

Energy Levels of Light Nuclei $A = 13$

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Abstract: An evaluation of $A = 13$ –15 was published in *Nuclear Physics A268* (1976), p. 1. This version of $A = 13$ differs from the published version in that we have corrected some errors discovered after the article went to press. Figures and introductory tables have been omitted from this manuscript. [Reference](#) key numbers have been changed to the NNDC/TUNL format.

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¹³Li
(Not illustrated)

¹³Li is not observed in the 4.8 GeV proton bombardment of a uranium target: the cross section is $\lesssim 0.2 \mu\text{b}$ (1974BO05). ¹³Li is predicted to have an atomic mass excess of 61.56 MeV: it is then unstable for breakup into ¹²Li + n and ¹¹Li + 2n by 0.6 and 4.5 MeV, respectively (1974TH01). The modified mass equation leads to a calculated amu of 60.34 MeV: ¹³Li would then be stable with respect to breakup into ¹²Li + n by 0.7 MeV, assuming the amu of ¹²Li to be 52.94 MeV, but would be unstable with respect to ¹¹Li + 2n by 3.3 MeV (1975JE02). See also (1972TH13, 1975BE31).

¹³Be
(Not illustrated)

¹³Be is not observed in the 5.5 GeV proton bombardment of uranium (1968PO04) nor in the bombardment of ²³²Th by 145 MeV ¹⁵N ions (1970AR27). ¹³Be is predicted to have an atomic mass excess of 35.35 MeV. It is then unstable with respect to decay into ¹²Be + n by 2.32 MeV (1974TH01). The modified mass equation leads to an amu of 34.60 MeV; ¹³Be would then be unstable with respect to decay into ¹²Be + n by 1.50 MeV (1975JE02). See also (1972TH13, 1973BA34, 1973KO1D, 1973VO1D, 1975BE31).

¹³B
(Figs. 1 and 4)

GENERAL: (See also (1970AJ04).):

Special reactions: (1971AR02, 1973KO1D, 1975AB1D, 1975FO09).

Theoretical papers: (1972AN05, 1973KII12, 1973MU11, 1973MU1B, 1973NA1H, 1973NA14, 1973SA30, 1973WI15, 1975BE31, 1975HU14).

$$Q = 0.048 \pm 0.005 \text{ b (1973HAVZ, 1974SHYR).}$$
$$\mu = 3.1771 \pm 0.0005 \text{ nm (1971WI09, 1973HAVZ).}$$

See also (1973TO16).

1. ¹³B(β^-)¹³C $Q_m = 13.437$

Table 13.1: Energy levels of ^{13}B

E_x (MeV \pm keV)	$J^\pi; T$	τ or Γ_{cm} (keV)	Decay	Reactions
g.s.	$\frac{3}{2}^-; \frac{3}{2}$	$\tau_{1/2} = 17.36 \pm 0.16$ msec	β^-	1, 2, 3, 4, 5
3.483 ± 5	$(\frac{1}{2}, \frac{3}{2}, \frac{5}{2})^+$		γ	2, 4
3.5347 ± 3.1	$(\frac{1}{2}, \frac{5}{2}, \frac{5}{2})^-$	$\tau_m > 0.3$ psec	γ	2, 4
3.681 ± 5	$(\frac{1}{2}, \frac{3}{2}, \frac{5}{2})^+$		(γ)	2, 4, 5
3.712 ± 5	$(\frac{1}{2}, \frac{5}{2}, \frac{7}{2})^-$	$\tau_m < 0.38$ psec	(γ)	2, 4, 5
4.131 ± 5	$(\frac{1}{2}, \frac{5}{2}, \frac{7}{2})^-$	$\tau_m = 0.062 \pm 0.050$ psec	γ	2, 4
4.828 ± 6			(γ)	2, 4
5.023 ± 6				2, 4
5.109 ± 10		$\Gamma = 60 \pm 8$ keV		4
5.390 ± 7		15 ± 5		2, 4
5.557 ± 7				2
6.168 ± 7				2, 4
6.419 ± 8				2
6.939 ± 15				2
7.516 ± 8				2
7.859 ± 20				2
8.129 ± 10				2
8.682 ± 9				2

The half-life of ^{13}B is 17.33 ± 0.17 msec (1971WI07), 17.6 ± 0.4 msec (1962MA19): the mean value is 17.36 ± 0.16 msec (1971WI07). This value leads to $(ft)^+/(ft)^- = 1.166 \pm 0.026$ (see ^{13}O). The induced tensor coupling constant, $g_{\text{IT}} = (2.6 \pm 0.5) \times 10^{-3}$ (1971WI07).

The branching ratios to various ^{13}C states are shown in Table 13.2 (1962MA19, 1969JO21, 1974AL12): they indicate $J^\pi = \frac{1}{2}^-$ or $\frac{3}{2}^-$ for $^{13}\text{B}_{\text{g.s.}}$. See also (1974AL11) and (1971WI18, 1972WI1C, 1973HA49, 1973KUID, 1973MA1K, 1973TO14, 1973WI11, 1974CH46, 1975GR03, 1975WIIE; theor.).

2. $^7\text{Li}(^7\text{Li}, p)^{13}\text{B}$

$$Q_m = 5.966$$

Observed proton groups are shown in Table 13.3 (1959MO12, 1963CA09, 1972WY01). Angular distribution measurements have been reported by (1969CA1A; $p_0, p_{1+2}, p_{3+4}, p_5, p_7$). The lifetimes of $^{13}\text{B}^*(3.53, 3.71, 4.13)$ are, respectively, $> 0.3, < 0.38$ and 0.062 ± 0.050 psec: $E_\gamma = 3536.3 \pm 4.2$ and 4133.4 ± 7.8 keV (1969TH01). See also ^{14}C .

Table 13.2: Beta decay of ^{13}B ^a

Decay to $^{13}\text{C}^*$ (MeV)	J^π	Branch (%)	$\log ft$ ^c
0	$\frac{1}{2}^-$	92.1 ± 0.8	4.01 ± 0.01
3.09	$\frac{1}{2}^+$	≤ 0.7	≥ 5.7
3.68	$\frac{3}{2}^-$	7.6 ± 0.8	4.45 ± 0.04
3.85	$\frac{5}{2}^+$	≤ 0.7	≥ 5.5
7.55 ^d	$\frac{5}{2}^-$	0.094 ± 0.020 ^b	5.33 ± 0.08
8.86	$\frac{1}{2}^-$	0.16 ± 0.03 ^b	4.60 ± 0.08
9.50	$(\frac{3}{2}^-)$	< 0.01	> 5.2
9.90	$\frac{3}{2}^-$	0.022 ± 0.007	4.95 ± 0.12

^a (1962MA19, 1969JO21, 1974AL12). See also Table 13.30.

^b See also (1965PO03, 1968CH28).

^c See also (1970ES03). $\log ft$ shown here are based on $\tau_{1/2} = 17.33 \pm 0.17$ msec.

^d $E_x = 7.577 \pm 0.030$ MeV (1974AL12).

3. $^{10}\text{Be}(\alpha, p)^{13}\text{B}$ $Q_m = -8.818$

See ^{14}C (1974GO1T).

4. $^{11}\text{B}(t, p)^{13}\text{B}$ $Q_m = -0.233$

Observed proton groups are displayed in Table 13.3. Angular distributions have been measured at $E_t = 11$ MeV (1964MI04) and 23 MeV (1975AJ1C). See also (1970AJ04) and (1971WI09).

5. $^{14}\text{C}(d, ^3\text{He})^{13}\text{B}$ $Q_m = -15.338$

At $E_d = 52$ MeV angular distributions for $^{13}\text{B}^*(0, 3.7)$ have been reported (1975MA41).

Table 13.3: Proton groups from ${}^7\text{Li}({}^7\text{Li}, \text{p}){}^{13}\text{B}$ and ${}^{11}\text{B}(\text{t}, \text{p}){}^{13}\text{B}$

${}^7\text{Li}({}^7\text{Li}, \text{p}){}^{13}\text{B}$		${}^{11}\text{B}(\text{t}, \text{p}){}^{13}\text{B}$			
(1959MO12, 1963CA09)	(1972WY01)	(1964MI04)			(1975AJ1C) ^f
E_x (MeV \pm keV)		E_x (MeV \pm keV)	L	J^π	E_x (MeV \pm keV)
0		0	0	$\frac{3}{2}^-$	0
3.50 ± 50 ^a		3.483 ± 5	1	$(\frac{1}{2}, \frac{3}{2}, \frac{5}{2})^+$	3.483 ± 10
		3.533 ± 5	2	$(\frac{1}{2}, \frac{5}{2}, \frac{7}{2})^-$	3.532 ± 10
		3.681 ± 5	1	$(\frac{1}{2}, \frac{3}{2}, \frac{5}{2})^+$	3.683 ± 10
3.70 ± 50 ^b		3.712 ± 5	2	$(\frac{1}{2}, \frac{5}{2}, \frac{7}{2})^-$	3.716 ± 10
4.16 ± 50 ^c	^d	4.13 ± 10	2	$(\frac{1}{2}, \frac{5}{2}, \frac{7}{2})^-$	4.130 ± 10
	4.833 ± 10	4.82 ± 10			4.832 ± 10
5.05 ± 80	5.033 ± 8	5.01 ± 10	1	$(\frac{1}{2}, \frac{3}{2}, \frac{5}{2})^+$	5.020 ± 10
	5.391 ± 8	5.38 ± 10 ^e			5.109 ± 10 ^g
	5.557 ± 8				5.388 ± 10 ^h
	6.169 ± 8	6.17 ± 20			6.165 ± 10
	6.419 ± 8				
	6.939 ± 15				
	7.516 ± 8				
	7.859 ± 20				
	8.129 ± 10				
	8.682 ± 9				

^a The decay is by γ_0 .

^b The decay is primarily by γ_0 : the upper limit to the cascade via ${}^{13}\text{B}^*(3.5)$ is 10%.

^c The decay is $75 \pm 10\%$, $25 \pm 10\%$ and $< 10\%$, respectively to ${}^{13}\text{B}^*(0, 3.5, 3.7)$.

^d All values in this column are based on $E_x = 4131$ keV for ${}^{13}\text{B}^*(4.13)$.

^e $\Gamma = 15 \pm 5$ keV.

^f And O. Hansen, private communication.

^g $\Gamma_{\text{cm}} = 60 \pm 8$ keV.

^h $\Gamma_{\text{cm}} = 10 \pm 10$ keV.

¹³C
(Figs. 2 and 4)

GENERAL (See also (1970AJ04).):

Shell model: (1970CO1H, 1970HS02, 1970TA1J, 1971AR1R, 1971GR02, 1971NO02, 1972DE1H, 1972EL1C, 1972GU05, 1972LE1L, 1973DE13, 1973HA49, 1973KU03, 1973MA1X, 1973MA1K, 1973MU18, 1973SA30, 1974PH1D, 1975ME24, 1975MI12).

Collective and deformed models: (1971AR1R).

Cluster model: (1969BA1J, 1971NO02, 1972LE1L, 1973KU03).

Special levels: (1970FR1C, 1970PE18, 1971AR03, 1971AR1R, 1971GR02, 1971JA13, 1971NO02, 1971SE1C, 1972BE1E, 1972DE1H, 1973MU18, 1973SA30, 1974HA1G, 1974PH1D, 1974TA1E, 1975KU21, 1975ME24, 1975MI12).

Giant resonance: (1970AL1E, 1971JA14, 1972GO27, 1972HA16, 1972LE06, 1973HA1Q, 1973MA1X, 1974HA1C, 1974MU13).

Electromagnetic transitions: (1971DI1G, 1971GR02, 1971JA13, 1972GU05, 1972NA05, 1973HA49, 1973HA1Q, 1973SA25, 1973SA30, 1974AD1B, 1974CH46, 1974HA1C, 1974MU13, 1974RO1R, 1974RO1T, 1975FO1L, 1975KU21, 1975ME24).

Special reactions: (1969GA18, 1971AR02, 1973KO1D, 1973KU03, 1974KO25, 1975HU14, 1975KU01).

Astrophysical questions: (1972CL1A, 1972UL1A, 1973AR1E, 1973AU1B, 1973AU1D, 1973AU1C, 1973BO1R, 1973CO1B, 1973DA1L, 1973SA1J, 1973SC1T, 1973SM1A, 1973TA1D, 1973TR1B, 1973UL1B, 1974BE1R, 1974BO2K, 1974DA1N, 1974LA1J, 1974LA1K, 1974SC1F, 1974TO1C, 1975AR1E, 1975AU1D, 1975BR1J, 1975DE1F, 1975DE1H, 1975EN1A, 1975KI1D, 1975NO1D, 1975SC1H, 1975SN1A, 1975TO1B, 1975TR1A).

Muon and neutrino capture and reactions: (1972BU29, 1973KI12, 1973MU11, 1973MU1B).

Pion capture and reactions (See also reaction 37.): (1970BJ1A, 1970DO04, 1970WE1D, 1971DA10, 1971IN1A, 1972KA1F, 1973AL1D, 1973AU06, 1973DI08, 1973EI01, 1973MI1H, 1973NA1H, 1973NA14, 1973RO10, 1974HO13, 1974KA07, 1974LE25, 1974LI15, 1974MI06, 1974MI11, 1974RE1E, 1974UL02, 1975AL1K, 1975EI1D, 1975GI1B, 1975HU1D, 1975KA1R, 1975KI1E, 1975RE01, 1975TO01, 1976GI01, 1976SH01).

Other topics: (1969WA1C, 1970CO1H, 1970PE18, 1970SH1C, 1970SU1B, 1971AR03, 1971AU1G, 1971BA2Y, 1971GR16, 1971JA13, 1971SE1C, 1971NG01, 1972AN05, 1972CA37, 1972CH16, 1972HA57, 1972LE1L, 1973DE13, 1973GO1H, 1973JU2A, 1973KO1J, 1973KU03, 1973MA48, 1973RA1E, 1973SA25, 1973WI15, 1974CA1H, 1974MU13, 1974SI04, 1974ZU1A, 1975GR03, 1975KU01, 1975MO1M, 1976MA04, 1976PA03).

Table 13.4: Energy levels of ^{13}C ^a

E_x (Mev \pm keV)	$J^\pi; T$	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
g.s.	$\frac{1}{2}^-; \frac{1}{2}$		stable	9, 10, 11, 12, 14, 16, 17, 18, 25, 26, 27, 28, 29, 30, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 82, 83, 84, 86, 87, 88, 89, 90, 91
3.0884 ± 0.2	$\frac{1}{2}^+$	$\tau_m = 1.55 \pm 0.15$ fsec	γ	9, 10, 11, 14, 16, 25, 27, 31, 37, 38, 39, 42, 45, 49, 53, 55, 56, 57, 58, 59, 60, 64, 65, 72, 73, 75, 76, 78, 82, 83, 86
3.68437 ± 0.14 ^b	$\frac{3}{2}^-$	1.59 ± 0.13 fsec	γ	9, 10, 12, 14, 16, 17, 25, 27, 30, 38, 39, 41, 45, 48, 49, 53, 56, 57, 58, 60, 64, 65, 66, 72, 73, 74, 75, 76, 82, 83, 86, 88
3.85362 ± 0.15 ^b	$\frac{5}{2}^+$	12.2 ± 0.4 psec	γ	10, 11, 14, 16, 25, 27, 37, 38, 39, 40, 41, 42, 45, 56, 57, 58, 60, 64, 65, 72, 73, 76, 82, 86
6.864 ± 3	$\frac{5}{2}^+$	$\Gamma = 6$ keV	γ, n	9, 10, 15, 16, 25, 27, 31, 37, 38, 53, 57, 58, 75, 76, 82
7.492 ± 10	$(\frac{7}{2}^+)$	< 5		9, 15, 25, 27, 37, 38, 58, 75, 76, 82
7.547 ± 3	$\frac{5}{2}^-$	1.2 ± 0.3	γ, n	9, 15, 25, 27, 31, 37, 38, 48, 53, 57, 58, 75, 76, 82
7.677 ± 12	$\frac{3}{2}^+$	70 ± 10	n	15, 25, 27, 31, 37, 38, 76
8.2 ± 100	$\frac{3}{2}^+$	1000 ± 100	n	31, 38
8.860 ± 20	$\frac{1}{2}^-$	150 ± 20	γ, n	25, 27, 31, 38, 48, 53, 57, 72, 75, 76, 82, 83
9.498 ± 4	$(\frac{3}{2}^-)$	5	n	9, 15, 25, 27, 31, 32, 37, 38, 57, 75, 76, 82
9.897 ± 5	$\frac{3}{2}^-$	26 ± 3	γ, n	9, 15, 25, 27, 31, 32, 38, 48, 53, 76
10.46		200	n	32
10.753 ± 4	$\frac{7}{2}^-$	55 ± 2	n	15, 25, 31, 32, 38, 76

Table 13.4: Energy levels of ^{13}C ^a (continued)

E_x (MeV \pm keV)	$J^\pi; T$	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
10.818 \pm 5	$(\frac{5}{2}^-)$	24 \pm 3	n	9, 15, 25, 32, 38, 76
10.996 \pm 6	$(\frac{1}{2}^+)$	37 \pm 4	n, α	5, 25, 31, 32, 38, 76
11.080 \pm 5	$(\frac{1}{2}^-)$	< 4	γ , n, α	5, 25, 31, 32, 38, 53, 76, 82
11.748 \pm 10		107 \pm 14	n	25, 31, 38, 53, 76, 82
11.851 \pm 5	$(\frac{3}{2}^-)$	68 \pm 4	n	12, 32, 38, 53, 57, 74, 75, 82
11.97 \pm 40 ^c	$(\frac{7}{2}^-, \frac{5}{2}^+)$	\approx 200	n, α	5, 8, 9, 38
12.106 \pm 5	$(> \frac{7}{2})$	81 \pm 8	n, α	5, 9, 31, 32, 38, 76
12.40 \pm 50	$\frac{7}{2}^-$	150	n, α	5, 31, 32, 82
(13.28)	$(\frac{3}{2}^-)$	340	α	8
13.3 \pm 1000		5000 \pm 1000	γ , n	50
13.41	$(\frac{9}{2}^-)$	35 \pm 3	n, α	5, 8, 9
13.56	$(\frac{3}{2}^+, \frac{5}{2}^+)$	500	n, α	5, 8, 31, 32
13.76	$(\frac{5}{2}^+, \frac{3}{2}^+)$	300	n, α	5, 8
14.12 ^b	$(\frac{5}{2}^-)$	\approx 200	n, α	5, 8, 9
14.39 \pm 100	$(\frac{1}{2}^-, \frac{5}{2}^-)$	260	n, α	5, 9
14.63		210	n, α	5, 9
14.94 \pm 50	$(\frac{3}{2}^+)$	380	n, α	5
15.106 \pm 2 ^d	$\frac{3}{2}^-; \frac{3}{2}$	5.0 \pm 0.7	γ , n, α	9, 25, 31, 53, 57, 66, 82
15.55 \pm 50		220	n, α	5
16.01		210	n, α	5, 31
16.15 \pm 50		230	n, α	5, 31, 53
16.95 \pm 50		330	n, α	5, 53
17.36 \pm 100		190	n, α	5
17.71 \pm 50		170	n, α	5, 53
18.30 \pm 50		300	n, α	5, 53
18.75 \pm 30		70	n, α	5
19.5	$(\frac{1}{2}, \frac{3}{2}, \frac{5}{2})^-$	\approx 450	n, d	19, 31, 32
19.9		\approx 600	n, p, d	19, 20
20.24		\approx 200	(γ), n, d, α	18, 19, 23
20.52 \pm 10		116 \pm 10	(γ), n, p, d	18, 19, 20
21.28 \pm 15		159 \pm 15	n, p, d	19, 20

Table 13.4: Energy levels of ^{13}C ^a (continued)

E_x (MeV \pm keV)	$J^\pi; T$	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
21.81 \pm 20		114 \pm 12	n, d	19
\approx 22 ^e		\approx 7000	γ , n	50
22.23		broad	n, d	19, 53
23		\approx 1000	n	31
23.5 ^e		\approx 3000	γ , p	51
25.5		broad	γ , n, p	50, 51, 53
26.8			n, d	19
27.5			n, d	19, 53

^a See also Tables 13.5, 13.6 and 13.7.

^b See (1969AL17).

^c May be unresolved.

^d See also Table 13.7.

^e In $^{13}\text{C}(e, e)$ the giant resonance is reported split into two peaks near $E_x = 20.5$ and 24.5 MeV, with widths of ≈ 3 and ≈ 4 MeV and $T = \frac{1}{2}$ and $\frac{3}{2}$, respectively (1971BE51): see reaction 53 and see also Table 13.21.

