^π ; T	$\Gamma_{\mathrm{c.m.}}$ (keV)	Decay	Reactions
g.s	0^+; 0	-	stable	3, 5, 6, 8, 9 ,13, 14, 15, 16, 17, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90
4.43891 ± 0.31	2^+; 0	$(10.8 \pm 0.6) \times 10^{-6}$	γ	3, 5, 6, 7, 8, 13, 14, 15, 16, 17, 20, 21, 22, 23, 24, 26, 31, 32, 34, 35, 36, 37, 38, 40, 42, 43, 44, 45, 46, 47, 48, 49, 50, 52, 53, 54, 55, 56, 60, 61, 62, 63, 64, 65, 67, 71, 72, 76, 77, 79, 80, 81, 82, 84
7.6542 ± 0.15	0^+; 0	$(8.5 \pm 1.0) \times 10^{-3}$	γ, π, α	3, 5, 6, 7, 8, 13, 15, 17, 21, 22, 23, 26, 32, 34, 36, 37, 38, 42, 43, 44, 45, 46, 47, 60, 62, 63, 72, 76, 80, 81, 82
9.641 ± 5	3^-; 0	34 ± 5	γ, α	5, 6, 7, 13, 15, 17, 20, 21, 22, 23, 31, 32, 34, 35, 36, 37, 38, 42, 43, 44, 45, 46, 47, 49, 62, 63, 80, 81, 82
10.3 ± 300	(0^+); 0	3000 ± 700	α	5, 26, 44, 60, 63
10.844 ± 16	1^-; 0	315 ± 25	α	5, 13, 20, 21, 22, 23, 36, 37, 40, 42, 43, 44, 47

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

$E_{\rm x}$ in ^{12}C (MeV ± keV)	J^π ; T	$\Gamma_{\rm c.m.}$ (keV)	Decay	Reactions
(11.16 ± 50)	(2^+); 0	430 ± 80		21
11.828 ± 16	2^-; 0	260 ± 25	γ, α	6, 13, 15, 20, 21, 22, 23, 31, 32, 36, 37, 40, 42, 43
12.710 ± 6 [b]	1^+; 0	$(18.1 \pm 2.8) \times 10^{-3}$	γ, α	6, 13, 15, 20, 21, 22, 23, 31, 32, 34, 37, 39, 40, 42, 43, 47, 60, 62, 63, 64, 65, 71, 72
13.352 ± 17	(2^-); [h] 0	375 ± 40	γ, α	13, 21, 31, 36, 37
14.083 ± 15	4^+; 0	258 ± 15	α	6, 13, 32, 36, 37, 39, 43, 47, 50, 62, 63, 71, 72, 76, 79, 80, 82
15.110 ± 3 [b]	1^+; 1	$(43.6 \pm 1.3) \times 10^{-3}$	γ, α	9, 13, 15, 20, 21, 22, 23, 32, 34, 36, 37, 40, 42, 43, 47, 60, 61, 62, 63, 64, 65, 71, 72
15.44 ± 40	$(2^+$; 0)	1500 ± 200		32, 37, 42, 43, 63
16.1058 ± 0.7	2^+; 1	5.3 ± 0.2	γ, p, α	8, 13, 17, 20, 21, 22, 23, 32, 34, 36, 37, 42, 43, 61, 62, 63, 64, 71, 76
16.57	2^-; 1	300	γ, p, α	13, 17, 19, 32, 37, 42, 63
17.23	$1^-; 1$	1150	γ, p, α	17, 19, 20, 31
17.76 ± 20	0^+; 1	80 ± 20	p, α	8, 17, 19, 32, 63, 76
18.16 ± 70	$(1^+$; 0)	240 ± 50	γ, p	17, 63
18.35 ± 50 [f]	3^-; 1	220 ± 50	γ, p, α	17, 19, 20, 21, 22, 23, 31, 42, 47
18.35 ± 50 [f]	2^-; $0 + 1$	350 ± 50	p	19, 20, 21, 22, 23, 31, 32, 34, 37, 39, 42, 47
(18.6 ± 100)	(3^-)	300		32
18.71	$(T = 1)$	100	p, α	17
18.80 ± 40	2^+; 1	100 ± 10	γ, n, p	17, 18, 19, 42, 63

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

E_x in ^{12}C (MeV ± keV)	J^π ; T	$\Gamma_{\text{c.m.}}$ (keV)	Decay	Reactions
19.2	$(1^-; 1)$	≈ 1100	γ, n, p, α	17, 18, 19, 21, 42, 62
19.40 ± 30 [f]	$(2^-; 1)$	480 ± 40	γ, p, α	17, 32, 34, 37, 39, 72
19.55 ± 50 [f, g]	$(4^-; 1)$	490 ± 60	γ, p, α	20, 21, 32, 34, 42, 72
19.69	1^+	230 ± 35	n, p	18, 34
20.0 ± 100	(2^+)	≈ 250	γ, n, p	18, 19, 32, 63
20.27 ± 50	$(1^+; 1)$	140 ± 50	n, p	18, 19, 37, 63
20.5 ± 100	$(3^+; 1)$	300 ± 50	γ, p, α	13, 17, 20, 31, 32, 62, 63, 72
20.62 ± 60	$(3^-; 1)$	200 ± 40	γ, n, p, α	17, 18, 19, 20, 21, 37, 39, 62, 63, 72
20.98		270	n, p	18
21.60 ± 100 [e]	$3^-, 2^+; 0$	1200 ± 150	γ, n, p, α	17, 18, 19, 32, 37, 39, 42, 43
22.0 ± 100	$1^-; 1$	800 ± 100 [i]	γ, n, p	18, 19, 32, 37, 39
22.40 ± 40	$1^-; 1$	275 ± 40	n, p	18, 19, 21, 37, 43, 72
22.65 ± 70	$1^-; 1$	3200	γ, n, p, α	17, 18, 27, 28, 31, 32, 34, 37, 62
23.04	$(2^-; 1)$	60	n, p	18, 62
23.52 ± 30	$1^-; 1$	230 ± 80	γ, n, p, α	8, 17, 18, 32, 37, 42
23.92 ± 80	$(1^-; 1)$	400 ± 100	γ, n, p	18, 32, 37
24.43		100	n, p	18
24.92		920	n, p	18, 32
25.3 ± 150	$(1^-; 1)$	510 ± 100	n, p	18, 37, 62
25.4	$1^-; 1$	≈ 2000 [d]	γ, n, p	17, 27, 28, 32, 42, 43, 50, 62, 63
25.95		≈ 400	n, p, d, α	10, 12, 18, 37
26.8		270	n, p, d, α	12, 18, 32
27.0 ± 300	$(1^-; 1)$	1400 ± 200	γ, p	17, 37, 40, 43
27.5950 ± 2.4	$0^+; 2$	≤ 30		8, 70
27.9		≈ 350	γ, n, p, ^{3}He	4, 17, 32
28.2	$1^-; 1$	1600	γ, ^{3}He	3

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

E_x in ^{12}C (MeV ± keV)	J^π ; T	$\Gamma_{\rm c.m.}$ (keV)	Decay	Reactions
28.83 ± 40		1540 ± 90	γ, p, d, ^{3}He, α	3, 12, 17, 42, 43
29.4 ± 300		1400 ± 200	γ, n, p, t, ^{3}He	4, 17, 31, 37
29.63 ± 50	$T = 2$	$\lesssim 200$		70
30.29 ± 30		1960 ± 150	γ, ^{3}He, α	3, 32
31.16 ± 30		2100 ± 150	γ, ^{3}He	3
32.29 ± 40		1320 ± 230	γ, n, p, ^{3}He, ^{6}Li	1, 3, 32
33.47 ± 210		1930 ± 50	γ, ^{3}He	3
[c]				

[a] See also Table 12.7 here and Table 12.12 in (1980AJ01).

[b] See also Table 12.10.

[c] See also reactions 2 and 27.

[d] See, however, Table 12.11.

[e] Probably unresolved states: see footnote [g] in Table 12.19.

[f] See the discussion in (1983NE11).

[g] (1983BA62) suggests an isospin-mixed doublet with $J^\pi = 4^-$.

[h] Probably 4^- (D.J. Millener, private communcation). I am indebted to Dr. Millener for his comments on the states of ^{12}C.

[i] See, however, Table 12.12.

Applications: (1984CA1D, 1984HO1E, 1986BR1Q, 1986DR1E, 1986EN1A, 1986FR1H, 1986HE1F, 1986KI1J, 1986KO2E, 1986KR1F, 1986PE1F, 1986ST1K, 1986WE1E, 1987NA1D, 1987ST1C, 1988AL1K, 1988BU1C, 1988GO1M, 1988ILZZ, 1988MA1I, 1988PU1A, 1988RO1L, 1988SC1C, 1989BO1L)

Complex reactions involving ^{12}*C*: (1983AG1A, 1983AL1G, 1983AL1H, 1983BO1D, 1983EL1A, 1984AB1C, 1984AI1B, 1984AN1G, 1984BA2F, 1984CH1L, 1984DE1Q, 1984FI17, 1984GA1G, 1984HO23, 1984KA1J, 1984KA1L, 1984KO1P, 1984MA1P, 1984NA12, 1985PA08, 1984ST1B, 1984XI1B, 1985AB1F, 1985AG1A, 1985BA1V, 1985FA02, 1985GA1H, 1985GH1A, 1985GU1A, 1985HA1N, 1985JA18, 1985KA1E, 1985KAZQ, 1985KA1G, 1985KI1E, 1985KW03, 1985LI1B, 1985MC03, 1985MO02, 1985MO08, 1985NE1G, 1985PO11, 1985PO14, 1985SI15, 1985SI19, 1985ST1B, 1985TA18, 1985UT01, 1985WA22, 1986AB06, 1986AL25, 1986AV1A, 1986BA1E, 1986BA1Q, 1986BE2M, 1986BO1R, 1986BO1B, 1986BU1K, 1986CH2G, 1986CS1A, 1986GH1A, 1986GR1L, 1986GR08, 1986GR1A, 1986GR1B, 1986GU1F, 1986HA1B, 1986KI1C, 1986MA19, 1986ME06, 1986MO15, 1986PL02, 1986PO06, 1986RA1L, 1986RE13, 1986SA30, 1986SH25, 1986SH1F, 1986SO10, 1986ST13, 1986UT01, 1986VA10, 1986VA18, 1986VA23, 1986WA1H,

1986WE1C, 1987AK1A, 1987AN1C, 1987AR19, 1987BA02, 1987BA1I, 1987BA31, 1987BA38, 1987BA1T, 1987BE58, 1987BE55, 1987BO23, 1987BO1K, 1987BU07, 1987CH1L, 1987DE37, 1987DO13, 1987FA09, 1987FE1A, 1987GE1A, 1987GH1A, 1987GO17, 1987GR1O, 1987JA06, 1987KI05, 1987KO15, 1987KW02, 1987LY04, 1987MU03, 1987MU1D, 1987NA01, 1987PA01, 1987PA1D, 1987PO23, 1987RI03, 1987RO10, 1987SH23, 1987SI10, 1987SN01, 1987SO15, 1987ST01, 1987TAZU, 1987VI02, 1987VI14, 1987YA16, 1987YI1A, 1988AV03, 1988AY03, 1988BA28, 1988BO1O, 1988BR1N, 1988CA06, 1988CA27, 1988CE01, 1988DE1J, 1988EL1D, 1988FE1A, 1988GA11, 1988GA12, 1988GA31, 1988GH1A, 1988GO1F, 1988GO11, 1988GU1K, 1988HA03, 1988KH1B, 1988KHZX, 1988KH1H, 1988KI06, 1988KW1C, 1988LI1H, 1988MI28, 1988MO1K, 1988MU1E, 1988PAZS, 1988POZZ, 1988PO1F, 1988PR1C, 1988RE13, 1988RU01, 1988SA19, 1988SH03, 1988SH1H, 1988SI01, 1988SM07, 1988TE03, 1988TS03, 1988TS01, 1988UC01, 1988UT02, 1989BL1D, 1989BR35, 1989CEZZ, 1989CH28, 1989CI1C, 1989FI05, 1989GH1B, 1989GU1C, 1989HA43, 1989HA08, 1989PA06, 1989PO06, 1989SA10, 1989SE03, 1989SU05, 1989TU1A, 1989YO02)

Muon and neutrino capture and reactions: (1983GM1A, 1984KU20, 1984KU11, 1984MI11, 1984RU12, 1985AG1C, 1985AR1B, 1985BO1U, 1985GR1A, 1985KI01, 1985MAZZ, 1985PA05, 1985PA12, 1986DA1J, 1986DO06, 1986DU06, 1986FI1G, 1986KE1Q, 1986KU05, 1986LI13, 1986MA16, 1986PA06, 1987BR1L, 1987FU13, 1987HA1Q, 1987KO1P, 1987KR1L, 1987MI17, 1987SU06, 1987VA1P, 1988AL1O, 1988BO1X, 1988BR24, 1988DO05, 1988FU08, 1988MI11, 1988MI20, 1989AR1I, 1989DR1A, 1989GM1A, 1989KR1C, 1989MI1I, 1989NA01)

Pion capture and reactions (See also reactions 28 and 34): (1981HO14, 1983AB1B, 1983AB1C, 1983AG1B, 1983AK1A, 1983BU1D, 1983GM1A, 1983KO1M, 1983MA16, 1984AL1K, 1984AL1L, 1984AS05, 1984BA1L, 1984BA2L, 1984BA1M, 1984BE28, 1984BE1Q, 1984BE1R, 1984BO1L, 1984BO1H, 1984BU11, 1984CE1D, 1984CH26, 1984CO16, 1984CO1D, 1984ER06, 1984GE1A, 1984GI1D, 1984GM01, 1984GR27, 1984JI03, 1984KA31, 1984KO1P, 1984LE11, 1984LI03, 1984MA1T, 1984MA1G, 1984MA1U, 1984MI11, 1984OH04, 1984RI12, 1984RO1D, 1984SA1H, 1984SC1B, 1984TO1A, 1984ZI1B, 1985AB1E, 1985ALZX, 1985AM1B, 1985AR15, 1985AS02, 1985AZ1A, 1985AZ1B, 1985BA2F, 1985BA1V, 1985BE1C, 1985BI01, 1985BI04, 1985BU1G, 1985CO11, 1985CO16, 1985DI02, 1985FU06, 1985FU14, 1985GI05, 1985GR1E, 1985GU13, 1985KA22, 1985KO06, 1985KO2C, 1985LA20, 1985LE1E, 1985LI1E, 1985MA1G, 1985MA1K, 1985ME1M, 1985MI04, 1985MI1L, 1985MO1H, 1985MO1M, 1985OH09, 1985RI04, 1985RO17, 1985RO1M, 1985SA06, 1985SE21, 1985SM06, 1985TA17, 1985TA24, 1985TO15, 1985TO14, 1985VA17, 1986AB1J, 1986AG1C, 1986ALZL, 1986AN40, 1986AR1F, 1986AS1A, 1986BA3E, 1986BA81, 1986BA3H, 1986BE22, 1986BE2L, 1986BL05, 1986BO03, 1986BO1N, 1986CH39, 1986CH1Z, 1986CH1J, 1986CO1V, 1986CZ01, 1986DI07, 1986DU1M, 1986ER1A, 1986FA03, 1986FO03, 1986GA33, 1986GA14, 1986GH1A, 1986GI13, 1986GR1K, 1986HA34, 1986HA26, 1986IV1A, 1986KA1J, 1986KH03, 1986KI1D, 1986LAZL, 1986MC04, 1986MI25, 1986MO1M, 1986MO1J, 1986MO26, 1986NA03, 1986OS01, 1986OS1H, 1986OS03, 1986PE1L, 1986PE05, 1986PR1C, 1986PR01, 1986RA1J, 1986RO03, 1986SU18, 1986TA1T, 1986VO1H, 1986VO17, 1986WA26, 1986WH02, 1986YO05, 1986ZO1A, 1987AB12, 1987AB1E, 1987AG1C, 1987AL1I, 1987AL26, 1987AN14, 1987AP1A, 1987AR1P, 1987AS1E, 1987BA2Q, 1987BE2A, 1987BE2B,

1987BL07, 1987BO1D, 1987BO1E, 1987BO1X, 1987BU20, 1987CH21, 1987CH1N, 1987CH24, 1987CH29, 1987CL02, 1987CO20, 1987EJ02, 1987FA05, 1987GA08, 1987GA11, 1987GI01, 1987GI1B, 1987GI1C, 1987GM02, 1987GM04, 1987GU07, 1987GU1I, 1987HA40, 1987HE04, 1987HO08, 1987HU13, 1987JO1B, 1987KA39, 1987KH1B, 1987KO30, 1987LE1B, 1987LO1F, 1987MA1I, 1987MA1Z, 1987MO1M, 1987NA04, 1987PI1B, 1987RA1H, 1987ST1E, 1987WE1A, 1987WU1B, 1988AB05, 1988AB1G, 1988AM04, 1988BA2G, 1988BE1V, 1988BE2D, 1988BE2F, 1988BU16, 1988CH49, 1988CH24, 1988CH31, 1988CU1C, 1988DH1A, 1988ER04, 1988ER1B, 1988FR02, 1988FR1D, 1988FR10, 1988FR1J, 1988GIZU, 1988GO13, 1988GO08, 1988GO14, 1988GR1E, 1988HA07, 1988HA12, 1988EL06, 1988IT02, 1988JO1E, 1988KH01, 1988KIZW, 1988KY1A, 1988LE1G, 1988MA27, 1988MA37, 1988MO23, 1988OH04, 1988OS1A, 1988PE1F, 1988PO1H, 1988RA1H, 1988RO1M, 1988SA24, 1988SA31, 1988WI1B, 1988WI1I, 1988YOZZ, 1989AR1K, 1989BA06, 1989BA1R, 1989BRZX, 1989EJ1A, 1989EN1B, 1989GH1B, 1989GO09, 1989GR06, 1989HA07, 1989KH01, 1989MO1D, 1989NA01)

Kaons and other mesons-capture and reactions (see also reaction 35): (1983AK1A, 1983AR1F, 1983GE1C, 1983TO21, 1984AB04, 1984AL1H, 1984BA2L, 1984BA1M, 1984BO1H, 1984CO21, 1984GI1E, 1984IW1B, 1984MA1G, 1984SI13, 1984TO1B, 1984YA04, 1984ZO02, 1985AB1E, 1985BE31, 1985BE62, 1985CO1H, 1985CO14, 1985CO05, 1985DA1D, 1985DI06, 1985DO1G, 1985GA1E, 1985GA1C, 1985GR10, 1985IA01, 1985MI04, 1985SH1H, 1985SI09, 1985WA1N, 1985YA01, 1985YA07, 1985ZH13, 1985ZH11, 1986AB07, 1986AG1B, 1986BA3L, 1986BA81, 1986BE1P, 1986BE2J, 1986BE42, 1986BI1G, 1986CH1P, 1986CH1I, 1986CO1U, 1986DA1G, 1986DA1B, 1986DO1B, 1986FI1A, 1986GA33, 1986GA14, 1986GA1H, 1986HA1Y, 1986HA34, 1986HA26, 1986HA39, 1986HU1B, 1986KA1J, 1986KI1K, 1986KI1D, 1986KO2D, 1986MA1J, 1986MI1N, 1986MO1J, 1986PE1L, 1986TA11, 1986YA1T, 1986ZH1E, 1986ZO1A, 1987AP1A, 1987BEYQ, 1987BE14, 1987BE1S, 1987BL1L, 1987CH10, 1987EJ02, 1987FA1A, 1987HA40, 1987KO30, 1987LE1B, 1987PI1B, 1987PO1H, 1987SM1A, 1987WU1B, 1987WU05, 1988BA1F, 1988BR16, 1988CH49, 1988FA1B, 1988GA1A, 1988HA07, 1988HA41, 1988HA44, 1988KO36, 1988MA09, 1988MO1B, 1988MO14, 1988MO23, 1988PA1B, 1988PE1F, 1988PO1H, 1988RO11, 1988TA29, 1988TA14, 1988WA1B, 1988YA05, 1989BA06, 1989EJ1A, 1989HA07)

Hypernuclei: (1983SH1E, 1984AL1H, 1984AS1D, 1984BA1M, 1984BA1N, 1984BO1H, 1984MA1G, 1984MA1U, 1984MI1E, 1984SA1J, 1984ZO02, 1985AH1A, 1985GA1E, 1985GR10, 1985MI04, 1985OS1C, 1985WA1N, 1986BA3L, 1986BA1H, 1986BA81, 1986BI1G, 1986CO1U, 1986DA1G, 1986DA1B, 1986DO1B, 1986DU1M, 1986DU1P, 1986ER1A, 1986FE1A, 1986FR1J, 1986GA33, 1986GA14, 1986GA1H, 1986HA1Y, 1986HA34, 1986HA39, 1986HE01, 1986HU1B, 1986KO1A, 1986MI1N, 1986OS1G, 1986PE1L, 1986PO1H, 1986SZ1A, 1986YA1T, 1986ZO1A, 1987BA2K, 1987DA1F, 1987DA30, 1987DO1B, 1987EJ02, 1987MA08, 1987MA2A, 1987MI38, 1987PI1C, 1987PO1H, 1987RU1A, 1988BA1F, 1988BA1G, 1988BA82, 1988BO1P, 1988CH48, 1988DL1A, 1988GA1A, 1988GA1I, 1988GR1B, 1988HA07, 1988HA44, 1988MA09, 1988MA1G, 1988MO1B, 1988MO14, 1988MO23, 1988MO1L, 1988PE1F, 1988PO1H, 1988TA29, 1988WA1B, 1989BA06, 1989EJ1A, 1989KI25, 1989MR01)

