Energy Levels of Light Nuclei
$A = 13$

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Abstract: An evaluation of $A = 13$–15 was published in *Nuclear Physics A*360 (1981), 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. Also, Reference key numbers have been changed to the NNDC/TUNL format.

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Table of Contents for $A = 13$

Below is a list of links for items found within the PDF document. Figures from this evaluation are not included in the PDF document but have been scanned in and are available on this website or via the link below.

^{13}Li

(Not illustrated)

^{13}Li has not been observed. ^{13}Li is predicted to have an atomic mass excess of 61.56 MeV: it is then unstable for breakup into ^{12}Li+n and ^{11}Li+2n by 0.6 and 4.5 MeV, respectively (1974TH01). The modified mass equation leads to a calculated atomic mass excess of 60.34 MeV: ^{13}Li would then be stable with respect to breakup into ^{12}Li + n by 0.7 MeV, assuming the a.m.u. of ^{12}Li to be 52.94 MeV, but would be unstable with respect to ^{11}Li + 2n by 3.3 MeV (1975JE02). See also (1976AJ04).

^{13}Be

(Not illustrated)

^{13}Be has not been observed. ^{13}Be is predicted to have an atomic mass excess of 35.35 MeV (1974TH01), 34.60 MeV (1975JE02). It is then unstable with respect to decay into ^{12}Be + n by 2.20 MeV or by 1.45 MeV, respectively, based on the atomic mass excess of ^{12}Be, 25.078 MeV (1978AL29). See also (1976AJ04) and (1977SE1D; theor.).

^{13}B

(Figs. 1 and 4)

GENERAL: (See also (1976AJ04).)

Experimental work on complex reactions in which ^{13}B is observed: (1976BU16, 1977AR06, 1978GE1C, 1978KO01, 1979LE1J).

Reviews and theoretical papers: (1976AB04, 1976VA29, 1977DO06, 1978AB08, 1978DE15, 1979AL22, 1979BE1H, 1979BO22, 1980MA1F, 1980MU1B).

$$Q = 0.0478 \pm 0.0046 \text{ b (1973HAVZ, 1978LEZA).}$$

$$\mu = +3.17778 \pm 0.00051 \text{ nm (1978LEZA).}$$

1. ^{13}B(β^-)^{13}C $\qquad Q_{\rm m} = 13.437$

The half-life of ^{13}B is 17.33 ± 0.17 msec (1971WI07). The mean of this and a previously reported measurement is 17.36 ± 0.16 msec (1971WI07). The branching ratios of various ^{13}C states are shown in Table 13.2: they indicate $J^\pi = \frac{1}{2}^-$ and $\frac{3}{2}^-$ for ^{13}B$_{\rm g.s.}$. See also (1976AJ04) and (1977AZ02, 1977MA16, 1977RI08, 1979DE15; theor.).

Table 13.1: Energy levels of ^{13}B

E_x (MeV ± 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, 6, 7, 8, 9
3.483 ± 5	[a]		γ	2, 4
3.5346 ± 3.1	[a]	$\tau_m > 0.3$ psec	γ	2, 4
3.681 ± 5	[a]		(γ)	2, 4, 7
3.7126 ± 4.5	[a]	$\tau_m < 0.38$ psec	(γ)	2, 4, 7
4.131 ± 6		$\tau_m = 0.062 \pm 0.050$ psec	γ	2, 4
4.834 ± 7			(γ)	2, 4
5.029 ± 7				2, 4
5.106 ± 10		$\Gamma = 60 \pm 10$ keV		4
5.392 ± 8		10 ± 10		2, 4
(5.557 ± 7)				2
6.167 ± 7				2, 4
6.425 ± 7		36 ± 5		2, 4
6.934 ± 9	[a]	55 ± 15		2, 4
(7.516 ± 8)				2
(7.859 ± 20)				2
8.134 ± 7		100 ± 15		2, 4
8.683 ± 7		89 ± 20		2, 4
9.44 ± 30		81 ± 25		4
10.22 ± 20		210 ± 20		4
10.89 ± 20				4
(11.80)				4

[a] See Table 13.3.

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

Decay to ^{13}C* (MeV)	J^{π}	Branch (%)	log ft [b]
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 [c]	$\frac{5}{2}^-$	0.094 ± 0.020	5.33 ± 0.08
8.86	$\frac{1}{2}^-$	0.16 ± 0.03	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] (1969JO21, 1974AL12). See also Table 13.24.

[b] Log ft shown here are based on $\tau_{1/2} = 17.33 \pm 0.17$ msec (1971WI07). See also (1977RI08; theor.).

[c] $E_x = 7.577 \pm 0.030$ MeV (1974AL12).

2. ^{7}Li(^{7}Li, p)^{13}B $\qquad Q_m = 5.965$

Observed proton groups are shown in Table 13.3 (1972WY01). For angular distribution measurements see (1969CA1A). The lifetimes of ^{13}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.

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

See ^{14}C.

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

Observed proton groups are displayed in Table 13.3. Angular distributions have been measured at $E_t = 11$ MeV (1964MI04) and 23 MeV (1978AJ02).

5. ^{12}C(^{9}Be, ^{8}B)^{13}B $\qquad Q_m = -28.136$

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

^{7}Li(^{7}Li, p)^{13}B	^{11}B(t, p)^{13}B				
(1972WY01)	(1964MI04)			(1978AJ02)	
E_x (MeV ± keV)	E_x (MeV ± keV)	L	J^π	E_x (MeV ± keV)	Γ_{cm} (keV)
0	0	0	$\frac{3}{2}^-$	0	
	3.483 ± 5	1	$(\frac{1}{2}, \frac{3}{2}, \frac{5}{2})^+$ [g]	3.482 ± 10	
[a]	3.533 ± 5	2	$(\frac{1}{2}, \frac{5}{2}, \frac{7}{2})^-$ [g]	3.531 ± 10	
	3.681 ± 5	1	$(\frac{1}{2}, \frac{3}{2}, \frac{5}{2})^+$ [g]	3.681 ± 10	
[a,b]	3.712 ± 5	2	$(\frac{1}{2}, \frac{5}{2}, \frac{7}{2})^-$ [g]	3.715 ± 10	
[c,d]	4.13 ± 10	2	$(\frac{1}{2}, \frac{5}{2}, \frac{7}{2})^-$ [g]	4.128 ± 10	
4.833 ± 10	4.82 ± 10			4.834 ± 10	
5.033 ± 8	5.01 ± 10	1	$(\frac{1}{2}, \frac{3}{2}, \frac{5}{2})^+$ [g]	5.023 ± 10	
				5.106 ± 10	60 ± 10
5.391 ± 8	5.38 ± 10 [e]			5.393 ± 10	10 ± 10
5.557 ± 8				[f]	
6.169 ± 8	6.17 ± 20			6.164 ± 10	
6.419 ± 8				6.434 ± 10	36 ± 5
6.939 ± 15				6.932 ± 10 [h]	55 ± 15
7.516 ± 8				[f]	
7.859 ± 20				[f]	
8.129 ± 10				8.138 ± 10	100 ± 15
8.682 ± 9				8.684 ± 10	89 ± 20
				9.44 ± 30	81 ± 25
				10.22 ± 20	210 ± 20
				10.89 ± 20	
				(11.80)	

[a] See text.

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

[c] The decay is 75 ± 10%, 25 ± 10% and < 10%, respectively to ^{13}B*(0, 3.5, 3.7).

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

[e] $\Gamma = 15 \pm 5$ keV.

[f] Not observed.

[g] See, however, (1978AJ02), p. 1289.

[h] $L \geq 4$.

See (1975WI26).

6. ^{13}C(π^-, γ)^{13}B $Q_{\rm m} = 126.130$

See (1979MA2C) and (1979TR1B).

7. ^{14}C(d, ^{3}He)^{13}B $Q_{\rm m} = -15.338$

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

8. ^{14}C(t, α)^{13}B $Q_{\rm m} = -1.017$

At $E_{\rm t} = 23$ MeV the angular distribution for α_0 has been analyzed by (1979SE07): the DWBA fit is poor. The extracted $S(\frac{3}{2}) = 5.7$, near that predicted for a filled $p_{3/2}$ shell.

9. ^{14}C(^{14}C, ^{13}B)^{15}N $Q_{\rm m} = -10.624$

See (1980NA14).

^{13}C
(Figs. 2 and 4)

GENERAL: (See also (1976AJ04).)

Shell model: (1977TE01, 1978BO31, 1979HO17).

Collective, rotational and deformed models: (1976BR26, 1977ME1E).

Cluster model: (1977SA19).

Special levels: (1977ME1E, 1977TE01, 1977RI08, 1978BO31, 1978MI04, 1979RO1E, 1980BA54).

Electromagnetic transitions: (1977ME1E, 1977YO1D, 1978KI08, 1978KR19, 1978MI04, 1980BA54).

Giant resonances: (1977AL18, 1977MA06, 1979DO17, 1979HO17).

Applied work: (1975GA1E, 1977AN1F, 1977SH1E, 1978EM1A, 1978KE1E, 1978LE1P, 1979AL1P, 1979EN1D, 1979JA1F, 1979KU20, 1979SM1B).

Special reactions: (1976AB04, 1976BE1K, 1976BU16, 1976HI05, 1976LE12, 1976LE1F, 1977AR06, 1977RE08, 1977SH1D, 1977UD1A, 1977YA1B, 1978AB08, 1978BI08, 1978GE1C, 1978HE1C, 1978KO01, 1978LE15, 1979AL22, 1979BO22, 1979HE1D, 1979PO16, 1979SA27, 1979ST1D, 1980MI01).

Astrophysical questions: (1975LO1E, 1976BE1C, 1976BO1M, 1976BR1K, 1976DE1F, 1976DE1G, 1976DE1H, 1976EP1A, 1976FI1E, 1976FU1C, 1976GA1F, 1976HI1D, 1976MA1N, 1976NO1C, 1976QU1A, 1976RE1B, 1976SP1B, 1976TO1D, 1976VA1D, 1976VI1B, 1976WA1G, 1977AU1E, 1977AU1F, 1977CA1H, 1977CA1J, 1977CA1K, 1977CH1J, 1977CL1B, 1977CL1C, 1977CO1J, 1977DA1E, 1977DE1N, 1977DI1C, 1977FU1L, 1977HA1L, 1977JO1D, 1977LA1F, 1977LA1G, 1977LI1H, 1977PA1D, 1977PR1E, 1977SC1H, 1977SH09, 1977ST1H, 1977TI1A, 1977TR1D, 1977WA1N, 1977WA1P, 1977WI1D, 1978BU1B, 1978DE1R, 1978DO1B, 1978IB1A, 1978LU1C, 1978SN1A, 1978ST1C, 1978ST1D, 1978TR1C, 1978VA1B, 1978WA1E, 1979BE1V, 1979BJ1A, 1979GE1D, 1979GU1D, 1979LA1H, 1979MC1B, 1979ME1D, 1979OL1B, 1979PE1E, 1979RA1C, 1979SA1M, 1979SW1B, 1979TU1A, 1979WI1H, 1980HE1D, 1980LA1G, 1980MC1G, 1980PE1F).