Ground state: (1969LE1B, 1971TA1A, 1972GL06, 1972GU05, 1972LE1L, 1972LE1N, 1972VA36, 1973MA1K, 1973SA25, 1973SA30, 1973SU1C, 1974DE1E, 1974HA27, 1974MU13, 1974NE1B, 1975AL19, 1975BE31, 1975ME24, 1976PA03).

Mass of ^{13}C :

$$13.003354831(\pm 10 \times 10^{-9}) \text{ amu (1975SM02);}$$

$$\mu = +0.702381 \pm 0.000002 \text{ nm (1964LI14);}$$

$$\mu = 0.7020 \pm 0.0004 \text{ nm (1973CO1P).}$$

See also (1969WO03, 1971SH26, 1973SU1B, 1974SHYR).

1. (a) $^6\text{Li}(^7\text{Li}, n)^{12}\text{C}$ $Q_m = 20.924$ $E_b = 25.871$
- (b) $^6\text{Li}(^7\text{Li}, p)^{12}\text{B}$ $Q_m = 8.337$
- (c) $^6\text{Li}(^7\text{Li}, 2n)^{11}\text{C}$ $Q_m = 2.203$
- (d) $^6\text{Li}(^7\text{Li}, d)^{11}\text{B}$ $Q_m = 7.192$
- (e) $^6\text{Li}(^7\text{Li}, t)^{10}\text{B}$ $Q_m = 1.993$
- (f) $^6\text{Li}(^7\text{Li}, \alpha)^9\text{Be}$ $Q_m = 15.223$

Table 13.5: Lifetimes of low-lying states of ^{13}C

$^{13}\text{C}^*$ (MeV)	τ_m	Refs.
3.09	1.0 ± 0.3 fsec	(1970WI04)
	1.50 ± 0.17 fsec	(1968RO02)
	1.7 ± 0.3 fsec	(1975RA22)
3.68	1.55 ± 0.15 fsec	mean of last two values
	1.50 ± 0.15 fsec	(1969RA20)
	1.83 ± 0.25 fsec	(1970WI04)
3.85	1.59 ± 0.13 fsec	mean
	7.5 ± 2.5 psec	(1962SI08)
	15 ± 2 psec	(1968AL03)
	9.0 ± 2.5 psec	(1968RI16)
	10.7 ± 1 psec	(1969HE22)
	9.9 ± 0.9 psec	(1970GA01)
	12.4 ± 0.8 psec	(1974BE48)
	13.0 ± 0.4 psec	(1975RA29)
12.2 ± 0.4 psec	mean of last five values	

Table 13.6: Summary of results on the total radiation widths of the low-lying levels of $^{13}\text{C}-^{13}\text{N}$ ^a

$J_i^\pi \rightarrow J_f^\pi$	$^{13}\text{C}^*$ (MeV)	Γ_γ (eV)	Refs.	$^{13}\text{N}^*$ (MeV)	Γ_γ (eV)	Refs.
$\frac{1}{2}^+ \rightarrow \frac{1}{2}^-$	3.09 ^b	0.43 ± 0.04	Table 13.5	2.37	0.64 ± 0.07	see (1975FO1L) ^g
$\frac{3}{2}^- \rightarrow \frac{1}{2}^-$	3.68 ^c	0.41 ± 0.04	Table 13.5	3.51 ^f	0.53	(1963YO06)
$\frac{5}{2}^+ \rightarrow \frac{1}{2}^-$	3.85 ^d	$(5.4 \pm 0.3) \times 10^{-5}$ ^e	Table 13.5	3.55	$< 2 \times 10^{-3}$	(1963YO06)

^a See also Tables 13.20 and 13.26.

^b $B(E1) = 0.040 \pm 0.005$ W.u.: $\delta = -0.69 \pm 0.05$ (see (1975MA21)).

^c Branching ratios for cascade via $^{13}\text{C}^*(3.09)$ is $1.6 \pm 0.3\%$ (1975TR07).

^d Branching ratios for cascades via $^{13}\text{C}^*(3.68, 3.09)$ are $35 \pm 2\%$ and $1.6 \pm 0.4\%$, respectively (1969LI07), $36.0 \pm 0.7\%$ and $0.6 \pm 0.2\%$, respectively (1975TR07).

^e Assuming the ground state branching ratio to be $69 \pm 4\%$ [but see footnote ^b] and the mixing ratio $\delta(E3/M2) = +(0.12 \pm 0.03)$ (1966PO11), $\Gamma(E3) = (5.2 \pm 2.6) \times 10^{-7}$ eV and $\Gamma(M2) = (3.61 \pm 0.23) \times 10^{-5}$ eV: then $|M(E3)|^2 = 2.0 \pm 1.0$ single particle units (1975RA29).

^f Branching ratio for cascade via $^{13}\text{N}^*(2.37)$ is $8 \pm 1\%$ (1974RO29).

^g See also (1968RI16, 1975MA21).

Table 13.7: Parameters of the first $T = \frac{3}{2}$ states in ^{13}C and ^{13}N ^a

	$^{13}\text{C}^*(15.11)$	$^{13}\text{N}^*(15.07)$
E_x (MeV)	15.106 ± 0.002	15.0651 ± 0.0009
J^π	$\frac{3}{2}^-$	$\frac{3}{2}^-$
Γ_{cm} (keV) ^b	5.0 ± 0.7	1.10 ± 0.09
Γ_{γ_0} (eV)	22.7 ± 2.6 (M1)[0.32 ± 0.04 W.u.] 0.59 ± 0.11 (E2)[0.52 ± 0.10 W.u.]	24.2 ± 1.5 (M1)[0.34 ± 0.02 W.u.] ^f 0.32 ± 0.12 (E2)[0.28 ± 0.11 W.u.] ^g
Γ_{γ_1} (eV)	4.12 ± 0.74 (E1)[$(6.4 \pm 1.1) \times 10^{-3}$ W.u.]	$\leq (2.82 \pm 0.30)$ (E1) [$\leq (3.7 \pm 0.4) \times 10^{-3}$ W.u.] ^h
Γ_{γ_2} (eV)	18.2 ± 2.4 (M1)[0.59 ± 0.08 W.u.] ^e	19.6 ± 1.4 (M1)[0.61 ± 0.04 W.u.] ^{e,i}
Γ_{n_0} or Γ_{p_0} (keV) ^c	0.35 ± 0.10	0.210 ± 0.011
Γ_{n_1} or Γ_{p_1} (keV) ^c	1.31 ± 0.24	0.165 ± 0.018
Γ_{n_2} or Γ_{p_2} (keV) ^c	0.130 ± 0.092	0.058 ± 0.017
Γ_{α_0} (keV) ^d	0.095 ± 0.028	0.044 ± 0.027
Γ_{α_1} (keV) ^d		0.035 ± 0.035
Γ_{α_2} (keV) ^d		0.065 ± 0.044

^a (1973AD02, 1973HU07, 1975HI07, 1975MA21). See also Table 13.8 in (1970AJ04) and reactions 13, 15 and 16 in ^{13}N .

^b Total Γ_{cm} adopted by (1973AD02).

^c Widths for $^{13}\text{C}^*(15.11) \rightarrow ^{12}\text{C}_{\text{g.s.}} + n_0$ or $^{13}\text{N}^*(15.07) \rightarrow ^{12}\text{C}_{\text{g.s.}} + p_0$ [n_1, p_1 and n_2, p_2 correspond to the decays to $^{12}\text{C}^*(4.4, 7.7)$ respectively].

^d Widths for $^{13}\text{C}^*(15.11) \rightarrow ^9\text{Be}_{\text{g.s.}} + \alpha_0$ or $^{13}\text{N}^*(15.07) \rightarrow ^9\text{B}_{\text{g.s.}} + \alpha_0$ [α_1 and α_2 refer to the decays to $^9\text{B}^*(1.6, 2.4)$].

^e May contain a small component of γ_3 (1975MA21).

^f $\delta = -0.07 \pm 0.13$ (1975MA21).

^g $\delta = 0.82^{+1.2}_{-0.6}$ (1975MA21).

^h $\delta \geq 0.83 \pm 0.29$ (1975MA21).

ⁱ $\delta = -0.04 \pm 0.14$ (1975MA21).

The yield curves for d_0 ($E(^6\text{Li}) = 4$ to 14 MeV), t_0 ($E(^7\text{Li}) = 5$ to 14 MeV) and α_0 ($E(^6\text{Li}) = 4$ to 14 MeV) show broad, uncorrelated structures. Energy-averaged differential cross sections are also reported for a number of ^{12}B , ^{11}B and ^{10}B states (1971WY01). Total cross section measurements have been measured for $E(^7\text{Li}) = 3.8$ to 6.0 MeV for $p_0 \rightarrow p_2, p_{3+4}, p_5$; $d_0 \rightarrow d_3, d_{4+5}, d_6$; $t_0 \rightarrow t_2$; and α_0 : the total cross sections generally increase smoothly with energy without showing any structure (1967KI03). The ^{11}C yield has been measured for $E(^6\text{Li}) = 1.2$ to 3.6 MeV by (1961NO05). See also ^9Be and ^{10}B in (1974AJ01), ^{11}B and ^{12}B in (1975AJ02), (1969KA1E) and (1972GA1E).

2. $^7\text{Li}(^7\text{Li}, n)^{13}\text{C}$ $Q_m = 18.620$

See (1970AJ04).

3. $^7\text{Li}(^{11}\text{B}, \alpha n)^{13}\text{C}$ $Q_m = 9.955$

See (1970AJ04).

4. $^9\text{Be}(\alpha, \gamma)^{13}\text{C}$ $Q_m = 10.648$

Earlier reports of the excitation of the first $T = \frac{3}{2}$ state in this reaction have not been published: see (1970AJ04).

5. (a) $^9\text{Be}(\alpha, n)^{12}\text{C}$ $Q_m = 5.702$ $E_b = 10.648$
 (b) $^9\text{Be}(\alpha, 2n)^{11}\text{C}$ $Q_m = -13.020$

Resonances for n_0 and n_1 , for γ -rays from $^{12}\text{C}^*(4.4, 12.7, 15.1)$ and resonances in the total neutron cross section are given in Table 13.8. The yield of neutrons to $^{12}\text{C}^*(7.66, 9.64)$ has been measured for $E_\alpha = 2.9$ to 6.4 MeV and 5.9 to 6.4 MeV, respectively (1972OB01). The n_0 and n_1 yields for $E_\alpha = 1.5$ to 7.5 MeV and the n_2 yield for $E_\alpha = 3.8$ to 7.5 MeV are reported by (1970VA23).

Polarization measurements have been reported at $E_n = 1.75$ and 1.96 MeV (1969KL09; n_0), 2.55 MeV (1970ST15, 1970ST16; n_0), 2.6 MeV (1971KL04; n_0), 4.5 to 5.85 MeV (1973DE14[†]; n_0, n_1) and 22.9 MeV (1973OK06; n_0, n_1). For earlier measurements see (1970AJ04). See also (1970TA06). For astrophysical implications see (1968DA1D, 1972OB01, 1975FO19). See also (1971AN1L, 1975KA26), (1971WA1D) and (1971EL1B; applied). Reaction (b) has been studied at a number of energies in the range $E_\alpha = 17$ to 44 MeV (1970KR09).

[†] The n_0 cross section and polarization are described for $E_n = 4$ to 6 MeV in terms of five broad states: see Table 13.8.

Table 13.8: Resonances in ${}^9\text{Be}(\alpha, n){}^{12}\text{C}$

E_α ^a (MeV)	E_α ^b (MeV)	E_α ^c (MeV)	Γ_{cm} (keV)	J^π	${}^{13}\text{C}^*$ ^d (MeV)	Refs.
0.52	0.52		≈ 55 ^e	$(\frac{1}{2}^+)$	11.01	(1956JA28, 1968DA05)
0.60	0.60		< 4 ^e		11.06	(1968DA05)
1.9	1.905	1.92	130	$(\frac{7}{2}^-)$	11.97	(1953TA06, 1954BE08, 1955TA28, 1956BO61, 1956JA28, 1965GI02, 1970VA23)
2.24		2.25	280		12.20	(1956BO61, 1965GI02)
2.58	2.6	2.58	≈ 200	$(\frac{1}{2}^-)$	12.43	(1953TA06, 1956BO61, 1956JA28, 1965GI02, 1965GR22)
4.00	3.98	4.00	35 ± 3 ^g		13.41	(1956BO61, 1959GI47, 1963SE04, 1965GI02, 1965GR22, 1972OB01)
4.18			570	$(\frac{3}{2}^+)$	13.54	(1957RI38, 1965GR22, 1973DE14)
4.50	4.47	4.50	≈ 350	$(\frac{5}{2}^+)$	13.76	(1956BO61, 1959GI47, 1963SE04, 1965GI02, 1965GR22, 1973DE14)
5.0	5.02	5.0	≈ 200		14.12	(1956BO61, 1963SE04, 1965GI02)
5.40 ± 0.10	5.3 ^f		260	$(\frac{1}{2}^-, \frac{5}{2}^-)$	14.39 ± 0.1	(1963SE04, 1965GR22, 1966MI12, 1973DE14)
	5.75	5.75	210		14.63	(1959GI47, 1963SE04, 1965GI02, 1965GR22, 1966MI12)
6.20 ± 0.05			380	$(\frac{3}{2}^+)$	14.94 ± 0.05	(1965GR22, 1966MI12, 1973DE14)
		(6.7)	broad		(15.29)	(1965GI02)
7.10 ± 0.05	7.00		220		15.56 ± 0.05	(1963SE04, 1965GR22, 1966MI12)
	7.75	7.8	210		16.01	(1959GI47, 1963SE04, 1965GI02, 1965GR22)
7.95 ± 0.05			230		16.15 ± 0.05	(1965GR22, 1966MI12)
9.10 ± 0.05		9.1	330		16.95 ± 0.05	(1965GI02, 1965GR22, 1966MI12)
9.7 ± 0.10	9.70		190		17.36 ± 0.1	(1965GR22, 1966MI12)
10.2 ± 0.05			170		17.71 ± 0.05	(1965GR22, 1966MI12)
(10.60)			40		(17.99)	(1965GR22)
11.05 ± 0.05			300		18.30 ± 0.05	(1965GR22, 1966MI12)
11.70 ± 0.03	11.60		70		18.75 ± 0.03	(1965GR22, 1966MI12)

^a Resonances in neutron yield.

^b Resonances in n_1 group and for 4.4 MeV γ -rays.

^c Resonances in total cross section.

^d Not corrected for effects of Coulomb barrier penetration.

^e $\omega\gamma = 3.79$ and 0.88 eV, respectively (1968DA05).

^f (1973DE14) suggest the possibility that $^{13}\text{C}^*(14.4)$ is composed of two states with the same J^π .

^g J.L. Weil, private communication.

$$6. \text{}^9\text{Be}(\alpha, \text{p})^{12}\text{B} \qquad Q_{\text{m}} = -6.886 \qquad E_{\text{b}} = 10.648$$

See (1968AJ02).

$$7. \text{(a) } ^9\text{Be}(\alpha, \text{d})^{11}\text{B} \qquad Q_{\text{m}} = -8.031 \qquad E_{\text{b}} = 10.648$$
$$\text{(b) } ^9\text{Be}(\alpha, \text{t})^{10}\text{B} \qquad Q_{\text{m}} = -13.229$$

Excitation curves have been measured for $E_\alpha = 26.5$ to 27.5 MeV for the $\text{d}_0 \rightarrow \text{d}_3$, d_{4+5} and d_6 groups: no structure is observed (1975PU01). See also ^{11}B in (1975AJ02). At $E_\alpha = 26.0$ to 27.5 MeV yield curves have been obtained for the t_0 , t_1 and t_3 groups: the t_2 group to $^{10}\text{B}^*(1.74)$ is not populated at $\theta = 25^\circ$ and 45° ; the yield curves do not display structure (1974KE06).

$$8. \text{(a) } ^9\text{Be}(\alpha, \alpha)^9\text{Be} \qquad E_{\text{b}} = 10.648$$
$$\text{(b) } ^9\text{Be}(\alpha, \alpha\text{n})^8\text{Be} \qquad Q_{\text{m}} = -1.6651$$
$$\text{(c) } ^9\text{Be}(\alpha, \text{n})^4\text{He}^4\text{He}^4\text{He} \qquad Q_{\text{m}} = -1.573$$

A number of excitation functions have been measured for elastically scattered alpha particles (reaction (a)) for $E_\alpha = 1.4$ to 20 MeV: these show considerable resonance structure with the variations being most prominent below 10 MeV but persisting up to 20 MeV (1965TA1C, 1970GO1G, 1973GO15, 1974SA16). The parameters resulting from a best-fit of the excitation functions are displayed in Table 13.9: see footnotes to that table for a summary of the most important caveats (1973GO15). For reactions (a) and (b) see ^9Be in (1974AJ01). For reaction (b) see (1973WE03). For a spallation study see (1974RA11).

$$9. \text{}^9\text{Be}({}^6\text{Li}, \text{d})^{13}\text{C} \qquad Q_{\text{m}} = 9.174$$

Table 13.9: Resonances in ${}^9\text{Be}(\alpha, \alpha_0)$ ^a

E_α (MeV)	Γ_{cm} (keV)	l_α	J^π	${}^{13}\text{C}^*$ (MeV)
1.93 ^e	180 ^e	1, 0	$\frac{5}{2}^+$	11.98
3.80	343	0, 2	$\frac{3}{2}^-$ ^b	13.28
4.00	58	(4, 6)	$(\frac{9}{2}^-)$	13.42
4.20	685	1, 3	$\frac{5}{2}^+$ ^c	13.56
4.50	247	1, 3	$\frac{3}{2}^+$ ^c	13.76
5.00	75	2, 4	$\frac{5}{2}^-$ ^d	14.11
5.075	73	3, 5	$\frac{7}{2}^+$ ^d	14.162
(5.50)	400	(1, 3)	$(\frac{5}{2}^+)$	(14.46)

^a (1973GO15): from analysis in the single-level approximation. This assumes the J^π ordering suggested by (1965LI09).

^b Favored by the analysis but the assignment is not certain and more than one state may be involved.

^c (1973DE14) suggest the opposite ordering [$\frac{3}{2}^+$, $\frac{5}{2}^+$]: see Table 13.8.

^d An equally good fit to the data is obtained with a $\frac{7}{2}^-$ state at 5.0 MeV and a $(\frac{3}{2}, \frac{5}{2}, \frac{7}{2})^+$ state at 5.08 MeV.

^e This resonance is reported by (1974SA16). It is not clear whether the Γ is in the c.m. or lab systems. Γ_α is given as 72 keV.

At $E({}^6\text{Li}) = 23.8$ MeV angular distributions are reported to ${}^{13}\text{C}^*(0, 3.1, 3.6, 6.9, 7.5, 9.9, 10.8, 12.0, 13.3)$. There is some indication of the population of ${}^{13}\text{C}^*(9.5, 13.9, 14.5, 15.2, 16.7, 18.5)$ (1971GO24). See also (1970OG1A, 1973OG1A).

$$10. {}^9\text{Be}({}^7\text{Li}, t){}^{13}\text{C} \quad Q_m = 8.181$$

At $E({}^7\text{Li}) = 5.6$ to 6.2 MeV, angular distributions are reported for t_0, t_1, t_{2+3}, t_4 (1969SN02). The t_0 angular distribution has been measured for $E({}^7\text{Li}) = 1.7$ to 1.9 MeV (1969KA1C). Many of the states populated in reaction 9 are also strongly populated in this reaction (1971GO24: $E({}^7\text{Li}) = 30.3$ MeV). See also (1970OG1A, 1972GA1E).

$$11. {}^9\text{Be}({}^{12}\text{C}, {}^8\text{Be}){}^{13}\text{C} \quad Q_m = 3.281$$

Angular distributions have been measured at $E({}^{12}\text{C}) = 12$ and 15 MeV involving the transitions to ${}^{13}\text{C}^*(0, 3.09, 3.85)$: the extracted neutron spectroscopic factors for these three states are 0.80, 1.02 and 0.89, respectively (1970BA49, 1971BA68).

$$12. {}^9\text{Be}({}^{14}\text{N}, {}^{10}\text{B}){}^{13}\text{C} \quad Q_m = -0.965$$

See (1970AJ04).

$$13. \begin{array}{lll} \text{(a) } {}^{10}\text{B}(\text{t}, \text{p}){}^{12}\text{B} & Q_m = 6.343 & E_b = 23.877 \\ \text{(b) } {}^{10}\text{B}(\text{t}, \text{d}){}^{11}\text{B} & Q_m = 5.198 & \\ \text{(c) } {}^{10}\text{B}(\text{t}, \alpha){}^9\text{Be} & Q_m = 13.229 & \end{array}$$

The p_0 and p_1 yields from reaction (a), the d_0 yield from reaction (b) and the α_0 yield from reaction (c) have been determined for $E_t = 0.8$ to 2.0 MeV. There is no evidence of resonance behavior (1963HO19).

$$14. {}^{10}\text{B}(\alpha, \text{p}){}^{13}\text{C} \quad Q_m = 4.0627$$

Proton groups have been observed to the first four states of ${}^{13}\text{C}$: see (1959AJ76) and (1975WI04). Angular distributions of ground state protons have been measured at many energies up to $E_\alpha = 30.4$ MeV: see (1970AJ04) and ${}^{14}\text{N}$.