Antinucleon interactions (see also reaction 38.): (1984BA39, 1984CL1C, 1984DA1J, 1984DA23, 1984DO1E, 1984GA26, 1984KR22, 1984RI1D, 1984SA1M, 1984SU07, 1984VO1D, 1985AB1E,

1985BA09, 1985BA51, 1985CA16, 1985DA1D, 1985DA06, 1985DA24, 1985DA1G, 1985DO1E, 1985DU05, 1985HE24, 1985KU04, 1985KU08, 1985LI1J, 1985NA14, 1985PI14, 1985SU11, 1985VO06, 1986AU1D, 1986BA22, 1986BO26, 1986BU1J, 1986DI04, 1986DO20, 1986DU10, 1986FR10, 1986HE05, 1986IN01, 1986JA04, 1986MA46, 1986MC04, 1986MO1J, 1986SP01, 1986ZA06, 1987BA21, 1987BE26, 1987DA12, 1987DA1D, 1987GR1I, 1987HE04, 1987IS03, 1987MA04, 1987MA46, 1987SM1A, 1987VO1B, 1987YA1E, 1987ZA08, 1988DA07, 1988DE40, 1988GO13, 1988LI1O, 1988OK03, 1989AR1K, 1989CH13, 1989MA24, 1989MU1D)

Other topics: (1984CH1L, 1984CL11, 1984CO16, 1984GR18, 1984JE02, 1984LO05, 1984SH1X, 1985AN28, 1985AR07, 1985AR1B, 1985BU1F, 1985CI04, 1985KE1G, 1985KU22, 1985PA1M, 1985SHZL, 1985TH1D, 1986AL1T, 1986BE23, 1986BE39, 1986BI01, 1986DU06, 1986FO03, 1986KU11, 1986KE1P, 1986KU1B, 1986KU1P, 1986SA02, 1986SH2E, 1986WE1G, 1986YA1F, 1987AB21, 1987FUZZ, 1987HO07, 1987KU1I, 1987MO14, 1987PR01, 1987ZE05, 1988BO04, 1988FL1A, 1988HA38, 1988JA13, 1988KW02, 1988MO1H, 1988OH01, 1988OR1C, 1988OS1E, 1988RO18, 1988RU1B, 1989BA60, 1989CE01, 1989FI04, 1989JI04, 1989OR02, 1989RE1C, 1989RO01)

Ground-state properties of ^{12}*C*: (1984AN1B, 1984BA2F, 1984BR25, 1984LO05, 1984RU12, 1985AN16, 1985AN28, 1985BE59, 1985CL1A, 1985GO1A, 1985KO02, 1985MI23, 1985OR01, 1985SA32, 1985SA30, 1985SH1A, 1985TA18, 1986AL1T, 1986AN35, 1986EL1A, 1986HE26, 1986KA2C, 1986KU1B, 1986LE16, 1986NI01, 1986RO03, 1986SA32, 1986SY1A, 1986WI04, 1987AB03, 1987AL05, 1987BL18, 1987BO42, 1987JI01, 1987ER1F, 1987FU1D, 1987GI1C, 1987GU1C, 1987HA30, 1987KI1C, 1987PR03, 1987RA01, 1987SA15, 1987ZE05, 1988BI1A, 1988CU1C, 1988DA1J, 1988DZ1A, 1988GU03, 1988HA38, 1988JO1C, 1988ME09, 1988OH01, 1988RA1G, 1988SP1A, 1988TA10, 1988VA03, 1988WO04, 1989BE03, 1989OR05, 1989RO01)

Isotopic abundance: (98.90 ± 0.03)% (1984DE53)

$\langle r^2\rangle^{1/2} = 2.4829 \pm 0.0019$ fm (1984RU12; charge radius). See also reaction 32.

The interaction nuclear radius of ^{12}C is 2.61 ± 0.02 fm (1985TA18). [See also for derived nuclear matter, charge and neutron matter r.m.s. radii.] See also (1989SA10).

^{12}*C*(4.44)*: $Q = 6 \pm 3$ e $\cdot$ fm^2, indicating a substantial oblate deformation (1983VE01).

1. (a) ^{6}Li(^{6}Li, n) ^{11}C $\quad Q_{\rm m} = 9.450 \quad E_{\rm b} = 28.171$
   (b) ^{6}Li(^{6}Li, p)^{11}B $\quad Q_{\rm m} = 12.214$
   (c) ^{6}Li(^{6}Li, d)^{10}B $\quad Q_{\rm m} = 2.985$
   (d) ^{6}Li(^{6}Li, α)^{8}Be $\quad Q_{\rm m} = 20.805$
   (e) ^{6}Li (^{6}Li, 2α)^{4}He $\quad Q_{\rm m} = 20.897$
   (f) ^{6}Li (^{6}Li, 2d)^{4}He^{4}He $\quad Q_{\rm m} = -2.950$
   (g) ^{6}Li(^{6}Li, ^{6}Li)^{6}Li

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

E_x (MeV)	Widths	E_x (MeV)	Widths
4.44	$\Gamma_\gamma = 10.8 \pm 0.6$ meV	15.11	$\Gamma_\gamma(15.11 \to 7.65) = 1.09 \pm 0.1$ eV [f]
7.65	$\Gamma_\pi/\Gamma = (6.8 \pm 0.7) \times 10^{-6}$		$\Gamma_\gamma(15.11 \to 12.71) = 0.59 \pm 0.14$ eV [f]
	$\Gamma_\pi = (60.5 \pm 3.9)$ μeV		$\Gamma_\gamma = 41.8 \pm 1.2$ eV [f]
	$\Gamma_{\rm rad}$ [b]$/\Gamma = (4.13 \pm 0.11) \times 10^{-4}$		$\Gamma_\alpha/\Gamma = 0.041 \pm 0.009$ [f]
	$\Gamma = 8.3 \pm 1.0$ eV		$\Gamma_\alpha = 1.8 \pm 0.3$ eV
	$\Gamma_{\rm rad} = 3.7 \pm 0.5$ meV		$\Gamma = 43.6 \pm 1.3$ eV
9.64	$\Gamma_{\rm rad}/\Gamma =< 4.1 \times 10^{-7}$	16.11 [g]	$\Gamma = 5.3 \pm 0.2$ keV
	$\Gamma_{\rm rad} < 14$ meV [c]		$\Gamma_{\gamma_0}/\Gamma_{\gamma_1} = (4.6 \pm 0.7)\%$
	$\Gamma_{\gamma_0} = (3.1 \pm 0.4) \times 10^{-4}$ eV		$\Gamma_{\gamma_1}/\Gamma = (2.42 \pm 0.29) \times 10^{-3}$
12.71	$\Gamma_{\gamma_0}/\Gamma = (1.93 \pm 0.12) \times 10^{-2}$		$\Gamma_\gamma(16.11 \to 9.64)/\Gamma_{\gamma_1} = (2.4 \pm 0.4)\%$
	$\Gamma_{\gamma_1}/\Gamma_{\gamma_0} = 0.150 \pm 0.018$ [d]		$\Gamma_\gamma(16.11 \to 12.71)/\Gamma_{\gamma_1} = (1.46 \pm 0.25)\%$
	$\Gamma_{\gamma_0} = 0.35 \pm 0.05$ eV		$\Gamma_{\gamma_0} = 0.59 \pm 0.11$ eV
	$\Gamma_{\gamma_1} = 0.053 \pm 0.010$ eV		$\Gamma_{\gamma_1} = 12.8 \pm 1.5$ eV
	$\Gamma = 18.1 \pm 2.8$ eV		$\Gamma_\gamma(16.11 \to 9.64) = 0.31 \pm 0.06$ eV
	$\Gamma_\alpha = 17.7 \pm 2.8$ eV [e]		$\Gamma_\gamma(16.11 \to 12.71) = 0.19 \pm 0.04$ eV
15.11	$\Gamma_{\gamma_0} = 38.5 \pm 0.8$ eV [h]	16.57	$\Gamma_{\gamma_0} = (48 \pm 8) \times 10^{-3}$ eV
	$\Gamma_{\gamma_1} = 0.96 \pm 0.13$ eV [f]		

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

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

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

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

[e] Assuming $\Gamma_\alpha + \Gamma_{\gamma_0} + \Gamma_{\gamma_1} = \Gamma$.

[f] Based on Γ_{γ_0} of (1983DE53) and on branching ratios of (1972AL03): ^{12}C*(15.11) →^{12}C*(0, 4.4, 7.65, 12.71) are $(92 \pm 2)\%$, $(2.3 \pm 0.3)\%$, $(2.6 \pm 0.7)\%$ and $(1.4 \pm 0.4)\%$, respectively. In addition, an undetected branching of 1.6% to ^{12}C*(10.3) is indicated by the β-decay work (1972AL03). See also (1980AJ01).

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

[h] (1983DE53).

The excitation functions for some final states in ^{11}B and ^{11}C (reactions (a) and (b)) are structureless while others (to states with $J^{\pi} = \frac{3}{2}^{-}, \frac{5}{2}^{-}, \frac{5}{2}^{+}$) exhibit pronounced structures. The most prominent of these is observed at $E(^{6}\mathrm{Li}) = 8.4$ MeV [^{12}C*(32.4)] in the p_2 and n_2 yields with a width $\Gamma_{\mathrm{c.m.}} \approx 1$ MeV (1987DO05). Reaction (d) has been studied for $E(^{6}\mathrm{Li}) = 2.4$ to 6.7 MeV in a kinematically complete experiment (1988LA11). See also 1984LA19, 1987LA25). For reactions (e) and (f) see (1983WA09). Broad structures have been observed in the elastic scattering at $E(^{6}\mathrm{Li})$ $\approx$ 13 and 26 MeV: see (1980AJ01). See also (1985AJ01), ^{6}Li and ^{8}Be in (1988AJ01), ^{11}B and ^{11}C here, (1985NO1A), (1988WE20) and (1988MC1E; applied).

2. ^{8}Be(α, γ)^{12}C $\qquad Q_{\mathrm{m}} = 7.36662$

This reaction, of great importance to nucleosynthesis, has been studied by (1985CA41, 1986LA16, 1987DE13). See also the “General” section here.

3. ^{9}Be(^{3}He, γ)^{12}C $\qquad Q_{\mathrm{m}} = 26.2790$

Observed resonances are displayed in Table 12.8. ^{12}C*(28.2) appears to be formed by s- and d-wave capture. The γ_0 and γ_2 transitions to the 0^{+} states ^{12}C*(0, 7.7) are strong and show a similar energy dependence. A strong non-resonant contribution is necessary to account for the γ_1 yield. The resonance structure appears to confirm the role of 3p3h configurations for ^{12}C excitations somewhat above the giant resonance region. The γ_3 yield is relatively unstructured: see (1980AJ01). See also (1984MAZP, 1985BL1B).

4. (a) ^{9}Be(^{3}He, n)^{11}C $\qquad Q_{\mathrm{m}} = 7.557 \qquad E_{\mathrm{b}} = 26.2790$
   (b) ^{9}Be(^{3}He, p)^{11}B $\qquad Q_{\mathrm{m}} = 10.3218$
   (c) ^{9}Be(^{3}He, d)^{10}B $\qquad Q_{\mathrm{m}} = 1.0922$
   (d) ^{9}Be(^{3}He, t)^{9}B $\qquad Q_{\mathrm{m}} = -1.087$
   (e) ^{9}Be(^{3}He, ^{3}He)^{9}Be
   (f) ^{9}Be(^{3}He, α)^{8}Be $\qquad Q_{\mathrm{m}} = 18.9124$
   (g) ^{9}Be(^{3}He, α)^{4}He^{4}He $\qquad Q_{\mathrm{m}} = 19.0043$

Excitation functions for neutrons, production cross sections for ^{11}C and polarizations have been measured for $E(^{3}\mathrm{He}) = 1.2$ to 10 MeV for several neutron groups. No sharp structure is observed but there is some suggestions from angular distribution data and excitation functions at forward angles for a structure ($\Gamma \approx 350$ keV) at $E(^{3}\mathrm{He}) \approx 2$ MeV: $E_{\mathrm{x}} = 27.8$ MeV. The total cross section for ^{11}C production shows a broad maximum, $\sigma = 113$ mb at $E(^{3}\mathrm{He}) = 4.3$ MeV. In the

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

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

[a] See (1980AJ01) for references.

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

range E(^{3}He) $= 5.7$ to 40.7 MeV it decreases monotonically. 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. No pronounced structures are reported. See also (1986SL1B; theor.).

Analyzing powers have been measured at $E(^3\vec{\text{He}}) = 33.3$ MeV for nine deuteron groups (reaction (c)). The cross section for ground-state tritons (reaction (d)) increases monotonically for E(^{3}He) $= 2.5$ to 4.2 MeV and then shows a broad maximum at E(^{3}He) ≈ 4.5 MeV.

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

Excitation functions for the α_0 group (reaction (f)) have been reported for E(^{3}He) $= 2$ to 10 MeV. Analyzing powers have been measured at $E(^3\vec{He}) = 33.3$ MeV. For reaction (g) see (1986LA26, 1987WA25).

See also (1968AJ02, 1975AJ02, 1980AJ01, 1985AJ01) for references and for additional work, ^{11}B and ^{11}C here, and ^{8}Be, ^{9}Be, ^{9}B and ^{10}B in (1988AJ01).

5. ^{9}Be(α, n) ^{12}C $\qquad Q_m = 5.7012$

Neutron groups have been observed to ^{12}C*(0, 4.4, 7.7, 9.6, (10.1), (10.8)). Angular distributions have been measured at many energies in the range $E_\alpha = 1.75$ to 23 MeV [see (1968AJ02, 1975AJ02)] and at 28 and 32 MeV (1985GUZQ; prelim.; $n_{0\to3}$). [The work at $E_\alpha = 35$ MeV reported in (1985AJ01) has not been published: see, however, Fig. 1 in (1986AS02).] See also (1985CA41, 1988CA26; astrophysics) and (1986PH1C, 1987TC1A; applications).

6. ^{9}Be(^{6}Li, t)^{12}C $\qquad Q_{\rm m} = 10.4835$

At $E(^{6}\rm Li) = 32$ MeV angular distributions have been studied to ^{12}C*(0, 4.4, 7.7, 9.6, 10.8, 11.8, 12.7, 14.1). There is no indication of the $T = 1$ states. ^{12}C*(9.64) is relatively strongly populated (1986AS02; FRDWBA). See also (1980AJ01).

7. ^{9}Be(^{9}Be, ^{6}He)^{12}C $\qquad Q_{\rm m} = 5.103$

See (1985AJ01).

8. ^{10}Be(^{3}He, n)^{12}C $\qquad Q_{\rm m} = 19.4670$

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).

9. ^{10}B(d, γ)^{12}C $\qquad Q_{\rm m} = 25.1868$

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

10. (a) ^{10}B(d, n)^{11}C $\qquad Q_{\rm m} = 6.4650 \qquad E_{\rm b} = 25.1868$

(b) ^{10}B(d, p)^{11}B $\qquad Q_{\rm m} = 9.2296$

The thin-target excitation function in the forward direction (reaction (a)) in the range $E_{\rm d} = 0.3$ to 4.6 MeV shows some indication of a broad resonance near $E_{\rm d} = 0.9$ MeV. Above $E_{\rm d} = 2.4$ MeV, the cross section increases rapidly to 210 mb/sr at 3.8 MeV, and then remains constant to 4.6 MeV. Excitation functions have also been measured for $E_{\rm d} = 3.2$ to 16.0 MeV. Thick target yields for 4.3 MeV γ-rays for $E_{\rm d} = 111$ to 170 keV have also been studied and astrophysical S-factors have been calculated. In reaction (b) yields of protons have been measured for $E_{\rm d} = 91$ keV to 12 MeV: no clear resonance structure is observed.

See also ^{11}B, ^{11}C here and (1968AJ02, 1975AJ02, 1985AJ01).

11. ^{10}B(d, d)^{10}B $E_{\rm b} = 25.1868$

The yield of elastically scattered deuterons has been measured for $E_{\rm d} = 1.0$ to 2.0 MeV (there is some suggestion of resonances) and for $E_{\rm d} = 14.0$ to 15.5 MeV. Excitation functions for the deuterons to ^{10}B*(1.74, 2.15) [J^π; $T = 0^+$; 1 and 1^+; 0, respectively] have been measured at several angles for $E_{\rm d} = 4.2$ to 16 MeV: they are characterized by rather broad, slowly varying structure: see (1980AJ01) [see also for polarization measurements]. See also ^{10}B in (1988AJ01).

12. ^{10}B(d, α)^{8}Be $Q_{\rm m} = 17.8202$ $E_{\rm b} = 25.1868$

Excitation functions have been measured for the α_0 and α_1 groups for $E_{\rm d} = 0.4$ to 12 MeV. Broad maxima in the α_0 yield are reported at $E_{\rm d} \approx 1$ ($\Gamma \approx 0.5$), 2 and 4.5 MeV ($\Gamma \gtrsim 1$ MeV) as well as, possibly, at 6 MeV. Involvement of the isoscalar giant quadrupole resonance [$E_{\rm x} \approx 28$ MeV, $\Gamma \approx 4$ MeV] is suggested: see (1980AJ01). See also ^{8}Be in (1988AJ01) and (1988KA1M; theor.).

13. (a) ^{10}B(^{3}He, p)^{12}C $Q_{\rm m} = 19.6933$
(b) ^{10}B(^{3}He, pα)^{8}Be $Q_{\rm m} = 12.3267$

Table 12.9 displays the proton groups observed in this reaction , and the work on their α-decay. For a study of the charge-dependent matrix element between ^{12}C*(12.7, 15.1) see Table 12.10.

14. ^{10}B(α, d)^{12}C $Q_{\rm m} = 1.3401$

Angular distributions have been measured at $E_\alpha = 15.1$ to 25.2 MeV [see (1980AJ01)], 29.5 MeV (1983VA28; $\rm d_0$, $\rm d_1$) and 31.2 MeV (1984KO1Q; $\rm d_0$, $\rm d_1$). For $\rm d\gamma_{4.4}$ angular correlation studies see (1987VA04, 1988IG04, 1988VA1D). See also (1984BE23; theor.).

15. ^{10}B(^{6}Li, α)^{12}C $Q_{\rm m} = 23.7118$

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

16. ^{10}B(^{14}N, ^{12}C)^{12}C $Q_{\rm m} = 14.9144$

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

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

[a] For references and additional information see Table 12.10 in (1980AJ01). The present table incorporates the results of ref. (c) in Table 12.9 of (1985AJ01) which has not been published.

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

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

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

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

$\Gamma_{\text{c.m.}}$	Reaction
110 ± 30 keV	^{10}B(^{3}He, p)
285 ± 30 keV	^{10}B(α, d)
$130 \rightarrow 165$ keV	^{12}C(e, e)
148 ± 29 keV	^{12}C($\pi^\pm$, $\pi^\pm$)
324 ± 33 keV	^{12}C(d, d)
180 ± 80 keV	^{13}C(d, t)
120 ± 30 keV	^{13}C(d, t)
340 ± 60 keV	^{13}C(^{3}He, α)

[a] See also reactions 44 and 86 in (1980AJ01). For references see (1985AJ01).

Angular distributions involving ^{12}C*(0, 4.4) have been measured at several energies, to $E(^{14}\text{N}) = 93.6$ MeV: see (1980AJ01). See also (1984MA1R).

17. (a) ^{11}B(p, γ)^{12}C $\quad Q_{\text{m}} = 15.9572$
(b) ^{11}B(p, α)^{8}Be $\quad Q_{\text{m}} = 8.5906$ $\quad E_{\text{b}} = 15.9572$
(c) ^{11}B(p, α)^{4}He^{4}He $\quad Q_{\text{m}} = 8.6825$

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

(a) In the range $4 < E_{\text{p}} < 14.5$ MeV $\sigma(\gamma_0)$ is dominated by the great dipole resonance at $E_{\text{p}} = 7.2$ MeV ($E_{\text{x}} = 22.6$ MeV, $\Gamma_{\text{c.m.}} = 3.2$ MeV), while the giant resonance in γ_1 occurs at $E_{\text{p}} \approx 10.3$ MeV ($E_{\text{x}} = 25.4$ MeV, $\Gamma_{\text{c.m.}} \approx 6.5$ MeV). Absolute cross section measurements from $E_{\text{p}} = 5$ to 14 MeV suggest that dσ/d$\Omega(90°)_{\text{L}} = 13.1 \pm 1.3$ μb/sr be used as a standard at the $E_{\text{p}} = 7.25$ MeV peak of the GDR.