Muon and neutrino capture and reactions: (1977BA1P, 1977DO06, 1977MU1A, 1978DE15, 1978LE04, 1979BE1N, 1979DE01, 1980MU1B).

Pion capture and reactions (See also reactions 35 and 53.): (1976AS1B, 1976AU1E, 1974BO1U, 1976DI11, 1976EN02, 1976GA06, 1976GA21, 1976JA1D, 1976LI04, 1976NI05, 1976OS06, 1977AU01, 1977DI1B, 1977FU10, 1977GI06, 1977HO1B, 1977LO19, 1977WA02, 1978DY01, 1978KI08, 1978KI13, 1978MI02, 1978RO1H, 1978WA02, 1979AL1R, 1979AL1J, 1979AN1J, 1979AN1F, 1979BA2D, 1979BA2E, 1979BE1N, 1979BO1U, 1979CO1H, 1979CO1C, 1979DE34, 1979GI1D, 1979GR1K, 1979GY1A, 1979GY1B, 1979HI1A, 1979HO1F, 1979IN1A, 1979JO1C,

1979JO08, 1979LA22, 1979LE1J, 1979LI1H, 1979MA2C, 1979MO1N, 1979MO1P, 1979MO1Q, 1979PI1C, 1979RE1A, 1979SA21, 1979ST1J, 1979TR1E, 1979TR1B, 1980BO03, 1980CH08, 1980ER01, 1980GA12, 1980JO06, 1980LA1C, 1980LE02, 1980MA1F, 1980NA1B, 1980PE1C, 1980SA04, 1980TH01).

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

E_x (MeV $\pm$ keV)	$J^\pi; T$	τ_m or Γ_{cm} (keV)	Decay	Reactions
g.s.	$\frac{1}{2}^-; \frac{1}{2}$		stable	7, 8, 9, 13, 15, 16, 17, 24, 25, 26, 27, 29, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 47, 48, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 65, 66, 67, 68, 69, 70, 71, 75, 77, 78, 79, 80, 81, 83, 85, 86, 87, 88, 89, 91, 92, 93, 94
3.089443 ± 0.020	$\frac{1}{2}^+$	$\tau_m = 1.55 \pm 0.15$ fsec	γ	8, 9, 13, 15, 24, 26, 35, 36, 37, 40, 43, 44, 52, 53, 54, 55, 56, 57, 58, 61, 69, 70, 71, 78, 80, 81, 83, 87, 88, 91
3.684482 ± 0.023	$\frac{3}{2}^-$	1.59 ± 0.13 fsec	γ	7, 8, 9, 13, 15, 16, 24, 26, 29, 35, 36, 37, 39, 40, 47, 52, 53, 54, 55, 56, 57, 58, 61, 69, 70, 71, 77, 78, 79, 80, 81, 87, 88, 91
3.853783 ± 0.022	$\frac{5}{2}^+$	12.5 ± 0.3 psec	γ	8, 9, 13, 15, 24, 26, 35, 36, 37, 38, 39, 40, 42, 43, 44, 52, 53, 54, 55, 56, 57, 58, 61, 69, 70, 71, 80, 81, 87, 91
6.864 ± 3	$\frac{5}{2}^+$	$\Gamma = 6$	γ, n	7, 8, 9, 14, 15, 24, 26, 30, 35, 36, 52, 55, 57, 58, 81
7.492 ± 10	$(\frac{7}{2}^+)$	< 5		7, 9, 14, 24, 26, 36, 43, 53, 58, 80, 81
7.547 ± 3	$\frac{5}{2}^-$	1.2 ± 0.3	γ, n	7, 9, 14, 16, 24, 26, 30, 35, 36, 47, 49, 52, 53, 55, 57, 58, 79, 80, 81, 87

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

E_x (MeV ± keV)	$J^\pi; T$	τ_m or Γ_{cm} (keV)	Decay	Reactions
7.686 ± 6	$\frac{3}{2}^+$	70 ± 5	γ, n	14, 24, 26, 30, 36, 49, 58, 81
8.2 ± 100	$\frac{3}{2}^+$	1000 ± 300	γ, n	9, 30, 36, 49
8.860 ± 20	$\frac{1}{2}^-$	150 ± 30	γ, n	24, 30, 36, 47, 49, 52, 57, 77, 80, 81, 87, 88
9.4998 ± 0.1	$\frac{9}{2}^+$	5	n	7, 9, 14, 24, 30, 35, 36, 52, 53, 57, 80, 81, 87
9.897 ± 5	$\frac{3}{2}^-$	26 ± 3	γ, n	7, 14, 24, 30, 36, 47, 49, 51, 52
10.46		200	n	30
10.753 ± 4	$\frac{7}{2}^-$	55 ± 2	n	14, 24, 30, 36, 81
10.818 ± 5	$(\frac{5}{2}^-)$	24 ± 3	n	7, 9, 14, 24, 36, 81
10.996 ± 6	$\frac{1}{2}^+$	37 ± 4	γ, n, α	4, 24, 30, 36, 49, 80, 81
11.080 ± 5	$(\frac{1}{2}^-)$	< 4	γ, n, α	4, 24, 30, 36, 52, 81, 87
11.748 ± 10		107 ± 14	n	24, 36, 53, 81
11.851 ± 5	$(\frac{3}{2}^-)$	68 ± 4	n	30, 36, 52, 57, 77, 80, 87
11.95 ± 40	$(\frac{5}{2}, \frac{7}{2})^+$	≈ 200	n, α	4, 6, 36, 55, 80
12.106 ± 5	$> \frac{7}{2}$	81 ± 8	n, α	4, 30, 36, 81
(12.187 ± 10)		110 ± 50		52
12.438 ± 12	$\frac{7}{2}^-$	160 ± 40	n, α	4, 30, 52, 87
13.0 ± 1000		broad	γ, n	49
(13.28)	$(\frac{3}{2}^-)$	340	α	6
13.41	$(\frac{9}{2}^-)$	35 ± 3	n, α	4, 6
13.56	$(\frac{3}{2}, \frac{5}{2})^+$	≈ 600	n, α	4, 6, 30
13.76	$(\frac{5}{2}, \frac{3}{2})^+$	≈ 300	n, α	4, 6
14.12	$(\frac{5}{2}^-)$	≈ 150	n, α	4, 6
14.390 ± 15	$(\frac{1}{2}, \frac{5}{2})^-$	280 ± 70	n, α	4, 52
14.582 ± 10		230 ± 50	n, α	4, 52
14.983 ± 10	$(\frac{3}{2}^+)$	380 ± 60	n, α	4, 52
15.1082 ± 1.2 [b]	$\frac{3}{2}^-; \frac{3}{2}$	5.49 ± 0.25	γ, n, α	4, 6, 7, 24, 49, 52, 53, 57, 87
15.526 ± 11		150 ± 30	n, α	4, 52

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

E_x (MeV ± keV)	J^π; T	τ_m or Γ_{cm} (keV)	Decay	Reactions
16.080 ± 7		150 ± 15	n, α	4, 52
16.15 ± 50		230	n, α	4, 52, 53
16.95 ± 50		330	n, α	4
17.36 ± 100		190	n, α	4, 53
17.699 ± 5		170	n, α	4, 53
18.30 ± 50		300	n, α	4
18.699 ± 5		100 ± 15	γ, n, p, α	4, 50, 52
19.5		≈ 450	n	30
19.9		≈ 600	n, p, d	18, 19
20.021 ± 13		230 ± 30	(γ), n, (p), d, α	17, 18, 22, 50, 52
20.429 ± 8		116 ± 10	(γ), n, p, d	17, 18, 19, 32, 52
21.28 ± 15		159 ± 15	n, p, d	18, 19, 53, 55
21.466 ± 8		270 ± 20		52
21.81 ± 20		114 ± 21	n, d	18, 55
22		≈ 1000	n, d	18, 52, 53
23		≈ 1000	n	30
24		≈ 4000	γ, n, p	49, 50, 52
25.5		broad	γ, p	50, 52
26.8			n, d	18
27.5			n, d	18, 52
30			γ, n	49, 52

[a] See also Tables 13.5 and 13.6.

[b] See Table 13.7.

Other topics: (1976BI1A, 1976BR26, 1976FE1B, 1976VA1C, 1978DA1A, 1978LI1D, 1978MC04, 1978PO1A, 1978SH1B, 1978SO1A, 1979BE1H, 1979HE1F).

Ground state of ^{13}*C:* (1976BR26, 1976DU04, 1976FU06, 1976JO1B, 1977AN21, 1977NO07, 1977YO1D, 1978AN07, 1978HE1D, 1978MI04, 1978TA09, 1978ZA1D, 1979SA27).

$$\mu = +0.702411 \pm 0.000001 \text{ nm (1978LEZA).}$$

Radius of ^{13}*C:* The rms nuclear charge radius is 2.51 ± 0.04 fm (1979BE1N; prelim.: see also reaction 52). The neutron rms radius is 2.35 ± 0.03 fm (1979JO08). See also (1979SA27; theor.).

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

^{13}C* (MeV)	τ_m	Refs.
3.09	1.50 ± 0.17 fsec	(1968RO02)
	1.7 ± 0.3 fsec	(1975RA22)
	1.55 ± 0.15 fsec	weighted mean
3.68	1.50 ± 0.15 fsec	(1969RA20)
	1.83 ± 0.25 fsec	(1970WI04)
	1.59 ± 0.13 fsec	weighted mean
3.85	10.7 ± 1 psec	(1969HE22)
	9.9 ± 0.9 psec	(1970GA01)
	12.4 ± 0.8 psec	(1974BE48)
	13.0 ± 0.4 psec	(1975RA29)
	12.6 ± 0.3 psec	(1977HE12)
	12.5 ± 0.3 psec	weighted mean

[a] See also Table 13.5 in (1976AJ04).

^{13}*C*(3.85)* [$J^\pi = \frac{5}{2}^+$]: g is negative (1976DY05).

1. (a) ^{6}Li(^{7}Li, n)^{12}C $\quad Q_m = 20.924 \quad E_b = 25.870$
   (b) ^{6}Li(^{7}Li, p)^{12}B $\quad Q_m = 8.337$
   (c) ^{6}Li(^{7}Li, 2n)^{11}C $\quad Q_m = 2.203$
   (d) ^{6}Li(^{7}Li, d)^{11}B $\quad Q_m = 7.192$
   (e) ^{6}Li(^{7}Li, t)^{10}B $\quad Q_m = 1.994$
   (f) ^{6}Li(^{7}Li, α)^{9}Be $\quad Q_m = 15.223$

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 $\alpha_0(E(^6\text{Li}) = 4$ 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: 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 ^{9}Be and ^{10}B in (1979AJ01) and ^{11}B and ^{12}B in (1980AJ01).