The τ_m of ${}^{13}\text{C}^*(3.85)$ is $9.0_{-1.5}^{+2.5}$ psec (1968RI16), 10.7 ± 1 psec (1969HE22), 9.9 ± 0.9 psec (1970GA01). The intensity ratio for the transitions $(3.85 \rightarrow 3.68)/(3.85 \rightarrow 0)$ is 0.55 ± 0.03 . The cascade decay via ${}^{13}\text{C}^*(3.09)$, relative to the g.s. decay, is $(2.5 \pm 0.5) \times 10^{-2}$. $E_\gamma = 3854 \pm 1$ keV (1969LI07). Studies of this reaction lead to $J^\pi = \frac{3}{2}^-$ and $\frac{5}{2}^+$ for ${}^{13}\text{C}^*(3.68, 3.85)$: see (1970AJ04) for a summary of the evidence and (1971HIZF). See also (1967SP09) and (1971BU1K; theor.).

$$15. {}^{10}\text{B}({}^6\text{Li}, {}^3\text{He}){}^{13}\text{C} \quad Q_m = 8.083$$

Comparisons of the relative intensities of the ${}^3\text{He}$ groups in this reaction and of the triton groups in the mirror reaction (see reaction 11 in ${}^{13}\text{N}$) at $E({}^6\text{Li}) = 18$ MeV suggest that the following states are analogs: $6.86 - 6.36$, $7.49 - 7.16$, $9.50 - 9.00$, $9.90 - 9.48$, $(10.82 + 10.75) - (10.36 + 10.36)$ [the first (set of) E_x is in ${}^{13}\text{C}$, the second in ${}^{13}\text{N}$]. An angular distribution is also reported for ${}^{13}\text{C}^*(9.50)$ and the widths for ${}^{13}\text{C}^*(7.55, 7.68, 9.50)$ are determined to be < 30 , 60 ± 30 and < 30 keV, respectively (1974HO06).

$$16. {}^{10}\text{B}({}^7\text{Li}, \alpha){}^{13}\text{C} \quad Q_m = 21.411$$

Angular distributions have been measured at $E({}^7\text{Li}) = 5.20$ MeV for the α_0 , α_1 , α_{2+3} and α_4 groups (1966MC05).

17. $^{10}\text{B}(^{14}\text{N}, ^{11}\text{C})^{13}\text{C}$ $Q_m = 1.141$

At $E(^{10}\text{B}) = 100$ MeV angular distributions are reported for the transitions to $^{13}\text{C}^*(0, 3.68, 7.5, 11.8)$ (1975NA15). See also (1970GO1B).

18. $^{11}\text{B}(\text{d}, \gamma)^{13}\text{C}$ $Q_m = 18.6790$

The $90^\circ \gamma_0$ excitation curve measured for $E_d = 1.0$ to 4.2 MeV shows a resonance at $E_d = 2.0 \pm 0.1$ MeV ($^{13}\text{C}^*(20.4)$) with $\Gamma_{\text{lab}} \approx 0.6$ MeV: the peak cross section is $\approx 1.1 \mu\text{b/sr}$. The angular distributions of γ_0 are isotropic to within 10% on and off ($E_d = 3.6$ MeV) resonance, consistent with E1 radiation (1973WE12).

19. $^{11}\text{B}(\text{d}, \text{n})^{12}\text{C}$ $Q_m = 13.7325$ $E_b = 18.6790$

The yield of neutrons and γ -rays has been measured for $E_d = 0.2$ to 11 MeV; observed resonances are displayed in Table 13.10 (1958KA31, 1964KU09, 1965AL17, 1967DI01, 1972TH14). The yields of 4.4 and 15.1 MeV γ -rays have been measured by (1972TH14) for $E_d = 2.7$ to 5.0 and 4.0 to 4.8 MeV, respectively. Angular correlations for these two γ -rays are reported at $E_d = 4.0, 4.5$ and 4.8 MeV (1972TH14). For a listing of polarization measurements, see Table 13.11: measurements at $E_d = 11.8$ MeV show that the transition to $^{12}\text{C}^*(4.4)$ predominantly involves $j = \frac{1}{2}$ for the transferred proton (1971HI09). See also (1970AJ04), (1970MI1G, 1975SE07; theor.) and ^{12}C in (1975AJ02).

20. $^{11}\text{B}(\text{d}, \text{p})^{12}\text{B}$ $Q_m = 1.145$ $E_b = 18.6790$

Some measurements show that the thin-target yield rises smoothly from $E_d = 0.3$ to 3.1 MeV with no evidence of resonance: see (1970AJ04). However, (1964BR1A) and (1968CH05) report a resonance in the yields of p_0, p_1 and p_2 , and of γ_1 and γ_2 : see Table 13.10. Polarization measurements at $E_d = 10$ and 12 MeV show that $p_{j=\frac{1}{2}}$ for both the p_0 and p_1 transitions are 0.85 ± 0.15 (1970FI07, 1972FI1E, 1973FI1C). See also (1970VO09, 1974DA13, 1975HU1H) and ^{12}B in (1975AJ02).

21. $^{11}\text{B}(\text{d}, \text{d})^{11}\text{B}$ $E_b = 18.6790$

A polarization measurement has been reported at $E_d = 12.6$ MeV (1971ZA04). See also (1970VE06) and ^{11}B in (1975AJ02).

Table 13.10: Resonant structure in $^{11}\text{B} + \text{d}$

Resonant structure in yield of (MeV \pm keV)									Γ_{cm} (keV)	E_x (MeV)
γ_0^{a}	n_0^{b}	n_1^{b}	n_2^{b}	n_3^{b}	$\gamma_{15.1}^{\text{c}}$	p	$\gamma_{0.9}, \gamma_{1.7}^{\text{d}}$	α^{e}		
2.0 ± 100		1.2							≈ 600	19.7^{i}
		1.45							≈ 200	19.90
		1.6	1.8^{f}							20.24
			2.2^{f}			2.180 ± 10	$2.2^{\text{g,h}}$	≈ 2.1	116 ± 10	20.52
						3.080 ± 15	3.0^{g}		159 ± 15	21.28
		3.6				3.71 ± 20			114 ± 21	21.81
		4.23	4.0	4.1		4.4			broad	22.23
			(5.2)							(23.1)
		9.6	9.6	9.6	9.6					26.8
	10.4		10.4	10.4					27.5	

^a (1973WE12): $\Gamma_{\text{lab}} \approx 600$ keV.

^b (1965AL17, 1967DI01, 1972TH14).

^c (1958KA31, 1964KU09).

^d Broad resonance in yields of $\gamma_{0.95}$ and $\gamma_{1.67}$ (1968CH05).

^e Yield of $\alpha_0, \alpha_1, \alpha_2, \alpha_3$ (1969FR03).

^f (1965AL17) report a resonance at 1.8 MeV while (1967DI01) report one at 2.2 MeV, in addition to a sharper structure at 1.2 MeV.

^g Resonance in polarization of ^{12}B recoils (1967PF02).

^h Yield of p_0, p_1 and p_2 (1964BR1A).

ⁱ (1971RI19, 1972SE09) suggest $J^\pi = \frac{5}{2}^-$.

 Table 13.11: Polarization measurements in $^{11}\text{B}(\text{d}, \text{n})^{12}\text{C}^{\text{a}}$

E_{d} (MeV)	Neutron groups	Refs.
0.9	n_0	(1971RI19, 1972SE09)
2.40 – 4.00	n_0, n_1, n_{2+3}	(1972ME06)
3.0 – 5.5	$n_0, n_1, n_2, n_3, n_6, n_7$	(1974TH02)
5.5	n_0, n_1	(1970BU15)
7.6, 9.6, 11.7	n_0, n_1	(1970TA1B, 1971TA1D, 1971TA1E)
10.0, 11.8	n_0, n_1	(1971HI09)

^a See also the previous measurements listed in reaction 17 of (1970AJ04).

22. (a) $^{11}\text{B}(\text{d}, \text{t})^{10}\text{B}$ $Q_{\text{m}} = -5.1984$ $E_{\text{b}} = 18.6790$
 (b) $^{11}\text{B}(\text{d}, ^3\text{He})^{10}\text{Be}$ $Q_{\text{m}} = -5.7356$

For polarization measurements of $t_0 \rightarrow t_3$ at $E_{\text{d}} = 27.8$ MeV see (1974VA1E). See also (1974AJ01).

23. $^{11}\text{B}(\text{d}, \alpha)^9\text{Be}$ $Q_{\text{m}} = 8.031$ $E_{\text{b}} = 18.6790$

At low energies the excitation functions for α_0 and α_1 increase monotonically: see (1970AJ04). Then at $E_{\text{d}} = 1.85$ MeV a pronounced resonance is observed in the α_0 , α_1 , α_2 and α_3 yields (1969FR03). Some gross structure is also observed in these yields for $E_{\text{d}} = 1.0$ to 3.2 MeV (1964BR1A, 1969FR03). See also ^9Be in (1974AJ01).

24. $^{11}\text{B}(\text{t}, \text{n})^{13}\text{C}$ $Q_{\text{m}} = 12.4214$

See ^{14}C .

25. $^{11}\text{B}(^3\text{He}, \text{p})^{13}\text{C}$ $Q_{\text{m}} = 13.1852$

Levels derived from proton groups are displayed in Table 13.12. The gamma, neutron and α -widths of the first $T = \frac{3}{2}$ state at $E_{\text{x}} = 15.11$ MeV are displayed in Table 13.7 where they are compared with corresponding quantities for $^{13}\text{N}^*(15.07)$ (1973AD02, 1975MA21). The particle decays of the $T = \frac{3}{2}$ states show strong charge asymmetries indicating that the isovector and isotensor mixing amplitudes have similar magnitudes (1973AD02). See (1970AJ04) for the earlier work on this state.

Angular distributions have been measured at many energies, see (1970AJ04) for the earlier work and (1970ME1N, 1970ME24, 1971ME01: $E(^3\text{He}) = 3$ MeV; Table 13.12) and (1973WU01, 1971WU1A: $E(^3\text{He}) = 4, 6, 8, 10, 12$ MeV; most states below $E_{\text{x}} = 10$ MeV). For $^{13}\text{C}^*(7.49, 7.55)$ $\Gamma_{\gamma}/\Gamma = 0.3 \pm 0.1\%$, $< 0.1\%$ (1971HIZF). See also (1970MA38, 1974GU1D; theor.).

26. $^{11}\text{B}(\alpha, \text{d})^{13}\text{C}$ $Q_{\text{m}} = -5.1686$

Angular distributions for the d_0 group have been measured at $E_{\alpha} = 23$ and 25 MeV (1968AL1C). See also (1971BU1K; theor.).

Table 13.12: Levels of ^{13}C from $^{11}\text{B}(^3\text{He}, \text{p})^{13}\text{C}$ ^a

E_x (MeV \pm keV)	$\Gamma_{\text{c.m.}}$ (keV)	Refs.
0		(1955BI26, 1958MO99, 1963GA03)
3.09		(1955BI26, 1958MO99, 1963GA03, 1971ME01)
3.68	< 5	(1955BI26, 1958MO99, 1963GA03, 1971ME01)
3.85	< 5	(1958MO99, 1963GA03, 1971ME01)
6.871 \pm 12 ^b	< 10	(1959YO25, 1963GA03, 1971ME01)
7.500 \pm 12	< 5	(1959YO25, 1963GA03, 1971ME01)
7.554 \pm 12	< 5	(1959YO25, 1963GA03, 1971ME01)
7.694 \pm 14	70 \pm 10	(1959YO25, 1963GA03, 1971ME01)
8.869 \pm 36	150 \pm 30	(1959YO25, 1971ME01)
9.509 \pm 12	< 10	(1959YO25, 1971ME01)
9.896 \pm 12 ^c	< 10	(1959YO25, 1971ME01)
10.76 \pm 10		(1971ME01)
10.82 \pm 10		(1971ME01)
11.01 \pm 10		(1971ME01)
11.09 \pm 10		(1971ME01)
(11.72) ^d		(1973AD02)
15.11		(1973AD02)

^a A number of higher states were reported in Table 13.7 in (1970AJ04): however, the references for these levels have not been published.

^b Decay is by n-emission to $^{12}\text{C}_{\text{g.s.}}$: branching ratio = 0.99 ± 0.09 (1973AD02).

^c Branching ratios for neutron decay to $^{12}\text{C}^*(0, 4.4) = 1.0 \pm 0.2$ and < 0.15 , respectively (1973AD02).

^d For this state these branching ratios are 0.67 ± 0.16 and 0.33 ± 0.08 , respectively (1973AD02).

Table 13.13: Neutron capture γ -rays in ^{13}C

E_γ (MeV \pm keV)	Transition	Intensities ^a	
		(1967TH05)	(1968SP01)
4.9458 ± 0.6	capt. \rightarrow g.s.		68 ± 1
4.94546 ± 0.17 ^b	capt. \rightarrow g.s.		
4.946	capt. \rightarrow g.s.	66 ± 3	
3.68428 ± 0.14	3.68 \rightarrow g.s.		32 ± 1
3.68394 ± 0.17 ^b	3.68 \rightarrow g.s.		
3.684	3.68 \rightarrow g.s.	34 ± 2	
1.26176 ± 0.07	capt. \rightarrow 3.68		32 ± 1
1.26192 ± 0.06 ^b	capt. \rightarrow 3.68		
1.2619 ± 0.4 ^c	capt. \rightarrow 3.68		
1.267	capt. \rightarrow 3.68	34 ± 2	

^a Gamma rays per 100 captures. See also (1970AJ04).

^b (1967PR10).

^c (1972OP01).

27. $^{11}\text{B}(^6\text{Li}, \alpha)^{13}\text{C}$ $Q_m = 17.205$

Angular distributions are reported at $E(^6\text{Li}) = 4.72$ MeV for α_0 , α_1 , α_{2+3} , α_4 and α_{5+6+7} (1966MC05).

28. $^{11}\text{B}(^{14}\text{N}, ^{12}\text{C})^{13}\text{C}$ $Q_m = 8.4065$

Angular distributions involving the ground state transitions have been measured at $E(^{14}\text{N}) = 41, 77$ and 113 MeV (1971LI11). See also (1970JA1B) and (1973DE1U; theor.).

29. $^{11}\text{B}(^{16}\text{O}, ^{14}\text{N})^{13}\text{C}$ $Q_m = -2.058$

See (1968OK06) and (1972KU1H; theor.).

Table 13.14: $^{12}\text{C} + n$ total cross section measurements ^a

E_n (MeV)	Refs.
0.001 – 15	(1975HE02)
0.07 – 7	(1970UT1A)
0.1 – 1.50	(1970ME1C)
0.1 – 5.0	(1975HO1N)
0.2 – 20	(1972PE1E)
2.1 – 4.7	(1973FA06)
2.5 – 15	(1971FO1A)
3.03 – 6.94	(1972GA13)
4.04 – 5.61	(1971BO07)
4.60 – 8.56 ^b	(1969PE1C)
5.3 – 6.3	(1968YA1A)
6.01 – 8.56 ^c	(1969PE1C)
7.73, 8.20, 9.00	(1973VE03)
8.0 to 14.5	(1975HA1Z, 1975HA2D)
14.1	(1969GR30)
14.5	(1970AN1F)
17 – 20.5	(1970DE14)
21.0 – 44.2	(1974BU05)
24.63 – 58.90	(1972AU01)
0.9 to 2.5 GeV/ c	(1973SC01)
26 – 54 GeV	(1974BA52, 1975BA2L)
34 – 273 GeV/ c	(1974JO13, 1975MU1B)

^a For earlier references see Table 13.11 in (1970AJ04).

^b Elastic scattering.

^c Inelastic scattering.

Table 13.15: $^{12}\text{C}(n, n)^{12}\text{C}$ polarization studies ^a

E_n (MeV)	Neutron groups	Refs.
1.9 – 5.0	n_0	(1972HO01, 1973HO39)
1.9 – 5.2	n_0	(1972DR03)
2.3	n_0	(1967RO1C)
2.63	n_0	(1973KN06)
2.72 – 2.92	n_0	(1971HA16)
4.55, 4.79., 5.15	n_0	(1974WE1Q)
14.1	n_0, n_1	(1971SE1D)
14.2	n_0, n_1	(1975CA1V)
15.85	n_0, n_1	(1971MA1M)

^a See Table 13.12 in (1970AJ04) for earlier references. See also (1972BU20).

30. $^{12}\text{C}(n, \gamma)^{13}\text{C}$

$$Q_m = 4.9464$$

$$Q_0 = 4.94603 \pm 0.00015 \text{ (1968SP01);}$$

$$Q_0 = 4.94647 \pm 0.00017 \text{ (1967PR10);}$$

$$Q_0 = 4.94643 \pm 0.00003 \text{ (1975SM02).}$$

The thermal capture cross section is 3.4 ± 0.3 mb (1973MU14). Reported γ -transitions are displayed in Table 13.13. See also (1967MO05, 1967RA24, 1975LA1K, 1975SH18), (1970CL1C, 1973CL1E; astrophys.) and (1974MA10; theor.). At $E_n = 14$ MeV, there is some indication that γ_0 peaks backwards (1975AR19).

31. $^{12}\text{C}(n, n)^{12}\text{C}$

$$E_b = 4.9464$$

The coherent scattering length $a_{\text{coh}} = 6.6572 \pm 0.0013$ fm (1971KO1F, 1975KO1K). (1973MU14) had adopted 6.65 ± 0.01 fm. A listing of recent σ_t measurements is displayed in Table 13.14, and the recent polarization measurements are shown in Table 13.15. See also (1972BU20, 1973FA06) and (1970GA1A) for a review of earlier angular distributions.

A number of resonances have been observed for $E_n = 2$ to 20 MeV: see Table 13.16. The parameters of the resonances with $E_n > 6.3$ MeV are poorly known.

See also (1969BE1F, 1969FA1B, 1970AH1B, 1971CR1C, 1974HE1E, 1976HO1B), (1971PL1C, 1972LA1F, 1973BR1C, 1975HA2C, 1975LA1K, 1975RO1G), (1970CO1J, 1970ER1A, 1970GN1A, 1970SH14, 1970YO1C, 1971CH01, 1971DO15, 1971GR48, 1971MI07, 1971WE08, 1972AD02,

Table 13.16: Resonances in $^{12}\text{C}(n, n)^{12}\text{C}$ ^a

E_{res} (MeV \pm keV)	Γ_{cm} (keV)	$^{13}\text{C}^*$ (MeV)	l_n	J^π		Refs.
		3.09	0	$\frac{1}{2}^+$	$\theta^2 = 0.185$ ^b	(1970ME1C)
2.079 ± 3 ^c	6	6.864	2	$\frac{5}{2}^+$	^f	(1961LA1A, 1963PI03, 1968DA1F, 1973HO39, 1975HE02)
2.819 ± 3 ^d	1.2 ± 0.3	7.547				(1968CI1A, 1975HE02)
2.94 ± 10 ^c	124 ± 7	7.66	2	$\frac{3}{2}^+$		(1973FA06, 1973HO39, 1975HU01)
3.472 ± 15 ^c	1000 ± 50	8.149	2	$\frac{3}{2}^+$	$\theta^2 = 0.35$ ^f	(1961FO07, 1973FA06, 1973HO39, 1975HU01)
4.259 ± 15 ^c	210 ± 15	8.875	1	$\frac{1}{2}^-$	$\Gamma_{\text{el}}/\Gamma = 1.00$ ^f	(1961FO07, 1972GA13, 1973FA06, 1973HO39)
4.935 ± 4	5	9.498	1	$(\frac{1}{2}^-, \frac{3}{2}^-)$	1.00 ^f	(1961FO07, 1969DA13, 1972GA13, 1975HE02)
5.368 ± 5	26 ± 3	9.897	1	$\frac{3}{2}^-$	0.70 ± 0.10 ^f	(1961FO07, 1969DA13, 1972GA13, 1975HE02)
6.294 ± 5	53 ± 4	10.751	3	$\frac{7}{2}^-$	0.70 ± 0.10	(1961FO07, 1969DA13, 1972GA13, 1975HE02)
6.5		10.9				(1961FO07)
6.558 ± 8	37 ± 4	10.994	(0)	$(\frac{1}{2}^+)$	0.40 ± 0.10	(1961FO07, 1972GA13)
6.7		11.1				(1961FO07)
(7.4)	(250)	(11.8)		$(\geq \frac{5}{2})$		(1961FO07)
7.759 ± 8	(200)	12.102		$(> \frac{7}{2})$		(1961FO07, 1969DA13)
(8.1)	(150)	(12.4)				(1961FO07)
9.3	370	13.5				(1961FO07)
11.1	450	15.2		$(\geq \frac{3}{2})$		(1961FO07)
12.1	230	16.1				(1961FO07)
15.8 ^e	≈ 460	19.5	1	$(\frac{1}{2}, \frac{3}{2})^-$		(1968BO34)
19.6 ± 200	≈ 1000	23.0				(1965HA21, 1968BO34, 1970DE14)

^a See Table 13.10 in (1970AJ04) for earlier references. See also (1973MU14).