A study of the giant dipole resonance region with polarized protons ($E_{\text{p}} = 6$ 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 $(1^-, 2^-)$. The 90° yield of γ_0, γ_1, γ_2 and γ_3 [to ^{12}C*(0, 4.4, 7.7, 9.6)] has been studied by (1977SN01): the γ_2 yield shows a peak at $E_{\text{p}} \approx 14.3$ MeV with a cross section $\approx 2.3\%$ that of γ_0 [in γ_0 yield, $E_{\text{res}} = 15.0$ MeV (1977SN01)] and perhaps as well a low intensity structure at $E_{\text{p}} = 11.8$ MeV. The γ_3 yield exhibits two asymmetric peaks at $E_{\text{p}} = 12.5$ and 13.8 MeV ($\Gamma \approx 0.7$ and 2.5 MeV) and a weaker structure at ≈ 9.8 MeV (1977SN01).

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

Peak number	$E_{\rm p}$ (MeV)	$\Gamma_{\rm c.m.}$ (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)	$\Gamma_{\rm p}$ (keV)	^{12}C* (MeV)	$J^\pi; T$
1	0.162 [b]	5.3 ± 0.2	5.5	152	res.	res.	0.58 [c]	12.6 ± 1.8 [c]	0.290 ± 0.045	(6.3 ± 0.5)	$0.0217\pm$ 0.0018	$16.1058\pm$ 0.0007	$2^+; 1$
2	0.675	300	non-res.	48	non-res.	600	< 0.4	8.0	< 0.27	150	150	16.576	$2^-; 1$
3	1.388	1150	[27] [d]	3	3.3	≈ 180	44	5	10	140	1000	17.230	$1^-; 1$
4	2.00 [e]	96 ± 5	non-res.	non-res.	9.0	(25)			4.6	11.4	76	17.79	$0^+; 1$
5	2.37	600 ± 1000		0.77 [f]								18.13	$(1^+; 0)$
6	2.64 [g]	≈ 400	weak?	res.	32.4 ± 4.8	270 ± 40	$\approx 2 \times 10^{-3}$	3.2	65	177	68	18.38	$3^-; 1$
7	2.66	43	non-res.	non-res.	non-res.	non-res.	< 0.5	< 0.5	< 1	< 5	33	18.39	0^-
8	3.01	100	non-res.	non-res.	3.4						< 10	18.71	n.π.[j]; (1)
9	3.12	100	weak	[20] [d]	non-res.	non-res.	(0.4)	2.0	< 0.2	< 1.5	97	18.81	$2^+; 1$
10	3.5	1100	[20] [d]	res.	5.2	res.	25	10	50	200	300	19.2	$(1^-; 1)$
11	3.75	(1100)	non-res.	res.	7.4 ± 1.1	300 ± 40	< 3	3	20	450	450	19.39	$(2^+; 0)$
12	4.93	180	non-res.	res.	res.	170 ± 40						20.47	
13	5.11	275	non-res.	[35] [d]	6.0 ± 0.9	non-res.						20.64	$(3^-; 1)$
14	5.85	300			res.							(21.31)	
15	6.0		res.	non-res.	res.							21.5	
16	6.7	500	res.	[35] [d]	res.							22.1	
17	7.25	3200	120	non-res.		res.	≥ 2500 [i]					22.6	$(1^-; 1)$
18	8.3		res.	res.	res.							23.6	
19	10.3	≈ 6500	[60] [d]	83								25.4	
20	11.76 [k]		non-res.	45 [h]	res.							26.72	(1^-)
21	12.5 [l]	≈ 700	21 [h]	non-res.								27.4	
22	13.0	≈ 6000			res.							27.9	
23	13.09		19 [h]	38 [h]								27.94	
24	13.8 [l]	≈ 2500	non-res.	25 [h]								28.6	
25	14.3 [k]		16 [h]	non-res.								29.0	
26	14.8	broad	res.									29.5	

[a] For references see (1975AJ02, 1980AJ01). See also (1985KI16; theor.).

[b] $E_{\rm res.}({\rm c.m.}) = 148.6 \pm 0.4$ keV. This is the mean of the two values quoted in reaction 17.

[c] See Table 12.7.

[d] Estimated.

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

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

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

[h] $4\pi \times \sigma(90°)$.

[i] Assuming a single resonance.

[j] Natural parity.

[k] Resonant in γ_2.

[l] Resonant in γ_3.

At $E_{\vec{p}} = 50$ MeV, angular distributions and analyzing power measurements are reported to ^{12}C*(0, 4.4, 9.6, 18.8 ± 0.5 [u], 22.3 ± 1.0 [u]) by (1985NO01) [u = unresolved]. Measurements are also reported at $E_{\vec{p}} = 28.5$ MeV (1984BL10) and 40 to 80 MeV (1986EJ1A, 1986SH1Y; prelim., γ_0, γ_1). (1988HA04) have studied the γ_0 group for $E_{\vec{p}} = 20$ to 100 MeV. See also (1985HA05). In earlier work (1982WE08) studied the γ_0 and γ_1 yields for $E_{\rm p} = 8$ to 60 MeV and the γ_{19} yield for $E_{\rm p} = 23$ to 60 MeV. Giant resonances based on various states of ^{12}C have been reported at $E_{\rm x} = 22.5$ and 25.5 MeV [γ_0], 25.5, 27.4 and (31) MeV [γ_1], 27.4, 31 and (37) MeV [γ_3], as well as in the γ-yield to higher states: see (1985AJ01). The γ_{19} yield shows a structure at $E_{\rm p} \approx 43$ MeV (1983AN16; $E_{\rm p} = 18$ to 45 MeV; also γ to ^{12}C*(0, 4.4, 9.6, 12.7 [u], 15.5 [u]).

(b) Excitation functions have been measured for $E_{\rm p} = 3.0$ to 24 MeV: see (1980AJ01, 1985AJ01) and Tables 12.11 and 12.12 here.

(c) This reaction has been studied at energies to 20 MeV. The cross sections for the reactions vie ^{8}Be$_{\rm g.s.}$ and ^{8}Be*(2.9) [α_0, α_1] have been determined for $E_{\rm c.m.} = 22$ to 1100 keV. The total cross section shows the 162 keV resonance and a broad peak centered at 600 keV. At $E_{\rm c.m.} = 300$ keV $\sigma(\alpha_0) = 1.03 \pm 0.06$ mb and $\sigma(\alpha_1) = 165 \pm 10$ mb (1987BE17). The parameters of the 162 keV resonance are $E_{\rm res}(\rm c.m.) = 148.3 \pm 0.1$ keV, $\Gamma_{\rm c.m.} = 5.3 \pm 0.2$ keV (1987BE17), 149.8 ± 0.2 keV, $5.2^{+0.5}_{-0.3}$ keV (1979DA03). Derived S-values lead to $S(0) = 197 \pm 12$ MeV $\cdot$ b (1987BE17). This reaction is of possible interest for fusion reactors.

See also ^{8}Be in (1988AJ01), (1985NO1G, 1986KU18), (1984BR1L, 1984SN01, 1985DO1F, 1986SN1B, 1986WE1D, 1988HA1W), (1983SG1B, 1984HA1J, 1986KA1U, 1986PR1D, 1986ZI01, 1988KI1C; applications), (1983HA1B, 1984YA1A, 1985CA41, 1987AS05, 1988CA26; astrophysics) and (1984CA18, 1984SE16, 1985GO1B, 1985KI16, 1985RA10, 1987AS05, 1987KI1C, 1987KO1X; theor.).

The parameters of the observed resonances are displayed in Table 12.11. The following summarizes the information on the low-lying resonances: for a full list of references see (1968AJ02, 1980AJ01, 1985AJ01).

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

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

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

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

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

Peak number	A			B			J^{π}	E_{x} (MeV)
	E_{p} (MeV)	Γ_{lab} (keV)	res. in	E_{p} (MeV)	Γ_{lab} (keV)	res. in		
1				0.67	330	p_0	2^-	16.57
2				1.4		p_0	1^-	17.24
3				1.98		p_0	0^+	17.77
4	2.664	48		2.66	47	$\mathrm{p}_0, \mathrm{p}_1$		18.40
5	3.16	100		3.15	100	$\mathrm{p}_0, \mathrm{p}_1$		18.85
6	3.5	500		3.4	500	p_1		19.1
7	3.78	50		3.78	50	$\mathrm{p}_0, \mathrm{p}_1$		19.42
8	4.08	200	n_0					19.69
9	4.28	100		4.28	100	p_1		19.88
10	4.68	170	n_0	4.68 [c]	330 ± 40	$\mathrm{p}_0, \mathrm{p}_1$	$1^+; 1$	20.24
11	5.065	190	n_0	5.10 [c, d]	350 ± 15	$\mathrm{p}_0, \mathrm{p}_1$	$3^-; 1$	20.61
12	5.49	400	n_0					20.98
13	6.02	560	$\mathrm{n}_0, \mathrm{n}_1$	6.08 [c]	290 ± 25	$\mathrm{p}_0, \mathrm{p}_1, \mathrm{p}_2$	3^-	21.50
14	6.4	wide	n_0	6.58 [c]	7800 ± 1100	$\mathrm{p}_0, \mathrm{p}_2, \mathrm{p}_3$	$1^-; 1$	22.00
15	≈ 7.0	340	n_0	7.11 [c]	720 ± 90	$\mathrm{p}_0, \mathrm{p}_2, \mathrm{p}_3$	3^-	22.47
16	7.29	360	$\mathrm{n}_0, \mathrm{n}_1$					22.63
17	7.74	65	$\mathrm{n}_0, \mathrm{n}_1$					23.04
18	8.25	380	$\mathrm{n}_0, \mathrm{n}_1$					23.51
19	8.65	180	$\mathrm{n}_0, \mathrm{n}_2$					23.88
20	9.0 [b]							24.2
21	9.25	110	$\mathrm{n}_0, \mathrm{n}_2$					24.43
22	9.79	1000	$\mathrm{n}_0, \mathrm{n}_1$					24.92
23	10.14	180	$\mathrm{n}_0, \mathrm{n}_2$					25.24
24	10.91	440	n_0					25.95
25	11.88	300						26.83

A: From the (p, n) reaction.
B: From the (p, p) reaction.

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[a] See also Tables 12.11 in (1968AJ02), 12.13 in (1980AJ01) and 12.12 in (1985AJ01) for additional work. The earlier references are listed there.

[b] Also resonance in $K_{\mathrm{y}}^{\mathrm{y}}(0°)$.

[c] (1983BO19). R-matrix analysis.

[d] See also α-decay in Table 12.11.

to ^{12}C*(12.71): $\Gamma_\gamma = 3.7 \pm 1.5$ eV. The angular distribution is isotropic, as expected.

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

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

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

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

The structure near $E_{\rm p} = 3.5 - 3.7$ MeV [^{12}C*(19.2, 19.4)] seems to require at least two levels. The large Γ_{γ_0} requires that one be $J^\pi = 1^-$, $T = 1$ and interference terms in $\sigma(\alpha_0)$ require another to have even spin and even parity: $J^\pi = 2^+$, $T = 0$ is favored. (1982WR01) report that they do not observe any evidence for an isospin mixed doublet near $E_{\rm x} = 19.5$ MeV [$E_{\rm p} = 2.9$ to 4.6 MeV (60° and 90°)]. Resonances at $E_{\rm p} = 4.93$ and 5.11 MeV, seen in $\sigma(\gamma_1)$ also appear in $\sigma(\alpha_1)$, but not in $\sigma(\alpha_0)$. Angular distributions suggest $J^\pi = 2^+$ or 3^- for the latter [^{12}C*(20.64)]; the strength of γ_1 and absence of γ_0 favors $J^\pi = 3^-$, $T = 1$.

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

18. ^{11}B(p, n)^{11}C $\quad Q_{\rm m} = -2.7646 \quad E_{\rm b} = 15.9572$

Excitation functions have been studied from threshold to 27.5 MeV [see (1980AJ01, 1985AJ01)] and at $E_{\rm p} = 13.7$ to 14.7 MeV (1985SC08; $\rm n_0 \rightarrow n_3, n_{4+5}, n_6, n_7$) and 16 to 26 MeV (1985GR09; $\rm n_0 \rightarrow n_3$). See also (1986AI04). At the lower energies many resonances are observed: see Table 12.12.

Polarization measurements have been carried out for $E_{\vec{\rm p}} = 7.0$ to 26.5 MeV [see (1980AJ01, 1985AJ01)]. For high-energy interactions see (1984BA1R, 1984BA1U). See also ^{11}C, (1989RA09), (1985CA41; astrophysics) and (1985RA10; theor.).

19. (a) ^{11}B(p, p)^{11}B $\quad E_{\rm b} = 15.9572$

(b)^{11}B(p, d)^{10}B $\quad Q_{\rm m} = -9.2296$

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

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

[a] See Tables 12.14 in (1980AJ01) and 12.13 in (1985AJ01) for the earlier references. Please note that the 1980 table also displays the S_{rel} obtained in several studies. See also the newer review by (1983NE11).

[b] (d, n): see also Table 12.12 in (1968AJ02).

[c] (^{3}He, d): see also Table 12.13 in (1968AJ02).

[d] There is some evidence that this state decays primarily by α_0 (1965OL01).

[e] This state decays by α-emission to ^{8}Be*(2.9) [90%] and to ^{8}Be$_{\text{g.s.}}$ [10%] (1965OL01).

[f] Decays via α_1 to ^{8}Be*(2.9) (1965OL01, 1985NE01).

[g] Not reported in (d, n): see Table 12.14 in (1980AJ01).

[h] From a study of slow neutron thresholds at $E_d = 1.627 \pm 0.004$ and ≈ 4.1 MeV [$E_x = 15.107$ and 17.2 MeV (broad)]. In another study at the lower threshold [$E_d = 1.633 \pm 0.003$ MeV, $E_x = 15.112$ MeV, $\Gamma < 2$ keV] 15.1 MeV γ-rays are observed: see (1980AJ01) for references.

[i] Decays 3% via α_0 and 97% via α_1 (1985NE01).

[j] Not reported in (^{3}He, d): see Table 12.14 in (1980AJ01).

[k] Strong and broad neutron groups to ^{12}C*(18.38, 19.55, 20.62) have been reported by (1985NE01, 1983NE11). The decay of ^{12}C*(18.38) is reported to be 5% via α_0, 32% via α_1, 63% via p_0; ^{12}C*(19.55) 1% α_0, 41% α_1, 52% p_0, 6% p_1; ^{12}C*(20.62) 2% α_0, 30% α_1, 56% p_0, 12% p_1 (1985NE01). ^{12}C*(19.55) is composed of at least two states separated by ≈ 300 keV, the lower of which α-decays. The p_0 angular correlation suggests (2^-).

[l] (1983NE11) find that this group is due to unresolved states with $J^\pi; T = 3^-; 1$ and 2^-; $T = 0 + 1$.

[m] A broader α-decaying region may lie under this peak (1985NE01).

Anomalies and maxima observed in the excitation functions of $\mathrm{p}_0 \rightarrow \mathrm{p}_3$ are displayed in Table 12.12. Studies of the scattering have been reported at $E_\mathrm{p} = 1.8$ to 47.4 MeV [see (1980AJ01, 1985AJ01)] and at $E_\mathrm{c.m.} \approx 0.15$ to 1.1 MeV (1987BE17; p_0). A study of the yield of γ-rays is reported to lead to ^{12}C*(18.98, 19.93, 20.63) (1988ABZW; prelim.). A review of the evidence on the states with $20.2 < E_\mathrm{x} < 22.5$ MeV suggests that in all the channels and throughout this energy range a strong 2^+ background is observed, which may be the low-energy tail of the isoscalar giant quadrupole resonance (1983BO19). For polarization measurements [$E_\mathrm{p} = 1.9$ to 155 MeV] see (1975AJ02, 1980AJ01, 1985AJ01). For reaction (b) see (1985AJ01) and ^{10}B in (1988AJ01). For studies of high-energy interactions see (1984BA1U, 1984BA1T). See also (1985MUZZ), (1986BA88) and (1985RA10, 1987RA14; theor.).

20. ^{11}B(d, n)^{12}C $\qquad Q_\mathrm{m} = 13.7326$

Reported neutron groups are displayed in Table 12.13. Angular distributions have been studied for $E_\mathrm{d} = 0.5$ to 12 MeV [see (1968AJ02, 1975AJ02, 1985AJ01)] and at $E_{\vec{\mathrm{d}}} = 79$ MeV (1985FO05, 1987FO22); to ^{12}C*(0, 4.4, 9.6, 12.7, 15.1; DWBA-EFR). For polarization measurements see (1987FO22, 1986FO08) and ^{13}C in (1991AJ01). For angular correlation studies see (1980AJ01) and (1985NE01) [Table 12.13].

21. ^{11}B(^{3}He, d) ^{12}C $\qquad Q_\mathrm{m} = 10.4637$

Observed deuteron groups are displayed in Table 12.13. Angular distributions have been studied at $E(^3\mathrm{He}) = 5.1$ to 44 MeV [see (1975AJ02, 1980AJ01)] and at 18.3 and 22.3 MeV (1988IG03; d_0, d_1; also $\mathrm{d}_1\gamma$ angular correlations). See also (1987BA2B, 1987ZE02; theor.).

22. ^{11}B(α, t)^{12}C $\qquad Q_\mathrm{m} = -3.8568$

Angular distributions have been studied in the range $E_\alpha = 15.1$ to 120 MeV [see (1980AJ01, 1985AJ01)] and at $E_\alpha = 30.1$ (1983VA28; t_0, t_1, t_2) and 31.2 MeV (1984KO1Q; t_0, t_1). Angular correlation measurements (t_1, γ) are reported at $E_\alpha = 21$ to 30 MeV: see (1987VA04, 1988IG04, 1988VA1D). See also (1987LE33) and (1984BE23, 1985ZE04, 1987BA2B, 1987ZE02, 1989BA90; theor.).

23. ^{11}B(^{7}Li, ^{6}He)^{12}C $\qquad Q_\mathrm{m} = 5.9826$

At $E(^7\text{Li}) = 34$ MeV, angular distributions have been measured for the groups to ^{12}C*(0, 4.4, 7.7, 9.6, 10.8, 11.8, 12.7, 15.1, 16.1, 18.35) (1983NE11). It is concluded on the basis of this and other work, that the group corresponding to $E_x = 18.35 \pm 0.05$ MeV ($\Gamma = 350 \pm 50$ keV) consists of unresolved states with $J^\pi = 3^-$ $(T = 1)$ and 2^- $(T = 0$ plus some mixing of $T = 1)$ (1983NE11; see for spectroscopic factors): no states were observed with $E_x > 18.35$ MeV. See also (1987CO16, 1988BEYJ).

24. ^{11}B(^{11}B, ^{10}Be)^{12}C $\quad Q_m = 4.7293$

Angular distributions involving ^{12}C*(0, 4.4) and ^{10}Be*(0, 3.4) have been measured at $E(^{11}\text{B}) = 11$ MeV (1985PO02).

25. (a) ^{11}B(^{14}N, ^{13}C)^{12}C $\quad Q_m = 8.4066$
(b) ^{11}B(^{16}O, ^{15}N)^{12}C $\quad Q_m = 3.8297$

See (1980AJ01). See also (1984CL09; theor.).

26. ^{12}B(β^-)^{12}C $\quad Q_m = 13.370$

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

^{12}C*(7.7) [$J^\pi = 0^+$] is of particular interest for helium burning processes in stars: $\Gamma_{\text{rad}} = 3.41 \pm 1.12$ meV. A search for transitions to ^{12}C*(12.7) has been unsuccessful: see (1968AJ02, 1975AJ02). The shapes of the β-spectra of ^{12}B and ^{12}N have been analyzed.

The results are in agreement with CVC and with the absence of second-class induced tensor currents: see (1980AJ01). See also reaction 60 here.

27. (a) ^{12}C(γ, n)^{11}C $\quad Q_m = -18.722$
(b) ^{12}C(γ, 2n)^{10}C $\quad Q_m = -31.8419$

The total absorption, mainly (γ, n) + (γ, p), is dominated by the giant resonance peak at 23.2 MeV, $\Gamma = 3.2$ MeV [$\sigma_{\text{max}} = 21$ mb] and by a smaller structure at 25.6 MeV, $\Gamma \approx 2$ MeV [$\sigma_{\text{max}} \approx 13$ mb]: see (1968AJ02, 1975AJ02, 1980AJ01) for a detailed listing of the earlier references and results. See also (1984GH1A, 1985GH1B).

The (γ, n) cross section shows a giant resonance, $\sigma_{\text{max}} \approx 7 - 8$ mb, centered at about 23 MeV and consisting of an $\approx$ 1 MeV-wide group at 22.3 MeV and an $\approx$ 2 MeV-wide group at

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

Decay to ^{12}C (MeV ± keV)	Branch (%)	Log ft [f]
g.s.	97.22 ± 0.30	4.066 ± 0.002
4.43891 ± 0.31	1.283 ± 0.04 [d]	5.108 ± 0.014
	1.182 ± 0.019 [e]	5.143 ± 0.007
7.6543 ± 2.1 [b]	1.5 ± 0.3	4.13 ± 0.09
10.3 ± 300 [c]	0.08 ± 0.02	4.2 ± 0.2

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

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

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

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

[e] (1981KA31).