Table 13.6: Summary of results on the total radiation widths of the low-lying levels of ^{13}C–^{13}N [a]

$J^{\pi}_{\rm i} \rightarrow J^{\pi}_{\rm f}$	^{13}C* (MeV)	Γ_{γ} (eV)	Refs.	^{13}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	0.45 ± 0.05	(1968RI16)
$\frac{3}{2}^{-} \rightarrow \frac{1}{2}^{-}$	3.68 [c]	0.41 ± 0.04	Table 13.5	3.51 [f]	0.70	(1963YO06)
$\frac{5}{2}^{+} \rightarrow \frac{1}{2}^{-}$	3.85 [d]	$(5.3 \pm 0.2) \times 10^{-5}$ [e]	Table 13.5	3.55	$< 2 \times 10^{-3}$	(1963YO06)

[a] See also Tables 13.15 and 13.21.
[b] $E_{\rm x} = 3089.443 \pm 0.020$ keV, $E_{\gamma} = 3089.049 \pm 0.020$ keV* (1980WA24: here, and in footnote [d] measured values are starred (*); the others are derived).
[c] Branching ratio for cascade via ^{13}C*(3.09) is 0.75 ± 0.04% (1980WA24). See also (1975TR07). $E_{\rm x} = 3684.482 \pm 0.023$ keV, $E_{\gamma} = 3683.921 \pm 0.023$ keV. δ(E2/M1) $= -0.094 \pm 0.009$. E_{γ} for transition to ^{13}C*(3.09) is 595.013 ± 0.011 keV (1980WA24).
[d] Branching ratios for cascades via ^{13}C*(3.68, 3.09) are 36.3 ± 0.6% and 1.20 ± 0.04%, respectively (1980WA24). See also (1975TR07). $E_{\rm x} = 3853.783 \pm 0.022$ keV, $E_{\gamma} = 3853.170 \pm 0.022$ keV; E_{γ} for the tranisitions to ^{13}C*(3.09, 3.68) are 764.316 ± 0.010 keV* and 169.300 ± 0.004 keV* (1980WA24).
[e] The ground state branching ratio is 62.5 ± 0.6% (1980WA24) and δ(E3/M2) $= +0.12 \pm 0.03$ (1966PO11).
[f] Branching ratio for cascade via ^{13}N*(2.37) is 8 ± 1% (1974RO29). See also footnote [j] in Table 13.21.

2. ^{7}Li(^{7}Li, n)^{13}C $\qquad Q_{\rm m} = 18.620$

See (1978KA1H) and (1970AJ04).

3. ^{9}Be(α, γ)^{13}C $\qquad Q_{\rm m} = 10.6479$

See (1976AJ04).

4. (a) ^{9}Be(α, n)^{12}C $\qquad Q_{\rm m} = 5.7015 \qquad E_{\rm b} = 10.6479$
(b) ^{9}Be(α, 2n)^{11}C $\qquad Q_{\rm m} = -13.020$

Resonances for n_0 and n_1, for γ-rays from ^{12}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}C*(7.65, 9.64) has been measured in the range $E_{\alpha} = 2.9-6.4$ MeV (1972OB01). The n_0 and n_1 excitation functions exhibit weak resonance anomalies at $E_{\alpha} = 6.44$ MeV corresponding to the $J^{\pi} = \frac{3}{2}^{-}$, $T = \frac{3}{2}$ state at $E_{\rm x} = 15.11$ MeV: see Tables 13.7 and 13.8 (1978HI06). Based on all available information the charge asymmetry of the reduced transition strengths, $\delta \equiv B(^{13}{\rm C})/B(^{13}{\rm N}) - 1$, δ(M1) $= -0.15 \pm 0.07$ and δ(E2) $= 1.0 \pm 0.6$ (1978HI06).

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

	^{13}C*(15.11)	^{13}N*(15.06)
E_x (MeV)	15.1082 ± 0.0012	15.0646 ± 0.0009
J^π	$\frac{3}{2}^-$	$\frac{3}{2}^-$
Γ_{cm} (keV)	5.49 ± 0.25	0.932 ± 0.028
$\Gamma_{\gamma 0}$ (eV)	22.4 ± 1.5 (M1), 0.6 ± 0.1 (E2) [k]	24.2 ± 1.5 (M1) [e] 0.32 ± 0.12 (E2) [f]
Γ_{γ_1} (eV)	4.12 ± 0.74	$\leq 2.82 \pm 0.30$ [g]
$\Gamma_{\gamma_{2+3}}$ (eV)	18.2 ± 2.4	19.6 ± 1.4 [h]
$\Gamma_{\gamma 0}/\Gamma$(%)	0.396 ± 0.030 [b]	
$\Gamma_{p0}\Gamma_{\gamma 0}/\Gamma$ (eV)		5.79 ± 0.20
$\Gamma_{\gamma 0}/\Gamma_{p0}$ (%)		12.1 ± 1.1
Γ_{n_0} or Γ_{p_0} (keV) [c]	0.38 ± 0.10	0.228 ± 0.016 [i]
Γ_{n_1} or Γ_{p_1} (keV) [c]	1.43 ± 0.18	0.140 ± 0.014 [i]
Γ_{n_2} or Γ_{p_2} (keV) [c]	0.14 ± 0.10	0.049 ± 0.015 [i]
Γ_{p_3} (keV) [c]		0.089 ± 0.014 [i]
Γ_{p_5} (keV) [c]		0.15 ± 0.04 [i] [j]
Γ_{α_0} (keV) [d]	0.104 ± 0.028	0.046 ± 0.026 [i]
Γ_{α_1} (keV) [d]		0.036 ± 0.036 [i]
Γ_{α_2} (keV) [d]		0.067 ± 0.042 [i]

[a] (1973AD02, 1973HU07, 1975HI07, 1975MA21, 1977MA16, 1978HI06, 1979AD01, 1980TH05).
[b] The decay width to ^{13}C*(7.55) is < 0.9 eV (1977MA16).
[c] Widths for ^{13}C*(15.11) $\to$ ^{12}C$_{g.s.}$ + n$_0$ or ^{13}N*(15.06) $\to$ ^{12}C$_{g.s.}$ + p$_0$ [n$_1$, p$_1$; n$_2$, p$_2$; and p$_3$ and p$_5$ refer to the decays to ^{12}C*(4.4, 7.7, 9.6, 10.8) respectively].
[d] Widths for ^{13}C*(15.11) $\to$ ^{9}Be$_{g.s.}$ + α_0 or ^{13}N*(15.06) $\to$ ^{9}B$_{g.s.}$ + α_0 [α_1 and α_2 refer to the decays to ^{9}B*((1.6), 2.4)].
[e] $\delta = -0.07 \pm 0.13$ (1975MA21). Here $\delta \equiv B(^{13}\text{C})/B(^{13}\text{N}) - 1$.
[f] $\delta = 0.82^{+1.2}_{-0.6}$ (1975MA21).
[g] $\delta \geq 0.83 \pm 0.29$ (1975MA21).
[h] $\delta = -0.04 \pm 0.14$ (1975MA21).
[i] Based on measured branching ratios and on $\Gamma_{cm} = 0.932 \pm 0.028$ keV (1980TH05).
[j] The decay width to ^{12}C*(12.71) is < 0.13 keV. It is expected to be ≈ 0.03 keV. The sum of the branching ratios for all measured decays of ^{13}N*(15.06) is 92 ± 8%. It is apparent from the character of the decay modes of this state that 2s-1d shell isospin admixtures are important (1979AD01).
[k] See also (1979JU01).

Table 13.8: Resonances in ^{9}Be(α, n)^{12}C

E_α [a] (MeV)	E_α [b] (MeV)	E_α [c] (MeV)	Γ_{cm} (keV)	J^π	^{13}C* [d] (MeV)	Refs.
0.52	0.52		≈ 55 [e]	$(\frac{1}{2}^+)$	11.01	A
0.60	0.60		< 4 [c]		11.06	A
1.9	1.905	1.92	130	$(\frac{7}{2}^-)$	11.97	A
2.24		2.25	280		12.20	A
2.58	2.6	2.58	≈ 200	$(\frac{1}{2}^-)$	12.43	A
4.00	3.98	4.00	35 ± 3 [g]		13.41	A
4.18			570	$(\frac{3}{2}^+)$	13.54	A, (1973DE14)
4.50	4.47	4.50	≈ 350	$(\frac{5}{2}^+)$	13.76	A, (1973DE14)
5.0	5.02	5.0	≈ 200		14.12	A
5.40 ± 0.10	5.3 [f]		260	$(\frac{1}{2}^-, \frac{5}{2}^-)$	14.39 ± 0.1	A, (1973DE14)
	5.75	5.75	210		14.63	A
6.20 ± 0.05			380	$(\frac{3}{2}^+)$	14.94 ± 0.05	A, (1973DE14)
	6.44 [h]			$\frac{3}{2}^-; T = \frac{3}{2}$	15.109	(1978HI06)
7.10 ± 0.05	7.00		220		15.56 ± 0.05	A
	7.75	7.8	210		16.01	A
7.95 ± 0.05			230		16.15 ± 0.05	A
9.10 ± 0.05		9.1	330		16.95 ± 0.05	A
9.7 ± 0.10	9.70		190		17.36 ± 0.1	A
10.2 ± 0.05			170		17.71 ± 0.05	A
11.05 ± 0.05			300		18.30 ± 0.05	A
11.70 ± 0.03	11.60		70		18.75 ± 0.03	A

A: References for this resonance are displayed in Table 13.8 (1976AJ04).

[a] Resonances in total 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}C*(14.4) is composed of two states with the same J^π.

[g] J.L. Weil, private communication.

[h] Anomalies in n_0 and n_1 yields at $E_\alpha = 6443.5 \pm 2.0$ keV: see Table 13.7 for parameters of 15.11 MeV state (1978HI06).

Polarization measurements have been reported for E_α to 22.9 MeV (see (1976AJ04)) and also at $E_\alpha = 2.4$ and 2.8 MeV (1976NI01; n_0, n_1) and 100 MeV (1978LE10). Reaction (b) has been studied at a number of energies in the range $E_\alpha = 17$ to 44 MeV (1970KR09). See also (1975GE1J, 1976GE1A, 1977LI19).

5. (a) ^{9}Be(α, p)^{12}B $\quad Q_m = -6.886 \quad E_b = 10.6479$
(b) ^{9}Be(α, d)^{11}B $\quad Q_m = -8.0308$
(c) ^{9}Be(α, t)^{10}B $\quad Q_m = -13.229$

Excitation curves have been measured for $E_\alpha = 15$ to 25 MeV (1975VA19; d_0, d_1) and 26.5 to 27.5 MeV (1975PU01; $d_0 \rightarrow d_3$, d_{4+5}, d_6): no sharp structures are observed. See also ^{11}B in (1980AJ01). At $E_\alpha = 26.0$ to 27.5 MeV yield curves have been obtained for the t_0, t_1 and t_3 groups: no structure is observed (1974KE06). See also (1976LE1K) and (1968AJ02) for reaction (a).

6. ^{9}Be(α, α)^{9}Be $\quad E_b = 10.6479$

A number of exciation functions have been measured for elastically scattered α-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. The parameters resulting from a best-fit of the exciation functions are displayed in Table 13.9: see the footnotes to that table for a summary of the most important caveats (1973GO15). A weak resonance is observed in the α_0 yield at $E_\alpha = 6.44$ MeV corresponding to the excitation of the first $T = \frac{3}{2}$ state at $E_x = 15.11$: see Table 13.7 for the parameters of that state (1978HI06). See also (1974LO1B, 1979AJ01).