^b $\gamma_n^2 = 540$ keV, radius = 4.80 fm (1970ME1C: single bound state + hard sphere scattering). See also (1970UT1A).

^c See also (1973AB07).

^d See also (1973KN06).

^e Resonance in elastic scattering: see also Table 13.17.

^f See also Table 13.18 and Table I in (1973DA17).

1972FR09, 1972JO11, 1972PE11, 1972PE1H, 1972RO07, 1972RO08, 1973AD01, 1973CO27, 1973LE02, 1973MO1F, 1973WE06, 1974OL1D, 1974PH03, 1974ZA04, 1975CA05, 1976AH02; theor.), ^{12}C in (1975AJ02) and (1970AJ04).

32. (a) $^{12}\text{C}(n, n')^{12}\text{C}^*$

$$E_b = 4.9464$$

(b) $^{12}\text{C}(n, n')^4\text{He}^4\text{He}^4\text{He}$

$$Q_m = -7.2748$$

From threshold to $E_n = 19$ MeV, twelve resonances are observed in the yield of 4.4 MeV γ -rays: see Table 13.17 (1959HA13, 1968BO34). Cross sections for production of 4.4 MeV γ -rays have been reported at $E_n = 5.8$ to 7.5 MeV (1970DR1B) and for the n_0 and n_1 groups at $E_n = 8$ to 14.5 MeV (1975HA1Z, 1975HA2D). Other inelastic cross sections to individual ^{12}C states have been measured by (1973VE03: $E_n = 7.7, 8.2, 9.0$ MeV) and by (1969GR30: $E_n = 14.1$ MeV). Earlier work is displayed in (1959AJ76, 1970AJ04). For reaction (b) see ^{12}C in (1975AJ02) and (1969GR30, 1975AN01). See also (1969RO1F, 1973VE03, 1974RO1U, 1975HA2C, 1975LA1K), (1970CA13; theor.) and (1974CR1E; applied).

Table 13.17: Resonances in $^{12}\text{C}(n, n'\gamma_{4.4})^{12}\text{C}$ ^a

E_n (MeV)	$\Gamma_{\text{c.m.}}$ (keV)	E_x in ^{13}C (MeV)
4.96	< 80	9.52
5.42	< 80	9.95
5.98	200	10.46
6.35	120	10.80
6.57	< 80	11.01
6.65	< 80	11.08
7.50	260	11.86
7.81	180	12.15
8.14	220	12.45
9.31	500	13.53
15.8	≈ 450	19.5
≈ 19		22.5 ^b

^a The first ten resonances are from (1959HA13), the two highest are reported by (1968BO34).

^b See, however, (1970DE14).

$$33. \text{}^{12}\text{C}(\text{n}, 2\text{n})^{11}\text{C} \quad Q_{\text{m}} = -18.722 \quad E_{\text{b}} = 4.9464$$

See (1969BR1F, 1975BI1K) and (1970AJ04).

$$34. \text{}^{12}\text{C}(\text{n}, \text{p})^{12}\text{B} \quad Q_{\text{m}} = -12.588 \quad E_{\text{b}} = 4.9464$$

The cross section exhibits a weak resonance corresponding to $E_{\text{x}} \approx 20.5$ MeV (1968RI02, 1972BO73) and stronger structures at $E_{\text{x}} \approx 21.5$ MeV (1968RI02, 1970BA1L), 22.8 and 23.6 MeV (1970BA1L; abstract). See also (1971CU1B, 1972ED01, 1975LA1K, 1975MC19) and (1974OL03; theor.).

$$35. \text{}^{12}\text{C}(\text{n}, \text{d})^{11}\text{B} \quad Q_{\text{m}} = -13.7325 \quad E_{\text{b}} = 4.9464$$

See (1974PO03, 1975LA1K, 1975MC19).

$$36. \text{}^{12}\text{C}(\text{n}, \alpha)^9\text{Be} \quad Q_{\text{m}} = -5.702 \quad E_{\text{b}} = 4.9464$$

The cross section for the α_0 group shows a broad structure at $E_{\text{n}} \approx 8$ MeV (1963DA12). See also (1971SA31, 1973VE03, 1974RO1U). (1975HA2C, 1975LA1K) and ^9Be in (1974AJ01).

$$37. \text{}^{12}\text{C}(\text{p}, \pi^+)^{13}\text{C} \quad Q_{\text{m}} = -135.405$$

At $E_{\text{p}} = 185$ MeV, angular distributions have been observed for the π^+ groups to the ground state of ^{13}C and to $E_{\text{x}} = 3.08 \pm 0.09, 3.80 \pm 0.12, 6.87 \pm 0.18, 7.57 \pm 0.16$ and 9.51 ± 0.22 MeV. The shape of the distributions and the differential cross sections to the various states are quite different: several kinds of reaction processes appear to be involved (1973DA24). See also (1972RH1A, 1973EI1B), (1973KE02, 1974GR1Q, 1975EI1B, 1975NO05, 1976LE02; theor.) and “Pion capture and reactions” section in the “GENERAL” section here.

$$38. \text{(a) } \text{}^{12}\text{C}(\text{d}, \text{p})^{13}\text{C} \quad Q_{\text{m}} = 2.7218$$

$$\text{(b) } \text{}^{12}\text{C}(\text{d}, \text{np})^{12}\text{C} \quad Q_{\text{m}} = -2.2246$$

$$Q_0 = 2721.9 \pm 0.8 \text{ keV (1974JO14).}$$

Measurements on the proton groups are summarized in Table 13.18. Angular distributions have been studied at many energies: recent experiments are listed in Table 13.19. For earlier work see (1959AJ76, 1970AJ04). Observed γ -rays are listed in Table 13.16 of (1970AJ04): ground state decays have been observed for $^{13}\text{C}^*(3.09, 3.68, 3.85)$. $^{13}\text{C}^*(3.68)$ decays via $^{13}\text{C}^*(3.09)$ with a $1.6 \pm 0.3\%$ branch (1975TR07). $^{13}\text{C}^*(3.85)$ also decays via $^{13}\text{C}^*(3.68)$ with a $37 \pm 4\%$ branch (1966GO15), $36.0 \pm 0.7\%$ (1975TR07), with $E_\gamma = 169.25 \pm 0.04$ keV (1969AL17) and via $^{13}\text{C}^*(3.09)$ with a $0.6 \pm 0.2\%$ branch (1975TR07). Mixing ratios are given in (1970AJ04). Lifetimes of the first three excited states are displayed in Table 13.5. Recent measurements give $\tau_m = 12.4 \pm 0.8$ psec (1974BE48), 13.0 ± 0.4 psec (1975RA29) for $^{13}\text{C}^*(3.85)$: its nuclear g-factor is 0.59 ± 0.05 (1974BE48).

Reaction (b) has been studied in a kinematically complete experiment at $E_d = 5.00$ to 9.85 MeV: there is some evidence for p-n final state interaction (1973SA03). See also (1969PH1B, 1972GE1G).

See also (1967SP09, 1970BO20, 1970HO37, 1973MU1H, 1975ZA06, 1976SC1G), (1974FO1J), (1969ST1D, 1970DO10, 1970EL01, 1970KU1B, 1970OH06, 1970OH1C, 1970PE1B, 1971BR1H, 1971BU02, 1971PE10, 1972DZ06, 1972GO27, 1973CO23, 1973CO27, 1973DO02, 1974GO02, 1974OR1A, 1975GR12, 1975HU01, 1975IS03; theor.) and ^{14}N .

$$39. \ ^{12}\text{C}(t, d)^{13}\text{C} \quad Q_m = -1.3112$$

At $E_t = 12$ MeV angular distributions have been studied by (1966GL01: $d_0 \rightarrow d_3$). See also (1969AR1B).

$$40. \ ^{12}\text{C}(^3\text{He}, 2p)^{13}\text{C} \quad Q_m = -2.7720$$

The angular distributions for the transitions to $^{13}\text{C}^*(0, 3.85)$ have been studied at $E(^3\text{He}) = 40$ MeV (1971ST21). The proton decay of various ^{14}N states to $^{13}\text{C}_{\text{g.s.}}$ has been studied by (1974NO01): see ^{14}N . See also (1970AJ04).

$$41. \ ^{12}\text{C}(\alpha, ^3\text{He})^{13}\text{C} \quad Q_m = -15.6321$$

Angular distributions of the ^3He particles have been measured at $E_\alpha = 56$ MeV (1969GA11: to $^{13}\text{C}^*(0, 3.68 + 3.85)$), 104 MeV (1972HA08: to $^{13}\text{C}(0)$) and 139 MeV (1973SM03: to $^{13}\text{C}^*(0, 3.85)$). A detailed comparison has been made between the angular distributions of the ground state ^3He particles and of the tritons from the mirror reaction $^{12}\text{C}(\alpha, t)^{13}\text{N}$ (1969GA11, 1972HA08). See also (1974HA32; theor.).

Table 13.18: Levels of ^{13}C from $^{12}\text{C}(\text{d}, \text{p})^{13}\text{C}$

E_x (MeV \pm keV)		Γ_{cm} (keV)	l_n^b	J^π^b	S	
A	(1955MC75)					(1973GO03, 1975TR07)
0	0		1	$\frac{1}{2}^-$	0.58 ± 0.04^c 1.1 ^d	
3.087 ± 5	3.09	3.0884 ± 0.2^g	0	$\frac{1}{2}^+$	0.36 ± 0.02^c 1.1 ^d	
3.685 ± 7	3.68	$\equiv 3.6841$	1	$\frac{3}{2}^-$	0.10 ^d	
3.855 ± 7	3.85	3.8535 ± 0.2^g	2	$\frac{5}{2}^+$	1.1 ^d	
	6.86		2	$\frac{5}{2}^+$	0.04 ^d	
	7.470 ± 20					
	7.533 ± 20					
	7.641 ± 20					
	8.4 ± 300	8.25^f	70 ± 15			
		8.86^f	1100 ± 300	2	$\frac{3}{2}^+$	1.0 ^{d,e}
	9.500 ± 20			1	$\frac{1}{2}^-$	0.5 ^{d,e}
	9.897 ± 20			(1)	$(\frac{3}{2}^-)$	
	10.759 ± 20			1	$\frac{3}{2}^-$	0.1 ^{d,e}
		10.755 ± 5	56 ± 2			
		10.818 ± 5	24 ± 3			
		10.997 ± 8	82 ± 15			
		11.080 ± 5	< 8			
		11.748 ± 10	107 ± 14			
		11.851 ± 5	68 ± 4			
		11.97 ± 40^a	≈ 260			
		12.108 ± 5	81 ± 8			

A: (1951ST19, 1951VA1A, 1954SP01).

^a May correspond to unresolved states.

^b See (1970AJ04, 1973DA17).

^c (1972PE11).

^d (1973DA17) [HD parameters]. See also (1974GM01, 1975HU01) and Table 13.14 in (1970AJ04).

^e $\Gamma_{\text{d,p}}/\Gamma_n = 0.68, 0.91$ and 2.2 for $^{13}\text{C}^*(8.25, 8.86, 9.90)$, respectively (1973DA17).

^f Nominal energies (1973DA17).

^g From E_γ measurements: E_x relative to adopted energy of $^{13}\text{C}^*(3.68)$ (Table 13.4) (1975TR07).

Table 13.19: $^{12}\text{C}(\text{d}, \text{p})^{13}\text{C}$ angular distribution studies ^a

E_d (MeV)	Proton groups	Refs.
0.39 – 1.36	p ₀	(1972HU13)
0.41, 0.51	p ₀	(1971PU01)
1.14, 1.18	p ₀	(1973LE26)
1.39 – 2.28	p ₀	(1970AL26)
1.44 – 1.46	p ₁	(1973TR02)
1.82 – 2.50	p ₀	(1974GM01)
2.26	p ₁ , p ₂	(1974GM01)
2.46 – 2.80	p ₀ → p ₃	(1973BE25)
2.64 – 2.82	p ₀ → p ₃	(1974DA06)
2.71 – 3.07	p ₀ , p ₁	(1972BO56)
3.31 – 3.69	p ₀	(1970LE20)
4.5	p ₀	(1969GU02)
9.2 – 13.9	p ₀ , p ₁	(1969GU1C)
9.3, 13.3	p ₀ → p ₄ , p ₈ → p ₁₁	(1973DA17)
51.0, 51.5	p ₀	(1969BR1E, 1971FE1D)
80.2	p ₀ , p ₁ , p ₃	(1971DU09)

^a For earlier measurements see Table 13.15 in (1970AJ04).

42. $^{12}\text{C}(^7\text{Li}, ^6\text{Li})^{13}\text{C}$ $Q_m = -2.304$

Angular distributions have been obtained at $E(^7\text{Li}) = 36$ MeV to $^{13}\text{C}^*(0, 3.09, 3.85)$ (1973SC26). See also (1973KU12; theor.).

43. $^{12}\text{C}(^{11}\text{B}, ^{10}\text{B})^{13}\text{C}$ $Q_m = -6.510$

See (1974AN36) and (1972MO1E, 1973SC1J). See also (1970AJ04).

44. (a) $^{12}\text{C}(^{12}\text{C}, ^{11}\text{C})^{13}\text{C}$ $Q_m = -13.7755$
 (b) $^{12}\text{C}(^{13}\text{C}, ^{12}\text{C})^{13}\text{C}$

For reaction (a) see (1974AN36). See also (1972BR21; theor.). For (b) see reaction 60.

$$45. {}^{12}\text{C}({}^{14}\text{N}, {}^{13}\text{N}){}^{13}\text{C} \quad Q_m = -5.607$$

Angular distributions have been reported at $E({}^{14}\text{N}) = 78$ MeV (1970VO02; transitions to both g.s., and also ${}^{13}\text{N}(0) + {}^{13}\text{C}^*(3.85)$), 100 MeV (1974DE03: to ${}^{13}\text{C}^*(0, 3.09, 3.68 + 3.85, 7.3 \pm 0.3$ [may be due to $6.86 + 7.50 + 7.55 + 7.68$]) and 154.8 MeV (1975NA15, 1975VO05, 1976NA1P: to g.s. and 3.85). The ratio of the differential cross section to ${}^{13}\text{C}_{\text{g.s.}}$ and that to ${}^{13}\text{N}_{\text{g.s.}}$ (observed via ${}^{12}\text{C}({}^{14}\text{N}, {}^{13}\text{C}){}^{13}\text{N}$), as a function of θ , is approximately 1 as expected if mirror symmetry holds (1969VO01, 1970VO02, 1975VO05). See also (1970JA1B, 1973BR1C, 1973SC1J, 1973VO1E, 1974AN36, 1974SC1M, 1975HA1P) and (1970AN1D, 1973DE02, 1973DE1U, 1974BR18, 1974BR1G, 1975RE04; theor.).

$$46. \text{(a) } {}^{12}\text{C}({}^{17}\text{O}, {}^{16}\text{O}){}^{13}\text{C} \quad Q_m = 0.804$$

$$\text{(b) } {}^{12}\text{C}({}^{18}\text{O}, {}^{17}\text{O}){}^{13}\text{C} \quad Q_m = -3.100$$

See (1974CH1Q).

$$47. {}^{12}\text{C}({}^{19}\text{F}, {}^{18}\text{F}){}^{13}\text{C} \quad Q_m = -5.484$$

See (1970AJ04).

$$48. {}^{13}\text{B}(\beta^-){}^{13}\text{C} \quad Q_m = 13.437$$

${}^{13}\text{B}$ decays to a number of states of ${}^{13}\text{C}$: see Table 13.2.

$$49. {}^{13}\text{C}(\gamma, \gamma){}^{13}\text{C}$$

For τ_m studied by resonant scattering see Table 13.5.

$$50. \text{(a) } {}^{13}\text{C}(\gamma, n){}^{12}\text{C} \quad Q_m = -4.9464$$

$$\text{(b) } {}^{13}\text{C}(\gamma, 2n){}^{11}\text{C} \quad Q_m = -23.668$$

The cross section exhibits structure at 13.3 ± 1 [$\Gamma = 5 \pm 1$ MeV] and at ≈ 22 MeV [$\Gamma \approx 7$ MeV] (1957CO57, 1975PA09, 1976MC1L). Indications of structures at other E_x are reported by (1965BE1A, 1970FU09, 1976JU1A, 1976MC1L). $^{12}\text{C}^*(15.11)$ [$J^\pi = 1^+$; $T = 1$] is populated to a large extent by neutrons emitted from the $T = \frac{3}{2}$ component of the giant resonance in ^{13}C (1971MU11). $^{12}\text{C}^*(4.4)$ is populated most strongly at $^{13}\text{C}^*(13.3)$ (1975PA09). See also (1973AR1L), (1974KI03, 1974MA10; theor.) and (1973FR1F; applied). For reaction (b) see (1975PA09, 1976MC1L).

$$51. \ ^{13}\text{C}(\gamma, p)^{12}\text{B} \qquad Q_m = -17.534$$

(1964DE12) report structures at $E_\gamma = 18.5, 20.0, 23.5, 26.0$ and 29.0 MeV. The main part of the cross section is in the 23.5 MeV peak which has $\Gamma \approx 3$ MeV. A broad maximum near 25.5 MeV has been reported by (1956CO72, 1957CO57). The cross section to $^{12}\text{B}^*(0.95)$ shows a broad maximum at $E_\gamma = 25$ MeV (1975PA09). See also (1974KI03; theor.).

$$52. \ ^{13}\text{C}(\gamma, \alpha)^9\text{Be} \qquad Q_m = -10.648$$

See (1970AJ04).

$$53. \ (a) \ ^{13}\text{C}(e, e)^{13}\text{C} \\ (b) \ ^{13}\text{C}(e, ep)^{12}\text{B} \qquad Q_m = -17.534$$

The radius of ^{13}C , $r_{\text{rms}} = 2.452 \pm 0.047$ [relative to r_{rms} of $^{12}\text{C} = 2.462 \pm 0.022$ fm] (1973FE13). See also (1967CR1C, 1970HE24, 1971BE25, 1971YA02) and (1970BR1C). The rms radius of the magnetization distribution of $^{13}\text{C} = 3.3 \pm 0.3$ fm (1975LA23). The elastic scattering has been studied for $E_e = 120$ to 750 MeV (1970HE24). A number of inelastic groups are seen: see Tables 13.20 and 13.21 (1970WI04, 1971BE51, 1971YA02). A distinct splitting of the giant resonance into two large peaks near $E_x = 20.5$ and 24.5 MeV, with widths of ≈ 3 and ≈ 4 MeV, respectively, is observed. It is suggested that these are groupings of narrower peaks [see Table 13.21]. The $E_x = 20.5$ and 24.5 MeV resonances are probably $T = \frac{1}{2}$ and $T = \frac{3}{2}$, although the 4 MeV splitting is somewhat smaller than expected (1971BE51). See also reactions 50 and 51. See also (1970BR1E, 1972THZF, 1974DE1E, 1975BE1T, 1975SI1H) and (1970BE1G, 1970TI1C, 1973GA19, 1974BE10; theor.).

At $E_e = 43$ MeV the energy and angular distributions of the protons emitted in reaction (b) suggest the involvement of $^{13}\text{C}^*(21.8?, 24.2, 25.5, 27.5, 31.5)$ (1970WO1E, 1971SH09). See also (1973DO1L).