[f] Based on $Q_{\rm m}$ and $\tau_{1/2} = 20.20 \pm 0.02$ ms (M.J. Martin, private communication).

≈ 23.3 MeV. A secondary maximum occurs at 25.5 MeV, $\Gamma \approx 2$ MeV. There is also evidence of other structure at $\approx 30 - 31$ and possibly at ≈ 35 MeV: see (1988DI02) and B.L. Berman, private communication.

The (γ, n_0) cross section has been measured at $90°$ for $21 < E_{\rm x} < 40$ MeV and compared with the (γ, p_0) cross section: the isospin mixing averages about 2% in intensity and shows structure at the giant resonance. Angular distributions of n_0 measured over the giant resonance region indicate that the main excitation mechanism is of a $1p_{3/2} \rightarrow 1d_{5/2}$ E1 single-particle character. No significant E2 strength is observed: see (1980AJ01). Differential cross sections at $\theta_{\rm lab} = 65°$ have been measured for the n_{0+1} and $n_{2\rightarrow 9}$ groups for $E_\gamma = 33.7$ to 99.4 MeV (1988HA01). See also the discussion in (1985FU1C).

The (γ, 2n) cross section (reaction (b)) 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: see (1980AJ01, 1985AJ01). See also (1985AH06, 1985GI1G, 1985HO27, 1985PY01), (1989BO1F; astrophysics) and (1984CA18, 1984MO13, 1984VA1G, 1985BO12, 1985GO1A, 1985KO2K, 1985VA1C, 1986VA14, 1987BR21, 1987FE05, 1987GO37, 1987KI1C, 1987VA35, 1988CO1G; theor.).

28. (a) ^{12}C(γ, p)^{11}B $\quad Q_{\rm m} = -15.9572$
(b) ^{12}C(γ, π^0)^{12}C $\quad Q_{\rm m} = -134.964$

The photoproton cross section exhibits two broad peaks, the giant resonance peak at 22.5 MeV, $\Gamma = 3.2$ MeV, $\sigma_{\rm max} = 13.1 \pm 0.8$ mb and a 2 MeV broad peak at 25.2 MeV, $\sigma_{\rm max} = 5.6 \pm 0.3$ mb: see (1976CA21) and Table 12.19 in (1968AJ02). The (γ, $\rm p_0$) cross section at the giant resonance is 11.0 ± 1.1 mb (1986KE06). While the E1 component dominates in the GDR, a 2% E2 contribution may possibly be present (1976CA21). In contrast with the giant resonance peak in the (γ, n) cross section, the (γ, p) cross section shows a strong peak in the center of the broad giant resonance peak. Above 24.5 MeV the ground state (γ, p) and (γ, n) excitation functions have the same shape up to at least 36 MeV: see (1985FU1C). There is agreement between the (γ, p) results and those from the inverse reaction ^{11}B(p, γ_0) [see reaction 17] when the population of ^{11}B*(4.4, 5.0) is taken into account. See also ^{11}B and (1986AN25, 1986MC15, 1988SH08). At $E_\gamma = 28$ MeV the branching ratios to ^{11}B*(0, 2.12, $4.4 + 5.0$) are, respectively, (76 ± 4)%, (13 ± 1.3)% and (11 ± 1.2)% (1989FE01). See also reaction 30. For the proton momentum spectrum at $E_\gamma = 357 \pm 10$ MeV see (1984HO24). For the cross section with polarized photons with $E_\gamma = 41.2$ to 93.0 MeV see (1988YO1A). For measurements in the Δ-resonance region see (1987KA13).

The photoproduction of neutral pions (reaction (b)) has been studied from threshold to 450 MeV [see (1985AJ01)] and at $E_\gamma = 132$ to 169 MeV (1989KO05), 138 to 146 MeV (1986GL07, 1987GL01), 138.0 to 181.9 MeV (1987JA1F, 1987MA07) and 234 to 449 MeV (1986AR06). At $E_\gamma = 157$ to 170 MeV the excitation of ^{12}C*(4.4) is reported (1989PF1A; prelim.). See also (1989KO1Q) and (1984HO24, 1988ST12). For other papers on pion production (including π^+ and π^-) see the “General” section here, and ^{12}B and ^{12}N. For high energy processes see (1984AL1J, 1984AL1K).

See also (1985AJ01), (1983AR24, 1983TO18, 1984ST18, 1986SH1M, 1988SC1B), (1985GI1G, 1985HO27, 1985MA1G, 1988OC1A), (1989BO1F; astrophysics) and (1984BO18, 1984CA18, 1985AL1K, 1985BO1A, 1985TO15, 1986HO11, 1987BE2A, 1987GOZK, 1987GO37, 1987KI1C, 1987PA1K, 1988AH03, 1988OR02; theor.).

29. (a) ^{12}C(γ, d)^{10}B $Q_{\rm m} = -25.1868$
(b) ^{12}C(γ, pn)^{10}B $Q_{\rm m} = -27.4114$
(c) ^{12}C(γ, pd)^{9}Be $Q_{\rm m} = -31.7726$
(d) ^{12}C(γ, t)^{9}B $Q_{\rm m} = -27.366$

Cross sections and angular distributions of the deuterons corresponding to transitions to ^{10}B$_{\rm g.s.}$ and/or low excited states have been measured at $E_\gamma \approx 40$ MeV: the results are consistent with E2. There is some evidence also for the excitation of higher states of ^{10}B via non-E2 transitions. For $E_{\rm bs} = 90$ MeV, the ratio of the yields of deuterons to protons is $\approx$ 2%, for particle energies 15 to 30 MeV. For higher particle energies, the ratio decreases: see (1980AJ01) for references. See also (1986SH1M). Momentum spectra for deuterons and tritons (reactions (a) and (d)) are reported at $E_\gamma = 300$ to 600 MeV by (1986BA07). The (γ, pn) reaction has been studied at $E_\gamma = 83$ to 133 MeV by (1988DA16) and in the Δ-resonance region by (1987KA13). For reaction (c) see (1987VO08). The yield of tritons has been measured for $E_\gamma = 35$ to 50 MeV: see (1980AJ01). See also (1985AJ01), (1984AL1J, 1984DO17) and (1985BU1H, 1986BU22, 1986GU1G, 1987BU1A; theor.).

30. ^{12}C(γ, α)^{8}Be $\qquad Q_{\rm m} = -7.3666$

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. For $E_\gamma < 22$ MeV, transitions are mainly to ^{8}Be(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. Surprisingly strong E1 contributions are observed below $E_\gamma \approx 17$ MeV: see (1980AJ01) for references. See also (1986LI22). The ratio for $\sigma(\gamma,\, \alpha_0)/\sigma(\gamma,{\rm p}_0)$ is 0.029 ± 0.012 at $E_\gamma = 28$ MeV (1989FE01). For other breakup processes see (1975AJ02, 1985AJ01). See also (1985CH27; theor.).

31. ^{12}C(γ, γ)^{12}C

Resonance scattering and absorption by ^{12}C*(15.11) have been studied by many groups: see (1980AJ01) and Table 12.7 here. Inelastic scattering has also been reported to ^{12}C*(4.4, 9.6 ± 0.2, 11.8 ± 0.2, 12.7, 13.3 ± 0.2, 17.2 ± 0.2, 18.3 ± 0.2, 20.5 ± 0.2, $22 - 24$ (giant resonance), 26.5 ± 0.4, 29.5 ± 0.3): see (1980AJ01, 1985AJ01). Measurements of the elastic differential cross sections for $E_\gamma = 22.5$ to 52.0 MeV ($\theta = 45°$, $90°$, $135°$) have been reported by (1985WR02). The difference between the (measured) energy-integrated values of σ_γ and the E1 part of the photoabsorption cross section $\sigma_\gamma^{\rm E1}$ is small and cannot be ascribed to E2 strength (1985WR02). Beyond $E_\gamma = 52$ MeV significant E2 strength may be present (1985WR02). For the earlier work see (1985AJ01). See also (1984NA18, 1986BEZM), (1984NA1J, 1985HA1H, 1985MU08) and (1984MA1W, 1985AR07, 1985VE09, 1987FE05, 1987VE03; theor.).

32. ^{12}C(e, e)^{12}C

Recent values of the nuclear charge radius are $\langle r^2 \rangle^{1/2} = 2.472 \pm 0.015$ fm, 2.464 ± 0.012 fm [2.468 ± 0.012 fm when the dispersion correction is made]: see (1985AJ01). A value obtained from muonic X-rays is displayed in the "General" section here. Elastic scattering has been studied up to 4 GeV: see (1968AJ02, 1975AJ02, 1985AJ01). (1986OF01, 1987OF1A) report evidence for an energy dependence of the elastic form factors, probably due to two-step processes, between $E_{\rm e} = 238$ and 431 MeV.

^{12}C states observed in inelastic scattering are displayed in Table 12.15. The variation of the form factor with momentum transfer yields unambiguous assignments of $J^\pi = 2^+$, 0^+, and 3^- for ^{12}C*(4.4, 7.7, 9.6). Longitudinal form factors show ^{12}C*(16.1, 18.6, 20.0, 21.6, 22.0, 23.8, 25.5) while the transverse form factors show ^{12}C*(15.1, 16.1, 16.6, 18.1, 19.3, 19.6, 20.6, 22.7, (25.5)). ^{12}C*(19.4) may be the expected giant magnetic quadrupole state, $J^{\pi} = 2^-$: see (1975AJ02, 1980AJ01) for references and additional information. The more recent work by (1984HI06, 1987HI09) is also displayed in Table 12.15. A study of the (e, e$'\gamma$) reaction by (1985PA01) shows that the relative phase of the longitudinal and transverse form factors of ^{12}C*(4.4) is negative. Studies of the excitation of the Δ-resonance are reported by (1987OC01; $E_e = 537$ and 737 MeV) and by (1988BA25; $E_e = 653$, 1300, 1500, and 1650 MeV). See also (1986OLZY, 1986TH1F, 1987GI1G).

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

E_x (MeV)	$J^{\pi}; T$	Γ_{γ_0} (eV)
4.44	$2^+; 0$	$(10.8 \pm 0.6) \times 10^{-3}$
7.65 [b]	$0^+; 0$	$(6.0 \pm 0.4) \times 10^{-5}$ [b]
9.64	$3^-; 0$	$(3.1 \pm 0.4) \times 10^{-4}$
10.84	$1^-; 0$	
11.83 [c]	$2^-; 0$	
12.71 [c, d]	$1^+; 0$	0.35 ± 0.05 (M1)
14.08 [e]	$4^+; 0$	
15.11 [c, d, f]	$1^+; 1$	38.5 ± 0.8
15.44 ± 0.04 [g]		
16.11 [c]	$2^+; 1$	0.35 ± 0.04
16.57 [c, f]	$2^-; 1$	$(48 \pm 8) \times 10^{-3}$
17.6 ± 0.2		
18.20 ± 0.05 [c, h]	$(2^-; 0)$	
18.6 ± 0.1	(3^-)	
19.35 ± 0.10 [c, i]	$2^-; 1$	
19.59 ± 0.04 [c, j]	$4^-; 1$	
20.0 ± 0.1	(2^+)	
20.56 ± 0.05 [c, k]	$3^+; 1$	
21.6 ± 0.1	(3^-)	
22.0 ± 0.1	(1^-)	
22.7 ± 0.1 [c, l]	$(2^-; 1)$	
23.8 ± 0.1	(1^-) [m]	
24.9 ± 0.2		
25.5	(1^-)	

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

E_x(MeV)	$J^\pi; T$	Γ_{γ_0}(eV)
25.5	(3^-)	
26.4 ± 0.3		
27.8 ± 0.2		
30.2 ± 0.4		
32.3 ± 0.3		

[a]) See also Tables 12.18 in (1975AJ02), 12.16 in (1980AJ01) and 12.15 in (1985AJ01) for additional information and for the earlier references.

[b]) The matrix element is 5.48 ± 0.22 fm^2 for the E0 decay by pair emission to ^{12}C$_{\text{g.s.}}$: see (1980AJ01). The value listed under Γ_{γ_0} is actually Γ_π.

[c]) Form factors have been studied at back angles: see (1984HI06; $E_e = 50.7$ to 338 MeV) and (1987HI09; $E_e = 415$ MeV). See also Table 12.15 in (1985AJ01).

[d]) $\Gamma_{\text{tot}} = 14.6 \pm 2.6$ eV.

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

[f]) The Γ_{γ_0} shown are from (1983DE53).

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

[h]) $\Gamma = 300 \pm 100$ keV (1984HI06).

[i]) $\Gamma = 400 \pm 100$ keV (1984HI06).

[j]) $\Gamma = 550 \pm 70$ keV (1984HI06).

[k]) $\Gamma = 300 \pm 50$ keV (1984HI06).

[l]) $\Gamma = 450 \pm 150$ keV (1984HI06).

[m]) The giant dipole resonance has an average $E_x = 23.0 \pm 0.7$ MeV and $\Gamma = 5.7 \pm 0.7$ MeV. It may involve fine structure at $E_x = 22.2$, 22.8, 23.4 and 23.8 MeV. A strong and relatively narrow peak is reported at 23.6 MeV by (1987HI09).

See also (1985AJ01), reaction 35, (1984BU1H, 1984DE1P, 1985BU09, 1987KU05, 1988KO21), (1984HE1F, 1984LI25, 1985HI04, 1985PA1N, 1986HI06, 1986LI1C, 1986PA1C, 1987BE25, 1987DE43, 1987FR1B, 1987HO1D, 1987LI30, 1987RA1O) and (1983NA1E, 1984CA22, 1984CE05, 1984CI1A, 1984DE51, 1984DO14, 1984ER06, 1984KA1G, 1984KR10, 1984KU1E, 1984MO13, 1984RA1H, 1984RA14, 1984RO15, 1984SA1H, 1985BO06, 1985CE09, 1985CH07, 1985FR08, 1985KE1F, 1985KO06, 1985ME1L, 1985MU1F, 1985SA06, 1985SH1L, 1985ST09, 1986AZ01, 1986CZ01, 1986KO30, 1986KU09, 1986MAZF, 1986MU14, 1986PE1E, 1986SA2L, 1986SH01, 1986TR04, 1986ZE1A, 1987AL05, 1987AL1M, 1987CO30, 1987DO12, 1987DR02, 1987JI01, 1987FE05, 1987FUZZ, 1987GM03, 1987RA25, 1987SC26, 1987VOZS, 1988BE01, 1988CA20, 1988CH37, 1988CL03, 1988GU03, 1988GU12, 1988NI08, 1988PA25, 1988TR04, 1989LI1G, 1989MA06, 1989MI1I, 1989OR05; theor.).

33. ^{12}C(e, ep)^{11}B $Q_{\rm m} = -15.9572$

I am extremely indebted to Dr. Larry Weinstein for his detailed comments which led to the writeup below.

The inclusive studies by (1983BA28, 1984AR02, 1984OC01) uncovered a lack of understanding of the quasielastic and dip region processes. The more recent studies have focused on (a) quasielastic processes involving various states of ^{11}B [see ^{11}B and (1985VA05, 1985VA16, 1988VA09, 1988VA21)]; (b) quasielastic reaction mechanism studies including longitudinal/transverse separations (1986VA17, 1987UL03, 1988VA09, 1988WE1E); (c) dip and Δ-region reaction mechanism studies (1986LO03, 1989BA03, 1989SE02); and (d) quasifree deuteron knockout spectroscopy to low-lying states of ^{10}B (1989EN01). See also (1987DA20, 1988AV01).

Nuclear spectroscopy studies produce momentum distributions that are well reproduced by DWIA calculations but with occupation numbers that are about 60% of the expected shell-model results (1985VA05, 1985VA16, 1988VA09, 1988VA21, 1987UL03, 1988WE1E).

Studies of the quasielastic longitudinal and transverse response functions versus missing energy have been carried out by (1986VA17, 1987UL03, 1988VA09). See also (1988VA1I, 1988VA1J). (1987UL03) find in the longitudinal response a broad bump at missing energies between 28 and 48 MeV, attributed to knockout from the s-shell. In the transverse response they find this bump on top of a broader feature with a threshold at 28 MeV extending beyond 65 MeV. This broad feature is attributed to two-particle knockout, a non-quasielastic reaction mechanism; it may account for the observed (e, e′) transverse-longitudinal difference. This feature is also observed in unseparated data at larger momentum transfers: it appears to grow with momentum transfer (1988WE1E).

(1984CA34) find evidence from the (e, ep$_0$) work for a monopole, 0^+, state near $E_{\rm x} \approx 20.5$ MeV which exhausts at least 1% of the EWSR. The decay of states in the giant resonance region via α-particles has been studied by (1987DEZU): the decay is primarily to ^{8}Be*(2.9) ($J^\pi = 2^+$). See also (1984FL02, 1986LI22). For other charged particle emission see (1984FL02). For pion emission see the “General” section here, ^{12}B, ^{12}N and (1986SH14, 1988SH36). For the early work see (1980AJ01, 1985AJ01).

See also reactions 27 and 28, 1983BU20, 1984BU18, 1984LI07, 1985LI15, 1986BA85, 1987CAZY, 1987VA1N, 1988BA1D, 1988BOZT, 1988GAZV, 1989BOZZ), (1984LA16, 1984WA1J, 1985BE1K, 1986DE1T, 1986DE1U, 1986DO1N, 1986LA1T, 1987RI1A, 1988HA12) and (1983NA1E, 1984CA22, 1984CI1B, 1984HA1K, 1984NA16, 1984ZI1C, 1985AF03, 1985CA32, 1985CO14, 1985DE20, 1985DO1G, 1985KE1G, 1985LA1F, 1986AK01, 1986CO1U, 1986DE05, 1986GO1T, 1986NI03, 1986RO24, 1986RO22, 1986ST05, 1987AL19, 1987BL10, 1987BO54, 1987CH10, 1987GI07, 1987GOZO, 1987GU21, 1987MO1J, 1987MO24, 1987MO1M, 1987PA1J, 1987ST02, 1987VA15, 1987WE02, 1987YO04, 1988ER05, 1988HO09, 1988HO10, 1988KO13, 1988OC01, 1988SU02, 1988WE03, 1989BR01, 1989HO02, 1989PIZZ, 1989RY03, 1989TA03, 1989TA02, 1989WE1G; theor.).

34. (a) ^{12}C($\pi^\pm, \pi^\pm$)^{12}C
(b) ^{12}C($\pi^\pm$, $\pi^\pm$p)^{11}B $Q_{\rm m} = -15.9572$

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

E_{π^+} (MeV)	E_{π^-} (MeV)	Angular distribution to ^{12}C	References
	19.5, 30	g.s.	(1987WR05)
50	50	g.s., 4.4	(1984SO13)
50		7.7	(1986LE11)
75.6	75.6	g.s.	(1984DE21)
100 $\rightarrow$ 291	100 $\rightarrow$ 291	g.s., 4.4, 7.7, 9.6, 12.7, 15.1, 16.1, 18.3, 19.3	(1987CO17)
162		g.s.	(1986BU13)
162		g.s., 4.4, 7.7	(1984MO18)
673	673	g.s., 4.4, 9.6	(1984MA42)

[a] For the earlier work see Table 12.16 in (1985AJ01).

Angular distributions of the elastic and inelastically scattered pions have been measured at many energies: see Table 12.16 in (1985AJ01) and Table 12.16 here. The study by (1987CO17) [$E_{\pi^\pm} = 100$ to 291 MeV] suggests $J^\pi = 2^-$ for ^{12}C*(18.25, 19.4) and 4^- for ^{12}C*(19.25). ^{12}C*(19.65) is also populated. A study of the giant resonance region suggests states at $E_x = 20.0 \pm 0.2$ and 22.7 ± 0.4 MeV, with $\Gamma = 3.2 \pm 0.3$ and 1.0 ± 0.2 MeV (1984BL12; $E_{\pi^+} = 170$ MeV).

The ratio of the cross sections to the 1^+; $T = 0$ and 1^+; $T = 1$ states, ^{12}C*(12.7, 15.1), has been measured at $E_{\pi^\pm} = 50$ MeV, where it is 7.1 ± 1 [isospin averaged] (1988RI03). The excitation of these two states has also been studied for $E_{\pi^\pm} = 80$ to 295 MeV by (1988OA03). See also (1988BA27). (1986AN01) have reported inelastic cross sections, including those to the "continuum" above ^{12}C*(9.6) at $E_{\pi^+} = 67$, 85 and 100 MeV. The elastic excitation function at $\theta = 175°$ has been measured for $E_{\pi^+} = 100$ to 250 MeV (1987DH01). Total reaction cross sections are reported at $E_{\pi^\pm} = 50$ and 65 MeV (1987ME12). See also (1987BE1R).

(π', $\gamma_{4.4}$) angular correlations have been studied at $E_{\pi^+} = 65$ and 90 MeV (1984SO12) and 116 to 226 MeV (1986OL07, 1988OL02). See also (1985KI05). The (π', $\gamma_{15.1}$) angular correlations are reported at $E_{\pi^+} = 116$ to 226 MeV (1988BA27).