7. ^{9}Be(^{6}Li, d)^{13}C $\quad Q_m = 9.174$

At $E(^6\text{Li}) = 23.8$ MeV angular distributions are reported to ^{13}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}C*(9.5, 13.9, 14.5, 15.2, 16.7, 18.5) (1971GO24).

8. ^{9}Be(^{7}Li, t)^{13}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). See also (1976AJ04).

Table 13.9: Resonances in ^{9}Be(α, α_0) [a]

E_α (MeV)	$\Gamma_{\rm cm}$ (keV)	l_α	J^π	^{13}C* (MeV)
1.93 [b]	180 [b]	1, 0	$\frac{5}{2}^+$	11.98
3.80	343	0, 2	$\frac{3}{2}^-$ [c]	13.28
4.00	58	(4, 6)	$(\frac{9}{2}^-)$	13.42
4.20	685	1, 3	$\frac{5}{2}^+$ [d]	13.56
4.50	247	1, 3	$\frac{3}{2}^+$ [d]	13.76
5.00	75	2, 4	$\frac{5}{2}^-$ [e]	14.11
5.075	73	3, 5	$\frac{7}{2}^+$ [e]	14.162
(5.50)	400	(1, 3)	$(\frac{5}{2}^+)$	(14.46)
6.44	[f]		$\frac{3}{2}^-; T = \frac{3}{2}$	15.11

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

[b] This resonance is reported by (1974SA16). It is not clear whether the Γ is in the cm or lab systems. Γ_α is given as 72 keV.

[c] Favored by the analysis but the assignment is not certain and more than one state may be involved.

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

[e] 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.

[f] Weak anomaly at $E_\alpha = 6443.5 \pm 2.0$ keV: see Table 13.7 for parameters of 15.11 MeV state, and reaction 4 (1978HI06).

9. ^{9}Be(^{12}C, ^{8}Be)^{13}C $\qquad Q_{\rm m} = 3.2812$

Angular distributions have been measured at $E(^{12}{\rm C}) = 12$ and 15 MeV (1970BA49, 1971BA68) and $E(^{9}{\rm Be}) = 20$ MeV (1979JA1G, 1979BO1K) for the transitions to ^{13}C*(0, 3.09, 3.85) and in addition to ^{13}C*(3.68) in the latter experiment. The neutron spectroscopic factors are 1.15, 0.95, 0.20, 1.02 for the first four states of ^{13}C (1979JA1G). See also (1976AJ04). At $E(^{9}{\rm Be}) = 50$ MeV ^{13}C*(6.86, 7.5, 8.2, 9.5, 10.8) are also populated (1977ST20). For yield measurements [total cross sections, and transitions involving ^{13}C*(0, 3.09, 3.68, 3.85, 6.86, 7.5)], see (1977SW05, 1978CH02, 1978MA44, 1979BO06). See also (1977UH1A).

10. ^{9}Be(^{14}N, ^{10}B)^{13}C $\qquad Q_{\rm m} = -0.9653$

See (1970AJ04).

11. ^{10}Be(α, n)^{13}C $\qquad Q_m = 3.8361$

See (1976EP1A; astrophys.).

12. (a) ^{10}B(t, p)^{12}B $\qquad Q_m = 6.343$ $\qquad E_b = 23.8766$

(b) ^{10}B(t, d)^{11}B $\qquad Q_m = 5.1979$

(c) ^{10}B(t, α)^{9}Be $\qquad Q_m = 13.2287$

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). See also (1977ST1N; p_0, p_1, p_5, p_6) and (1977CI1A; $\alpha_0 \to \alpha_3$), both in the interval $E_t = 0.5$ to 1.25 MeV.

13. ^{10}B(α, p)^{13}C $\qquad Q_m = 4.0626$

Proton groups have been observed to the first four states of ^{13}C: see (1976AJ04). Angular distributions of p_0 have been measured at many energies up to $E_\alpha = 30.4$ MeV: see (1970AJ04) and ^{14}N. For $\tau_{1/2}$ measurements see Table 13.5 in (1976AJ04). For the decay of ^{13}C*(3.85) see Table 13.6 (1980WA24). See also (1976EP1A; astrophys.).

14. ^{10}B(^{6}Li, ^{3}He)^{13}C $\qquad Q_m = 8.083$

Comparisons of the relative intensities of the ^{3}He groups in this reaction and of the triton groups in the mirror reaction (see reaction 9 in ^{13}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}C, the second inn ^{13}N]. An angular distribution is also reported for ^{13}C*(9.50) and the widths for ^{13}C*(7.55, 7.69, 9.50) are determined to be < 30, 60 ± 30 and < 30 keV, respectively (1974HO06).

15. ^{10}B(^{7}Li, α)^{13}C $\qquad Q_m = 21.4099$

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).

16. ^{10}B(^{14}N, ^{11}C)^{13}C $\qquad Q_{\rm m} = 1.140$

At $E(^{10}{\rm B}) = 100$ MeV angular distributions are reported for the transitions to ^{13}C*(0, 3.68, 7.5, 11.8) (1975NA15, 1976NA09). See also (1979MO14).

17. ^{11}B(d, γ)^{13}C $\qquad Q_{\rm m} = 18.6787$

The $90°$ γ_0 excitation curve measured for $E_{\rm d} = 1.0$ to 4.2 MeV shows a resonance at $E_{\rm d} = 2.0 \pm 0.1$ MeV (^{13}C*(20.4)) with $\Gamma_{\rm lab} \approx 0.6$ MeV. The angular distributions of γ_0 are isotropic to within 10% on and off resonance, consistent with E1 radiation (1973WE12).

18. ^{11}B(d, n)^{12}C $\qquad Q_{\rm m} = 13.7323 \qquad E_{\rm b} = 18.6787$

The yield of neutrons and γ-rays has been measured for $E_{\rm d} = 0.2$ to 11 MeV: observed resonances are displayed in Table 13.10. For a listing of polarization measurements see Table 13.11 in (1976AJ04) and (1975SI22; $E_{\rm d} = 0.9$ and 1.2 MeV; n_0, n_1). See also (1974LO1B, 1977SE09) and ^{12}C in (1980AJ01).

19. ^{11}B(d, p)^{12}B $\qquad Q_{\rm m} = 1.145 \qquad E_{\rm b} = 18.6787$

Some measurements show that the thin-target yield rises smoothly from $E_{\rm d} = 0.3$ to 3.1 MeV with no evidence of resonances: 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. For polarization measurements see (1976AJ04) and (1976TA07; 1.0 to 4.0 MeV; p_0). See also (1974FI1D, 1976HA1J), (1977SA25; theor.) and ^{12}B in (1980AJ01).

20. ^{11}B(d, d)^{11}B $\qquad E_{\rm b} = 18.6787$

A polarization measurement has been reported at $E_{\rm d} = 12.6$ MeV (1971ZA04). See also ^{11}B in (1980AJ01).

21. (a) ^{11}B(d, t)^{10}B $\qquad Q_{\rm m} = -5.1979 \qquad E_{\rm b} = 18.6787$

(b) ^{11}B(d, ^{3}He)^{10}Be $\qquad Q_{\rm m} = -5.7352$

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

Resonant structure in yield of									Γ_{cm} (keV)	E_x (MeV)
γ_0 [a]	n_0 [b]	n_1 [b]	n_2 [b]	n_3 [b]	$\gamma_{15.1}$ [c]	p	$\gamma_{0.9}$, $\gamma_{1.7}$ [d]	α [e]		
(MeV ± keV)										
		1.2								19.7 [i]
	1.45					1.5 [g]			≈ 600	19.90
	1.6	1.8 [f]						1.85	≈ 200	20.24
2.0 ± 100										
		2.2 [f]			2.180 ± 10	2.2 [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): $\Gamma_{lab} \approx 600$ 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 α_0, α_1, α_2, α_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 $J^\pi = \frac{5}{2}^-$.

See (1976AJ04) and ^{10}B and ^{10}Be in (1979AJ01).

22. ^{11}B(d, α)^{9}Be $\qquad Q_m = 8.0308 \qquad E_b = 18.6787$

At low energies the excitation functions for α_0 and α_1 increase monotonically: see (1970AJ04). Then at $E_d = 1.85$ 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 $E_d = 1.0$ to 3.2 MeV (1964BR1A, 1969FR03). See also (1978GR07) and ^{9}Be in (1979AJ01).

23. ^{11}B(t, n)^{13}C $\qquad Q_m = 12.4214$

See ^{14}C.

24. ^{11}B(^{3}He, p)^{13}C $\qquad Q_m = 13.1851$

Levels derived from proton groups are displayed in Table 13.11. The decay parameters for the first $T = \frac{3}{2}$ state at $E_x = 15.11$ MeV are displayed in Table 13.7 (1973AD02, 1975MA21, 1977MA16). See also reactions 11 and 13 in ^{13}N. The reduced aymmetries $B(^{13}\text{C})/B(^{13}\text{N}) - 1$ are -0.07 ± 0.13, $0.82^{+1.2}_{-0.6}$, $\leq 0.83 \pm 0.29$ and -0.04 ± 0.14 for the γ_0(M1), γ_0(E2), γ_1(E1) and γ_2(M1) transitions. Changes in the wave functions due to binding energy differences in ^{13}C and ^{13}N do not account for the observed asymmetry of the E1 decays of the first excited states in ^{13}C and ^{13}N (1977MA16): see Table 13.6.

Angular distributions of proton groups have been measured at many energies to $E(^3\text{He}) = 12$ MeV: see (1970AJ04, 1976AJ04). See also (1979HA1M) and (1976EP1A; astrophys.).

25. ^{11}B(α, d)^{13}C $\qquad Q_m = -5.1680$

Angular distributions of the d_0 group have been measured at $E_\alpha = 15.1$ to 25.2 MeV (1975VA19) and 23 and 25 MeV (1968AL1C). See also (1976LE1K).

26. ^{11}B(^{6}Li, α)^{13}C $\qquad Q_m = 17.205$

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

27. ^{11}B(^{14}N, ^{12}C)^{13}C $\qquad Q_m = 8.4063$

Angular distributions involving the ground state transitions have been measured at $E(^{14}\text{N}) = 41$, 77 and 113 MeV (1971LI11). See also (1978DZ1A; theor.).

28. ^{11}B(^{16}O, ^{14}N)^{13}C $\qquad Q_m = -2.0576$

See (1976AJ04).

29. ^{12}C(n, γ)^{13}C $\qquad Q_m = 4.94639$

$Q_0 = 4946.32 \pm 0.05$ keV (1978HA14).

Table 13.11: Levels of ^{13}C from ^{11}B(^{3}He, p)^{13}C [a]

E_x (MeV $\pm$ keV)	$\Gamma_{c.m.}$ (keV)
0	
3.09	
3.68	< 5
3.85	< 5
6.871 ± 12 [b]	< 10
7.500 ± 12	< 5
7.554 ± 12	< 5
7.694 ± 14	70 ± 10
8.869 ± 36	150 ± 30
9.509 ± 12	< 10
9.896 ± 12 [c]	< 10
10.76 ± 10	
10.82 ± 10	
11.01 ± 10	
11.09 ± 10	
(11.72) [d]	
15.11 [e]	

[a] A number of higher states were reported in Table 13.7 of (1970AJ04): however, the references for these levels have not been published. References for the data shown here are displayed in Table 13.12 (1976AJ04).