Table 13.20: Electromagnetic transitions ^a in ¹³C from ¹³C(e, e')¹³C ^b

E_x (MeV \pm keV)	J^π	Mult.	Γ_{γ_0} (eV)	$\Gamma_{\gamma_0}/\Gamma_W$ (W.u.)
3.08 \pm 30	$\frac{1}{2}^+$	E1	0.68 \pm 0.23	0.62
3.69 \pm 20	$\frac{3}{2}^-$	E2	$(3.61 \pm 0.40) \times 10^{-3}$	3.52
		M1	0.358 \pm 0.047	0.339
6.85 \pm 60	$\frac{5}{2}^+$	M2	$(6.9 \pm 3.6) \times 10^{-5}$	0.055
7.54 \pm 20	$\frac{5}{2}^-$	M3	(1.01×10^{-5})	(35)
		E2	0.115 \pm 0.007	3.15
8.86 \pm 20 ^d	$\frac{1}{2}^-$	M1	3.36 \pm 0.47	0.230
		E0	2.09 ^c	
9.90 \pm 30	$\frac{3}{2}^-$	E2	$(6.3 \pm 1.1) \times 10^{-3}$	0.045
		M1	0.324 \pm 0.038	0.0159
11.07 \pm 20	$\frac{1}{2}^-$	M1	1.02 \pm 0.12	0.0359
		E0	2.62 ^c	
	$\frac{3}{2}^-$	E2	0.256 \pm 0.047	1.03
		M1	0.172 \pm 0.020	0.006
11.80	$\frac{3}{2}^-$	M1	3.45 \pm 0.86	0.100
15.11 \pm 20	$\frac{3}{2}^-$	E2	0.59 \pm 0.11	0.50
		M1	22.7 \pm 2.7	0.313

^a See also Tables 13.6 and 13.7.

^b (1969WI22, 1970WI04). See also (1970YA1C, 1971YA02, 1975LU1B) and (1975FA1A).

^c Monopole matrix element in fm².

^d $\Gamma = 190 \pm 35$ keV.

Table 13.21: States of ^{13}C from $^{13}\text{C}(e, e')^{13}\text{C}^*$ (1971BE51)^a

E_x (MeV)	Γ_{cm} (keV)	E_x (MeV)	Γ_{cm} (keV)
11.1		20.1	700
11.8		20.5	400
(12.3)		21.3	400
15.1		22.2	1100
16.2	300	24.7	600
(16.9)		25.5	500
17.7	300	27.3	600
18.3	400	28.1	500
18.7	1200	(29.4)	1200
19.3	500		

^a See also Tables 13.4 and 13.20 and (1970YA1C, 1971YA02, 1973FI1F).

54. $^{13}\text{C}(n, n)^{13}\text{C}$

See ^{14}C .

55. (a) $^{13}\text{C}(p, p)^{13}\text{C}$

(b) $^{13}\text{C}(p, pn)^{12}\text{C}$

$$Q_m = -4.9464$$

Angular distributions have been studied at $E_p = 1.37$ to 2.38 MeV (1966GE03; p_0), 6.36 and 6.48 MeV (1971VA29; p_1), 7 MeV (1969GU02) and 30.4 MeV (1972GR02; p_0, p_1). Angular distributions of the 3.09 MeV γ -rays are isotropic for E_p up to 5 MeV consistent with the assignment $J = \frac{1}{2}$ for the ground state (1960BA35). For τ_m measurements see (1968RI16) and Table 13.5. See also (1970OH1C, 1973KA04, 1974GU1D; theor.).

Reaction (b) has been studied at $E_p = 7.9$ to 12 MeV (1970OT1A, 1971OT02) and at $E_p = 46$ MeV (1974MI05). One or more ^{13}C states at $E_x = 7.5$ MeV seem to be involved in the sequential decay (1971OT02). See also (1974AV02; theor.), ^{13}N and ^{14}N .

56. $^{13}\text{C}(d, d)^{13}\text{C}$

Angular distributions have been measured at $E_d = 0.71$ MeV (1971PU01; d_0), 4.7, 5.0 and 5.3 MeV (1968CO04; d_0), 12.8 MeV (1973VA07; d_1), 13.7 MeV (1970GU01; d_0, d_1, d_{2+3}) and 15 MeV (1974BU06). See also (1970LIIE), (1974GU1D; theor.) and ^{15}N .

57. $^{13}\text{C}(^3\text{He}, ^3\text{He})^{13}\text{C}$

Angular distributions of elastically scattered ^3He have been studied at $E(^3\text{He}) = 12, 15$ and 18 MeV (1966KE08), 14 MeV (1970NU02), 35.7 MeV (1969AR08) and at 40 MeV (1969BA06). Angular distributions at $E(^3\text{He}) = 40$ MeV have also been reported to ^{13}C states at $E_x = 3.09, 3.68, 3.85, 6.86, 7.55 \pm 0.03, 8.86 \pm 0.03$ and 11.84 ± 0.03 MeV. ^3He groups to $^{13}\text{C}^*(9.50 \pm 0.03)$ and (15.11) are also reported: the latter is weak (1969BA06). See also (1974CH58; theor.).

58. $^{13}\text{C}(\alpha, \alpha)^{13}\text{C}$

Elastic angular distributions have been measured at $E_\alpha = 15, 18$ and 20 MeV (1971CO14), 18 to 24 MeV (1973KU18), 18.3 MeV (1973LE28), 24 MeV (1974FE08), 26.6 MeV (1972KU19), 28.4 MeV (1965KO1A), 33.4 MeV (1968AR1A) and 40.5 MeV (1966HA19). In addition, (1968AR1A) report distributions to $^{13}\text{C}^*(3.68, 7.5)$, (1966HA19) to $^{13}\text{C}^*(3.09, 3.68+3.85, 7.5)$ and (1965KO1A, 1974FE08) to $^{13}\text{C}^*(3.09, 3.68 + 3.85, 6.85, 7.5)$. See also (1974CH58, 1975KU1K; theor.).

59. (a) $^{13}\text{C}(^6\text{Li}, ^6\text{Li})^{13}\text{C}$
 (b) $^{13}\text{C}(^7\text{Li}, ^7\text{Li})^{13}\text{C}$

Angular distributions of elastically scattered Li ions have been studied at $E(\text{Li}) = 4.5, 5.8, 9.0$ and 13 MeV (1976PO02; ^6Li and ^7Li [not 4.5]), 20 MeV (1969BE90; ^6Li and ^7Li), 28 MeV (1972BA52; ^6Li) and 34 MeV (1973SC26; ^6Li and ^7Li). The inelastic scattering to $^{13}\text{C}^*(3.09)$ in reaction (a) has also been studied (1973SC26). See also (1971BA2V, 1972WA31; theor.).

60. (a) $^{13}\text{C}(^{12}\text{C}, ^{12}\text{C})^{13}\text{C}$
 (b) $^{13}\text{C}(^{13}\text{C}, ^{13}\text{C})^{13}\text{C}$
 (c) $^{13}\text{C}(^{14}\text{C}, ^{14}\text{C})^{13}\text{C}$

Angular distributions for reaction (a) have been studied at $E(^{12}\text{C}) = 10$ to 30 MeV (1968GO1H; elastic), 15 and 19 MeV (1971BO52, 1972BO68; elastic), 20 to 36 MeV (1973CH1L: to $^{13}\text{C}^*(0, 3.09, 3.68+3.85)$) and 87 MeV (1971LI11; elastic). See also (1971WI1J, 1972CH1H, 1974CR03),

(1970GO1B, 1973BR1C, 1973SC1B, 1974GO1L), (1970VO1D, 1973BA2K, 1973DE1U, 1973MC1J, 1973SA1K, 1973VO04, 1974GA1L, 1974IM1B, 1975DE09, 1975VO1B; theor.) and ^{12}C in (1975AJ02).

For reaction (b), elastic angular distributions have been measured at $E(^{13}\text{C}) = 15$ to 24 MeV (1973HE12), while for reaction (c) the elastic distribution has been measured at $E(^{13}\text{C}) = 15$ MeV (1972BO68). See also (1972HA2B), (1974GO1L) and (1973MC1J, 1973VO04, 1975DE09, 1975VO1B; theor.).

61. $^{13}\text{C}(^{14}\text{N}, ^{14}\text{N})^{13}\text{C}$

The elastic angular distribution has been studied at $E(^{14}\text{N}) = 19.3$ MeV (1971VO01). See also (1973MC1J, 1973VO04, 1975DE09; theor.).

62. (a) $^{13}\text{C}(^{16}\text{O}, ^{16}\text{O})^{13}\text{C}$
 (b) $^{13}\text{C}(^{17}\text{O}, ^{17}\text{O})^{13}\text{C}$
 (c) $^{13}\text{C}(^{18}\text{O}, ^{18}\text{O})^{13}\text{C}$

Elastic angular distributions have been measured for reaction (a) at $E(^{16}\text{O}) = 10$ to 30 MeV (1968GO1H) and 14, 17 and 20 MeV (1970BA49) and at $E(^{13}\text{C}) = 36$ MeV (1975WE1D, 1975RA33), and, for reaction (c), at $E(^{18}\text{O}) = 15, 20$ and 24 MeV (1971KN05). See also (1974CH1Q). For reaction (b) see (1974CH1Q). See also (1974BE1J; theor.).

63. $^{13}\text{N}(\beta^+)^{13}\text{C}$ $Q_m = 2.221$

See ^{13}N .

64. $^{14}\text{C}(\text{p}, \text{d})^{13}\text{C}$ $Q_m = -5.9524$

Angular distributions have been measured at $E_p = 12$ MeV (1966GL01; d_0), 14.5 MeV (1971CU01; d_0 , partial d_2), 18.5 MeV (1963LE03; d_1, d_2, d_3) and 27 MeV (1975CE04; $d_0 \rightarrow d_3$). The spectroscopic factors for $^{13}\text{C}^*(0, 3.09, 3.68, 3.85)$ are 1.4, 0.02, 1.8 and 0.13, respectively (1975CE04).

65. $^{14}\text{C}(\text{d}, \text{t})^{13}\text{C}$ $Q_m = -1.9194$

Angular distributions have been studied at $E_d = 12$ MeV (1966GL01; $t_0 \rightarrow t_3$) and 14 MeV (1976WE01; $t_0 \rightarrow t_3$; polarized deuterons). The spectroscopic factors for $^{13}\text{C}^*(0, 3.09, 3.68, 3.85)$ are 1.00, 0.06, 1.0 and 0.08, respectively (1976WE01). See also ^{16}N in (1977AJ02).

$$66. \ ^{14}\text{C}(^3\text{He}, \alpha)^{13}\text{C} \quad Q_m = 12.4015$$

Angular distributions have been measured at $E(^3\text{He}) = 6, 8$ and 10 MeV (1971CO14; α_0) and 44.8 MeV (1966BA13; α_0, α_2 and α to $^{13}\text{C}^*(15.11)$).

$$67. \ ^{14}\text{C}(^{11}\text{B}, ^{12}\text{B})^{13}\text{C} \quad Q_m = -4.808$$

See (1972KU1H; theor.).

$$68. \ ^{14}\text{C}(^{12}\text{C}, ^{13}\text{C})^{13}\text{C} \quad Q_m = -3.2306$$

See (1972BO68).

$$69. \ ^{14}\text{C}(^{14}\text{N}, ^{13}\text{C})^{15}\text{N} \quad Q_m = 2.657$$

See (1975VO1B).

$$70. \ ^{14}\text{C}(^{16}\text{O}, ^{17}\text{O})^{13}\text{C} \quad Q_m = -4.035$$

Angular distributions have been measured at $E(^{16}\text{O}) = 20, 25$ and 30 MeV (1975SC35, 1975SC42): they are well described by DWBA (fixed range approximation). See also (1973BR1C).

$$71. \ ^{14}\text{C}(^{18}\text{O}, ^{19}\text{O})^{13}\text{C} \quad Q_m = -4.220$$

See (1972EY01).

$$72. \ ^{14}\text{N}(\gamma, p)^{13}\text{C} \quad Q_m = -7.5507$$

For $E_{bs} = 15.5$ to 29.5 MeV a large fraction of the neutron yield appears to be associated with sequential decay to ^{12}C via $^{13}\text{C}^*(7.75, 8.86, 11.80)$ (1970SH06, 1972GE11). Angular distributions measured in the giant resonance region of ^{14}N are consistent with the proton decay of $(p_{1/2})^{-1}$ ($2s1d$) giant dipole states to $^{13}\text{C}_{g.s.}$ and of $(p_{3/2})^{-1}$ ($2s1d$) states to $^{13}\text{C}^*(3.68)$ (1974BA37). The population of $^{13}\text{C}^*(3.09, 3.85)$ has also been reported (1970TH01: $E_{bs} = 29$ MeV). See also ^{14}N and (1973KI05; theor.).

$$73. \ ^{14}\text{N}(n, d)^{13}\text{C} \quad Q_m = -5.3260$$

Angular distributions of d_0 have been determined at $E_n = 14.1$ to 14.7 MeV: see (1970AJ04). See also (1971MI12). Gamma rays with energies of 3.686 and 3.853 MeV are reported by (1971NY03: ± 3 keV). Differential cross sections for formation of $^{13}\text{C}^*(3.09, 3.68)$ have been measured for $E_n = 10.1$ to 11.0 MeV by (1970DI1A). See also ^{15}N and (1970BO1K; theor.).

$$74. \text{ (a) } \ ^{14}\text{N}(e, ep)^{13}\text{C} \quad Q_m = -7.5507$$

$$\text{ (b) } \ ^{14}\text{N}(p, 2p)^{13}\text{C} \quad Q_m = -7.5507$$

For reaction (a) see (1969BA1F). At $E_p = 46$ MeV, the summed proton spectrum shows transitions to $^{13}\text{C}^*(0, 3.68, 7.5, 11.9)$ (1970WE09, 1970WE1J). At $E_p = 460$ MeV $^{13}\text{C}^*(0, 7.8, 12.3)$ are populated: the two excited states are formed by ejection of $p_{3/2}$ protons. There is also some indication of other structure (1966TY01). See also (1972CH21, 1973DE1T; theor.).

$$75. \ ^{14}\text{N}(d, \ ^3\text{He})^{13}\text{C} \quad Q_m = -2.0569$$

At $E_d = 52$ MeV, angular distributions have been measured for the ^3He particles to $^{13}\text{C}^*(0, 3.09, 3.68, 6.86, 7.5, 8.86, 9.50, 11.9 \pm 0.15)$ and analyzed by DWBA: $J^\pi = \frac{5}{2}^-, \frac{1}{2}^-, \frac{3}{2}^-$ and $\frac{3}{2}^-$, respectively, are assigned to $^{13}\text{C}^*(7.5, 8.86, 9.50, 11.9)$ (1968HI01). As expected, angular distributions of ^3He and of tritons (from $^{14}\text{N}(d, t)^{13}\text{N}$) to analog states are closely the same: this has been shown for the ground state ^3He and triton groups (1966DE1C, 1968GA13: $E_d = 28.5$ MeV; (1974LU06): $E_d = 15$ MeV) and for the groups to $^{13}\text{C}^*(8.9+9.5)$ and $^{13}\text{N}^*(9.2)$ (1968HI01: $E_d = 52$ MeV). See also ^{16}O in (1977AJ02) and (1974DA1D; theor.).

$$76. \ ^{14}\text{N}(t, \alpha)^{13}\text{C} \quad Q_m = 12.2640$$

Observed particle groups at $E_t = 2.6$ MeV are displayed in Table 13.22 (1962SI04). See also ^{16}O in (1977AJ02).

Table 13.22: Energy levels of ^{13}C from $^{14}\text{N}(t, \alpha)^{13}\text{C}$ (1962SI04) and from $^{15}\text{N}(p, ^3\text{He})^{13}\text{C}$ (1968FL03)

E_x in ^{13}C ^a (MeV \pm keV)	$\Gamma_{\text{c.m.}}$ (keV)	E_x in ^{13}C ^b (MeV \pm keV)	J^π
0		0	$\frac{1}{2}^-$
3.09 ^c		3.08 ± 20	$\frac{1}{2}^+$
3.68 ^c		3.68 ^c	$\frac{3}{2}^-$
3.85 ^c			
6.86 ^c		6.87 ^c	$\frac{5}{2}^+$
7.5 ^c		7.55 ± 20	$\frac{5}{2}^-$
7.68 ^c			
8.860 ± 20	145 ± 20	8.86 ± 60	$\frac{1}{2}^-$
9.509 ^d		9.52 ± 30	$(\frac{3}{2}^-)$
9.897 ^d			
10.736 ± 20	< 30		
10.809 ± 20	< 30		
11.000 ± 20	< 30		
11.078 ± 20	< 30	11.09 ± 50	$(\frac{1}{2}^-)$
11.721 ± 30	125 ± 20	11.80 ± 30	$(\frac{3}{2}^-)$
12.131 ± 30	125 ± 30		
		12.40 ± 50	$\frac{7}{2}^-$
		15.103 ± 45 ^e	$\frac{3}{2}^-$

^a From $^{14}\text{N}(t, \alpha)^{13}\text{C}$ (1962SI04).

^b From $^{15}\text{N}(p, ^3\text{He})^{13}\text{C}$ (1968FL03).

^c Observed but E_x not determined.

^d E_x values of other levels given in terms of E_x of these two levels. [See, however, Table 13.4.]

^e (1966CE02).

77. $^{14}\text{N}(\alpha, p\alpha)^{13}\text{C}$ $Q_m = -7.5507$

This sequential reaction has been studied at $E_\alpha = 22.9$ MeV (1969BA17).

78. $^{14}\text{N}(^6\text{Li}, ^7\text{Be})^{13}\text{C}$ $Q_m = -1.944$

An angular distribution has been obtained at $E(^6\text{Li}) = 32$ MeV for the transition to $^{13}\text{C}_{\text{g.s.}}$ and $^7\text{Be}^*(0, 0.43)$ [for the mirror reaction see reaction 38 in ^{13}N]: the relative cross sections show a deviation from isospin symmetry which is attributed to Coulomb effects. $^{13}\text{C}^*(3.09)$ was also populated (1971GR44, 1971ZE1C).

79. $^{14}\text{N}(^{14}\text{N}, ^{15}\text{O})^{13}\text{C}$ $Q_m = -0.259$

See (1966GA04).

80. $^{15}\text{N}(\gamma, d)^{13}\text{C}$ $Q_m = -16.1597$

See (1973DE30) and ^{15}N .

81. $^{15}\text{N}(n, t)^{13}\text{C}$ $Q_m = -9.9021$

Not reported.

82. $^{15}\text{N}(p, ^3\text{He})^{13}\text{C}$ $Q_m = -10.6659$

At $E_p = 43.7$ MeV, ^3He groups have been observed to eleven states of ^{13}C : see Table 13.19 (1966CE02, 1968FL03). Angular distributions of the ^3He particles to these states are generally found to be in agreement with DWBA predictions, using intermediate coupling wave functions to obtain the two-nucleon structure factors (1968FL03). Detailed comparisons are made with the results of the mirror reaction $^{15}\text{N}(p, t)^{13}\text{N}$: the (p, t) transitions are generally stronger than expected relative to the mirror (p, ^3He) transitions. This may arise from interference effect terms due to a spin-orbit interaction in the optical potential, or to interference terms between direct-reaction and core excitation (1968FL02, 1968FL03). A study of both angular distributions and analyzing powers in this reaction and in the mirror (p, t) reaction shows that DWBA generally fails to predict the analyzing powers (1974MA12: $E_p = 43.8$ MeV; pol. protons). Angular distributions have also been measured for the ^3He groups to $^{13}\text{C}^*(0, 3.68, 7.55)$ at several energies in the range $E_p = 24.0$ to 43.5 MeV (1974PI05, 1975MI01). See also (1969TE1A, 1972HA1X) and ^{16}O in (1977AJ02).

83. $^{15}\text{N}(\text{d}, \alpha)^{13}\text{C}$ $Q_{\text{m}} = 7.6879$

Alpha-particle groups have been observed to excited states at $E_{\text{x}} = 3.083$ and 3.677 MeV ([1951MA08](#): ± 5 keV) and 8.80 ± 0.04 MeV ([1957WA01](#): other states were excited but their E_{x} were not determined). Angular distributions of α_0 have been measured at $E_{\text{d}} \approx 1$ MeV and ≈ 21 MeV: see ([1970AJ04](#)). See also ([1967SP09](#)).

84. $^{15}\text{N}(\alpha, ^6\text{Li})^{13}\text{C}$ $Q_{\text{m}} = -14.686$

At $E_{\alpha} = 42$ MeV, the angular distribution of the ^6Li particles to $^{13}\text{C}_{\text{g.s.}}$ has been measured ([1968MI05](#)).

85. $^{15}\text{N}(^{11}\text{B}, ^{13}\text{C})^{13}\text{C}$ $Q_{\text{m}} = 2.519$

See ([1972KU1H](#); theor.).