For reaction (b) see ^{11}B and (1984FA11; $E_{\pi^\pm} = 220$ MeV) and (1987HU02; $E_{\pi^+} = 150$ MeV). The polarization of protons in the $\pi^\pm$ A $\rightarrow$ px process has been studied at 1.5 GeV/c (1984BU11). For studies of ($\pi^\pm$, 2p), (π^+, pd), and ($\pi^\pm$, pn) reactions see (1986AL22, 1986NA03, 1987YO01, 1989YO03). For the (π^+, 3p) reaction see (1985TA14, 1987BR17). See also the "General" section here, (1985AJ01) for the earlier work, (1984GO1F, 1989ROZZ), (1984KI16, 1985MI16) and (1985CO03, 1985KA04, 1986PE1E, 1986TA08, 1988ST07; theor.).

35. ^{12}C(K$^{\pm}$, K$^{\pm}$)^{12}C

At $E_{\mathrm{K}^{\pm}} = 442$ MeV angular distributions have been obtained for ^{12}C*(0, 4.4, 9.6) (1982MA16). See also the "General" section here, (1988AF02) and (1988BR16; theor.).

36. (a) ^{12}C(n, n)^{12}C
(b) ^{12}C(n, nα)^{8}Be $\qquad Q_{\mathrm{m}} = -7.3666$

Angular distributions of elastic and inelastically scattered neutrons have been studied at many energies up to 350 MeV [see (1980AJ01, 1985AJ01)] and at $E_{\mathrm{n}} = 11.05$ and 13.81 MeV (1986ROZW; prelim.; n_0, n_1), 14.1 and 14.5 MeV (1983HU14; n_0, n_1), 14.6 MeV (1985HA02; n_0), 18.2 MeV (n_0; quoted in (1987TO03)), 20.8, 22, 24 and 26 MeV (1985ME16; to ^{12}C*(0, 4.4, 7.7, 9.6, 10.8, 11.8, 13.4, 14.1, 15.1, 16.1 [the latter two at $E_{\mathrm{n}} = 22$ and 24 MeV (A.S. Meigooni, Ph.D. Thesis, Ohio University (1984) and R.W. Finlay, private communication)]) and 40.3 MeV (1986WI01; n_0). See also (1985FI09) and (1985PE10; theor.). For cross sections and polarization studies see (1985TO02, 1987TO07, 1987TO03, 1988TO01) and ^{13}C in (1991AJ01).

Angular correlations (n_1, $\gamma_{4.4}$) have been studied at $E_{\mathrm{n}} = 13.9$ to 15 MeV: see (1975AJ02). The quadrupole deformation parameter $\beta_2 = -0.67 \pm 0.04$ (1983WO02). For a kinematically complete study of reaction (b) at $E_{\mathrm{n}} = 11$ to 35 MeV see (1983AN02): the sequential decay via ^{12}C*(9.6) and ^{8}Be$_{\mathrm{g.s.}}$ is clearly observed at the higher energies. See also (1986AN22) and (1980AJ01). For pion production see (1988BU16).

See also (1985MA68, 1985PE1C, 1985WE1D, 1986BO1M, 1986ZH1F, 1987NEZY, 1988WE06), (1985FIZW, 1985HO1J, 1986HAYU), (1986KE1H, 1988AN1F; applications) and (1983KO44, 1983SH1P, 1985AU1C, 1985BE59, 1985DI1B, 1985GU1D, 1985TI08, 1986AL1L, 1986IS1F, 1986LI16, 1986SH35, 1987KO1N, 1987WI16; theor.).

37. ^{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 12.17 here and (1968AJ02, 1975AJ02, 1980AJ01, 1985AJ01).

Table 12.18 displays the information on excited states of ^{12}C. A summary of the decay of some excited states is shown in Table 12.7. The angular distributions have been analyzed by DWBA (and CCBA), DWIA, (including microscopic calculations) and DWTA (DW t-matrix approximation with density-dependent interactions). Microscopic DWIA calculations give good results for transitions which take place through the $S = T = 1$ part of the effective interaction and also gives a reasonable description of the $S = T = 0$ transition. However the mechanism for the excitation of ^{12}C*(12.71) ($S = 1, T = 0$) remains a puzzle. At $E_p = 402$ MeV the differential cross sections for ^{12}C*(12.7, 15.1) ($J^\pi = 1^+$) are very similar for large q. This may be due to the smallness of precursor effects [precursor to a pion condensate] (1981ES04).

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

E_p (MeV)	To states in ^{12}C at E_x (MeV)	References
$19 \rightarrow 35$ [b]	4.4, 7.7	(1985BAZZ) [c]
$12.1 \rightarrow 83.8$ [b]	0	(1987IE01)
$29.5 \rightarrow 39.9$	0, 4.4, 7.7	see (1986PI01)
65 [b]	0, 4.4, 7.7, 9.6, 14.1	(1985KA10)
80 [b]	12.7, 15.1	(1986HO1H, 1986NO1E) [c]
250 [b]	0	(1988ME02)
300	0	(1985ME07)
398, 597, 698 [b]	0, 4.4, 9.6, 14.1	(1986JO01)
800 [b]	0	(1987LIZZ) [c]
1 GeV	0	(1985AL16)
E_d (MeV)	To states in ^{12}C at E_x (MeV)	References
35-70 [b]	0	(1985KA1A, 1986KA1Z)
56 [b]	0	(1984HA26, 1986MA32)
E_t (MeV)	To states in ^{12}C at E_x (MeV)	References
33	0	(1987EN06)
36	0	(1986PE13)
E(^{3}He) (MeV)	To states in ^{12}C at E_x (MeV)	References
12	0	(1986SO1E)
22, 50, 60, 72	0	(1988AD1B) [c]
39.6	0	(1987BUZR) [c]
72	0, 4.4, 7.7, 9.6	(1988GOZF) [c]
E_α (MeV)	To states in ^{12}C at E_x (MeV)	References
$1.47 \rightarrow 6.56$	0	(1987PL03)
35	10.8, 11.8	(1984PE24)
48.7, 54.1	0	(1987AB03)
99.6	0	(1985BE1Q) [c]

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

E_{p} (MeV)	To states in ^{12}C at E_{x} (MeV)	References
120	7.7	(1986PI01)
172.5	0, 4.4, 7.7, 9.6, 14.0, 15.3, 18.4, 21.6, 24.0, 26.2, 29.2 [d]	(1987KI16)

[a] For the earlier work see Tables 12.17 in (1980AJ01, 1985AJ01).

[b] Polarized.

[c] Preliminary report.

[d] Uncertainty in E_{x} is ± 0.2 MeV.

The spin-flip probability (SFP) for the transition to ^{12}C*(4.4) has been measured for $E_{\mathrm{p}} = 15.9$ to 41.1 MeV: two bumps appear at ≈ 20 and ≈ 29 MeV. It is suggested that the lower one is due to a substructure of the E1 giant dipole resonance while the upper one results from the E2 giant quadrupole resonance. The SFP has also been studied at $E_{\vec{\mathrm{p}}} = 24.1$, 26.2, 28.7 MeV (to ^{12}C*(4.44)), at $E_{\mathrm{p}} = 42$ MeV (to ^{12}C*(12.7)), at $E_{\vec{\mathrm{p}}} = 397$ MeV (to ^{12}C*(9.6, 12.7, 15.1, 16.1)) [the SFP to ^{12}C*(9.6) is consistent with zero; the others exhibit large SFP at forward angles] and at $E_{\mathrm{p}} = 398, 597$ and 698 MeV (to ^{12}C*(18.3, 19.4)). See also (1987GRZY; prelim.).

(1980HO07) have measured the angular distribution of γ-rays from the decay of ^{12}C*(12.7, 15.1) at $E_{\mathrm{p}} = 21.5$ to 27 MeV. Microscopic DW calculations were performed for the A_0 and a_2 coefficients from these and earlier data. The theoretical calculations underestimate A_0 for energies below 35 MeV and are in agreement with the experimental A_0 for higher energies. The calculations also predict significant difference in the a_2 values for the transitions from ^{12}C*(12.7, 15.1), and these are observed (1980HO07).

(p$\gamma_{15.1}$) angular correlations have been studied at $E_{\mathrm{p}} = 400$ MeV by (1988HI12): the data are best described by a relativistic model of p-nucleus scattering in the impulse approximation. See also (1986SH1X). A search for a short-lived neutral particle emitted in the decay of ^{12}C*(15.1) is reported by (1988DA01) [see for upper limits].

For polarization and yield measurements see ^{13}N in (1986AJ01, 1991AJ01) and (1988FE09, 1989CH08). For other ^{12}C + p interactions see reaction 39, here. For other work and for earlier references see reaction 40 in (1985AJ01).

See also (1983AP1A, 1985WIZW, 1986BA2U, 1986LI1Q, 1986SA2F, 1986TRZZ, 1987RO1F, 1988HI03, 1988LYZZ, 1989OPZZ), (1984GA32, 1984TA1L, 1985BL22, 1985BR1G, 1985CA1B, 1985HO1J, 1985ME16, 1985PE10, 1985SH1C, 1986CA1N, 1986GL1G, 1986HA2K, 1986MC1K, 1987BR32, 1988BO1I), (1987LA11, 1988LE08, 1988SA1B; astrophysics), (1987KO1M, 1988BA2A; applications) and (1983KO44, 1983LY07, 1983ZA09, 1984AM07, 1984LI1J, 1984LI1M, 1984LO20, 1984PH02, 1984SH14, 1985AU1C, 1985BA1Z, 1985CL1B, 1985DA24, 1985EL04, 1985IN01, 1985IV1A, 1985IV1B, 1985PI09, 1985PI11, 1985SH1H, 1985SM06, 1985SP03, 1985TI06, 1985ZH07, 1986BA62, 1986BL03, 1986CO1V, 1986DEZK, 1986DI04, 1986ES01, 1986IN01, 1986IS1F,

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

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

[a] See Tables 12.18 in (1980AJ01, 1985AJ01) for the earlier references.

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

[c] Γ are in c.m. system.

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

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

[f] See Table 12.7.

[g] Footnote not defined in publication (appeared in (1985AJ01).)

1986JA18, 1986KA1Y, 1986LO1A, 1986MO12, 1986PE1E, 1986POZW, 1986SH01, 1986SH35, 1986VD01, 1986YA16, 1987BI20, 1987CUZZ, 1987DA1D, 1987KA1G, 1987LI01, 1987MO13, 1987MU05, 1987NA1H, 1987RO02, 1987SCZV, 1987WI16, 1987ZA1F, 1988BEYI, 1988DA07, 1988HO09, 1988HO1K, 1988NA04, 1988PI02, 1988PR06, 1989TA03, 1989TU1A; theor.).

38. ^{12}C($\bar{\text{p}}$, $\bar{\text{p}}$) ^{12}C

Antiproton scattering angular distributions have been measured at $E(\bar{\text{p}}) = 46.7$ and 179.7 MeV (1986LE13, 1984GA32; to ^{12}C*(0, 4.4, 9.6)). See also (1985JA1J; also at 30 MeV; Ph.D. thesis). ^{12}C*(7.7) and some other, unresolved, groups were also populated (1986LE13). Cross section measurements are also reported at 1.45 and 1.8 GeV/c (1984AF1A). The knockout ($\bar{\text{p}}$, p) reaction has been studied at $E(\bar{\text{p}}) = 180$ MeV (1985GA02) and 600 MeV/c (1987AS06):

there is no evidence for narrow bound or resonant $\overline{\mathrm{p}}$-nucleus states. For a polarization study see (1988MA48). For spectra of ^{3}He and α-particles see (1988MA44). See (1985AJ01) for the earlier work, the “General” section here and (1984DA20, 1985AM01, 1985DA24, 1985LI16, 1986KL01, 1987AD04, 1988IN01; theor.).

39. (a) ^{12}C(p, 2p)^{11}B $\quad Q_\mathrm{m} = -15.9572$
(b) ^{12}C(p, pn)^{11}C $\quad Q_\mathrm{m} = -18.722$
(c) ^{12}C(p, pd)^{10}B $\quad Q_\mathrm{m} = -25.1868$
(d) ^{12}C(p, pα)^{8}Be $\quad Q_\mathrm{m} = -7.3666$
(e) ^{12}C(p, 3p)^{10}Be $\quad Q_\mathrm{m} = -27.1852$

Recent work on reaction (a) has involved the distribution of protons [and of deuterons from reaction (c)] associated with backward energetic protons over a wide kinematical range (1985MI09; $E_\mathrm{p} = 800$ MeV). Spectra from coincident proton emission from the continuum have been studied at $E_\mathrm{p} = 200$ MeV by (1988CO02). At $E_\mathrm{p} = 156$ MeV states at 18.4, 19.4, 20.6 and ≈ 22 MeV appear to be involved (1989TEZZ; prelim.). At 2.1 GeV (1984TR09) have searched for interactions between the incident protons and a fast dinucleon constituent inside C. For inclusive proton spectra see (1985SE15, 1988FO06). See also (1985HAZW, 500 MeV; prelim.). For reaction (a) see also ^{11}B and (1984VD01, 1985BE30, 1985DO16). For reaction (b) see ^{11}C and (1985BE30, 1985DO16).

For reaction (c) [and for the (p, p^{3}He) reaction] see (1985DE17, 1984DE1F). See also (1984TR09). At $E_\mathrm{p} = 56.5$ MeV reaction (d) proceeds primarily by sequential α-decay. ^{12}C*(22.2 ± 0.5, 26.3 ± 0.5) which subsequently decay to ^{8}Be$_\mathrm{g.s.}$ must therefore have natural parity and a significaant $T = 0$ admixture. ^{12}C*(19.7, 21.1, 26.3) decay to ^{8}Be*(2.9). These states must also have a $T = 0$ component. It is suggested that ^{12}C*(21.1) has unnatural parity. At $E_\mathrm{p} = 44.2$ MeV ^{12}C*(12.7, 14.1, 21.6, 26.6) are observed in the angular correlation involving α_0 and ^{12}C*(21.6, 24.1, 26.6) decay via α_1 to ^{9}Be*(2.9) [suggesting 2^+ for these states, assuming that only resolved states are involved].

For reaction (e) see (1984NA17). A search for a bound ppπ^+ state is reported at $E_\mathrm{p} = 500$ MeV by (1988FR1D, 1988FR1J; prelim.). For isobar production at 3.88 GeV/c see (1987NA11). For inclusive pion production at $E_\mathrm{p} = 330$, 400, and 500 MeV see (1985DI01). See also (1987AB1E). For K$^+$ production see (1986AB07, 1988KO36). For η production see (1987BL1L). For other work at high energies see (1986AG1C, 1986CH2H, 1987AG04, 1987AL1J, 1987CH1K, 1987DE1L).

For the earlier work see (1985AJ01). See also the “General” section here, (1986VO17, 1987AR1M, 1988AG1A, 1988BE2B, 1988CHZV), (1985KI1A, 1986BA2D, 1986CH1J, 1987VD1A, 1988LE1I, 1988MO1H, 1988NA1H) and (1983KA1A, 1984GU14, 1985BU04, 1985GA1A, 1985GA1B, 1985KO2C, 1985SM1D, 1986ER1A, 1986GO1U, 1986HO10, 1986OS08, 1986VD01, 1986ZH03, 1987HO1G, 1987HO08, 1987VD1B, 1988BA83, 1988DZ1A, 1988KU16, 1988VD1B, 1989TA03; theor.).

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

(b) ^{12}C(d, pn)^{12}C $Q_{\rm m} = -2.22459$
(c) ^{12}C(d, dα)^{8}Be $Q_{\rm m} = -7.3666$
(d) ^{12}C(d, 2p)^{12}B $Q_{\rm m} = -14.8117$

The angular distribution of elastically and inelastically scattered deuterons has been studied at many energies: see (1968AJ02) and Tables 12.22 in (1975AJ02), 12.17 in (1980AJ01, 1985AJ01) and here. In addition to well-known states in ^{12}C such as ^{12}C*(4.4) [$E_{\rm x} = 4440.5 \pm 1.1$ keV] and ^{12}C*(12.7, 15.1) [see Table 12.10 for charge-dependent matrix element], the population of ^{12}C*((10.8 ± 0.2), (11.8 ± 0.2), 18.3 ± 0.3, 20.6 ± 0.3, 21.9 ± 0.3 (broad), $\approx$ 27 (broad)) is also reported. See (1980AJ01) for references and for additonal structures which have not been published. Calculated deformation parameters listed in (1980AJ01) are $\beta_2 = -0.48 \pm 0.02$ and 0.47 ± 0.05, and $\beta_3 = 0.35 \pm 0.06$.

Reaction (b) has been studied at $E_{\rm d} = 5.0$ to 9.85 MeV and at 56 MeV: see (1980AJ01, 1985AJ01). The breakup of deuterons on C has been investigated at 2.1 GeV (1989PU01). For reaction (c) see ^{8}Be in (1984AJ01). Energy spectra for the (d, 2p) reaction, with the two protons in the singlet (^{1}S$_0$) state, have been studied at $E_{\vec{\rm d}} = 650$ MeV and 2 GeV [reaction (d)]: the reaction appears to proceed via a one-step process and therefore can be used to study isospin-spin excitations. The Δ-excitation is observed (1987EL08). For work at very high energies see (1987AG04, 1987AL1J, 1987AR1M, 1987AZ1C, 1988AG1A, 1988SI1B). For high-energy γ-production see (1988TA22). See also ^{14}N in (1986AJ01, 1991AJ01), (1986JA14) and (1984YA01, 1985GA1A, 1985GA1B, 1986IS1F, 1986KA1B, 1987AU1F, 1987SI10, 1988SI04, 1989TU1A; theor.).

41. ^{12}C(t, t)^{12}C

Angular distributions of elastically scattered tritons have been determined at $E_{\rm t} = 1.0$ to 20.0 MeV [see (1975AJ02) and Table 12.17 in (1985AJ01)] and at 33 and 36 MeV (see Table 12.17). See also (1985SA31; theor.).

42. (a) ^{12}C(^{3}He, ^{3}He)^{12}C

(b) ^{12}C(^{3}He, pd)^{12}C $Q_{\rm m} = -5.49354$
(c) ^{12}C(^{3}He, 2p)^{13}C $Q_{\rm m} = -2.77178$

Angular distributions of ^{3}He ions have been measured for $E(^{3}{\rm He}) = 2$ to 217 MeV: see (1968AJ02, 1975AJ02, 1980AJ01, 1985AJ01) and Table 12.17 here. Parameters of observed ^{3}He groups are displayed in Table 12.19.

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

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

[a] See also Table 12.23 in (1975AJ02). For references see Tables 12.19 in (1980AJ01, 1985AJ01). Energies listed without uncertainties are from Table 12.6.

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

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

[d] See also (1983YA01).

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

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

Angular distributions of the ^{3}He groups to ^{12}C*(15.11, 16.11, 16.57, 19.55) have been compared with those for the tritons to ^{12}N*(0, 0.96, 1.19, 4.25) in the analog (^{3}He, t) reaction: the correspondence is excellent and suggests strongly that these are $T = 1$ isobaric analog states. See also Tables 12.12 in (1980AJ01) and 12.19 here. ^{12}C*(4.4, 15.2, 18.4, 18.9, 21.3, 23.5, 25.9, 28.8) all appear to correspond to E2 transitions: their strengths add up to 46% of the EWSR (energy-weighted sum rule). See (1980AJ01) for references and (1985AJ01) for additional comments.

For reaction (b) see (1985AJ01). Inclusive proton and deuteron spectra have been studied at $E(^{3}\mathrm{He}) = 52$ MeV by (1984AA01). For reaction (c) see ^{13}C and ^{15}O in (1991AJ01) and (1986KA44). For $\pi^{\pm}$ production see (1986MI25). See also ^{15}O in (1986AJ01, 1991AJ01), (1987AD1C), (1987MA2D) and (1985GO19, 1985KH08, 1985SH1A, 1986EV01, 1986EV02, 1986IS1F, 1986KA1B, 1986ZE04, 1987RA36, 1987TR01; theor.).

43. (a) ^{12}C$(\alpha, \alpha)^{12}$C

(b) ^{12}C$(\alpha, 2\alpha)^{8}$Be $\qquad\qquad Q_{\mathrm{m}} = -7.3666$

Angular distributions have been measured at many energies up to 1.37 GeV: see Tables 12.24 in (1968AJ02), 12.22 in (1975AJ02), 12.17 in (1980AJ01, 1985AJ01) and 12.17 here. Parameters of observed states of ^{12}C are displayed in Table 12.19. The quadrupole deformation parameter $\beta_2 = -0.30 \pm 0.02$ [see (1980AJ01)], -0.40 ± 0.02 (1983YA01), while $\beta_3 \approx 0.23$ [see (1980AJ01)] and $\beta_4 = +0.16 \pm 0.03$ (1983YA01; see also for a review of deformation parameters). In the region of the GDR prominent gross structure is observed consisting of two ≈ 2 MeV wide peaks at 26.2 and 29.2 MeV (1987KI16; see also for a discussion of deformation parameters).