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

[c] Branching ratios for neutron decay to ^{12}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).

[e] See Table 13.7 for the parameters of this state.

See also previous values listed in (1976AJ04) and (1974SP04, 1979GR1J [preliminary value 4946.329 ± 0.024 keV]). The thermal capture cross section is 3.4 ± 0.3 mb (1973MU14). The capture is 32 ± 1% via ^{13}C*(3.68) and 68 ± 1% to $^{13}C_{g.s.}$ (1968SP01). ^{13}C*(3.68) decays with $E_\gamma = 3684.28 \pm 0.14$ keV (1968SP01), 3683.94 ± 0.17 keV (1967PR10): see Table 13.13 in (1976AJ04) for other data. See also (1978AR1N), (1980DO1C; astrophys.) and (1977MA06; theor.).

30. (a) ^{12}C(n, n)^{12}C $E_b = 4.94639$
(b) ^{12}C(n, n′)^{12}C*
(c) ^{12}C(n, n′)^{4}He^{4}He^{4}He $Q_m = -7.2748$

The coherent scattering length (thermal, bound) $a_{coh} = 6.6535 \pm 0.0014$ fm; $\sigma_{scatt} = 4.7456 \pm 0.0020$ b (1979KO26). See (1978FU1G) for an R-matrix analysis of all the data below the inelastic channel and for best values of the elastic svattering cross sections.

Total cross section measurements in the range 1 keV to 273 GeV/c are listed in Table 13.14 of (1976AJ04) and displayed in (1976GAYV). Recent σ_t measurements are reported by (1979SM08; 0.1 to 4.5 MeV), (1979AU07; 1.2 to 13.9 MeV) and (1980CI03; 4.5 to 8 MeV). Cross sections for populating ^{12}C*(4.4) [by observing n_1 or 4.4 MeV γ-rays] have recently been reported by (1975RO30; $4.8 \to 20$ MeV), (1977DI1A; $5 \to 19$ MeV), (1978HA1P; $8.0 \to 14.5$ MeV; also n_0), (1978NO04; $8.1 \to 9.0$ MeV) and (1976GL11; $9 \to 15$ MeV; also n_0). For the earlier measurements see (1959AJ76, 1970AJ04, 1976AJ04, 1976GAYV).

Observed resonances are displayed in Tables 13.12 and 13.13. The parameters of the resonances with $E_n > 6.3$ MeV are poorly known.

Polarization measurements have recently been reported at 4.60, 4.82, 5.17 MeV (1979WE1D, 1979WE1E; n_0), 14.2 MeV (1976BR1J, 1976CA13; n_0, n_1) and 15.85 MeV (1976LE1M, 1976TH1B; n_0, n_1). For the earlier work see Table 13.15 in (1976AJ04). For reaction (c) see (1976CO1N) and ^{12}C in (1980AJ01). See also (1975BL07, 1976HA1N, 1976TO1C, 1978ME12, 1978SU1E, 1979BE50, 1979FI1B, 1979LA1D, 1979LA1J, 1979UR1A, 1980LA1D), (1975HO1F, 1976KI1F, 1976LI1H, 1976WA1B, 1976WA1C, 1977LA1H), (1977SM1D; applied) and (1976TH10, 1977PU02, 1978AD1A, 1978CA03, 1978MI1E, 1978MI04, 1979RO1E, 1980SH01; theor.).

31. ^{12}C(n, 2n)^{11}C $Q_m = -18.721$ $E_b = 4.94639$

See (1975AC1A) and (1976AJ04, 1976GAYV).

32. ^{12}C(n, p)^{12}B $Q_m = -12.587$ $E_b = 4.94639$

Table 13.12: Resonances in $^{12}C(n, n)^{12}C$ [a]

E_{res} (MeV ± keV)	Γ_{cm} (keV)	$^{13}C^*$ (MeV)	l_n	J^π	
		3.09	0	$\frac{1}{2}^+$	$\theta^2 = 0.185$ [b]
2.079 ± 3	6	6.864	2	$\frac{5}{2}^+$	[c]
2.819 ± 3	1.2 ± 0.3	7.547			
2.94 ± 10	124 ± 7 [d]	7.66	2	$\frac{3}{2}^+$	
3.472 ± 15	1000 ± 50 [d]	8.149	2	$\frac{3}{2}^+$	$\theta^2 = 0.35$ [c]
4.259 ± 15	210 ± 15 [d]	8.875	1	$\frac{1}{2}^-$	$\Gamma_{el}/\Gamma = 1.00$ [c]
4.93707 ± 0.07 [e]	1.9 ± 0.15 [e]	9.4998	1	$(\frac{1}{2}^-, \frac{3}{2}^-)$	1.00 [c]
5.368 ± 5	26 ± 3	9.897	1	$\frac{3}{2}^-$	0.70 ± 0.10 [c]
6.294 ± 5	53 ± 4	10.751	3	$\frac{7}{2}^-$	0.70 ± 0.10
6.5		10.9			
6.558 ± 8	37 ± 4	10.994	(0)	$(\frac{1}{2}^+)$	0.40 ± 0.10
6.7		11.1			
(7.4)	(250)	(11.8)		$(\geq \frac{5}{2})$	
7.759 ± 8	(200)	12.102		$(> \frac{7}{2})$	
(8.1)	(150)	(12.4)			
9.3	370	13.5			
11.1	450	15.2		$(\geq \frac{3}{2})$	
12.1	230	16.1			
15.8	≈ 460	19.5	1	$(\frac{1}{2}, \frac{3}{2})^-$	
19.6 ± 200	≈ 1000	23.0			

[a] See Tables 13.10 in (1970AJ04) and 13.16 in (1976AJ04) for references. See also (1973MU14).
[b] $\gamma_n^2 = 540$ keV, radius $= 4.80$ fm (1970ME1C: single bound state + hard sphere scattering).
[c] See also Table 1 in (1973DA17).
[d] Γ_n for $^{13}C^*$(7.69, 8.2, 8.86) are reported to be 170, 1110 and 170 keV, respectively (1980HO11; $^{13}C(\gamma, n_0)$).
[e] Derived from a lorentzian probability plot (1980CI03).

Table 13.13: Resonances in ^{12}C(n, n$'\gamma_{4.4}$)^{12}C [a]

E_n (MeV)	$\Gamma_{c.m.}$ (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).

The cross section exhibits a weak resonance corresponding to $E_x \approx 20.5$ MeV and a stronger structure at $E_x \approx 21.5$ MeV: see (1976AJ04). Polarization measurements are reported at $E_{\overline{n}} = 50$ MeV (1977FI1B). See also ^{12}B in (1980AJ01) and (1974BO1E, 1975NI1C, 1976GAYV, 1976SL2A, 1979RO1F).

33. (a) ^{12}C(n, d)^{11}B $\quad Q_m = -13.7323 \quad E_b = 4.94639$
(b) ^{12}C(n, t)^{10}B $\quad Q_m = -18.9302$

For reaction (a) see (1976AJ04). For reaction (b) see (1978QA01). For both see (1976GAYV, 1976SL2A).

34. ^{12}C(n, α)^{9}Be $\quad Q_m = -5.7015 \quad E_b = 4.94639$

The cross section for the α_0 group shows a broad structure at $E_n \approx 8$ MeV (1963DA12). See also (1978SU1D) and (1976AJ04, 1976GAYV, 1976SL2A).

35. ^{12}C(p, π^+)^{13}C $\qquad Q_m = -135.403$

At $E_p = 185$ MeV, angular distributions have been observed for the π^+ groups to the ground state of ^{13}C and to $E_x = 3.08 \pm 0.09$, 3.80 ± 0.12, 6.87 ± 0.18, 7.57 ± 0.16 and 9.51 ± 0.22 MeV. The shapes 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). Polarization measurements are reported at $E_{\overline{p}} = 200$ MeV to ^{13}C*(0, $3.09 + 3.68 + 3.85$) (1978AU07)[†] . See also (1979PI1E, 1979SO1C, 1979TS1B), (1975HU1D, 1976AJ04), (1976MI14, 1976NO1D, 1977KU1G, 1977LE1H, 1978WE1G, 1979CE1A; theor.) and the "*Pion capture and reactions*" section here.

36. (a) ^{12}C(d, p)^{13}C $\qquad Q_m = 2.7218$

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

Measurements of the proton groups are summarized in Table 13.14. Angular distributions have been studied at many energies to $E_d = 80.2$ MeV: see Table 13.19 in (1976AJ04) for a listing of earlier work and (1979OS11; $E_d = 1.58 \rightarrow 2.20$ MeV; p_1). Observed γ-rays are listed in Table 13.16 of (1970AJ04) and in Table 13.6 here: ground state decays have been observed for ^{13}C*(3.09, 3.68, 3.85). ^{13}C*(3.68) decays via ^{13}C*(3.09) with a 0.75 ± 0.04% branch (1980WA24). ^{13}C*(3.85) also decays via ^{13}C*(3.68) with a 36.0 ± 0.7% branch (1975TR07), 36.3 ± 0.6% (1980WA24) with $E_\gamma = 169.300 \pm 0.004$ keV (1980WA24) and via ^{13}C*(3.09) with a 1.20 ± 0.04% branch (1980WA24). Mixing ratios are given in (1970AJ04). Lifetimes of the first three excited states are displayed in Table 13.5: see (1976AJ04) and (1977HE1D, 1977HE12). The nuclear *g* factor of ^{13}C*(3.85) 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 (1966YO1A, 1976DY05, 1979SI07), (1976EP1A; astrophys.), (1977FI1A, 1978BO1L; applied), (1976HE17, 1976OS07, 1976SE1F, 1976SH13, 1976TA1D, 1977AN1G, 1977TA08, 1978HA1Q, 1979NE1B, 1979ZE1B; theor.) and ^{14}N.

37. ^{12}C(t, d)^{13}C $\qquad Q_m = -1.3109$

At $E_t = 12$ MeV angular distributions have been studied for the $d_0 \rightarrow d_3$ groups (1966GL01).

38. ^{12}C(^{3}He, 2p)^{13}C $\qquad Q_m = -2.7718$

[†] For cross section measurements near threshold see (1979MA38, 1979MA39).