86. $^{16}\text{O}(\text{n}, \alpha)^{13}\text{C}$ $Q_{\text{m}} = -2.2152$

Angular distributions have been measured at many energies. The earlier results are listed in ([1970AJ04](#)). Recent measurements have been carried out at $E_{\text{n}} = 4.9$ MeV ([1973KI1G](#); α_0), 13.9 MeV ([1971BR33](#); $\alpha_0, \alpha_1, \alpha_{2+3}$) and 14.1 MeV ([1970AJ03](#); α_{1+2+3} ; ([1973BO26](#)); α_0, α_{1+2+3}). Excitation energies derived from γ -ray measurements are 3685 ± 3 and 3854 ± 3 keV ([1971NY03](#)). See also ([1970DI1C](#)) and ^{17}O in ([1977AJ02](#)).

See also ([1969KA1D](#), [1970BR17](#)) and ([1973CL1E](#); astrophys. questions).

87. $^{16}\text{O}(\alpha, ^7\text{Be})^{13}\text{C}$ $Q_{\text{m}} = -10.496$

At $E_{\alpha} = 42$ MeV the angular distribution of the reaction involving $^{13}\text{C}(0)$ and $^7\text{Be}^*(0 + 0.43)$ has been measured by ([1972RU03](#)).

88. $^{16}\text{O}(^{14}\text{N}, ^{17}\text{F})^{13}\text{C}$ $Q_{\text{m}} = -6.950$

This reaction has been studied at $E(^{14}\text{N}) = 79$ MeV ([1976MO03](#)) and 155 MeV ([1975NA15](#)).

$$89. \text{}^{17}\text{O}(\text{d}, \text{}^6\text{Li})\text{}^{13}\text{C} \quad Q_{\text{m}} = -4.884$$

See (1966DE09).

$$90. \text{}^{18}\text{O}(\text{d}, \text{}^7\text{Li})\text{}^{13}\text{C} \quad Q_{\text{m}} = -5.680$$

See (1967DE03).

$$91. \text{}^{20}\text{Ne}(\text{n}, 2\alpha)\text{}^{13}\text{C} \quad Q_{\text{m}} = -6.945$$

$$Q_0 = -7.00 \pm 0.02 \text{ (1971KA18)}.$$

At $E_{\text{n}} = 14.3$ MeV the cross section is 42 ± 8 mb (1971KA18). See also (1966PE08).

¹³N
(Figs. 3 and 4)

GENERAL (See also (1970AJ04).):

Model calculations: (1971AR1R, 1972DE1H, 1972EL1C, 1972LE1L, 1973DE13, 1973HA49, 1973SA30, 1974PH1D, 1975ME24).

Special levels: (1970PE18, 1971AR03, 1971AR1R, 1971JA13, 1971SE1C, 1972BE1E, 1972DE1H, 1973JO1G, 1973SA30, 1974HA1G, 1974PH1D, 1974VA24, 1975KU21, 1975ME24).

Electromagnetic transitions: (1971JA13, 1972NA05, 1973HA1Q, 1973LE06, 1973MA1K, 1973SA25, 1973SA30, 1974AD1B, 1974CH46, 1974RO1R, 1974RO1T, 1975FO1L, 1975KU21, 1975ME24).

Special reactions: (1969GA18, 1969HI1A, 1969KR21, 1970KR1C, 1970LE1D, 1971AR02, 1971BI22, 1974HA61, 1974WO1F, 1975HU14, 1975KU01).

Astrophysical questions: (1973BA1H, 1975EN1A).

Pion reactions: (1972KA1F, 1973AL1D, 1973AU06, 1973CH20, 1973NA1H, 1973NA14, 1974RE1E, 1975AL1K, 1975EI1D, 1975GI1B, 1975KA1R).

Applied work: (1973PH1B, 1973WE1N, 1975AL1B, 1975AU1F, 1975VA1J).

Other topics: (1969WA1C, 1970PE18, 1971AR03, 1971AU1G, 1971JA13, 1971SE1C, 1971NG01, 1972AN05, 1972CA37, 1972CH16, 1972LE1L, 1973DE13, 1973GO1H, 1973KA1H, 1973SA25, 1974VA24, 1975GR03, 1975KU01, 1975SH20).

Ground state: (1971AU02, 1971TA1A, 1972LE1L, 1972VA36, 1973MA1K, 1973RO1R, 1973SA25, 1973SA30, 1974HA27, 1975BE31, 1975ME24).

$$\mu = -0.32212 \pm 0.00035 \text{ nm (1964BE24)}.$$

See also (1971SH26, 1974SHYR).

1. ¹³N(β^+)¹³C $Q_m = 2.221$

Measured values of the half-life are displayed in Table 13.22 of (1970AJ04): the weighted mean value of $\tau_{1/2} = 9.961 \pm 0.004$ min. The decay is entirely to ¹³C_{g.s.}: $\log ft = 3.643 \pm 0.001$ (1974WI1M). The positrons are completely polarized: see (1970AJ04). See (1969BA1M, 1972KO1A, 1974UL1B) for astrophys. considerations. See also (1972CH1G) and (1970DA21, 1970KO41, 1970PA23, 1970ST04, 1971BL12, 1971LI1H, 1971VA1C, 1971WI18, 1972WI28, 1972WI1C, 1973EM1B, 1973MU1D, 1973SA25, 1973WI04, 1973WI11, 1974LE1G, 1975KR14, 1975ME24, 1975WI1E; theor.).

Table 13.23: Energy levels of ^{13}N

E_x (MeV \pm keV)	$J^\pi; T$	Γ_{cm} (keV)	Decay	Reactions
g.s.	$\frac{1}{2}^-$	$\tau_{1/2} = 9.961 \pm 0.004$ min	β^+	1, 2, 3, 10, 12, 13, 14, 15, 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
2.3653 ± 1.1	$\frac{1}{2}^+$	$\Gamma = 33.7 \pm 2$ keV ^b	γ, p	10, 13, 15, 16, 21, 22, 25, 28, 29, 30, 35, 37, 38, 43
3.511 ± 2	$\frac{3}{2}^-$	66 ± 4	γ, p	3, 10, 12, 13, 15, 16, 21, 22, 24, 25, 28, 29, 30, 31, 33, 35, 36, 37, 41, 43
3.547 ± 4	$\frac{5}{2}^+$	47 ± 7	p	3, 10, 12, 13, 16, 21, 22, 24, 25, 28, 29, 30, 31, 35, 37
6.364 ± 9	$\frac{5}{2}^+$	11	p	11, 13, 16, 22, 30, 37, 41
6.885 ± 8	$\frac{3}{2}^+$	115 ± 5	p	11, 13, 16, 22, 35
7.155 ± 5	$\frac{7}{2}^+$	9 ± 0.5	p	3, 11, 13, 16, 22, 30, 37
7.376 ± 9	$\frac{5}{2}^-$	75 ± 5	p	3, 11, 12, 13, 16, 22, 30, 33, 35, 36, 37, 41, 43
8.0	$\frac{3}{2}^+$	≈ 1500	p	13, 16, 37
8.918 ± 11	$\frac{1}{2}^-$	230	p	13, 16, 30, 33, 35, 36, 37, 41
9.00		280 ± 30		11
9.476 ± 8	$\frac{3}{2}^-$	30	p	3, 11, 13, 16, 30, 33, 36
10.25 ± 150	$(\frac{1}{2}, \frac{3}{2})^+$	270 ± 65	γ, p	15
10.36	$\frac{5}{2}^-$	30	p	11, 13, 16, 33
10.36	$\frac{7}{2}^-$	76	p	11, 16
10.833 ± 9	$(\frac{1}{2}^-)$			11, 13, 30, 41
11.530 ± 12	$\frac{5}{2}^+$	430 ± 35	p	11, 13, 16
11.70 ± 30	$\frac{5}{2}^-$	115 ± 30	p	16
11.74 ± 40	$\frac{3}{2}^+$	250 ± 30	γ, p	15, 16
11.74 ± 50	$\frac{3}{2}^-$	530 ± 80	p	16
11.878 ± 12	$(\frac{3}{2}^-)$	380 ± 50	p	12, 13, 16, 30, 35, 36, 37, 41
12.13 ± 50	$\frac{7}{2}^-$	250 ± 30	p	16, 43
12.558 ± 23		> 400		13
12.937 ± 24		> 400		13
13.5 ± 200	$\frac{3}{2}^+$	≈ 6500	γ, p	15
14.04 ± 90	$\frac{3}{2}^+; \frac{1}{2}$	155 ± 20	γ, p, α	15, 16, 19
14.1		≈ 500	p	16

Table 13.23: Energy levels of ^{13}N (continued)

E_x (MeV \pm keV)	$J^\pi; T$	Γ_{cm} (keV)	Decay	Reactions
14.7		≈ 500	p	16
15.0651 ± 0.9 ^a	$\frac{3}{2}^-; \frac{3}{2}$	1.10 ± 0.09	γ, p, α	13, 15, 16, 19, 30, 41
15.3 ± 200	$(\frac{3}{2}^+)$	350 ± 150	γ, p	15
15.7		≈ 500	p	16
16.0		≈ 500	p	16
16.02 ± 30	$\frac{7}{2}^+; \frac{1}{2}$	130 ± 30	p	16, 30
16.3		≈ 500	p	16
17.2		≈ 500	p	16
18.23	$\frac{1}{2}^-; \frac{1}{2}$	300	p, α	16, 19
18.4		≈ 500	p	16
18.406 ± 5	$\frac{3}{2}^+; \frac{3}{2}$	66 ± 8	p, α	13, 16, 19
18.7		≈ 500	p	16
18.961 ± 10	$\frac{3}{2}^-$ or $\frac{7}{2}^+; \frac{3}{2}$	23 ± 5	p, α	13, 16, 19
19.3		≈ 500	p	16
19.83	$\frac{5}{2}^-; \frac{1}{2}$	1000	p, α	16, 19
19.88	$\frac{3}{2}^+; \frac{1}{2}$	520	p, α	16, 19
20.9 ± 300	$(\frac{5}{2}^+)$	≈ 1100	n, p	16, 17
21.68			p	16
21.97			p	16
22.4 ± 500	$(\frac{5}{2}^-)$	≈ 2000	p	16
23.3		400	p, ^3He	5
23.83 ± 50		350 ± 50	n, p, ^3He	5, 16, 17
24.5		$\lesssim 500$	$\gamma, \text{p}, ^3\text{He}$	5, 15
25.4	$(\frac{3}{2})^-$		p, ^3He	5, 16
25.9	$\geq \frac{3}{2}$	≈ 1000	p, ^3He	5, 6, 9
26.84			p	16
28	$\geq \frac{7}{2}$		p, ^3He	5
31.9	$T = \frac{1}{2}$	≈ 2000	$\gamma, \text{p}, \text{d}, ^3\text{He}, \alpha$	6, 9, 15

^a See also Table 13.7.

^b See reaction 15 (1974BL06).

2. $^9\text{Be}(^6\text{Li}, 2\text{n})^{13}\text{N}$

$$Q_m = 3.947$$

See (1957NO17).

$$3. {}^{10}\text{B}({}^3\text{He}, \gamma){}^{13}\text{N} \quad Q_m = 21.638$$

The 90° γ_0 cross section has been measured for $E({}^3\text{He}) = 4.8$ to 14 MeV: it is typically 40 nb/sr and does not show any pronounced structure. In the same energy interval to 90° cross section for $\gamma_{3.5}$ decreases monotonically from ≈ 500 nb/sr to ≈ 100 nb/sr. Capture transitions to ${}^{13}\text{N}^*(7.25 \pm 0.15, 9.8 \pm 0.3)$ may also have been observed (1972BE05).

$$4. {}^{10}\text{B}({}^3\text{He}, n){}^{12}\text{N} \quad Q_m = 1.569 \quad E_b = 21.638$$

The activation cross section has been measured for $E({}^3\text{He}) = 1$ to 6.3 MeV (1963PE10) and 6 to 30.6 MeV (1970SI16). See also (1971ADZZ). There is some evidence of broad structures. See also ${}^{12}\text{N}$ in (1975AJ02).

$$5. {}^{10}\text{B}({}^3\text{He}, p){}^{12}\text{C} \quad Q_m = 19.6948 \quad E_b = 21.638$$

Observed resonances in the yields of proton groups and γ -rays are displayed in Table 13.24. Recent measurements have been carried out at $E({}^3\text{He}) = 11.6$ to 18.6 MeV (1972BE56; p_0, p_1) [no indication of resonances] and $E({}^3\text{He}) = 4$ to 17 MeV ($\gamma_{15.1}$) and 5 to 12 MeV ($\gamma_{12.7}$) (1972BE05) [some indication in the 90° yield of both γ for the population of ${}^{13}\text{N}^*(26., 28.)$]. See also (1970BE1F), (1970AJ04) and ${}^{12}\text{C}$ in (1975AJ02).

$$6. {}^{10}\text{B}({}^3\text{He}, d){}^{11}\text{C} \quad Q_m = 3.198 \quad E_b = 21.638$$

Excitation functions have been measured for $E({}^3\text{He}) = 3.5$ to 10 MeV (1965PA10; d_0) and 11 to 19 MeV (1972BE56; $d_0 \rightarrow d_3, d_{4+5}$). Resonances are reported in the d_0 yield at $E({}^3\text{He}) = 5.8$ MeV and in the 150° d_{4+5} yield at 13.6 MeV [${}^{13}\text{N}^*(26, 32)$]: see Table 13.24. See also (1970BE1F) and ${}^{11}\text{C}$ in (1975AJ02).

$$7. {}^{10}\text{B}({}^3\text{He}, t){}^{10}\text{C} \quad Q_m = -3.669 \quad E_b = 21.638$$

The excitation function for ${}^{10}\text{C}$ production has been measured from threshold to $E({}^3\text{He}) = 10.5$ MeV: no detailed structure is observed (1964OS1A).

$$8. {}^{10}\text{B}({}^3\text{He}, {}^3\text{He}){}^{10}\text{B} \quad E_b = 21.638$$

Table 13.24: Structure in $^{10}\text{B} + ^3\text{He}$

E_{res} (MeV \pm keV)	Γ (keV)	Res. in	$^{13}\text{N}^*$ (MeV)	Refs.
2.1 ^{a,b}	500	$p_0, (p_1)$	23.3	(1956SC01, 1966PA10)
2.85 ± 50	450 ± 50	$\gamma_{15.1}$	23.83 ^g	(1964KU09)
3.6 ^a	700	p_0, p_1	24.4 ^g	(1956SC01, 1966PA10)
3.9	120	p_0	24.6	(1956SC01, 1966PA10)
4.6 ^a	150	$p_0, (p_1)$	25.2	(1956SC01)
5.2 ± 100 ^c	240 ± 80	$p_0, \gamma_{15.1}, p_2, p_3$	25.6	(1964KU09)
5.6	1000 ^d	$(n), p_0, p_2, p_3, \gamma_{12.7}, \gamma_{15.1}, d_0, \alpha_0$	25.9 ^g	(1965PA05, 1972BE05, 1972BE56)
8.5	^e	$(\gamma_0), p_0, \gamma_{12.7}, \gamma_{15.1}, (\alpha_0)$	28 ^g	(1972BE05, 1972BE56)
13.5 ^f	≈ 2000	$(\gamma_0), d_{4+5}, \alpha_1$	32	(1972BE05, 1972BE56)

^a See, however, (1964KU09).

^b See also (1967SI05).

^c See, however, (1966BA01, 1966PA10).

^d $J \geq \frac{3}{2}$ (1965PA10, 1966PA10).

^e $J \geq \frac{7}{2}$ (1966PA10).

^f This may correspond to more than one state (1972BE56).

^g See also (1970GI04).

See (1970DU07) and ^{10}B in (1974AJ01).

9. $^{10}\text{B}(^3\text{He}, \alpha)^9\text{B}$

$$Q_m = 12.143$$

$$E_b = 21.638$$

Excitation functions for α_0 and α_1 have been measured for $E(^3\text{He}) = 2$ to 10 MeV (1965PA05) and 9 to 19 MeV (1972BE56). Strong resonances are observed at $E(^3\text{He}) = 5.8$ MeV (α_0) and ≈ 13.3 MeV (α_1 at 150°): see Table 13.24. See also (1970BE1F, 1970GI04) and ^9B in (1974AJ01).

10. $^{10}\text{B}(\alpha, n)^{13}\text{N}$

$$Q_m = 1.060$$

Angular distributions have been measured for $E_\alpha = 1.5$ to 4.6 MeV (n_0) and at ≈ 4.6 MeV (n_1, n_{2+3}) (1973VA25). See also ^{14}N , (1975WI04) and (1970AJ04).

11. $^{10}\text{B}(^6\text{Li}, t)^{13}\text{N}$

$$Q_m = 5.844$$

At $E(^6\text{Li}) = 18$ MeV the known states of ^{13}N with $6.3 < E_x < 11.7$ MeV are observed, with the exception of $^{13}\text{N}^*(8.0, 8.92)$. In addition, evidence is presented for a new ^{13}N state at $E_x = 9.00$ MeV with $\Gamma_{\text{cm}} = 280 \pm 30$ keV: it is very strongly excited and its angular distribution is similar to that for $^{13}\text{C}^*(9.50)$ in the mirror reaction ($^6\text{Li}, ^3\text{He}$) suggesting that these two states are analogs. Other analog assignments made on the basis of corresponding intensities in the mirror reaction are given in reaction 15 of ^{13}C . The widths of $^{13}\text{N}^*(6.89, 7.38)$ are, respectively, 120 ± 30 and 70 ± 30 keV (1974HO06). See also (1970AJ04).

$$12. \ ^{10}\text{B}(^{14}\text{N}, ^{11}\text{B})^{13}\text{N} \quad Q_m = 0.902$$

At $E(^{10}\text{B}) = 100$ MeV, angular distributions are reported for the transitions to $^{13}\text{N}^*(0, 3.5, 7.4, 11.9)$ (1975NA15). See also (1970GO1B) and (1970SC1G, 1972AN25, 1973MC17, 1973OS03, 1975OS01; theor.).

$$13. \ ^{11}\text{B}(^3\text{He}, n)^{13}\text{N} \quad Q_m = 10.182$$

Neutron groups have been observed to a number of states in ^{13}N : see Table 13.25 (1969AD02, 1971HS03). The gamma, proton and α -widths of the first $T = \frac{3}{2}$ state at $E_x = 15.07$ MeV are displayed in Table 13.7 where they are compared with the corresponding quantities for $^{13}\text{C}^*(15.11)$ (1973AD02, 1975MA21). Branching ratios of 0.096 ± 0.014 and 0.164 ± 0.036 are obtained for the proton decay of $^{13}\text{N}^*(15.07)$ to $^{12}\text{C}^*(9.6, 10.8)$, respectively: these values suggest the importance of 2s-1d shell isospin admixtures in $^{13}\text{N}^*(15.07)$ (1974AD1D). [See ^{13}N , reaction 11 in (1970AJ04) for the earlier work.] See also (1974GO23).

$$14. \ ^{11}\text{B}(^{11}\text{B}, ^9\text{Li})^{13}\text{N} \quad Q_m = -12.976$$

See (1974AN36).

$$15. \text{ (a) } ^{12}\text{C}(p, \gamma)^{13}\text{N} \quad Q_m = 1.944$$

$$\text{ (b) } ^{12}\text{C}(p, p'\gamma)^{12}\text{C}$$

Resonances for capture radiation are displayed in Table 13.26. [See also Table 13.6 for a summary of the total radiation widths of the low-lying levels of ^{13}C - ^{13}N .] No resonance is observed at $E_p = 1.73$ MeV corresponding to $^{13}\text{N}^*(3.55)$: $\omega\Gamma_\gamma < 0.006$ eV (1963YO06).

Excitation functions have been measured for $E_p = 150$ to 2500 keV. In addition to the two resonances at $E_p = 0.46$ and 1.70 MeV, direct radiative capture is observed. From the cross

Table 13.25: States of ^{13}N from $^{11}\text{B}(^3\text{He}, n)^{13}\text{N}$

E_x^a (MeV \pm keV)	$\Gamma_{\text{c.m.}}$ (keV)	L^a	$J\pi^a$
0		2	$\frac{1}{2}^-$
2.358 ± 10		1	$\frac{1}{2}^+$
3.502 ± 10		0, 2	$\frac{3}{2}^-$
3.55 ± 18			
6.353 ± 9		1, 3	$\frac{5}{2}^+$
6.875 ± 10		1, 3	$\frac{3}{2}^+$
7.145 ± 9		3, 5	$\frac{7}{2}^+$
7.363 ± 8		2, 4	$\frac{5}{2}^-$
8.2 ± 22			
8.918 ± 11			
9.476 ± 8		0, 2	$\frac{3}{2}^-$
10.381 ± 8		2, 4	$\frac{5}{2}^-$
10.833 ± 9			
11.530 ± 12			
11.878 ± 12		0, 2	$\frac{3}{2}^-$
12.558 ± 23	> 400		
12.937 ± 24	> 400		
$15.068 \pm 8^{b,c}$	< 15		$\frac{3}{2}^-; T = \frac{3}{2}$
18.44 ± 40^b			$T = \frac{3}{2}$
18.98 ± 20^b	40 ± 20		$T = \frac{3}{2}$

^a (1971HS03) except for those states labeled ^b; $E(^3\text{He}) = 4.7, 6.1$ and 6.49 MeV.