Angular correlation measurements (α_1, $\gamma_{4.4}$) have been carried out for $E_{\alpha} = 10.2$ to 104 MeV [see (1980AJ01, 1985AJ01)] and at 25 to 30 MeV (1984TE01, 1986GU06, 1986ZE1C; see for a study of the spin tensors for ^{12}C*(4.4)). Reaction (b) has been studied for E_{α} up to 700 MeV [see (1975AJ02, 1985AJ01)], at 27.2 MeV (1986KO1B; prelim.) and at 31.2 MeV (1986XI1A). For cross sections see ^{16}O in (1986AJ04) and (1987BU27). For other comments on these two reactions see (1985AJ01). For $\pi^{\pm}$ emission see (1986ALZL, 1986ALZK, 1987AL1G; prelim.). For high-energy γ-production see (1988TA22). For work at very high energies see (1984AN1H, 1985AB1A, 1986BA3D, 1987AG04, 1987AL1J, 1987AR1M, 1988AG1A, 1988SI1B).

See also (1984SA28, 1985XI1C, 1987GOZL, 1988AI1B, 1989ES06, 1989LE09), (1983SA07, 1985HO1J), (1988MU1G, 1989LA1G; astrophysics) and (1983AL1F, 1983GE10, 1983GO27, 1985GA1A, 1985GA1B, 1985KH08, 1985SA09, 1986SH1I, 1985ZE02, 1985ZE04, 1986BA11, 1986BE45, 1986EL08, 1986LI1U, 1987BA83, 1987CUZZ, 1987KA1G, 1987KH06, 1987KO1E, 1987KU18, 1987NO05, 1987SA55, 1987VOZS, 1987ZE02, 1988BA1Q, 1988GR1C, 1988KH08, 1988KU1D, 1988KUZU, 1988MA10, 1989TU1A; theor.).

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

(b) ^{12}C(^{6}Li, αd) ^{12}C $\qquad\qquad Q_{\mathrm{m}} = -1.4750$

(c) $^{12}\mathrm{C}(^{7}\mathrm{Li}, {}^{7}\mathrm{Li})^{12}\mathrm{C}$

(d) $^{12}\mathrm{C}(^{7}\mathrm{Be}, {}^{7}\mathrm{Be})^{12}\mathrm{C}$

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

E (MeV)	To states in ^{12}C at E_{x} (MeV)	References
$E(^{6}\mathrm{Li}) = 24$, 30	0	(1984VI02)
24, 30	0, 4.4, 7.7, 9.6	(1985VI03)
30 [b]	0	(1989VA04)
90	4.4, 9.6	(1987DE02)
123.5, 168.6	0, 4.4, 7.7, 9.6	(1988KA09)
150 [b]	0	(1987TA21)
156	0	(1989JE01)
156	7.7, 9.6, ≈ 10.2, 10.8	(1987EY01)
210	0	(1988NA02, 1987WI09)
210	4.4	(1986MCZZ, 1988MCZY) [c]
$E(^{7}\mathrm{Li}) = 34$	0	(1984VI02)
34	0, 4.4, 9.6	(1986CO02)
78	0, 4.4, 7.7	(1986GLZU) [c]
131.8	0, 4.4, 7.7, 9.6	(1988KA09)
$E(^{9}\mathrm{Be}) = 158.3$	0, 4.4	(1984FU10)
$E(^{12}\mathrm{C}) = 65$ [d]	0, 4.4, 7.7, 9.6	(1985GO1H) [c]
$E(^{11}\mathrm{B}) = 10.4$, 12.4, 14.6	0	(1985JA01)
42.5, 60.0, 80.0, 100.0	0	(1985MA10)
48 and $E(^{12}\mathrm{C}) = 52.4$ [e]	0	(1986MA13)
$E(^{12}\mathrm{C}) = 65$ [e]	0, 4.4, 7.7, 9.6	(1985GO1H) [c]
$E(^{12}\mathrm{C})$ (MeV)	To states in ^{12}C at E_{x} (MeV)	References
4	0	(1989VE03)
35, 43	0	(1985PA24)
$53 \to 61$	7.7	(1988PA04)
139.5, 158.8	0, 4.4, 14.1	(1985KU12)

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

139.5, 158.8	0, 4.4, 7.7, 9.6	(1985KU23)
180, 300, 420	0	(1986SA29)
240	0, 4.4	(1985BO39)
360, 1016	0, 4.4	(1984BU22)
1449, 2400	0	(1986ME14, 1987HO03)
1449, 2400	0, 4.4	(1988HO18)
E(^{16}O) (MeV) [f]	To states in ^{12}C at E_x (MeV)	References
$62 \longrightarrow 125$	0	(1985BE40)
112.2	0	(1986BA80)
608	0, 4.4	(1986BR25)
1503	0	(1985RO08, 1988RO01)

[a] For the earlier work see (1980AJ01) and Table 12.20 in (1985AJ01).

[b] Polarized beam.

[c] Preliminary results.

[d] Reaction 45.

[e] Reaction 46 (b).

[f] Reaction 49.

Angular distributions in reactions (a) and (c) have been studied at $E(^{6}\text{Li}) = 4.5$ to 210 MeV and $E(^{7}\text{Li}) = 4.5$ to 131.8 MeV: see (1975AJ02, 1980AJ01, 1985AJ01) for the earlier work and Table 12.20 here. See also (1989TRZZ). Reaction (b) takes place via ^{12}C*(0, 4.4, 7.7): see (1985AJ01, 1986AJ04) and (1985CU04). See also (1988AR22). For VAP measurements (reaction (a)) see (1989VA04; g.s., 4.4) and (1987TA21; g.s.) See also (1988TA08, 1989TRZZ) and ^{18}F in (1987AJ02).

A search by (1987EY01) for the distribution of the E0 strength determines 10%, (5 ± 1)% and (5 ± 2)% of the EWSR, respectively for ^{12}C*(7.7, 10.3) and for $19 < E_x < 21.5$ MeV. For fusion and other cross section measurements (reaction (a)) see (1987PA12). For the ^{6}Li and ^{7}Li + C interaction cross section at 790 MeV/A see (1985TA18). For pion emission see (1984BE35, 1984CH16). The elastic scattering in reaction (d) has been studied at $E(^{7}\text{Be}) = 140$ MeV (1989YA02). See also (1986DAZP, 1986SHZP, 1986YOZU), (1984HA53, 1986KA1C, 1986MO1E) and (1983DE48, 1983GO18, 1984MU1D, 1984UH1A, 1985CO21, 1985HE25, 1985KH08, 1985SA13, 1985SH1A, 1986BE45, 1986IO01, 1986KA1B, 1986MI24, 1986SA15, 1986SAZL, 1986SA1D, 1986YO1A, 1987AR13, 1987KA1I, 1987SA21, 1988DEZU, 1988KH08, 1988OT01, 1988SA10, 1988SA15, 1988SE07, 1989KAZY; theor.).

45. ^{12}C(^{9}Be, ^{9}Be) ^{12}C

Angular distributions have been obtained at $E(^{9}\text{Be}) = 14$ to 158.3 MeV and at $E(^{12}\text{C}) = 12$ to 21 and 65 MeV: see Table 12.20 here and (1980AJ01, 1985AJ01). For fusion and yield measurements see (1985AJ01) and (1985DE22). For the ^{9}Be + C interaction cross section at 790 MeV/A see (1985TA18). See also (1988HAZS), (1984FR1A, 1984HA53, 1985BE1A, 1985CU1A) and (1984HA43, 1986BA69, 1986HA13, 1986KA22, 1986MI24, 1988KH08; theor.).

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

Angular distributions in reaction (a) have been measured at $E(^{10}\text{B}) = 18$ and 100 MeV. Those for reaction (b) have been studied at $E(^{11}\text{B}) = 10.4$ to 100.0 MeV and $E(^{12}\text{C}) = 15$ to 87 MeV: see (1980AJ01, 1985AJ01) and Table 12.20 here. For fusion and yield studies see (1985AJ01) and (1985MA10, 1986MA13). See also (1984DEZX, 1984HAZK, 1987SAZW, 1988SAZT). See also (1987PO15), (1984FR1A, 1984HA53, 1985BE1A, 1985CU1A, 1986MA19, 1988MA07), (1982BA1D, 1985BA1T; astrophysics) and (1984HA43, 1984IN03, 1985KO1J, 1986BA69, 1986HA13, 1986RO12, 1988DI08; theor.).

47. (a) ^{12}C(^{12}C, ^{12}C)^{12}C
(b) ^{12}C(^{12}C, α^{8}Be)^{12}C $\qquad Q_{\text{m}} = -7.3666$

Angular distributions have been measured at $E(^{12}\text{C}) = 10$ to 1020 MeV: see (1980AJ01, 1985AJ01) and Table 12.20 here.

Angular distributions of the magnetic substate population for the single and mutual ^{12}C*(4.4) excitation have been measured by (1985SU07) for $E(^{12}\text{C}) = 38$ to 110 MeV. The yields of 12.7 and 15.1 MeV γ-rays have been studied at $E(^{12}\text{C}) = 180$ MeV (1988HA23), and hard photon collisions have been investigated at $E(^{12}\text{C}) = 576$ to 1008 MeV (1986GR19). For other studies of excitation functions and reaction cross sections see (1984KO12, 1984SI15, 1985KO17, 1985KO24, 1985ME1K, 1985PA24, 1986HAZA, 1986HA30, 1986SA29, 1987HO11, 1987KO12, 1988DE18, 1988PA04, 1989LI10, 1989PA05). See also (1984HO1K). For a study of the effects of vacuum polarization in hadron-hadron scattering see (1989VE03). For reaction (b) see (1986SH10, 1988CAZU) and ^{16}O in (1986AJ04): the excitation of ^{12}C*(9.6, 10.8, 14.1) is reported at $E(^{12}\text{C}) = 90$ to 140 MeV. For fragmentation studies see (1985HA1U, 1985KR03, 1986EN1D, 1986FO04, 1987FO08, 1988FO03, 1988KI05). See also (1985KR21, 1986LIZP, 1987PO15) and (1989CO1C, 1989HA43; theor.).

For pion production see (1983AN1L, 1984AG1A, 1984BE35, 1984CH16, 1985AR1M, 1986AN40, 1988BA21, 1988NO09). See also (1985OB1A) and the “General” section here. For other studies at very high energies see (1984AD1C, 1984AD1B, 1984AN1H, 1985RO12, 1986AG1B, 1986AN1X, 1986CH2H, 1987AD1E, 1987AG04, 1987AG1A, 1987AL1J, 1987AN20, 1987AR1M, 1988AG1A, 1988SI1B).

See also (1985GO1H, 1985SU16, 1985VI03, 1985XI1B, 1986BL1K, 1986BL1L, 1986CO02, 1988HAZS, 1988KW1B, 1988SAZT, 1989OG03), (1982CI1C, 1984BR1L, 1984FR1A, 1984GE1D, 1984HA53, 1984NA1D, 1984TA1L, 1984TR1E, 1985BE1A, 1985CU1A, 1985NA1B, 1986BA2D, 1986BE2H, 1986BE1D, 1986CA30, 1986DU1N, 1986GR1K, 1986SN1B, 1986ST1J, 1987BA1G, 1987BL1D, 1987BR1R, 1987GE1B, 1987HO1C, 1987SC1D, 1988BA12, 1988BE1W, 1988BO46, 1988CA1L, 1988HA1R, 1988RA1G, 1989BL1D), (1982BA1D, 1985BA1T, 1986MA44, 1987RO25, 1989KH02; astrophysics) and (1983SH1Q, 1984AI02, 1984CA28, 1984DA1M, 1984GA1G, 1984GA12, 1984HA43, 1984KA1H, 1984LA1L, 1984SH18, 1984TR14, 1984ZA1B, 1985AI1A, 1985AI1B, 1985AM1B, 1985BA42, 1985BA63, 1985BL09, 1985BL17, 1985BO1A, 1985CH03, 1985CS02, 1985GR1F, 1985GU1J, 1985HA1N, 1985HU04, 1985IV1B, 1985KA1W, 1985KA1X, 1985KH1E, 1985LA14, 1985LE25, 1985LI1K, 1985MA1L, 1985ME14, 1985ME15, 1985MR1A, 1985NO06, 1985PA1P, 1985SA1D, 1985SH1A, 1985TA07, 1985TA12, 1985TO01, 1985TO04, 1985UM01, 1985VA17, 1986AB1H, 1986BA01, 1986BA30, 1986BA1D, 1986BA62, 1986BL05, 1986CA26, 1986CO17, 1986CS1A, 1986CS01, 1986DE07, 1986DI1D, 1986FA1A, 1986GA1F, 1986GR1M, 1986GR1A, 1986HA1Z, 1986HA13, 1986HN01, 1986HO1P, 1986KA22, 1986KA1B, 1986KH04, 1986KI1L, 1986MA44, 1986NI01, 1986OR01, 1986PH01, 1986POZW, 1986PR1C, 1986PR01, 1986RE05, 1986RO26, 1986SA03, 1986SA30, 1986SA1D, 1986SH04, 1986ST1N, 1986VI07, 1986WU03, 1986YA1U, 1987AB1K, 1987AR13, 1987AS05, 1987BA2D, 1987BA50, 1987BI20, 1987BO45, 1987BO28, 1987DA1L, 1987DI1A, 1987FR06, 1987GU13, 1987KH06, 1987KU1B, 1987MA17, 1987MA1J, 1987MA2D, 1987OC1B, 1987OH02, 1987OH08, 1987OH09, 1987OH13, 1987PA24, 1987PH01, 1987RA28, 1987RE03, 1987RE11, 1987RE1G, 1987SC33, 1987ST1E, 1987YA1L, 1988AB1E, 1988AB1F, 1988AD1C, 1988AI1D, 1988AS03, 1988BA04, 1988BA2X, 1988BA43, 1988BA37, 1988BO21, 1988BR04, 1988BR20, 1988BR29, 1988CA08, 1988DE39, 1988DJ1A, 1988FR14, 1988GA1C, 1988GAZW, 1988HE12, 1988IW02, 1988KA1S, 1988KH07, 1988KH09, 1988KH1B, 1988KHZX, 1988LE20, 1988MA10, 1988NA10, 1988OH01, 1988OH09, 1988PO06, 1988PR02, 1988PR04, 1988SE1D, 1988TO02, 1988WU1A, 1988ZU01, 1988ZW1A, 1989EL01, 1989MR01, 1989SH05, 1989TU1A; theor.).

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

Angular distributions for reaction (a) have been studied at $E(^{12}\text{C}) = 15$ to 87 MeV and $E(^{13}\text{C}) = 12$, 36 and 87 MeV [see (1975AJ02, 1985AJ01)] and at $E(^{12}\text{C}) = 94.5$ MeV (1986BA80; g.s.) and $E(^{13}\text{C}) = 16.3$ to 20.6 MeV (1984FR05; g.s.), 17.3 to 26.5 MeV (1988VO01; g.s.), 36 MeV (1985BY01; ^{12}C*(4.4)) and 260 MeV (1985BO39; ^{12}C*(0, 4.4)). Elastic angular distributions (reaction (b)) are reported at $E(^{12}\text{C}) = 12$ to 20 MeV [see (1980AJ01)] and at $E(^{14}\text{C}) = 31.0$ to 56 MeV (1985KO04). The spin-flip probability to ^{12}C*(4.4) has been studied at $E(^{13}\text{C}) = 36$

and 56 MeV by (1985BY01). See (1985AJ01) for the earlier work. For yield and cross section measurements see (1985KO04, 1985RI1C, 1986HA30, 1986STZY, 1987KO12) and (1985AJ01).

See also ^{13}C and ^{14}C in (1991AJ01), (1984FR1A, 1984HA53, 1985BE1A, 1985CU1A, 1986SN1B, 1987IM1C, 1988BE1W, 1988JA14, 1989VO1D), (1982BA1D, 1985BA1T; astrophysics) and (1983HU1C, 1984IN03, 1984SA31, 1984VO11, 1985HU04, 1985IM1B, 1985KO1J, 1985SA1D, 1985VO01, 1986BA1D, 1986BA69, 1986EL02, 1986HA13, 1986KA1B, 1986SA1D, 1986VI08, 1987AR1E, 1987BO48, 1987FR06, 1987IM01, 1987KAZK, 1987MA22, 1988BR29, 1988KA27, 1988PA07; theor.).

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

Angular distributions (reaction (a)) have been measured at $E(^{14}\mathrm{N}) = 21$ to 155 MeV [see (1975AJ02, 1980AJ01, 1985AJ01)] and at $E(^{14}\mathrm{N}) = 150$ MeV (1986GO1H; prelim.). Angular distributions for reaction (b) are reported at $E(^{15}\mathrm{N}) = 31.5$ to 94 MeV: see (1980AJ01, 1985AJ01). High-energy γ-ray emission has been studied at $E(^{14}\mathrm{N}) = 280$ to 560 MeV (1986ST07). See also (1987ST1F). For yield, fragmentation and cross-section measurements see (1985AJ01) and (1985CA01, 1986HA1F, 1986MO13, 1987GO01, 1987ST01, 1988KI06). For the ^{12}C(^{14}N, d^{12}C)^{12}C reaction see (1985ARZW, 1986AR1G; prelim.).

See also ^{14}N and ^{15}N in (1991AJ01), (1987VE1D, 1988HAZS), (1984FR1A, 1984HA53, 1985BE1A, 1985CU1A, 1987GE1B, 1989BL1D), (1982BA1D, 1985BA1T; astrophysics) and (1984HA43, 1985HU04, 1985KO1J, 1985VI09, 1986BA62, 1986BA69, 1986HA13, 1986POZW, 1986RE14, 1987BI20, 1987RE03, 1987RE11, 1988BA2X, 1988BA37, 1988HE12, 1988PR02, 1989SH05; theor.).

50. (a) ^{12}C(^{16}O, ^{16}O)^{12}C
(b) ^{12}C(^{16}O, α)^{12}C^{12}C $\qquad Q_{\mathrm{m}} = -7.16195$

Angular distributions have been measured at $E(^{16}\mathrm{O}) = 17.3$ to 1503 MeV and at $E(^{12}\mathrm{C}) = 65$ to 76.8 MeV: see (1975AJ02, 1980AJ01, 1985AJ01) and Table 12.20 here. The excitation of ^{12}C*(0, 4.4, 14.1, 26) has been reported. The latter is due to the wide ($\Gamma \approx 4$ MeV) giant quadrupole resonance. It contains 25^{+15}_{-10}% of the E2 strength: see (1985AJ01).

For fusion, yield, cross-section and fragmentation studies see (1985AJ01) and (1984TS07, 1985BE02, 1985BE40, 1985CA01, 1985KA03, 1985MU18, 1986CH27, 1986CH41, 1986GA13, 1986HA30, 1986IK03, 1987SU03, 1988KO17). See also (1984RU1A, 1987NA1C, 1988SZ02, 1989KRZX, 1989WE1E). For work at very high energies see (1987YO1A).

See also ^{16}O in (1986AJ04), (1988CAZV, 1988HAZS), (1982CI1C, 1984GE1D, 1984HA53, 1984SN01, 1984TR1E, 1985BE1A, 1985CU1A, 1985GA1J, 1985KA1J, 1985SN1A, 1986RE1A, 1986SN1B, 1987BA1G, 1987BO1H, 1987HO1C, 1988RA1G, 1989CI1C, 1989ST1G), (1982BA1D, 1985BA1T; astrophysics) and (1983HU1C, 1984FR1A, 1984HA43, 1984IN03, 1984KA1H, 1984LA1L, 1984SA31, 1985AI1A, 1985BA63, 1985HU04, 1985HU1C, 1985KA1X, 1985KA28, 1985KO1J, 1985ME14, 1985NO1E, 1985SA1D, 1985TR1D, 1985VI09, 1986BA1D, 1986CH44, 1986DE15, 1986DE40, 1986HA13, 1986KA1B, 1986KL06, 1986POZW, 1986SA1D, 1986WU03, 1987AR13, 1987BA50, 1987DA02, 1987PA24, 1987SC33, 1988AB1E, 1988AB1F, 1988BA43, 1988BR04, 1988BR20, 1988BR29, 1988FR14, 1988JI02, 1988KA13, 1988KO27, 1988SE1D, 1989EL01, 1989MA25; theor.).

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

The elastic scattering angular distributions have been studied at $E(^{17}\mathrm{O}) = 30.5$ to 35 MeV and at $E(^{18}\mathrm{O}) = 32.0$ to 140 MeV [see (1980AJ01, 1985AJ01)] and at $E(^{17}\mathrm{O}) = 40$ to 70 MeV (1986FR04). For fusion, yields, and cross-section measurements see (1985BE40, 1985BE37, 1985CA01, 1986FR04, 1986GA13) and (1985AJ01). For the decay of ^{18}O* into ^{14}C + α, see reaction 34 in ^{18}O (1987AJ02). See also (1984FR1A, 1984HA53, 1989CI1C, 1989FR04), and (1986CI01, 1986HA13, 1987AR1E, 1987MO27, 1987VO05, 1988TH02, 1988THZZ; theor.).