Table 13.14: Levels of ^{13}C from ^{12}C(d, p)^{13}C

^{13}C (MeV ± keV)		$\Gamma_{\rm cm}$	l_n [b]	J^π [b]	S
(1955MC75)	(1973GO03, 1980WA24)	(keV)			
0			1	$\frac{1}{2}^-$	0.58 ± 0.04 [c]
					1.1 [d]
3.09	3.089443 ± 0.020 [g]		0	$\frac{1}{2}^+$	0.36 ± 0.02 [c]
					1.1 [d]
3.68	3.684482 ± 0.023 [g]		1	$\frac{3}{2}^-$	0.10 [d]
3.85	3.853783 ± 0.022 [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		70 ± 15			
8.4 ± 300	8.25 [f]	1100 ± 300	2	$\frac{3}{2}^+$	1.0 [d,e]
	8.86 [f]		1	$\frac{1}{2}^-$	0.5 [d,e]
9.500 ± 20			(1)	$(\frac{3}{2}^-)$	
9.897 ± 20			1	$\frac{3}{2}^-$	0.1 [d,e]
10.759 ± 20	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] May correspond to unresolved states.
[b] See (1970AJ04, 1973DA17).
[c] (1972PE11).
[d] (1973DA17) [HD parameters]. See also Table 13.14 in (1970AJ04).
[e] $\Gamma_{\rm d,p}/\Gamma_{\rm n} = 0.68$, 0.91 and 2.2 for ^{13}C*(8.2, 8.86, 9.90), respectively (1973DA17).
[f] Nominal energies (1973DA17).
[g] From E_γ measurements (1980WA24). See also (1975TR07).

The angular distributions for the transitions to ^{13}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.

39. ^{12}C(α, ^{3}He)^{13}C $\qquad Q_{\text{m}} = -15.6314$

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

40. ^{12}C(^{7}Li, ^{6}Li)^{13}C $\qquad Q_{\text{m}} = -2.304$

Angular distributions at $E(^7\text{Li}) = 48$ MeV to ^{13}C*(0, 3.09, 3.68, 3.85) have been analyzed and yield spectroscopic factors of 0.80, 0.44, 0.17 and 0.74 for the first four states of ^{13}C (1979ZE01). See (1973SC26) for earlier work at $E(^7\text{Li}) = 36$ MeV.

41. ^{12}C(^{11}B, ^{10}B)^{13}C $\qquad Q_{\text{m}} = -6.5088$

See (1974AN36) and (1976AJ04).

42. ^{12}C(^{12}C, ^{11}C)^{13}C $\qquad Q_{\text{m}} = -13.775$

Angular distributions at $E(^{12}\text{C}) = 93.8$ MeV have been measured for the transitions to ^{13}C*(0, 3.85) (1979FU04). See also (1979HE1E) and (1976AJ04).

43. ^{12}C(^{14}N, ^{13}N)^{13}C $\qquad Q_{\text{m}} = -5.607$

Angular distributions have been reported at $E(^{14}\text{N}) = 78$, 100 and 154.8 MeV involving ^{13}C*(0, 3.85) [and at 100 MeV ^{13}C*(3.09, 7.3 ± 0.3)]: see (1976AJ04) and (1976NA09). More recently angular distributions have been studied at $E(^{14}\text{N}) = 28$, 32, 34 and 36 MeV (1976BA16). 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}C(^{14}N, ^{13}C)^{13}N), as a function of θ is approximately 1 as expected if mirror symmetry holds (1969VO01, 1970VO02, 1975VO05). See also (1978MA1F) and (1977WE1H, 1978DZ1A, 1978NA15, 1978WE1F, 1979DO13; theor.).

44. ^{12}C(^{16}O, ^{15}O)^{13}C $\qquad Q_m = -10.7175$

Angular distributions are reported at $E(^{16}\mathrm{O}) = 128$ MeV to ^{13}C*(0, 3.85) (1979PR07).

45. (a) ^{12}C(^{17}O, ^{16}O)^{13}C $\qquad Q_m = 0.802$
(b) ^{12}C(^{18}O, ^{17}O)^{13}C $\qquad Q_m = -3.098$

Angular distributions have been studied at $E(^{17}\mathrm{O}) = 30.5$ and 33.8 MeV (to ^{13}C*(0, 3.09)) and at $E(^{18}\mathrm{O}) = 32.3$ and 35 MeV (to $^{13}\mathrm{C}_{\mathrm{g.s.}}$) (1978CH16).

46. ^{12}C(^{19}F, ^{18}F)^{13}C $\qquad Q_m = -5.4849$

See (1970AJ04).

47. ^{13}B(β^-)^{13}C $\qquad Q_m = 13.437$

See ^{13}B and Table 13.2.

48. ^{13}C(γ, γ)^{13}C

For τ_m studied by resonance scattering see Table 13.5.

49. (a) ^{13}C(γ, n)^{12}C $\qquad Q_m = -4.94639$
(b) ^{13}C(γ, 2n)^{11}C $\qquad Q_m = -23.668$

The main features of the cross section are a sharp peak corresponding to the $T = \frac{3}{2}$ state ^{13}C*(15.11) [$\Gamma_{\gamma_0} = 19.7 \pm 2.0$ eV], the broad pigmy resonance at $E_x = 13$ MeV [on which peaks are superimposed at $E_x = 11.0$, 13.8, 16.5 and 17.8 MeV] and the giant resonance at $E_x = 24$ MeV ($\sigma_{\max} = 9.5$ mb) [surrounded by shoulder resonances at $E_x = 20.8$ and ≈ 30 MeV, both of which appear to decay substantially to highly excited states of ^{12}C]. There is also some evidence for a weak resonance at ≈ 37 MeV superimposed on the high energy tail of the GDR (1979JU01: monoenergetic photons). A recent study of the angular distributions of n_0 suggests states at $E_x = 7.70$ $(\frac{3}{2}^+)$, 7.95 $(\frac{3}{2}^+)$, 8.95 $((\frac{1}{2}^-))$, 10.0 $((\frac{3}{2}^-))$, 11.0 $((\frac{1}{2}^+))$ and 12.05 MeV $((\frac{3}{2}^+))$ (1979WO06). Γ_n and Γ_{γ_0} deduced from (γ, n_0) measurements are displayed in Tables 13.12 and

Table 13.15: Electromagnetic transitions [a] in ^{13}C from ^{13}C(e, e′)^{13}C [b]

E_x (MeV ± keV)	J^π	Mult.	Γ_{γ_0} (eV)	$\Gamma_{\gamma_0}/\Gamma_W$ (W.u.)
3.08 ± 30 [g]	$\frac{1}{2}^+$	E1	0.68 ± 0.23	0.062
3.69 ± 20 [g]	$\frac{3}{2}^-$	E2	$(3.61 \pm 0.40) \times 10^{-3}$	3.52
3.85 [g]		M1	0.358 ± 0.047	0.339
6.85 ± 60 [g]	$\frac{5}{2}^+$	M2	$(6.9 \pm 3.6) \times 10^{-5}$	0.055
7.54 ± 20	$\frac{5}{2}^-$	M3	(1.01×10^{-5})	(35)
		E2	0.115 ± 0.007 [e]	3.15
8.86 ± 20 [d,g]	$\frac{1}{2}^-$	M1	3.36 ± 0.47 [f]	0.230
		E0	2.09 [c]	
9.90 ± 30	$\frac{3}{2}^-$	E2	$(6.3 \pm 1.1) \times 10^{-3}$	0.045
		M1	0.324 ± 0.038	0.0159
11.07 ± 20	$\frac{1}{2}^-$	M1	1.02 ± 0.12	0.0359
		E0	2.62 [c]	
	$\frac{3}{2}^-$	E2	0.256 ± 0.047	1.03
		M1	0.172 ± 0.020	0.006
15.11 ± 20	$\frac{3}{2}^-$	E2	0.6 ± 0.1	0.50
		M1	22.4 ± 1.5	0.31

[a] See also Tables 13.6, 13.7 and 13.16.

[b] (1969WI22, 1970WI04). (1978SO1B, 1979CR1B, 1979CR1C) also report the population of ^{13}C*(3.85, 9.50).

[c] Monopole matrix element in fm^2.

[d] $\Gamma = 190 \pm 35$ keV.

[e] 0.11 ± 0.015 eV (1980HO11; ^{13}C(γ, n)).

[f] 5.4 ± 0.5 eV (1980HO11); Γ_{γ_0} for ^{13}C*(7.69, 8.2) are reported to be 0.6 ± 0.1 and 7.0 ± 0.9 eV, respectively (1980HO11).

[g] Observed by (1980SO1B).

13.15 (1980HO11). For other differential cross section measurements derived from bremsstrahlung measurements see (1977WO04; n_0, 6.0 to 37 MeV; n_1, 10.5 to 35.5 MeV). For reports of other structures see (1976AJ04) and (1976KO22). See also (1977AL18; theor.). For reaction (b) see (1979JU01) and (1976AJ04). See also (1976BE1H, 1976CR1C), (1977DA1B, 1979BE1X) and (1977HO32, 1977MA06, 1979HO17, 1979JO1E; theor.).

50. ^{13}C(γ, p)^{12}B $\quad Q_{\rm m} = -17.533$

(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}B*(0.95) shows a broad maximum at $E_\gamma = 25$ MeV (1975PA09). See also (1977HO32, 1977MA06, 1979HO17; theor.).

51. ^{13}C(γ, α)^{9}Be $\quad Q_{\rm m} = -10.6479$

See (1970AJ04).

52. (a) ^{13}C(e, e$'$)^{13}C
(b) ^{13}C(e, ep)^{12}B $\quad Q_{\rm m} = -17.533$

The elastic scattering has been studied for $E_{\rm e} = 120$ to 750 MeV (1970HE24). A number of inelastic groups are seen: see Tables 13.15 and 13.16 (1970WI04, 1971BE51, 1980SO1B). A distinct splitting of the giant resonance into two large peaks near $E_{\rm x} = 20.5$ 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 13.16]. The $E_{\rm x} = 20.5$ 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 49 and 50. For radius measurements see (1976AJ04) and the "GENERAL" section here. See also (1977AL1H, 1977AL1J, 1979KI1J, 1979SE06, 1980ER01; theor.).

At $E_{\rm e} = 43$ MeV the energy and angular distributions of the protons emitted in reaction (b) suggest the involvement of ^{13}C*(21.8?, 24.2, 25.5, 27.5, 31.5) (1971SH09).

53. (a) ^{13}C(π^-, π^-)^{13}C
(b) ^{13}C(π^+, π^+)^{13}C

Table 13.16: States of ^{13}C from ^{13}C(e, e$'$)^{13}C* (1980SO1B) [a]

E_x (MeV ± keV)	Γ (keV)	E_x (MeV ± keV)	Γ (keV)
9.500 ± 7 [b]		18.699 ± 5	98 ± 11
11.845 ± 5	144 ± 5	20.021 ± 13	232 ± 27
12.187 ± 10	109 ± 48	20.429 ± 8	112 ± 23
12.438 ± 12	160 ± 37	21.466 ± 8	268 ± 14
14.390 ± 15	281 ± 65	22.2	1100
14.582 ± 10	227 ± 41	24.7	600
14.983 ± 10	380 ± 53	25.5	500
15.526 ± 11	147 ± 23	27.3	600
16.080 ± 7	148 ± 13	28.1	500
(16.183 ± 28)	(40 ± 20)	(29.4)	1200
(18.497 ± 10)	(91 ± 23)		

[a] $E_e = 165.8$, 221.5 and 276.8 MeV. See also Tables 13.4 and 13.15.
[b] Data are consistent with $J^\pi = \frac{9}{2}^+$.
[c] (1971BE34).