^b (1969AD02): $E(^3\text{He}) = 7.0$ to 13.5 MeV.

^c See also Table 13.7.

Table 13.26: Resonances in $^{12}\text{C}(p, \gamma)^{13}\text{N}$ ^a

E_p (MeV \pm keV)	Γ_{lab} (keV)	Γ_{γ_0} (eV)	$^{13}\text{N}^*$ (MeV)	Res. in yield of	J^π	Refs.
0.4568 ± 0.5	39.5 ± 1.0 36.7 ± 1.0 39 ± 2 36 ± 2 ^b	0.67 0.45 ± 0.05 ^k	2.3649 ± 0.0011	γ_0	$\frac{1}{2}^+$	(1951SE67, 1953HU18) (1968RI16) (1974RO29) (1974BL06)
1.699 ± 2 ^g	67 ± 4	0.53	3.511	γ_0	$\frac{3}{2}^-$	(1963YO06, 1974RO29)
9.01 ± 150	280 ± 100 300 ± 100	≥ 0.6 ≥ 6 ^c	10.25	γ_0	$\frac{3}{2}^+$ $\frac{1}{2}^+$	(1973ME12) ^j
10.62 ± 120	220 ± 50	≈ 4.2 ^d	11.74	γ_0	$\frac{3}{2}^+$	(1973ME12) ^j
12.5 ± 200	7000	≥ 1100	13.5	γ_0	$\frac{3}{2}^+$	(1973ME12) ^{h,j}
13.12 ± 90	170 ± 20	3.7 ± 1.0 ^e	14.04	γ_0	$\frac{3}{2}^+$	(1973ME12) ^j
14.2	[see text and Table 13.7]		15.0	γ_0, γ_2	$\frac{3}{2}^-; T = \frac{3}{2}$	(1968DI04, 1975MA21)
14.5 ± 200 ^f	380 ± 150	≥ 0.5	15.3	γ_1	$(\frac{3}{2}^+)$	(1973ME12) ^j
20 ⁱ			20	γ_0		(1963FI07)
24.5			24.5	γ_2		(1963FI07)
32.5 ⁱ			31.9	γ_0		(1963FI07)

^a See also Table 13.24 in (1970AJ04).

^b See text: $\Gamma_{\text{cm}} = 33.3 \pm 1.8$ keV (1974BL06).

^c Assuming interfering background.

^d A value of 0.30 ± 0.05 is assumed for Γ_{p_0}/Γ : see Table 13.27.

^e A value of 126 keV is taken for Γ_{p_0} (1969LE18).

^f This peak may be due to an unresolved doublet.

^g See also (1972JO1B) for possible additional resonances.

^h See also (1972JO1B).

ⁱ $T = \frac{1}{2}$ dipole states (1963FI07, 1964TA05).

^j See also (1972HA32).

^k 0.64 ± 0.07 eV: see (1975FO1L).

section for that process C^2S ($l = 1$) is determined to be 0.49 ± 0.15 for the $\frac{1}{2}^-$ $^{13}\text{N}_{\text{g.s.}}$. In reaction (b), studied for $E_p = 610$ to 2700 keV the capture γ -ray yield is dominated by a direct capture process to $^{13}\text{N}^*(2.37)$: C^2S ($l = 0$) = 1.02 ± 0.15 . The cascade decay $^{13}\text{N}^*(3.51 \rightarrow 2.37)$ has an intensity of $8 \pm 1\%$ (1974RO29). Extrapolating the cross section to $E_{\text{cm}} = 25$ keV yields a cross section factor $S = 1.45 \pm 0.20$ keV \cdot b (1974RO29). For other discussions of astrophysical questions see (1971BA1A, 1972CA1N, 1973CL1E, 1973SM1D, 1973TR1E, 1973TR1B).

There have been a number of measurements of the width of $^{13}\text{N}^*(2.37)$ in this and in other reactions and suggestions have been made that the width may be reaction dependent: we refer the reader to p.1327 of (1974BL06) for an excellent discussion of this question. It appears that there is no reaction dependence and that the apparent discrepancies arise from questions of detector efficiency, background subtraction and penetrability variations. For the values for Γ reported in this reaction see Table 13.26.

At $E_p = 14.2$ MeV, capture radiation from the first $T = \frac{3}{2}$ state, $^{13}\text{N}^*(15.07)$, is reported: $\Gamma_p \Gamma_{\gamma_0} / \Gamma = 5.79 \pm 0.20$ eV which, combined with $\Gamma_p / \Gamma = 0.20 \pm 0.025$ from (1969AD01) yields $\Gamma_{\gamma} = 24.5 \pm 1.5$ eV. The amplitude ratio of E2/M1 = 0.013 ± 0.005 . For the transitions to $^{13}\text{N}^*(2.37, 3.51 + 3.55)$, $\Gamma_{\gamma} < 2.8 \pm 0.3$ and 19.6 ± 1.4 eV, respectively (1975MA21). The angular distributions of the γ -rays determine $J = \frac{3}{2}$ for $^{13}\text{N}^*(15.07)$ (1968DI04): see Table 13.7.

See also (1973RO1U, 1975CR06, 1975NA1C, 1975SW1C), (1973SU1E), (1968SE1A, 1973EI1B, 1974KI03, 1974RO1T; theor.), (1974LO1G; applied) and (1970AJ04).

16. (a) $^{12}\text{C}(p, p)^{12}\text{C}$		$E_b = 1.944$
(b) $^{12}\text{C}(p, 2p)^{11}\text{B}$	$Q_m = -15.9572$	
(c) $^{12}\text{C}(p, p\alpha)^8\text{Be}$	$Q_m = -7.367$	

Yield curves for elastic protons, protons inelastically scattered to $^{12}\text{C}^*(4.4, 7.7, 9.6, 12.7, 15.1)$, and for γ -rays from $^{12}\text{C}^*(12.7, 15.1)$ have been studied at many energies up to $E_p = 48.5$ MeV: see Table 13.27 for a display of the characteristics of the observed structure. The excitation functions of p_0 , p_1 and α_0 have been measured in the region of the $T = \frac{3}{2}$ state at $E_x = 15.07$ MeV: $\Gamma = 1.10 \pm 0.09$ keV, $\Gamma_p = 210 \pm 11$ eV, $\Gamma_p / \Gamma = 0.191 \pm 0.017$ (1975HI07): see Table 13.7.

Total reaction cross section measurements have been made at $E_p = 9.88$ to 19.46 MeV (1970DI08), 22 to 35 MeV (1975SL02), 23.2 to 47.7 MeV (1969MC1A, 1974MC19), 30, 40, 49.5 and 60.8 MeV (1971ME09), 180 to 560 MeV (1972SC1M) and 231, 345, 464 and 552 MeV (1972RE06). The nuclear absorption cross section for p to \bar{p} has been studied at 6 to 60 GeV/c (1973GO41). See (1970AJ04) for a listing of the earlier measurements in the range 10 MeV to 1 GeV. See also ^{12}C in (1975AJ02).

See also (1975CA1L, 1975JA1A, 1975RI1A), (1969TE1A, 1970SL1B, 1971SA1E, 1972BE23) and (1969AB1A, 1969SO1A, 1970CA13, 1970SH01, 1970SH14, 1970SH1J, 1971MI07, 1971IN05, 1971JA13, 1972DA1J, 1972ER1A, 1972JO11, 1972PE11, 1973AD01, 1973CL01, 1973VA1L, 1974IN06, 1974IN07, 1974RE1B, 1974RO1T, 1975BA05, 1975CA05, 1975VI09; theor.).

Spin-flip measurements have been carried out at $E_p = 5.2$ to 6 MeV (1973SA1N), 7.0 to 8.0 MeV

Table 13.27: ^{13}N levels from $^{12}\text{C}(\text{p}, \text{p})$, $^{12}\text{C}(\text{p}, \text{p}')$ and $^{12}\text{C}(\text{p}, \alpha)$ ^a

E_{res} (MeV \pm keV)	$^{13}\text{N}^*$ (MeV)	Γ_{cm} (keV)	l_{p}	J^{π}		Refs.
0.461 ± 3	2.369	31^{h}	0	$\frac{1}{2}^{+}$	$\theta^2 = 0.54$	(1953JA1B, 1954MI05)
1.686 ± 6	3.499	63	1	$\frac{3}{2}^{-}$	0.031	(1953JA1B, 1966AR03, 1973AN07)
$1.734 \pm 6^{\text{i}}$	3.543	74	2	$\frac{5}{2}^{+}$	0.21	(1953JA1B, 1966AR03, 1973AN07)
4.808 ± 10	6.378	11	2	$\frac{5}{2}^{+}$	0.0031	(1956RE39, 1967BA1C)
5.370 ± 10	6.896	115 ± 5	2	$\frac{3}{2}^{+}$	0.13	A
5.65 ± 10	7.15	9 ± 0.5	4	$\frac{7}{2}^{+}$	0.016	(1963BA36, 1963BA43, 1963NI05)
5.891	7.38	75 ± 5	3	$\frac{5}{2}^{-}$	0.069	B
6.5	7.9	≈ 1500	2	$\frac{3}{2}^{+}$	0.14	C
7.54	8.90^{b}	230	1	$\frac{1}{2}^{-}$	0.02	D, (1973BE37)
8.18	9.49^{c}	30	1	$\frac{3}{2}^{-}$	0.001	D, (1966SW04, 1972BE15, 1976SO02)
9.13^{d}	10.36	30	3	$\frac{5}{2}^{-}$		E
9.13^{d}	10.36	76	3	$\frac{7}{2}^{-}$		E
					$\Gamma_{\text{p}}/\Gamma =$	
10.35 ± 50	11.49	430 ± 35	2	$\frac{5}{2}^{+}$	0.70 ± 0.05	(1972WI26, 1973ME03)
10.58 ± 30	11.70	115 ± 30	3	$\frac{5}{2}^{-}$	0.60 ± 0.04	(1972WI26, 1973ME03)
10.62 ± 40	11.74	250 ± 30	2	$\frac{3}{2}^{+}$	0.30 ± 0.05	(1973ME03) ^e
10.62 ± 50	11.74	530 ± 80	1	$\frac{3}{2}^{-}$	0.55 ± 0.05	(1973ME03) ^e
10.75 ± 40	11.86	380 ± 50	0	$\frac{1}{2}^{+}$	0.35 ± 0.05	(1973ME03) ^e
11.05 ± 50	12.13	250 ± 30	3	$\frac{7}{2}^{-}$	0.30 ± 0.05	(1973ME03)
12.5	13.5	≈ 500				(1961NA02)
13.035	13.96	140	2	$\frac{3}{2}^{+}; T = \frac{1}{2}$		(1969LE18)
13.2	14.1	≈ 500				(1961NA02, 1969FA04)

Table 13.27: ^{13}N levels from $^{12}\text{C}(p, p)$, $^{12}\text{C}(p, p')$ and $^{12}\text{C}(p, \alpha)$ ^a (continued)

E_{res} (MeV \pm keV)	$^{13}\text{N}^*$ (MeV)	Γ_{cm} (keV)	l_p	J^π	Refs.
13.8	14.7	≈ 500			(1961NA02, 1964DA03)
14.23075 \pm 0.2	15.06	1.10 \pm 0.09	1	$\frac{3}{2}^-; T = \frac{3}{2}$	F, Table 13.7
14.9	15.7	≈ 500			(1964DA03)
15.2	16.0	≈ 500			(1961NA02, 1964DA03, 1967KU02)
15.27 \pm 30	16.02	130 \pm 30	4	$\frac{7}{2}^+; T = \frac{1}{2}$	(1969LE18, 1973ME12)
15.6	16.3	≈ 500			(1964DA03)
16.5	17.2	≈ 500			(1964DA03)
17.670	18.23	300	1	$\frac{1}{2}^-; T = \frac{1}{2}$	(1964DA03, 1967KU02, 1969LE18)
17.857 \pm 5	18.406	66 \pm 8	2	$\frac{3}{2}^+; T = \frac{3}{2}$	(1967KU02, 1969LE18, 1969LE1C)
17.9	18.4	≈ 500			(1964DA03)
18.2	18.7	≈ 500			(1964DA03)
18.460 \pm 10	18.961	23 \pm 5		$\frac{3}{2}^-$ or $\frac{7}{2}^+; T = \frac{3}{2}$	(1967KU02, 1969LE18, 1969LE1C)
18.8	19.3	≈ 500			(1964DA03)
19.40	19.83	1000	3	$\frac{5}{2}^-; T = \frac{1}{2}$	(1964DA03, 1969LE18) ^{f,g}
19.46	19.88	520	2	$\frac{3}{2}^+; T = \frac{1}{2}$	(1963ME04, 1965MA26, 1966LO16, 1967SC11) ^{f,g}
20.55 \pm 300	20.9	≈ 1100		$(\frac{5}{2})^+$	(1973ME12) ^f
21.41	21.68				(1963DI16, 1966CR04)
21.73	21.97				(1963DI16, 1966CR04)
22.2 \pm 500	22.4	≈ 2000		$(\frac{5}{2})^-$	(1963ME04, 1966LO16, 1967SC11, 1973ME12) ^f
24.0	24.0	$\lesssim 500$			(1963ME04, 1966LO16, 1975SL02) ^f
25.7	25.6			$(\frac{3}{2})^-$	(1967SC11, 1975SL02) ^f
27.02	26.84				(1963DI16, 1966CR04)

A: (1956RE39, 1961AD04, 1962SH22, 1963BA36, 1963BA43, 1963NI05, 1966BA35, 1967BA1C, 1967DU1A, 1968BE2C). See also (1973SA1N).
B: (1956BR27, 1961AD04, 1962SH22, 1963BA36, 1963BA43, 1963NI05, 1966BA35, 1966SH10, 1968BE2C).
C: (1956SC29, 1961NA02, 1962SH22, 1966BA35).
D: (1961AD04, 1962SH22, 1966BA35).
E: (1961AD04, 1962SH22, 1966BA35, 1966SW04, 1967SW1A, 1968BE2C, 1970DA1G, 1974MU1G, 1976SO02).
F: (1967KU02, 1969LE18, 1969LE1C, 1973HU07, 1975GO03, 1975HI07). See also (1972BA14, 1973SZ1B).

^a See also Table 13.25 in (1970AJ04).

^b Decays predominantly by $f_{5/2}$ waves: the reduced width for $f_{5/2}$ emission is \approx the single particle limit (1973BE37).

^c More than $\approx 90\%$ of inelastic width is in the $p_{1/2}$ channel (1972BE15).

^d The resonant energies probably do not differ by more than 2 keV (1968BE2C).

^e See also (1972WI26) and (1970AJ04).

^f See also (1970GI04).

^g See also (1973ME12).

^h See reaction 15.

ⁱ See also (1975CR06).

(1973BE37), 8.0 to 8.3 and 8.9 to 9.4 MeV (1972BE15, 1974MU1G, 1976SO02), 12 to 14 MeV (1970KO15), 12 to 15 MeV and at 20 MeV (1969KO07) and 15.9 to 35.3 MeV (1975DE32); the absolute values of the spin-flip probabilities show pronounced structure at ≈ 20 and 29 MeV, suggesting giant resonance effects. See also ^{12}C in (1968AJ02). Polarization measurements have been carried out for $E_p = 0.5$ MeV to 3.6 GeV: see Table 13.26 in (1970AJ04) and Table 13.28 here.

See also (1969RE1A, 1970TS03, 1971CR1A, 1973BI1H), (1971PL1C), (1975ME1E; astro-phys.) and (1970SH01, 1971CH01, 1972DE13, 1972SI19, 1973ME1J, 1973MO1E, 1974IN04; theor.).

For reaction (b) see (1970AJ04), ^{11}B in (1975AJ02) and (1975ME1E; astrophys.). For reaction (c) see (1972MA62) and ^8Be in (1974AJ01).

For spallation studies see (1969DA1D, 1969EP1B, 1970AZ1A, 1970DA1D, 1970JU1B, 1971FO06, 1972AL1K, 1973BA81, 1973BE36, 1973KR09, 1974BE65, 1975RA14, 1976ED1B, 1976KO03). See also (1968ED1A, 1970KO25, 1973BA1M, 1973RO1V, 1974CL1G, 1974KO1V) and (1970SC1F; theor.).

17. (a) $^{12}\text{C}(p, n)^{12}\text{N}$	$Q_m = -18.126$	$E_b = 1.944$
(b) $^{12}\text{C}(p, pn)^{11}\text{C}$	$Q_m = -18.722$	

The cross section for reaction (a) has been measured from threshold to $E_p = 50$ MeV. Resonant structure is observed corresponding to $E_x = 21, 24$ and, possibly ≈ 27 MeV (1968RI01). See also (1970AM1A, 1971JU05), (1974RE1B; theor.) and ^{12}N in (1975AJ02).

Cross sections for reaction (b) have been measured to $E_p = 385$ MeV (see (1970AJ04)), at 450 MeV (1972WA30), at 7.6 GeV (1972BU31) and at 300 GeV (1976KA01). See also (1970DA26, 1970VA1K, 1971DE18, 1973SK1B, 1973WA1G) and (1972DA09; theor.).

18. (a) $^{12}\text{C}(p, d)^{11}\text{C}$	$Q_m = -16.497$	$E_b = 1.944$
(b) $^{12}\text{C}(p, t)^{10}\text{C}$	$Q_m = -23.364$	
(c) $^{12}\text{C}(p, ^3\text{He})^{10}\text{B}$	$Q_m = -19.6948$	

For polarization measurements (reaction (a)) see (1970AJ04). See also (1973TA27, 1974IN07, 1974RE1B; theor.) and ^{11}C in (1975AJ02).

Polarization measurements involving the t_0 and t_1 groups have been carried out at $E_p = 49.5$ MeV (1970NE17). See also ^{10}B and ^{10}C in (1974AJ01) and (1974RE1B; theor.).

19. $^{12}\text{C}(p, \alpha)^9\text{B}$	$Q_m = -7.551$	$E_b = 1.944$
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Table 13.28: Summary of $^{12}\text{C}(p, p)^{12}\text{C}$ polarization measurements ^a

E_p (MeV)	Groups	Refs.
≈ 0.5	p_0	(1973DI1F)
1.3 – 2.2	p_0	(1971KL03)
2.0 – 4.5	p_0	(1973HA59)
2.4 – 3.9	p_0	(1965BL02)
4.5 – 6.0	p_0	(1974AL31)
4.7 – 4.9	p_0	(1972NA1C)
4.8 – 6.2	p_0	(1974RO42)
5.8 – 6.3	p_0	(1974GU04)
6 – 15	$\gamma_{4.4}$	(1975GL1C)
9.5 – 11.5	p_0, p_1	(1973ME03)
9.95 – 10.90	p_0	(1972WI26)
12 – 18	p_0	(1975ME1H)
$\approx 20, 24.5$	p_1, p_2	(1974PL02, 1974PL05)
20.3	p_0, p_1, p_2	(1970BL03)
22.3, 26.7, 30.5	p to all states up to $^{12}\text{C}^*(14.1)$	(1974PE1E)
22.3, 26.7, 30.5	p to $^{12}\text{C}^*(12.7)$	(1974AM05, 1974GE1G)
30.4	p_0, p_1, p_2, p_3	(1972GR02)
40.5	p_0, p_1, p_2, p_3	(1971BE1D)
49.4	p_0, p_1	(1970CL10)
51.8	p_1	(1973HA2F)
180 – 270	p	(1970RE1C)
185	p_0, p_3, p to $^{12}\text{C}^*(15.1)$	(1973IN09, 1974IN01, 1974IN06)
399 – 576	p	(1974AE01, 1975AE1A)
990	p	(1973VO1L)
2.1 GeV/c	p	(1974ZH1B)

^a For a listing of earlier polarization measurements [$E_p = 1$ MeV to 3.6 GeV] see Table 13.26 in (1970AJ04).