52. ^{12}C(^{19}F, ^{19}F)^{12}C

Angular distributions have been measured at $E(^{12}\mathrm{C}) = 30.0$, 40.3, 50.0 and 60.1 MeV and at $E(^{19}\mathrm{F}) = 40$, 60, and 68.8 MeV [see (1980AJ01, 1985AJ01)] as well as at $E(^{19}\mathrm{F}) = 29.3$ to 34.8 MeV (1984MA32; elastic) and $E(^{12}\mathrm{C}) = 30.0$, 40.3, 50.0 and 60.1 MeV (1988TA12; ^{12}C*(0, 4.4) and several states in ^{19}F). The substate population probability for ^{12}C*(4.4) has been studied by (1986IKZZ) at $E(^{19}\mathrm{F}) = 63.8$ MeV. For fusion and yield measurements see (1985AJ01) and (1984MA32, 1986GA13, 1986VO12). For the α-decay of ^{19}F* see reaction 42 in ^{19}F in (1987AJ02) and (1985SM04). See also (1986MA1Z), (1984FR1A, 1984HA53) and (1985HU04, 1986HA13, 1986HE1A, 1987CO01, 1988DI08; theor.).

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

Elastic angular distributions (reaction (a)) have been measured at $E(^{12}\mathrm{C}) = 20$ to 77.4 MeV and at $E(^{20}\mathrm{Ne}) = 65.7$ MeV: see (1980AJ01, 1985AJ01). For fusion, reaction cross section, yield and evaporation residue studies see (1985AJ01) and (1984KO12, 1984RA10, 1985MU18, 1985OS05, 1987KO12, 1987SI06). See also (1985FL1B). For pion production see (1985AJ01) and (1983AN1L). For other work at very high energies see (1984AN1H, 1987AN20, 1988DU01).

See also (1983AN1K, 1986BL1K), (1984FR1A, 1984HA53, 1984NA1D, 1984ST1B, 1985BE1A, 1985CU1A, 1985ST1B, 1986IK03, 1986ST1J, 1987LA05, 1987SC1D, 1988BO46, 1989CI1C) and (1984HA43, 1984IN03, 1984SH1T, 1985CH11, 1985GA1G, 1985GU1J, 1985HU04, 1985KO1J, 1986GA1F, 1986GI03, 1986HA13, 1986HE1A, 1987SC33, 1988IW02; theor.).

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

Elastic angular distributions have been measured at $E(^{12}\text{C}) = 20$ to 60 MeV (reaction (a)) and at $E(^{12}\text{C}) = 20$ to 56 MeV (reaction (b)): see (1985AJ01). For fusion, yields and cross-section measurements see (1985AJ01) and (1986GL03, 1988DU11). The fission of ^{24}Mg into 2 ^{12}C (involving ^{12}C*(0, 4.4)) has been studied by (1986FUZW; prelim.). See also (1982CI1C, 1982ME1A, 1984FR1A, 1984HA53, 1986BE1D, 1987KA2A, 1987LA05, 1988RA1G, 1989CI1C) and (1985AN16, 1985LE25, 1986BO14, 1986HA13, 1987BR1H, 1987GR04, 1988AY03, 1988KU1H; theor.).

55. ^{12}C(^{27}Al, ^{27}Al)^{12}C

Angular distributions have been measured at $E(^{12}\text{C}) = 30.0$ to 39.9 MeV and at 82 MeV: see (1985AJ01). For fusion, yield, and breakup measurements see (1985AJ01) and (1984KO12, 1985HA19, 1987KO12). See also (1987PO15). For work at very high energies see (1986AN1X). See also (1985XI1B, 1986BL1L), (1984FR1A, 1986CA30, 1988SN1A) and (1984FO21, 1984NA27, 1986POZW, 1986RO12, 1987ST1E, 1988TO02, 1989SH05; theor.).

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

Elastic angular distributions have been studied for reaction (a) at $E(^{12}\text{C}) = 19$ to 186.4 MeV and at $E(^{28}\text{Si}) = 58.3$ to 116.7 MeV [see (1980AJ01, 1985AJ01)] as well as at $E(^{12}\text{C}) = 56$, 59, 66 and 69.5 MeV (1985SH1K) and 65 MeV (1988YA06).

Alpha-γ angular correlations have been studied at $E(^{28}\text{Si}) = 112.3$ and 142.7 MeV: ^{12}C*(4.4) is found to be produced almost entirely in the $m = 0$ magnetic substate (1986RA08). For fusion, yield and breakup measurements see (1985AJ01) and (1984SH19, 1986HA33, 1987ZH1G). See also (1985SAZZ, 1986FEZY, 1986HAZS, 1987SHZY, 1988MAZZ). For pion production see (1983AN1L). For other work at very high energies see (1987AN20).

See also (1988SA1S, 1988SH33), (1982CI1C, 1984FR1A, 1984HA53, 1986BE2H, 1987LA05, 1989CI1C) and (1986GR1A, 1986KUZZ, 1987AR13, 1987BR1A, 1987KI12, 1987SH06, 1988AL06, 1988AY03, 1988KU1G, 1988KU1H; theor.).

57. ^{12}C(^{32}S, ^{32}S)^{12}C

Elastic angular distributions are reported at $E(^{12}\text{C}) = 35.8$ MeV and $E(^{32}\text{S}) = 73.3$ to 160 MeV [see (1980AJ01, 1985AJ01)] as well as $E(^{32}\text{S}) = 194$, 239 and 278 MeV (1987HI10). For fusion, yield and evaporation residue studies see (1985AJ01) and (1985KO21, 1986PL02, 1987HI10, 1988AR21). See also (1987LA05) and (1989CI1C).

58. (a) ^{12}C(^{39}K, ^{39}K)^{12}C
(b) ^{12}C(^{40}Ar, ^{40}Ar)^{12}C

Elastic angular distributions (reaction (a)) have been studied at $E(^{12}\text{C}) = 54$ and 63 MeV: see (1985AJ01). For reaction (b) see (1989PL02) and (1985MO1K; prelim.).

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

The elastic scattering in all three reactions has been studied at $E(^{12}\text{C}) = 51.0$, 49.9 and 49.9 MeV, respectively [see (1985AJ01)] and, for reaction (a), at $E(^{12}\text{C}) = 180$, 300 and 420 MeV (1986SA29). For fusion, yield, cross-section and fragmentation studies see (1980AJ01, 1985AJ01) and (1984GR20, 1984KO12, 1986SA29, 1987KO12). See also (1985XI1B), (1989BE17, 1989GR04) and (1984SH1T, 1985BL18, 1986CH20, 1986CH38; theor.).

60. ^{12}N(β^+)^{12}C $\qquad Q_{\text{m}} = 17.338$

The decay is mainly to the ground state via an allowed transition. Branching ratios to other states of ^{12}C are displayed in Table 12.21. The half-life of ^{12}N is 11.000 ± 0.016 ms (1978AL01). See also (1968AJ02). The ratio of the branching ratios ^{12}N/^{12}B for the decays to ^{12}C*(4.4) is 1.528 ± 0.027 (1988NA09). See also (1985AJ01). This leads to the following values for the mirror asymmetries of ^{12}B and ^{12}N for decay to ^{12}C*(0, 4.4): $\delta_{\text{g.s.}} = +0.129 \pm 0.008$ (1978AL01), $\delta_{4.4} = +0.066 \pm 0.018$ (1988NA09). See also (1989KR1C).

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

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

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

61. ^{13}C(γ, n) ^{12}C $\qquad Q_{\rm m} = -4.9463$

The decay of the giant resonance in ^{13}C takes place predominantly to ^{12}C*(15.1, 16.1) [and to their analogs in ^{12}B]. Below $E_\gamma = 21$ MeV transitions to ^{12}C*(4.4) are dominant: see (1980AJ01). See also ^{13}C in (1991AJ01).

62. (a) ^{13}C(π^+, p)^{12}C $\qquad Q_{\rm m} = 135.405$
(b) ^{13}C(π^+, π^0p)^{12}C $\qquad Q_{\rm m} = 0.440$

Angular distributions (reaction (a)) have been measured at $E_{\pi^+} = 90$ to 170 MeV to ^{12}C*(0, 4.4, 7.7, 9.6, 12.7, 14.1, 15.1, 16.1, 19.1, 20.6, 22.9, 25.3): an energy dependent ratio for the excitation of ^{12}C*(12.7, 15.1) is reported. Similarities in the population of states seen in this reaction and in the (p, d) reaction are observed. Angular distributions at $E_{\pi^+} = 32$ MeV are also reported: see (1985AJ01). For reaction (b) see (1988POZV).

63. ^{13}C(p, d)^{12}C $\qquad Q_{\rm m} = -2.7218$

Angular distributions have been measured at $E_{\rm p} = 8$ to 800 MeV [see (1980AJ01, 1985AJ01)], at $E_{\rm p} = 18.6$ MeV (1986GO23, 1987GO27; ^{12}C*(0, 4.4)), 41.5 MeV (1987CA20; ^{12}C*(0, 4.4, 12.7, 15.1, 16.1)) and 800 MeV (1984SM04; ^{12}C*(0, 4.4, 12.7, 14.1, 15.1, 16.1)) and at $E_{\vec{\rm p}} = 119$ MeV (1987LE24; ^{12}C*(0, 4.4, 7.7, 9.6, 12.7, 14.1, 15.1, 16.1, 16.6, 17.8, 18.16 ± 0.07, 18.8, 19.9, 20.3, 20.6)) and 500 MeV (1984OH06; g.s.). The population of ^{12}C*(10.3, 15.4) is also reported, and the $\Gamma_{\rm c.m.}$ of the structures at $E_{\rm x} = 18.2$, 18.8, 19.9, 20.3 and 20.6 MeV are, respectively, 240 ± 50, 120 ± 30, ≈ 400, ≈ 220 and ≈ 210 keV (1987LE24). (1984SM04) report structures at 20.61 ± 0.04 and 25.4 ± 0.1 MeV, the latter with $\Gamma \geq 0.5$ MeV. The earlier work [see (1980AJ01)] indicated states at 17.76 ± 0.02 $[80 \pm 20]$, 18.80 ± 0.04 $[80 \pm 30]$, 21.5 ± 0.2 $[< 200]$ and 22.55 ± 0.05 $[< 200]$ MeV [the numbers shown in brackets are $\Gamma_{\rm c.m.}$, in keV].

For (d, γ) correlations via ^{12}C*(15.1) see (1987CA20). See also ^{14}N in (1991AJ01), (1987GIZZ, 1988LE08) and (1988BE1I, 1988GUZW; theor.).

64. ^{13}C(d, t)^{12}C $\qquad Q_{\rm m} = 1.3109$

Angular distributions have been studied at $E_{\rm d} = 0.41$ to 27.5 MeV [see (1975AJ02, 1980AJ01)] and 18 MeV (1988GO02, 1988GU20; $\rm t_0$, $\rm t_1$) as well as $E_{\vec{\rm d}} = 29$ MeV [to ^{12}C*(0, 4.4, 12.7, 15.1, 16.1)]: see (1985AJ01). For charge-dependent matrix elements between ^{12}C*(12.7, 15.1) see Table 12.10. See also (1986GU1J; applications) and (1988GUZW; theor.).

65. (a) ^{13}C(^{3}He, α)^{12}C $\qquad Q_{\rm m} = 15.6314$
(b) ^{13}C(^{3}He, 2α)^{8}Be $\qquad Q_{\rm m} = 8.2648$

Angular distributions have been measured at many energies up to $E(^3{\rm He}) = 45$ MeV [see (1980AJ01, 1985AJ01)] and at 22.7 MeV (1987VA1I; α_0, α_1; prelim.). See (1984VA39, 1985VA1E, 1986ZE1C) for a study of the spin tensors for ^{12}C*(4.4).

A study of reaction (b) leads to Γ_α/Γ for ^{12}C*(15.11) $= (4.1 \pm 0.9)$%; together with the other parameters for the decay of the state (see Table 12.7) this leads to $\Gamma_\alpha = 1.8 \pm 0.3$ eV. If this isospin-forbidden α-width is the result of mixing between ^{12}C*(12.71, 15.11) via a charge-dependent interaction the matrix element is 340 ± 60 keV: see, however, Table 12.10 here, and (1980AJ01). See also (1987BA2B, 1987ZE02, 1988GOZB; theor.) and ^{16}O in (1986AJ04).

66. ^{13}C(α, αn)^{12}C $\qquad Q_{\rm m} = -4.9463$

See ^{13}C in (1991AJ01) and (1984DE44, 1985DE1Q).

67. (a) ^{13}C(^{6}Li, ^{7}Li)^{12}C $\qquad Q_{\rm m} = 2.3037$
(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: see (1980AJ01) and (1987CO16; reaction (b)).

68. (a) ^{13}C(^{13}C, ^{14}C)^{12}C $\quad Q_\text{m} = 3.2302$
    (b) ^{13}C(^{14}C, ^{15}C)^{12}C $\quad Q_\text{m} = -3.7283$
    (c) ^{13}C(^{16}O, ^{17}O)^{12}C $\quad Q_\text{m} = -0.8029$

Angular distributions have been reported for reaction (a) at $E(^{13}\text{C}) = 16.0$ to 50.0 MeV : (see (1985AJ01) [also excitation functions]) and at $E(^{13}\text{C}) = 20.0$ to 27.5 MeV (1988BI11) for reaction (b). See also (1984BA31) and (1987TH04; theor.). For reaction (c) see (1989FR04). See also (1980AJ01).

69. ^{14}C(γ, 2n)^{12}C $\quad Q_\text{m} = -13.1229$

See ^{14}C in (1991AJ01), (1985PY01) and (1987GO09; theor.).

70. ^{14}C(p, t)^{12}C $\quad Q_\text{m} = -4.6410$

Angular distributions have been measured at $E_\text{p} = 14.5$, 18.5, and 39.8 MeV: see (1975AJ02). At $E_\text{p} = 54$ MeV angular distributions are reported to two states at $E_\text{x} = 27.57 \pm 0.03$ and 29.63 ± 0.05 MeV [$\Gamma_\text{c.m.} \lesssim 200$ keV]: their identification as the first $T = 2$ states is supported by the similar angular distributions to the first two $T = 2$ states in ^{12}B, reached in the (p, ^{3}He) reaction [see reaction 28 in ^{12}B]. The lower $T = 2$ state is well fitted by $L = 0$; the angular distribution to ^{12}C*(29.63) is rather featureless. It is suggested that its shape is somewhat more consistent with $L = 0$ than with $L = 2$ (1976AS01): [(1976BA24) has suggested that the second $T = 2$ state in $A = 12$ may have $J^\pi = 0^+$.] It is not excluded that the group to ^{12}C*(29.63) may be due to unresolved states (1976AS01). (1976AS01) report $\Gamma_\text{p}/\Gamma \approx 0.3 \pm 0.1$ and $\Gamma_{\alpha_1}/\Gamma < 0.1$ for the first $T = 2$ state and $\Gamma_\text{p}/\Gamma = 0.8 \pm 0.2$, $\Gamma_{\text{p}_0}/\Gamma \approx 0.4$ and $\Gamma_\alpha/\Gamma \approx 0.2$ for ^{12}C*(29.63). (1978RO08) report $E_\text{x} = 27595.0 \pm 2.4$ keV, $\Gamma \leq 30$ keV for the first $T = 2$ state and calculate the decay properties for two values of the total width, 0 and 30 keV. Branching ratios for the decays to $^8\text{Be}(0)+\alpha$; ^{11}B*(0, 2.12, 4.45, 5.02, $6.74+6.79)+$p; and ^{10}B(0)$+$d are, repectively, (10.5 ± 3.0)%; (3.0 ± 2.2)%, (8.0 ± 2.3)%, (0 ± 3.3)%, (8.4 ± 3.2)%, (8 ± 5)%; and (2.8 ± 2.0)% (1979FR04).

71. (a) ^{14}N(p, ^{3}He)^{12}C $\quad Q_\text{m} = -4.7789$
    (b) ^{14}N(p, pd)^{12}C $\quad Q_\text{m} = -10.2724$

Angular distributions (reaction (a)) have been studied at $E_{\rm p} = 7.5$ to 52 MeV [at the higher energies to ^{12}C*(12.7, 14.1, 15.1, 16.1)] as well as to ^{12}C*(0, 4.4): see (1980AJ01). For reaction (b) see (1985DE17) and (1986VDZY). See also (1987VD03, 1987VD1A) and (1986GO28; theor.).

72. ^{14}N(d, α)^{12}C $\quad Q_{\rm m} = 13.5743$

Observed α-particle groups are displayed in Table 12.19. Angular distributions have been measured at energies up to 40 MeV: see (1980AJ01) [also for J^π assignments]. See also (1987SI1D; applications), (1983US01; theor.) and ^{16}O in (1986AJ04).

73. ^{14}N(α, ^{6}Li)^{12}C $\quad Q_{\rm m} = -8.7974$

See (1988SH1E; theor.).

74. ^{14}N(^{7}Li, ^{9}Be)^{12}C $\quad Q_{\rm m} = 6.4233$

See (1986GO1B).

75. ^{14}N(^{12}C, d)^{12}C^{12}C $\quad Q_{\rm m} = -10.2724$

See (1987AR25) and ^{14}N in (1991AJ01).

76. ^{15}N(p, α)^{12}C $\quad Q_{\rm m} = 4.9656$

Angular distributions of α_0 and α_1 have been measured for $E_{\rm p}$ up to 43.7 MeV. At the highest energy the angular distributions to the 0^+ states ^{12}C*(0, 7.7, 17.8) are fitted by $L = 1$. The distributions to ^{12}C*(14.1, 16.1) [$J^\pi = 4^+, 2^+$] are consistent with $L = 3$; see (1980AJ01). For work on cross sections and resonances see ^{16}O in (1986AJ04) and (1988HO1F). See also (1987WE1C, 1988CA26; astrophysics) and (1984BE1A, 1984HA1Q, 1986LE1L, 1986RO18, 1988GN1A; applications).

77. ^{15}N(α, ^{7}Li)^{12}C $\quad Q_{\rm m} = -12.3806$

At $E_\alpha = 42$ MeV angular distributions involving ^{12}C*(0, 4.4) and ^{7}Li*(0, 0.48) have been obtained: see (1980AJ01). See also (1988SH1E; theor.).

78. (a) ^{16}O$(\gamma, \alpha)^{12}$C $Q_{\rm m} = -7.1619$
(b) ^{16}O(e, e$'\alpha)^{12}$C $Q_{\rm m} = -7.1619$

For reaction (a) see (1986BA50; astrophysics) and (1984GL11, 1987BU1A; theor. [γ, 2d]). For reaction (b) see (1987HO1E). See also ^{16}O in (1986AJ04) and (1988BU06; theor.).

79. ^{16}O(p, p$\alpha)^{12}$C $Q_{\rm m} = -7.1619$

This reaction proceeds primarily to ^{12}C*(0, 4.4) at $E_{\rm p} = 101.5$ MeV (1984CA09): ^{12}C(14.1) is also populated. The breakup into 4α has been studied by (1986VD04). See also (1985AJ01), (1987LA11, 1988LE08, 1988MU1G; astrophysics) and (1985VD03, 1987VD1A) and (1986GO28; theor.).

80. ^{16}O(d, ^{6}Li)^{12}C $Q_{\rm m} = -5.6869$

Angular distributions have been measured at $E_{\rm d} = 12.7$ to 80 MeV [see (1980AJ01, 1985AJ01)], at 54.2 MeV (1984UM04; ^{12}C*(0, 4.4, 7.7, 9.6, 14.1)) [see also for spectroscopic factors] and at $E_{\vec{\rm d}} = 18$ and 22 MeV (1987TA07; ^{12}C*(0, 4.4)) and 51.7 MeV (1986YA12; ^{12}C*(0, 4.4, 14.1)). For polarization measurements see ^{18}F in (1987AJ02).

81. ^{16}O(^{3}He, ^{7}Be)^{12}C $Q_{\rm m} = -5.5746$

Angular distributions have been studied at $E(^{3}{\rm He}) = 30$, 41 and 70 MeV: see (1980AJ01, 1985AJ01). ^{12}C*(0, 4.4, 7.7, 9.6) are populated. See also (1986BA89; astrophysics) and (1987RA37; theor.).

82. (a) ^{16}O$(\alpha, 2\alpha)^{12}$C $Q_{\rm m} = -7.1619$
(b) ^{16}O(α, ^{8}Be)^{12}C $Q_{\rm m} = -7.2538$

At $E_\alpha = 90$ MeV angular distributions involving ^{12}C*(0, 4.4) (reaction (a)) have been analyzed by PWIA and DWBA: $S_\alpha = 2.9 \pm 0.5$ and 0.70 ± 0.23, respectively. At $E_\alpha = 65$ MeV angular distributions involving ^{8}Be$_{\rm g.s.}$ (reaction (b)) and ^{12}C*(0, 4.4, 7.7, 9.6, 14.1) have been measured [the ground state distributions have also been studied for $E_\alpha = 55$ to 72.5 MeV]: $S_\alpha = 0.25$, 1.07, 0.05, 1.40 for ^{12}C*(0, 4.4, 7.7, 14.1): see (1980AJ01) for references.

83. (a) ^{16}O(^{9}Be, ^{13}C)^{12}C $Q_{\rm m} = 3.4856$
(b) ^{16}O(^{16}O, ^{20}Ne)^{12}C $Q_{\rm m} = -2.4263$

For reaction (a) see (1988WE17) and ^{13}C in (1991AJ01). For reaction (b) see (1986CA24) and ^{20}Ne in (1987AJ02). See also (1988AU03), (1984ME10, 1989VO1D) and (1984AP03, 1984KO13, 1987GA1L, 1988GA19, 1988GA1L; theor.).