The elastic scattering of π^+ has been studied at $E_{\pi^+} = 48.6$ MeV by (1978DY01). At $E_\pi = 162$ MeV the inelastic transition to ^{13}C*(9.5) is very strongly enhanced in π^- scattering. The enhancement factor $\sigma(\pi^-)/\sigma(\pi^+) \approx 9$ is consistent with a pure neutron transition and a $\frac{9}{2}^+$ assignment. Also enhanced in π^- scattering (but less strongly) are ^{13}C*(0, 3.09, $3.68 + 3.85$), (7.49)). ^{13}C*(7.55) and a group of states close to 16 MeV are enhanced in π^+ scattering. The centroid of a group of states near 22 MeV is found in (π^-, $\pi^{-\prime}$) at a higher excitation energy than in (π^+, $\pi^{+\prime}$) (1979DE34). At $E_\pi = 180$ MeV angular distributions are reported for the transitions to ^{13}C*(0, 3.68, 7.55, 9.5, 11.7, 15.0, 17.5): the transitions to ^{13}C*(9.5) is enhanced by a factor of $4.0^{+2.0}_{-0.7}$ (1979SC25) in π^- scattering. Preliminary work is also reported for the inelastic scattering to ^{13}C*(16.1, 21.4) [large M4 strength] (1980TR1B). See also teh “GENERAL” section here.

54. ^{13}C(n, n)^{13}C

Angular distributions have been measured at $E_n = 1.6$ to 6.6 MeV for the n_0 group, and for the n_1, n_2 and n_3 groups at several energies in that range (1978LA1H, 1979KO1Q; abstracts). See also (1977NO07; theor.) and ^{14}C.

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

(b) ^{13}C(p, pn)^{12}C $\qquad Q_{\rm m} = -4.94639$

Angular distributions have been studied at $E_{\rm p} = 1.37$ to 30.4 MeV [see (1976AJ04)] and at $E_{\rm p} = 6$ MeV (1975DE26, 1977SA1B; $\rm p_0$, $\rm p_1$, $\rm p_3$), $E_{\overline{\rm p}} = 10.0$ to 17.5 MeV (1978WE13; $\rm p_0$), $E_{\rm p} = 35.2$ MeV (1980FA07; $\rm p_0$), 135 MeV (1980RI1A; to ^{13}C*(9.50)), 800 MeV (1978BL02; to ^{13}C*(0, 3.09, 3.68, 6.86, 7.55, 11.92 ± 0.06)) and 1 GeV (1979AL26; $\rm p_0$). The work of (1978BL02) suggests $J^\pi = (\frac{5}{2}, \frac{7}{2})^+$ for ^{13}C*(11.92). Inelastic scattering to ^{13}C*(21.3, 21.8), the former with $\Gamma \approx 0.3$ MeV [may be due to unresolved states] is observed at $E_{\rm p} = 135$ MeV (1980DE1L; prelim.). Microscopic analyses of the angular distribution to ^{13}C*(9.50) [$J^\pi = \frac{9}{2}^+$] show that the transition is an essentially pure $1{\rm p}_{3/2}$ to $1{\rm d}_{5/2}$ neutron transition with a total angular momentum transfer of 4, consistent with the results of the pion scattering (see reaction 53) (1980RI1A).

Reaction (b) has been studied at $E_{\rm p} = 7.9$ to 12 MeV (1971OT02: one or more of the ^{13}C states at 7.5 MeV seem to be involved) and at $E_{\rm p} = 46$ MeV (1974MI05). See also ^{14}N, (1977BA2G, 1978AL36) and (1977AM1C; theor.).

56. ^{13}C(d, d)^{13}C

Angular distributions have been measured at $E_{\rm d} = 0.71$ to 15 MeV [see (1976AJ04)] and at $E_{\overline{\rm d}} = 13$ MeV (1978DA17; $\rm d_0 \rightarrow d_3$) and $E_{\rm d} = 13.6$ MeV (1975ZA08; $\rm d_0$). See also ^{15}N and (1979DO03; theor.).

57. (a) ^{13}C(t, t)^{13}C

(b) ^{13}C(^{3}He, ^{3}He)^{13}C

For reaction (a) see (1980DE1M). Angular distributions of elastically scattered ^{3}He have been studied at $E(^3{\rm He}) = 12$ to 40 MeV [see (1976AJ04)], at 18, 20 and 24 MeV (1976MA26), at 20 MeV (1977PE23) and at 41 MeV (1980TR02). Angular distributions at $E(^3{\rm He}) = 40$ MeV have also been reported to ^{13}C states at $E_{\rm x} = 3.09$, 3.68, 3.85, 6.86, 7.55 ± 0.03, 8.86 ± 0.03 and 11.84 ± 0.03 MeV. ^{3}He groups to ^{13}C*(9.50 ± 0.03) and (15.11) are also reported: the latter is weak (1969BA06). At $E(^3{\rm He}) = 43.6$ MeV angular distributions to ^{13}C*(9.498) and to ^{13}N*(8.918) [$J^\pi = \frac{1}{2}^-$] (in the (^{3}He, t) reaction) are identical but the cross section in the latter reaction is 1.25 ± 0.15, rather than the factor of 2 expected from isospin symmetry (1980PE1E; prelim.). See also (1980DE1M) and (1977FU1G, 1977FU1H; theor.).

58. ^{13}C(α, α)^{13}C

Elastic angular distributions have been measured at $E_\alpha = 15$ to 40.5 MeV. In the range $E_\alpha = 24$ to 40.5 MeV angular distributions have been reported to ^{13}C*(3.09, $3.68 + 3.85$, 6.86, 7.5). At $E_\alpha = 22$ MeV, $E_x = 7686$ keV, $\Gamma_{cm} = 70 \pm 5$ keV (1980FU04; also line shapes). (1976WO11) report $S_\alpha = 0.67$ for $^{12}C_{g.s.}$. The excitation of ^{4}He*(20.1) [$J^\pi = 0^+$] has been studied at $E_\alpha = 65$ MeV (1976JA17). See also (1976PA25, 1977DM1A, 1977SA19, 1978ZE03; theor.).

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

Angular distributions of elastically scattered Li ions have been studied at E(Li) $= 4.5$ to 34 MeV [see (1976AJ04)], at $E(\overline{\text{Li}}) = 9$ MeV (1978DR07) and at $E(^6\text{Li}) = 40$ MeV (1979ZE01). See also (1971SC21) and (1976ST22, 1979SU1F; theor.).

60. ^{13}C(^{9}Be, ^{9}Be)^{13}C

The elastic scattering has been studied at $E(^{13}\text{C}) = 28.1$ and 36.2 MeV (1979JA04, 1979UN01).

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

Angular distributions for reaction (a) have been studied at $E(^{12}\text{C}) = 10$ to 87 MeV [see (1976AJ04)], 15 MeV (1980VO05; elastic, and to ^{13}C*(3.09, 3.85)), 20 to 35.5 MeV (1978CH29; elastic, and to ^{13}C*(3.09, $3.68 + 3.85$) from 30 MeV), 80 MeV (1979TA1E; elastic), and for the elastic scattering at $E(^{13}\text{C}) = 12$ MeV (1976WE28, 1977GU07) and 36 MeV (1976WE21). The spectroscopic factor for $^{13}C_{g.s.} = 0.81 \pm 0.04$ (1977GU07). For fusion studies see (1976ST12, 1979KO20). See also ^{12}C in (1980AJ01), (1978LE1N), (1977WI1C), (1978RO1D; astrophys.) and (1977TR1A, 1978AV1A, 1978CH30, 1978PA1B, 1978TA1B, 1979IM02, 1979GR20, 1979ZE1B; theor.).

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). For a fusion study see (1980CH01). See also (1978TE02, 1980SC1D; theor.).

62. ^{13}C(^{14}N, ^{14}N)^{13}C

The elastic angular distribution has been studied at $E(^{14}\text{N}) = 19.3$ MeV (1971VO01). See also (1976AJ04) and (1980WI09) for fusion measurements.

63. (a) ^{13}C(^{16}O, ^{16}O)^{13}C
(b) ^{13}C(^{17}O, ^{17}O)^{13}C
(c) ^{13}C(^{18}O, ^{18}O)^{13}C

Elastic angular distributions have been measured for reaction (a) at $E(^{16}\text{O}) = 10$ to 30 MeV [see (1976AJ04)] and 14 MeV (1976DU04), and at $E(^{13}\text{C}) = 36$ MeV (1976WE21) and 105 MeV (1979BR03). For fusion measurements see (1979CH07). Elastic scattering distributions in reaction (b) are reported at $E(^{17}\text{O}) = 29.8$ and 32.3 MeV (1977CH22, 1978CH03; see also ^{17}O in (1982AJ01)). For fusion syudies see (1980WI09). Elastic scattering in reaction (c) has been studied at $E(^{18}\text{O}) = 15$, 20 and 24 MeV (1971KN05) and 31 MeV (1978CH03). For a fusion study see (1978CO07). See also (1979GA1H) and (1978SC1E, 1979PA1B; theor.).

64. ^{13}C(^{24}Mg, ^{24}Mg)^{13}C

See (1979DU10).

65. ^{13}C(^{28}Si, ^{28}Si)^{13}C

Backward elastic angular distributions are reported at $E(^{28}\text{Si}) = 77.6$ to 94.6 MeV (1979OS01). See also (1975RA33, 1979DE1N).

66. ^{13}C(^{32}S, ^{32}S)^{13}C

See (1975RA33).

67. (a) ^{13}C(^{40}Ca, ^{40}Ca)^{13}C
(b) ^{13}C(^{48}Ca, ^{48}Ca)^{13}C

See (1978HO1C) and (1977FU1K, 1977UD1A, 1978BA26, 1978PE1E, 1979SA27; theor.).

68. ^{13}N(β^+)^{13}C $\qquad Q_m = 2.221$

See ^{13}N.

69. ^{14}C(p, d)^{13}C $\qquad Q_m = -5.9519$

Angular distributions have been measured at $E_p = 12$ to 18.5 MeV [see (1976AJ04)] and at 27 MeV (1975CE04; $d_0 \rightarrow d_3$). The spectroscopic factors for the first four states of ^{13}C are 1.4, 0.02, 1.8 and 0.13, repspectively (1975CE04).

70. ^{14}C(d, t)^{13}C $\qquad Q_m = -1.9192$

Angular distributions for $t_0 \rightarrow t_3$ have been studied at $E_d = 12$ MeV (1966GL01) and $E_{\overline{d}} = 14$ MeV (1976WE01). The spectroscopic factors for ^{13}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 (1982AJ01).

71. ^{14}C(^{3}He, α)^{13}C $\qquad Q_m = 12.4013$

Angular distributions have been measured at $E(^3\text{He}) = 3$ to 4.5 MeV (α_0, α_1) and 3 to 6.6 MeV (α_2, α_3) (1972KE08), at 6, 8 and 10 MeV (1971CO14; α_0) and 44.8 MeV (1966BA13; α_0, α_2 and α to ^{13}C*(15.11)). See also ^{17}O.

72. ^{14}C(^{11}B, ^{12}B)^{13}C $\qquad Q_m = -4.807$

See (1976AJ04).