Yield curves for α_0 have been measured over the 14.2 MeV resonance, corresponding to the first $T = \frac{3}{2}$ state at $E_x = 15.07$ MeV, and from $E_p = 17$ to 20 MeV. The yield for the α_1 group has been determined for $E_p = 17$ to 21.5 MeV. Parameters of observed resonances are displayed in Table 13.27 (1969LE18, 1975HI07). Excitation functions for α_0 have also been measured for $E_p = 18.5$ to 44 MeV at a number of angles: they exhibit structures which are typically 1 MeV broad (1971GU23). See also (1969KO1D), (1974RE1B; theor.) and ${}^9\text{B}$ in (1974AJ01).

$$20. \text{}^{12}\text{C}(\text{p}, \text{}^6\text{Li})\text{}^7\text{Be} \qquad Q_m = -22.569 \qquad E_b = 1.944$$

Excitation functions have been measured for $E_p = 36$ to 43 MeV: no structure is apparent (1971HO25). See also (1975FU01) and (1974RE1B; theor.).

$$21. \text{(a) } \text{}^{12}\text{C}(\text{d}, \text{n})\text{}^{13}\text{N} \qquad Q_m = -0.281$$

$$\text{(b) } \text{}^{12}\text{C}(\text{d}, \text{pn})\text{}^{12}\text{C} \qquad Q_m = -2.2246$$

Measurements of angular distributions of neutrons are tabulated in Table 13.27 of (1970AJ04). Recent measurements are by (1972DA02: 7.0 \rightarrow 12.0 MeV; n_0), (1971MU18: 11.8 MeV; n_0, n_1, n_{2+3}) and (1970GA07: 12, 15, 17 MeV; angular distributions of recoils in coincidence with n_0). Forward differential cross sections have been measured by (1972DU01) at 1.69 GeV/ c . The cm width of ${}^{13}\text{N}^*(2.37)$ is reported by (1973CL04) as 36.15 ± 0.54 keV: see, however, the discussion in (1974BL06, 1975BO32) and in reaction 15 here; the neutron group to ${}^{13}\text{N}^*(2.37)$ shows a pronounced asymmetry (1975BO32). See also ${}^{14}\text{N}$, (1974MA1T, 1975BO35), (1969PH1B), (1970BO1K, 1972PE11, 1974BO53, 1975BO1W; theor.) and (1970DA1F, 1973WE19; applied).

Reaction (b) is dominated at $E_d = 5.0$ to 6.5 MeV and at 9.20 and 9.85 MeV by sequential decay via ${}^{13}\text{N}^*(3.51 + 3.55)$. At lower energies ${}^{13}\text{N}^*(2.37)$ participates also: see (1972VA10, 1972LA03, 1970SA1K, 1972GE1G, 1973SA03, 1973SH04). See also (1972BE54; theor.) and (1970AJ04).

$$22. \text{(a) } \text{}^{12}\text{C}(\text{}^3\text{He}, \text{d})\text{}^{13}\text{N} \qquad Q_m = -3.550$$

$$\text{(b) } \text{}^{12}\text{C}(\text{}^3\text{He}, \text{pd})\text{}^{12}\text{C} \qquad Q_m = -5.4938$$

Angular distributions have been studied to the first eight states of ${}^{13}\text{N}$ at $E({}^3\text{He})$ up to 29 MeV: see (1970AJ04) for a listing of the earlier work and (1971CO07: 21 MeV; d_0), (1971ST21: 40 MeV; d_0, d_{2+3}). The energies and widths of the first three excited states are $E_x = 2368.2 \pm 2.8$, 3507.8 ± 7.6 and 3549.1 ± 5.0 keV, with $\Gamma_{\text{cm}} = 36.1 \pm 2.8$, 54.8 ± 11.5 and 46.5 ± 7.1 keV, respectively (1974BL06). See also (1970BO1K; theor.).

23. $^{12}\text{C}(\alpha, t)^{13}\text{N}$ $Q_m = -17.871$

Angular distributions of the ground state tritons have been measured at $E_\alpha = 56$ MeV (1969GA11) and 104 MeV (1972HA08). See also reaction 41 in ^{13}C .

24. $^{13}\text{C}(^7\text{Li}, ^6\text{He})^{13}\text{N}$ $Q_m = -8.034$

Angular distributions have been obtained at $E(^7\text{Li}) = 36$ MeV for the ^6He ions to $^{13}\text{N}^*(0, 3.51 + 3.55)$ (1973SC26).

25. $^{12}\text{C}(^{10}\text{B}, ^9\text{Be})^{13}\text{N}$ $Q_m = -4.642$

Angular distributions have been measured at $E(^{10}\text{B}) = 100$ MeV for the transitions to $^{13}\text{N}^*(0, 2.37, 3.51 + 3.55)$ (1975NA1M). See also (1973YO1D) and (1975RA13; theor.).

26. $^{12}\text{C}(^{11}\text{B}, ^{10}\text{Be})^{13}\text{N}$ $Q_m = -9.286$

See (1973SC1J, 1974AN36). See also (1970AJ04).

27. $^{12}\text{C}(^{12}\text{C}, ^{11}\text{B})^{13}\text{N}$ $Q_m = -14.014$

See (1971SC1F, 1972SC21, 1974AN36).

28. $^{12}\text{C}(^{14}\text{N}, ^{13}\text{C})^{13}\text{N}$ $Q_m = -5.607$

Angular distributions involving $^{13}\text{N}_{\text{g.s.}}$ and various ^{13}C states (see reaction 45 in ^{13}C) have been studied at $E(^{14}\text{N}) = 78$ MeV (1970VO02), 100 MeV (1974DE03) and 155 MeV (1975NA15, 1976NA1P; also $^{13}\text{N}^*(2.37, 3.51 + 3.55)$). For a symmetry test at 155 MeV, see reaction 45 in ^{13}C (1975VO05) and (1969VO01). See also (1974AN36), (1970JA1B, 1973BR1C, 1973SC1J, 1973VO1E, 1974SC1M, 1975HA1P) and (1970AN1D, 1973DE02, 1973DE1R, 1973DE1U, 1974BR18, 1974BR1G, 1975RE04; theor.).

29. (a) $^{12}\text{C}(p, n)^{13}\text{N}$ $Q_m = -3.003$
 (b) $^{13}\text{C}(p, pn)^{12}\text{C}$ $Q_m = -4.9464$

Angular distributions of ground state neutrons have been measured at $E_p = 3.1$ to 18.5 MeV [see (1970AJ04)] and at 30 and 50 MeV (1970CL01; also (n_1) , (n_2)), at $E_p = 16.3$ and 22.8 MeV (1975LI11; also (n_1) , $(n_2 + n_3)$). Neutron thresholds have been observed to $^{13}\text{N}^*(0, 3.51)$ (1966RI09). $^{13}\text{N}^*(2.37)$ is weakly populated in this reaction: see e.g., (1961DA09, 1970CL01). See also (1969MO32), (1973CL1E; astrophys. questions), (1970AT1A, 1970DA1E, 1970LA1B, 1970LO1B, 1971GE12; theor.), (1975AU1F, 1975DO1J, 1975LI11; applied work).

In sequential decay of reaction (b) at $E_p = 7.9$ to 12 MeV one or more of the ^{13}N states at $E_x = 3.5$ MeV appear to be involved (1970OT1A, 1971OT02).

$$30. \ ^{13}\text{C}(^3\text{He}, t)^{13}\text{N} \quad Q_m = -2.239$$

At $E(^3\text{He}) = 39.6$ MeV, angular distributions have been obtained for the tritons corresponding to the ground state of ^{13}N and to the excited states at 2.37 , 3.53 ± 0.03 (unresolved), 6.36 , 7.16 , 7.38 , 8.92 ± 0.04 , 11.85 ± 0.04 and 15.07 MeV. States at $E_x = 9.5$, 10.78 ± 0.04 and 15.98 ± 0.05 MeV were also populated, the first of these weakly. The transitions to $^{13}\text{N}^*(7.38, 8.92, 11.85, 15.07)$ are $L = 2$ [$J^\pi = \frac{5}{2}^-, \frac{1}{2}^-, \frac{3}{2}^-, \frac{3}{2}^-$, respectively] (1969BA06). Angular distributions have also been reported at $E(^3\text{He}) = 14$ MeV (1970NU02; t_0, t_1).

$$31. \ ^{13}\text{C}(^6\text{Li}, ^6\text{He})^{13}\text{N} \quad Q_m = -5.730$$

At $E(^6\text{Li}) = 31.8$ MeV, angular distributions have been measured for the transitions to $^{13}\text{N}^*(0, 3.51 + 3.55)$ (1970CH19, 1971CH1B). See also (1975DI1J; theor.).

$$32. \ ^{13}\text{C}(^{14}\text{N}, ^{14}\text{C})^{13}\text{N} \quad Q_m = -2.377$$

See (1971GA05) and (1973TO05; theor.).

$$33. \ ^{13}\text{O}(\beta^+)^{13}\text{N} \rightarrow ^{12}\text{C} + \text{p} \quad Q_m = 15.816$$

See ^{13}O .

$$34. \ ^{14}\text{N}(\gamma, n)^{13}\text{N} \quad Q_m = -10.554$$

See (1973KI05; theor.) and ^{14}N .

35. $^{14}\text{N}(\text{p}, \text{d})^{13}\text{N}$ $Q_{\text{m}} = -8.329$

Angular distributions have been measured for the deuterons to $^{13}\text{N}^*(0, 2.37, 3.51 + 3.55, 7.38, 8.92, 11.87)$ at many energies up to $E_{\text{p}} = 155.6$ MeV: see (1970AJ04) for a listing of the earlier work and (1971CU01: $E_{\text{p}} = 14.5$ MeV; d_0) and (1975RO27: $E_{\text{p}} = 65$ MeV; to states listed above; spectroscopic factors). The separation energy spectrum has been measured at $E_{\text{p}} = 185$ MeV (1973FA10). See also (1971MC15; theor.).

36. $^{14}\text{N}(\text{d}, \text{t})^{13}\text{N}$ $Q_{\text{m}} = -4.296$

Angular distributions of the tritons to $^{13}\text{N}^*(0, 3.51, 7.38, 8.93 + (9.00) + 9.48, 11.8)$ have been obtained at $E_{\text{d}} = 52$ MeV and analyzed by DWBA. The spectroscopic factors for the ^{13}N states [and the mirror states reached in the $^{14}\text{N}(\text{d}, ^3\text{He})^{13}\text{C}$ reaction] are in good agreement with theory and are additional evidence for the J^{π} assignments of $\frac{1}{2}^{-}$, $\frac{3}{2}^{-}$, $\frac{5}{2}^{-}$, $\frac{1}{2}^{-}$, $\frac{3}{2}^{-}$ and $\frac{3}{2}^{-}$ to these states (1968HI01). Comparisons of (d, t) and (d, ^3He) angular distributions are also reported by (1966DE1C, 1968GA13) and by (1974LU06: $E_{\text{d}} = 15$ MeV): see reaction 75 in ^{13}C . See also ^{16}O in (1977AJ02) and (1971BO50, 1974DA1D; theor.).

37. (a) $^{14}\text{N}(^3\text{He}, \alpha)^{13}\text{N}$ $Q_{\text{m}} = 10.025$
 (b) $^{14}\text{N}(^3\text{He}, \text{p}\alpha)^{12}\text{C}$ $Q_{\text{m}} = 8.081$

Alpha-particle groups have been observed to the first seven excited states of ^{13}N , including two at $E_{\text{x}} = 7.166$ and 7.388 MeV (1962CL12: ± 8 keV). Angular distributions have been studied at many energies up to $E(^3\text{He}) = 45$ MeV: see (1970AJ04) for a listing of the earlier work and (1973MO1C: $3.60 \rightarrow 6.24$ MeV; α_0) and (1970KN01: $4.5, 5.5, 7.0$ MeV; $\alpha_0, \alpha_1, \alpha_{2+3}$). Reaction (b), studied at $E(^3\text{He}) = 8$ MeV, appears to involve some excited states of ^{13}N , possibly $^{13}\text{N}^*(7.93, 8.92, 11.87)$ (1969HO13).

38. $^{14}\text{N}(^6\text{Li}, ^7\text{Li})^{13}\text{N}$ $Q_{\text{m}} = -3.303$

An angular distribution has been measured at $E(^6\text{Li}) = 32$ MeV for the transition to $^{13}\text{N}_{\text{g.s.}}$ and $^7\text{Li}^*(0, 0.48)$. $^{13}\text{N}^*(2.37)$ was also populated (1971GR44, 1971ZE1C). See also (1973OG1A), (1974FL1A; theor.) and reaction 77 in ^{13}C .

39. $^{14}\text{N}(^9\text{Be}, ^{10}\text{Be})^{13}\text{N}$ $Q_{\text{m}} = -3.742$

See (1973TO05; theor.).

$$40. {}^{14}\text{N}({}^{14}\text{N}, {}^{15}\text{N}){}^{13}\text{N} \quad Q_{\text{m}} = 0.280$$

See (1970GO1B), (1970AN1D, 1970KA41, 1970TR1B, 1971AL1D, 1971AN12, 1973OS03, 1974OS1A, 1975OS01; theor.) and (1970AJ04).

$$41. {}^{15}\text{N}(\text{p}, \text{t}){}^{13}\text{N} \quad Q_{\text{m}} = -12.905$$

At $E_{\text{p}} = 43.7$ MeV, angular distributions have been obtained for the tritons corresponding to the ground state of ${}^{13}\text{N}$ and the excited states at 3.51 ($\frac{3}{2}^{-}$), 6.38 ± 0.03 ($\frac{5}{2}^{+}$), 7.38 ($\frac{5}{2}^{-}$), 8.93 ± 0.05 ($\frac{1}{2}^{-}$), 10.78 ± 0.06 ($\frac{1}{2}^{-}$), 11.88 ± 0.04 ($\frac{3}{2}^{-}$) and 15.07 ($\frac{3}{2}^{-}$; $T = \frac{3}{2}$) MeV states [J^{π} values in parentheses, as determined by DWBA analyses using intermediate-coupling wave functions to obtain the two-nucleon structure factors] (1968FL03). Detailed comparisons have been made with the (p, ${}^3\text{He}$) reaction to the mirror states in ${}^{13}\text{C}$ (1968FL02, 1968FL03, 1974MA12): see reaction 82 in ${}^{13}\text{C}$. Angular distributions have also been measured for the triton groups to ${}^{13}\text{N}^*(0, 3.51 + 3.55, 7.39)$ at several energies in the range $E_{\text{p}} = 24.0$ to 43.5 MeV (1974PI05, 1975MI01). See also (1970HA23, 1972HA1X), (1969TE1A), (1971KA04; theor.) and ${}^{16}\text{O}$ in (1977AJ02).

$$42. {}^{16}\text{O}(\gamma, \text{t}){}^{13}\text{N} \quad Q_{\text{m}} = -25.033$$

See ${}^{16}\text{O}$ in (1977AJ02).

$$43. \text{(a) } {}^{16}\text{O}(\text{p}, \alpha){}^{13}\text{N} \quad Q_{\text{m}} = -5.218$$
$$\text{(b) } {}^{16}\text{O}(\text{p}, \text{p}\alpha){}^{12}\text{C} \quad Q_{\text{m}} = -7.1616$$

Measurements of angular distributions have been reported at $E_{\text{p}} = 19$ to 44 MeV (1970GU06, 1971GU23; α_0, α_1) and at 54.1 MeV (1972MA21; α_0, α_2 and α to ${}^{13}\text{N}^*(7.38, 12.13)$). The parameters of the latter state are: $E_{\text{x}} = 12.13 \pm 0.06$ MeV, $\Gamma_{\text{cm}} \approx 300$ keV, $J^{\pi} = \frac{7}{2}^{-}$ (1972MA21). For earlier work on angular distributions to $E_{\text{p}} = 38$ MeV see (1970AJ04). See also (1967SP09) and (1973CL1E; astrophys. questions). For reaction (b) see (1967CH04, 1973BO1D). See also ${}^{17}\text{F}$ in (1977AJ02).

$$44. {}^{16}\text{O}({}^3\text{He}, {}^6\text{Li}){}^{13}\text{N} \quad Q_{\text{m}} = -9.238$$

Angular distributions have been studied at $E(^3\text{He}) = 30$ and 40.7 MeV for the ^6Li ions corresponding to $^{13}\text{N}_{\text{g.s.}}$ (1972OH01). See also (1966CE02).

$$45. \ ^{16}\text{O}(\alpha, ^7\text{Li})^{13}\text{N} \quad Q_{\text{m}} = -22.566$$

The angular distribution for the transition to $^{13}\text{N}_{\text{g.s.}} + ^7\text{Li}_{\text{g.s.}+0.48}$ has been measured at $E_{\alpha} = 42$ MeV (1972RU03).

$$46. \ ^{16}\text{O}(^{14}\text{N}, ^{17}\text{O})^{13}\text{N} \quad Q_{\text{m}} = -6.411$$

This reaction has been studied at $E(^{14}\text{N}) = 79$ MeV (1976MO03) and 155 MeV (1975NA15).

$$47. \ ^{18}\text{O}(\text{d}, ^7\text{Li})^{13}\text{N} \quad Q_{\text{m}} = -7.901$$

See (1970AJ04).

¹³O
(Fig. 4)

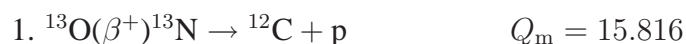
GENERAL (See also (1970AJ04)):

Theoretical papers: (1973HA49, 1973RO1R, 1973SP1A, 1975GR03, 1975BE31, 1975HU14).

Review papers: (1972CE1A, 1972WA07, 1973HA77).

Mass of ¹³O:

From the Q -value of the ¹⁶O(³He, ⁶He)¹³O reaction [$Q_0 = -30.508 \pm 0.010$ MeV] the atomic mass excess of ¹³O is determined to be 23.105 ± 0.010 MeV (1971TR03). ¹³O is then bound with respect to ¹²N + p and ¹¹C + 2p by 1.528 and 2.123 MeV, respectively.



The half-life of the delayed proton emitter ¹³O is 8.7 ± 0.4 msec (1965MC09), 8.95 ± 0.20 msec (1970ES03): we adopt $\tau_{1/2} = 8.90 \pm 0.20$ msec as suggested by (1970ES03). ¹³O decays to a number of states of ¹³N some of which subsequently decay to ¹²C*(0, 4.4): see Table 13.30 (1970ES03). See also (1973TO14, 1974CH46; theor.).

Table 13.29: Energy levels of ¹³O

E_x (MeV)	$J^\pi; T$	$\tau_{1/2}$ (msec)	Decay	Reactions
g.s.	$(\frac{3}{2}^-); \frac{3}{2}$	8.90 ± 0.20	β^+	1, 2, 3



See (1965MC09, 1970ES03).



Table 13.30: Beta decay of ^{13}O ^a

Decay to		$E_p(\text{cm})$ (MeV) to		Relative intensity	% of all β -decays	log ft
$^{13}\text{N}^*$ (MeV)	J^π	$^{12}\text{C}^*(\text{g.s.})$	$^{12}\text{C}^*(4.4)$			
g.s.	$\frac{1}{2}^-$				88.1 ± 3.4 ^b	4.10 ± 0.02 ^b
3.51	$\frac{3}{2}^-$	observed		100	10.7 ± 3.1	4.52 ± 0.13
7.38	$\frac{5}{2}^-$	5.48 ± 0.05	not seen	0.33 ± 0.10	0.40 ± 0.19	5.22 ± 0.23
8.92	$\frac{1}{2}^-$	observed		3.5 ± 0.3		
					0.54 ± 0.16	4.73 ± 0.14
9.48	$\frac{3}{2}^-$	observed	2.56 ± 0.05	1.5 ± 0.3		
				0.8 ± 0.1		
					0.13 ± 0.04	5.18 ± 0.14
10.36	$\frac{5}{2}^-$	observed	3.12 ± 0.05	0.43 ± 0.15		
				0.05 ± 0.03 ^c		
					0.019 ± 0.012	5.8 ± 0.3
			3.97 ± 0.05	0.13 ± 0.07		

^a (1970ES03). In addition there is some evidence for weak proton groups with $E_p = 3.44$ and 6.38 MeV (± 0.05 MeV). See also (1965MC09).

^b The ground state ft was taken to be 1.15 times that for ^{13}B (1970ES03). (1971WI07) find $(ft)^+/(ft)^- = 1.17 \pm 0.03$: see reaction 1 in ^{13}B .

^c Calculated value from the known ratio of the elastic and inelastic widths.

$$Q_0 = -30.506 \pm 0.013 \text{ (1971TR03);}$$

$$Q_0 = -30.511 \pm 0.015 \text{ (1970ME11: recalculated on basis of } ^9\text{C mass excess of 28.908 MeV (see (1974AJ01)).}$$

The ground state of ^{13}O has been populated at $E(^3\text{He}) = 62.6$ and 66.3 MeV (1970ME11) and at 68.2 to 68.6 MeV (1970TR05, 1970TR1F, 1971TR03).

^{13}F , ^{13}Ne
(Not illustrated)

^{13}F and ^{13}Ne have not been observed. See (1975BE31; theor.).

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(Closed 31 January 1976)

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