84. ^{19}F(d, ^{9}Be)^{12}C $Q_{\rm m} = 0.2662$

Angular distributions have been obtained at $E_{\rm d} = 9$ to 14.5 MeV: see (1980AJ01, 1985AJ01). ^{12}C*(0, 4.4) are populated.

85. ^{20}Ne(α, ^{12}C)^{12}C $Q_{\rm m} = -4.6229$

Angular distributions have been measured in the range $E_\alpha = 13.4$ to 20.8 MeV: see (1985AJ01). See also (1985ST1B) and (1988SH1F; theor.).

86. ^{23}Na(p, ^{12}C)^{12}C $Q_{\rm m} = -2.2433$

Angular distributions involving ^{12}C$_{\rm g.s.}$ have been studied at $E_{\rm p} = 7.9$ to 18.6 MeV (1987KI26).

87. ^{23}Na(d, ^{13}C)^{12}C $Q_{\rm m} = 0.4785$

See (1986GO26; $E_{\rm d} = 13.6$ MeV).

88. ^{24}Mg(p, p^{12}C)^{12}C $Q_{\rm m} = -13.9335$

The fission of ^{24}Mg has been studied at $E_{\rm p} = 190$ MeV (1987DA01).

89. ^{24}Mg(α, ^{16}O)^{12}C $\qquad$ $Q_{\rm m} = -6.7716$

Angular distributions have been reported at $E_\alpha = 22.8$ to 25.4 MeV and at 90 MeV [see (1980AJ01)], at 25.13 to 27.76 MeV (1986SK01) and at 27.8 to 29.4 MeV (1989ES06). See also (1987SH1B) and (1988SH1F; theor.).

90. ^{24}Mg(^{12}C, ^{12}C)^{12}C^{12}C $\qquad$ $Q_{\rm m} = -13.9335$

The fission of ^{24}Mg has been studied at $E(^{24}{\rm Mg}) = 357$ MeV (1986WI14).

^{12}N

(Figs. 4 and 5)

GENERAL (See also (1985AJ01)).

Model calculations: (1984KA1H, 1984SA19)

Astrophysical questions: (1985CA41, 1987RA1D, 1988CA26, 1988LE08, 1989KR1C)

Applied work: (1987KU17, 1987MI24)

Complex reactions involving ^{12}*N*: (1985NO1E, 1986GA1P, 1987BA1T, 1987RI03, 1988BE02, 1988LE08)

Muon and neutrino capture and reactions: (1986DA1J, 1987KR1L, 1988AL1O, 1988BO1X, 1988FU08, 1988MI1H, 1988MI20, 1989DR1A, 1989KR1C, 1989MI1I)

Pion capture and reactions: (1983AS01, 1984AS05, 1988HA12, 1988KIZW)

Other topics: (1984KA1H, 1984SA19, 1985AN28, 1986YA1F)

Ground-state properties of ^{12}*N*: (1985AN28, 1985NA1A, 1986GL1A, 1986HA1P, 1987VA26, 1988VA03)

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

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

The half-life of ^{12}N is 11.000 ± 0.016 ms: ^{12}N decays to ^{12}C*(0, 4.44, 7.65, 10.3, 12.71, 15.11): see Table 12.21. Since the transitions to ^{12}C*(0, 4.4) are allowed the J^π of ^{12}N$_{\rm g.s.}$ is 1^+. For measurements of the angular distribution functions from aligned ^{12}N nuclei see (1986MI1P, 1986MI1T, 1987MI1P). See also (1985AJ01), (1986CA1P, 1986MI1Q, 1986MI1R, 1987MI20, 1987VA1P), (1985BA2L; applied), (1985GR1A, 1985MI1A) and (1984DU1E, 1985MO13, 1986KE1A, 1986KO2C, 1986TO1A, 1987DR1A, 1987SA1N, 1988AL1E, 1988SA12, 1989SA1H; theor.).

2. ^{10}B(^{3}He, n) ^{12}N $\qquad Q_{\rm m} = 1.573$

Observed neutron groups are displayed in Table 12.23.

3. ^{12}C(γ, π^-)^{12}N $\qquad Q_{\rm m} = -156.907$

The total cross section has been measured from threshold to $E_{\rm e} = 360$ MeV: see (1985AJ01).

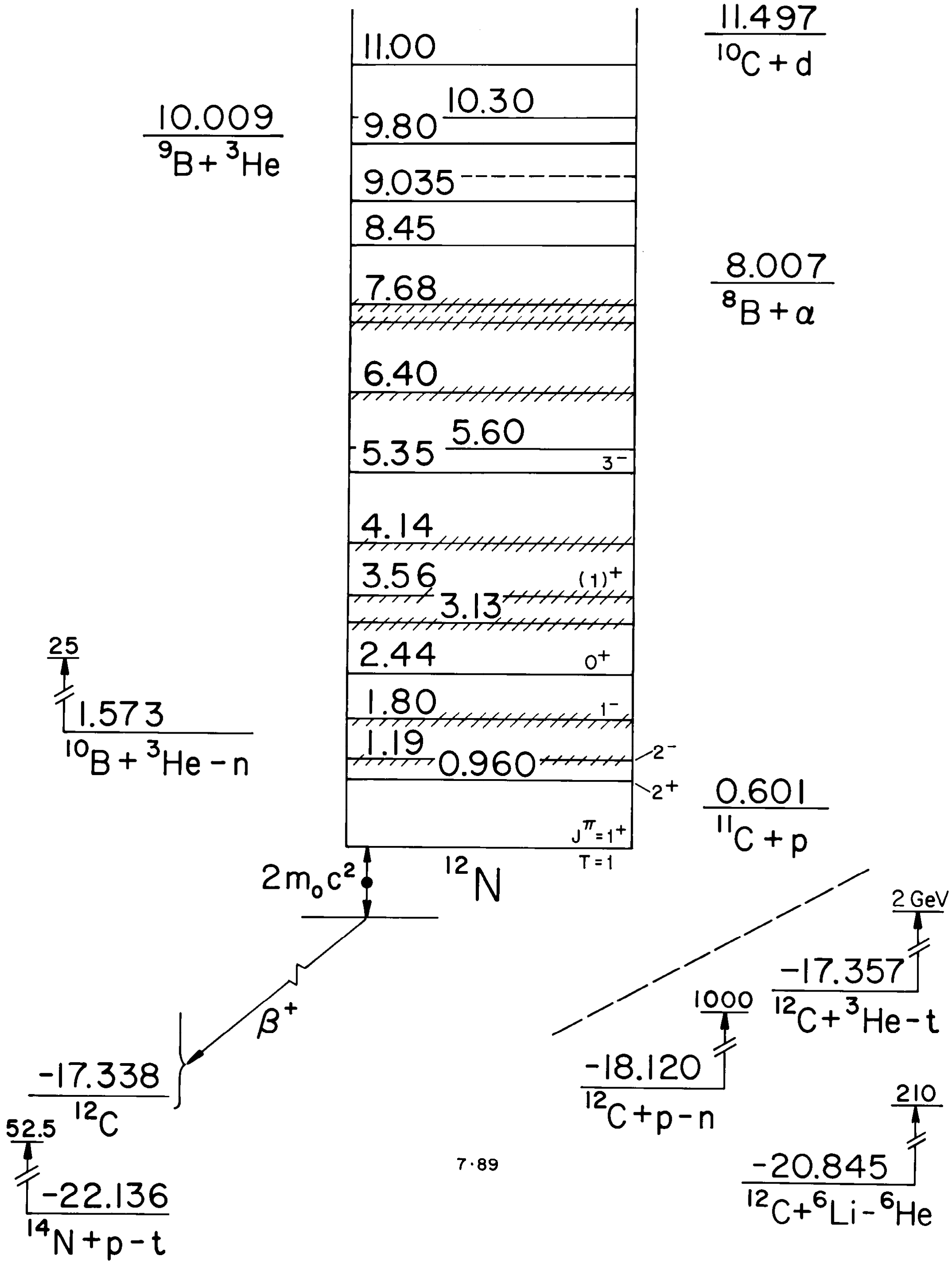

Fig. 4: Energy levels of ^{12}N. For notation see Fig. 2.

Table 12.22: Energy levels of ^{12}N

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

[a] Probably corresponds to unresolved states. See Table 12.23 and reactions 5 and 8.

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

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

[a] ^{10}B(^{3}He, n)^{12}N: see Table 12.26 in (1975AJ02) for references.

[b] ^{12}C(^{3}He, t)^{12}N: see Table 12.23 in (1980AJ01) for references. See also reaction 5 here.

[c] Weighted means of values shown in Table 12.22 (1980AJ01).

[d] ^{12}C(^{3}He, t)^{12}N: (1983ST10: $E(^{3}\mathrm{He}) = 75$ and 81 MeV), and M.N. Harakeh, private communication. See also (1984VA17, 1985VA1A).

[e] DWBA calculations (1983ST10). Some of the J^{π} assignments also reflect knowledge of the analog region in ^{12}B.

[f] May be due to unresolved states.

[g] No other states observed with $E_{\mathrm{x}} < 13$ MeV.

[h] $J^{\pi} = 2^{+}$, (2^{-}), and (0^{+}) for ^{12}N*(0.96, 1.19, 2.42), repectively: see Table 12.23 in (1980AJ01).

4. ^{12}C(p, n)^{12}N $\qquad Q_{\rm m} = -18.120$

Angular distributions have been studied at $E_{\rm p} = 30.5$ to 200 MeV [see (1980AJ01, 1985AJ01)] and at 35 and 40 MeV (1987OH04; $\rm n_0$, $\rm n_1$, $\rm n_2$; DWBA), at 160 MeV (1984GA11; $\rm n_0$; also $A_{\rm y}$; comparison with (p, p′) to ^{12}C*(15.1)). The angular distribution to ^{12}N(4.2) [u?] is consistent with $J^\pi = 2^-$ predicted by theory. A structure at $E_{\rm x} \approx 7.2$ MeV is also observed. Unresolved angular distributions over the range $E_{\rm x} = 2 - 17$ MeV (and $\theta = 5° - 13°$) are dominated by $l = 1$ transitions (1984GA11) [as would be expected at those angles]. (1987TA13, 1989RA09) discuss the relationships between the GT strength and the $0°$ differential cross section in this and other (p, n) reactions. At $E_{\vec{\rm p}} = 65$ MeV the spin transfer coefficient $K_{\rm y}^{\rm y'}$ $(0°)$ for $\vec{\rm n}_0 + \vec{\rm n}_1$ has been measured by (1984SA12). See also (1985AJ01), ^{13}N in (1991AJ01), (1984BA1R, 1988HIZX, 1988NI1C, 1988TAZY, 1989PRZZ), (1988LE08; astrophysics), (1985BA2L), (1984GA36, 1984TAZS, 1985SH1C, 1986GA1P, 1986LI1T, 1987EL08, 1987EL14, 1987LI29, 1987RA32) and (1984SA19, 1987BE1D, 1988HO09, 1988PI08, 1988UD03; theor.).

5. ^{12}C(^{3}He, t)^{12}N $\qquad Q_{\rm m} = -17.357$

Observed triton groups are displayed in Table 12.23. Angular distributions of inelastically scattered ^{3}He to ^{12}C*(15.11, 16.11, 16.58, 17.77, 19.57) have been compared with those of tritons to ^{12}N*(0, 0.96, 1.19, 2.42, 4.25). When the ^{3}He cross sections are corrected for phase-space and isospin factors the angular distributions are closely similar to those for the triton groups, strongly suggesting isobaric analogs: see (1980AJ01) for references. [If ^{12}C*(17.77) and ^{12}N*(2.42) are analogs, then the latter is a 0^+ state.] Angular distributions have been reported at 81 MeV (1983ST10) [to many of the states shown in Table 12.23]. [Compare the ^{12}B and the ^{12}N level structure: it is clear that not all the analog states have been observed in ^{12}N.] Angular distributions have also been studied at $E(^3{\rm He}) = 0.6$ to 2 GeV (1987BE25; to ^{12}N*$(0 + 0.96$, 4., 7.). ^{12}N*(4.) is assumed to be a 2^- state while ^{12}N*(7.) corresponds to a group of 1^- states. The reaction appears to be single-step direct and is well described by DWIA (1987BE25). At $E(^3{\rm He}) = 197$ MeV ($\theta = 0°$) the spectrum shows ^{12}N*(0, 0.96), an ≈ 1 MeV wide state at 4.3 MeV (possibly 2^-, 4^-) and the GDR at $\approx$ 10 MeV ($\approx$ 84% of the strength is 1^-). No structure is observed between $E_{\rm x} = 15$ and 70 MeV (1984TA11). The spectra of inelastically scattered ^{3}He ions (see ^{12}C) and of tritons have been studied at $E(^3{\rm He}) = 170$ MeV. The triton spectrum has been compared with photoabsorption results. (1982TA05) conclude that the isovector GDR is preferentially excited in the (^{3}He, t) process while the (^{3}He, ^{3}He) process preferentially excites the isoscalar giant multipole resonances. Delta isobar excitation has been studied at 1.5, 2.0 and 2.3 GeV (1986CO03). See also (1988AB08), (1984AB06, 1988JA1F, 1989JAZY), (1984GA36, 1984GE1A, 1985RO1N, 1986EL1C, 1986GA1P, 1987EL08, 1987EL14, 1988RO17) and (1984CH1N, 1985JA13, 1987DM02, 1987GU07, 1988ES1A, 1988UD03; theor.).

6. ^{12}C(^{6}Li, ^{6}He)^{12}N

At $E(^6\text{Li}) = 25$ and 35 MeV/A angular distributions have been studied to $^{12}\text{N}_{\text{g.s.}}$ (1987WI09). At the higher energy ^{12}N*(1.0) is also populated as is a broad structure near 4.25 MeV. At forward angles the cross section for the GT transition in this and in other (^{6}Li, ^{6}He) reactions is found to be proportional to the β-deay strength (1986AN29). See also (1984GL06) and (1987AU04, 1988AN06, 1988AU1E, 1989AU1B).

7. ^{12}C(^{12}C, ^{12}B)^{12}N $\qquad Q_{\text{m}} = -30.708$

See ^{12}B.

8. ^{12}C(^{13}C, ^{13}B)^{12}N $\qquad Q_{\text{m}} = -30.776$

At $E(^{13}\text{C}) = 30$ MeV/A ^{12}N*(0, 1.0) are populated but the dominant groups in the forward direction are broad structures at $E_{\text{x}} = 4.2$ and 7.5 MeV attributed to 2^- and 1^- states (1986VO02, 1988VO06).

9. ^{12}C(^{14}N, ^{14}C)^{12}N $\qquad Q_{\text{m}} = -17.495$

See (1986BA16, 1986EL1C, 1986RO1Q).

10. ^{14}N(p, t)^{12}N $\qquad Q_{\text{m}} = -22.136$

At $E_{\text{p}} = 51.9$ MeV angular distributions of the tritons to ^{12}N*(0, 0.96) and of the ^{3}He ions to the analog $T = 1$ states [^{12}C*(15.11, 16.11)] have been measured. At $E_{\text{p}} = 52.5$ MeV the angular distribution to ^{12}N*(2.44) has been studied. See (1980AJ01) for references.

^{12}O

(Fig. 9)

^{12}O has been observed in the ^{16}O(α, ^{8}He) reaction and in the ^{12}C(π^+, π^-) reaction: see (1985AJ01). The mass excess of ^{12}O is 32.06 ± 0.04 MeV (1988WA18). ^{12}O is thus unstable to decay into $^{10}\text{C} + 2\text{p}$ by 1.78 MeV. See also (1985AN28) and (1987BL18, 1987SA15; theor.).

The width of the ground state is $\approx 400 \pm 250$ keV. The diproton branching ratio of $^{12}\text{O}_{\text{g.s.}}$ is estimated to be (60 ± 30)%. It is suggested that the first $T = 2$ state in ^{12}N should occur at $E_{\text{x}} = 12.29 \pm 0.02$ MeV. There is some indication from the ^{16}O(α, ^{8}He) work of an excited state of ^{12}O at $E_{\text{x}} = 1.0 \pm 0.1$ MeV, which would imply an appreciable downward shift from the position of the analog first excited state in ^{12}Be (1978KE06). See also the spectrum shown as Fig. 1 of (1985MO18).

The ^{12}C(π^+, π^-) reaction has been studied for $E_{\pi^+} = 50$ to 240 MeV: see (1985AJ01) and (1985MO18, 1987FA05, 1989GR06). See also (1986GI13), (1989BA1R) and (1986CH39, 1988CO15, 1988GO21, 1988MA27; theor.).

^{12}F, ^{12}Ne

(Not illustruated)

These nuclei have not been observed: see (1980AJ01, 1985AJ01).

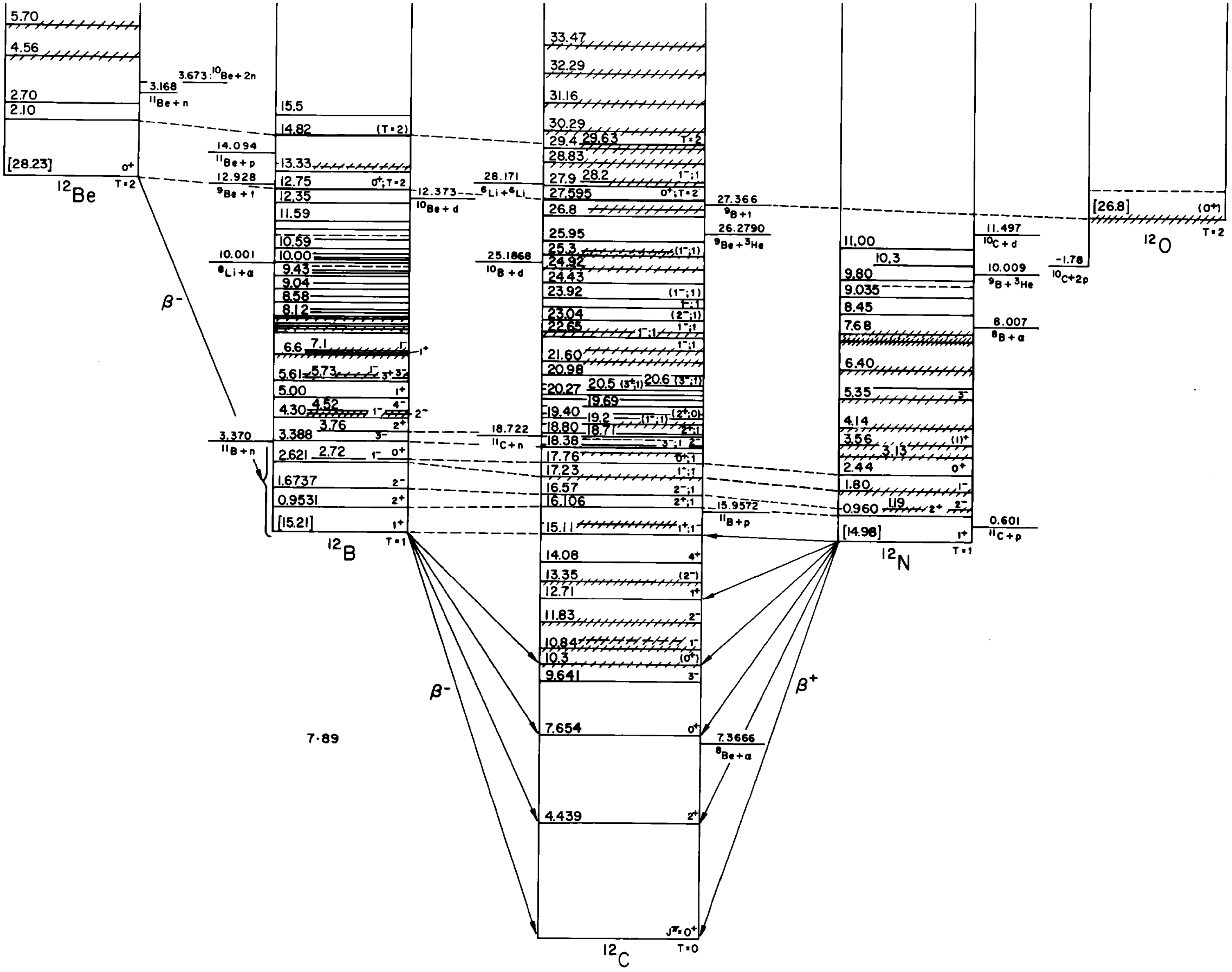

Fig. 5: Isobar diagram, $A = 12$. The diagrams for individual isobars have been shifted vertically to eliminate the neutron-proton mass difference and the Coulomb energy, taken as $E_{\rm C} = 0.60Z(Z-1)/A^{1/3}$. Energies in square brackets represent the (approximate) nuclear energy, $E_{\rm N} = M(Z, A) - ZM({\rm H}) - NM({\rm n}) - E_{\rm C}$, minus the corresponding quantity for ^{12}C: here M represents the atomic mass excess in MeV. Levels which are presumed to be isospin multiplets are connected by dashed lines.

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