73. ^{14}C(^{12}C, ^{13}C)^{13}C $\qquad Q_m = -3.2302$

See (1976AJ04).

74. ^{14}C(^{14}N, ^{13}C)^{15}N $\qquad Q_m = 2.6568$

See (1976AJ04).

75. ^{14}C(^{16}O, ^{17}O)^{13}C $\qquad Q_{\rm m} = -4.0322$

Angular distributions have been measured at $E(^{16}{\rm O}) = 20$, 25 and 30 MeV (1975SC35, 1975SC42): they are well described by DWBA (fixed range approximation). See also (1977GO1D, 1977WE1H; theor.).

76. ^{14}C(^{18}O, ^{19}O)^{13}C $\qquad Q_{\rm m} = -4.220$

See (1976AJ04).

77. (a) ^{14}N(γ, p)^{13}C $\qquad Q_{\rm m} = -7.5506$
(b) ^{14}N(γ, np)^{12}C $\qquad Q_{\rm m} = -12.4970$

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

78. ^{14}N(n, d)^{13}C $\qquad Q_{\rm m} = -5.3260$

Angular distributions of d_0 have been determined at $E_{\rm n} = 14.1$ to 14.7 MeV: see (1970AJ04). Differential cross sections for formation of ^{13}C*(3.09, 3.68) have been measured for $E_{\rm n} = 10.1$ to 11.0 MeV (1970DI1A). See also ^{15}N and (1976KI1D, 1978NE1B).

79. (a) ^{14}N(e, ep)^{13}C $\qquad Q_{\rm m} = -7.5506$
(b) ^{14}N(p, 2p)^{13}C $\qquad Q_{\rm m} = -7.5506$

For reaction (a) see (1969BA1F). At $E_{\rm p} = 46$ MeV, the summed proton spectrum shows transitions to ^{13}C*(0, 3.68, 7.5, 11.9) (1970WE09). See also (1976AJ04) and (1977KO1P, 1979MA20; theor.).

80. ^{14}N(d, ^{3}He)^{13}C $\qquad Q_{\rm m} = -2.0571$

At $E_d = 52$ MeV, angular distributions have been measured for the ^{3}He particles to ^{13}C*(0, 3.09, 3.68, 7.5, 8.86, 9.50, 11.9 ± 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}C*(7.5, 8.86, 9.50, 11.9) (1968HI01). As expected, angular distributions of ^{3}He and of tritons (from ^{14}N(d, t)^{13}N) to analog states are closely the same: this has been shown for the ground state ^{3}He and triton groups (1966DE1C, 1968GA13: $E_d = 28.5$ MeV; (1974LU06: $E_d = 15$ MeV) and for the groups to ^{13}C*($8.9 + 9.5$) and ^{13}N*(9.2) (1968HI01; $E_d = 52$ MeV). See also ^{16}O in (1982AJ01).

81. ^{14}N(t, α)^{13}C $\qquad Q_m = 12.2634$

Observed particle groups at $E_t = 2.6$ MeV are displayed in Table 13.22 of (1976AJ04). See also ^{16}O in (1977AJ02).

82. ^{14}N(α, αp)^{13}C $\qquad Q_m = -7.5506$

See ^{14}N.

83. ^{14}N(^{6}Li, ^{7}Be)^{13}C $\qquad Q_m = -1.944$

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}Be*(0, 0.43) [for the mirror reaction see reaction 40 in ^{13}N]: the relative cross sections show a deviation from isospin symmetry which is attributed to Coulomb effects. ^{13}C*(3.09) was also populated (1971GR44).

84. ^{14}N(^{14}N, ^{15}O)^{13}C $\qquad Q_m = -0.2536$

See (1976AJ04).

85. ^{15}N(γ, d)^{13}C $\qquad Q_m = -16.1594$

See (1979SK04) and ^{15}N.

86. ^{15}N(n, t)^{13}C $\qquad Q_m = -9.9020$

Table 13.17: Energy levels of ^{13}C from ^{15}N(p, ^{3}He)^{13}C (1968FL03)

E_x in ^{13}C (MeV ± keV)	J^π
0	$\frac{1}{2}^-$
3.08 ± 20	$\frac{1}{2}^+$
3.68 [a]	$\frac{3}{2}^-$
6.86 [a]	$\frac{5}{2}^+$
7.55 ± 20	$\frac{5}{2}^-$
8.86 ± 60	$\frac{1}{2}^-$
9.52 ± 30	$(\frac{3}{2}^-)$
11.09 ± 50	$(\frac{1}{2}^-)$
11.80 ± 30	$(\frac{3}{2}^-)$
12.40 ± 50	$\frac{7}{2}^-$
15.103 ± 45 [b]	$\frac{3}{2}^-$

[a] Observed but E_x not determined.
[b] (1966CE02): see Table 13.7.

See (1978BA1M) and ^{16}N in (1982AJ01).

87. ^{15}N(p, ^{3}He)^{13}C $\qquad Q_m = -10.6658$

At $E_p = 43.7$ MeV ^{3}He groups have been observed to eleven states of ^{13}C: see Table 13.17 (1966CE02, 1968FL03). For a summary of the analysis see (1976AJ04). 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; $E_{\vec{p}} = 43.8$ MeV). Angular distributions have also been measured for the ^{3}He groups to ^{13}C*(0, 3.68, 7.55) at several energies in the range $E_p = 24.0$ to 43.5 MeV (1974PI05, 1975MI01). See also ^{16}O in (1982AJ01).

88. ^{15}N(d, α)^{13}C $\qquad Q_m = 7.6874$

For α_0 angular distributions see (1970AJ04). ^{13}C*(3.09, 3.68, 8.80) are also populated: see (1976AJ04).

89. ^{15}N(α, ^{6}Li)^{13}C $\qquad Q_{\rm m} = -14.6859$

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

90. ^{15}N(^{11}B, ^{13}C)^{13}C $\qquad Q_{\rm m} = 2.5193$

See (1976AJ04).

91. ^{16}O(n, α)^{13}C $\qquad Q_{\rm m} = -2.2156$

Angular distributions have been measured for $E_{\rm n}$ to 18.8 MeV for α_0, α_1, α_{2+3}: see (1970AJ04, 1976AJ04). See also (1976NO1F, 1979SU1C).

92. ^{16}O(α, ^{7}Be)^{13}C $\qquad Q_{\rm m} = -21.207$

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

93. ^{16}O(^{14}N, ^{17}F)^{13}C $\qquad Q_{\rm m} = -6.9503$

This reaction has been studied at $E(^{14}{\rm N}) = 76$ and 79 MeV (1976MO03, 1977MO1A) and 155 MeV (1975NA15, 1976NA09). See also (1979MO14).

94. ^{16}O(^{17}O, ^{20}Ne)^{13}C $\qquad Q_{\rm m} = -1.629$

At $E(^{17}{\rm O}) = 35$ MeV angular distributions have been measured involving ^{13}C$_{\rm g.s.}$ and ^{20}Ne*(0, 1.63) (1977KA26).

95. (a) ^{17}O(d, ^{6}Li)^{13}C $\qquad Q_{\rm m} = -4.886$

(b) ^{18}O(d, ^{7}Li)^{13}C $\qquad Q_{\rm m} = -5.680$

See (1976AJ04).

96. ^{20}Ne(n, 2α)^{13}C $\qquad Q_{\rm m} = -6.9465$

See (1976AJ04).

^{13}N
(Figs. 3 and 4)

GENERAL: (See also (1976AJ04).)

Shell model: (1977TE01).

Collective, rotational and deformed models: (1976BR26, 1977ME1E).

Special levels: (1977ME1E, 1977RI08, 1977TE01, 1979RO1E, 1980BA54).

Electromagnetic transitions: (1977ME1E, 1977YO1D, 1978KR19, 1980BA54).

Applied work: (1975PA1F, 1977JO1C, 1977ME1D, 1977ST1M, 1978FI1F, 1978HI1D, 1978PE1F, 1978TI1A, 1978TI1B, 1978WI1F, 1978WO1C, 1979DE1H, 1979LI1G, 1979WI1G).

Special reactions: (1976AB04, 1976BE1K, 1976BU16, 1976LE1F, 1976MA62, 1977AR06, 1977AS03, 1977SC1G, 1978GE1C, 1978HE1C, 1979KA07, 1980MI01).

Astrophysical questions: (1976DE1G, 1977BA1V, 1977SI1D, 1979PE1E).

Pion capture and reactions (See also reaction 29.): (1975KA1G, 1976AU1E, 1976BU1D, 1976ED1A, 1976GA06, 1976GA21, 1976LI04, 1976NI05, 1976OS06, 1977AU01, 1977BA2H, 1977FU10, 1977LO19, 1977MA1M, 1977WA02, 1978WA02, 1979AL1R, 1979AL1J, 1979GI1D, 1979HI1A, 1979LA22, 1979MO1N, 1979MO1P, 1979MO1Q, 1979SA21, 1980BO03, 1980CH08, 1980LE02, 1980LI1E, 1980SA04).

Other topics: (1976BR26, 1978SH1B, 1979BE1H, 1979RO1E).

Ground state of ^{13}N: (1976BR26, 1976FU06, 1976JO1B, 1977YO1D).

$$\mu = -0.32224 \pm 0.00035 \text{ nm (1964BE24, 1978LEZA).}$$

1. ^{13}N(β^+)^{13}C $\qquad Q_m = 2.2206$

The weighted mean of the three measurements of $\tau_{1/2} = 9.965 \pm 0.005$ min (1960JA12), 9.963 ± 0.009 min (1968RI15) and 9.965 ± 0.010 min (1977AZ01) is 9.965 ± 0.004 min. See also Table 13.22 of (1970AJ04). The decay is entirely to $^{13}C_{g.s.}$: $\log ft = 3.667 \pm 0.001$ from the tables of (1971GO40). The positrons are completely polarized: see (1970AJ04). See also (1978MA1P), (1976AJ04, 1977BA48, 1978RA2A), (1979DA1D; astrophys.) and (1977AZ02, 1977RI08, 1977YO1E, 1979DE15; theor.).

2. ^{10}B(^{3}He, γ)^{13}N $\qquad Q_m = 21.637$

Table 13.18: Energy levels of ^{13}N

E_x (MeV ± keV)	$J^\pi; T$	Γ_{cm} (keV)	Decay	Reactions
g.s.	$\frac{1}{2}^-; \frac{1}{2}$	$\tau_{1/2} = 9.965 \pm 0.004$ min	β^+	1, 2, 8, 10, 11, 12, 13, 19, 20, 21, 22, 24, 25, 26, 27, 28, 29, 30, 31, 32, 34, 35, 36, 37, 38, 39, 40, 42, 43, 44, 45, 46, 47, 48, 49, 51
2.3648 ± 1.1	$\frac{1}{2}^+$	$\Gamma_{cm} = 33.7 \pm 0.9$	γ, p	8, 11, 13, 19, 20, 27, 30, 31, 37, 39, 40, 46
3.511 ± 2	$\frac{3}{2}^-$	62 ± 4	γ, p	2, 8, 10, 11, 13, 19, 20, 22, 25, 30, 31, 32, 34, 37, 38, 39, 44, 46
3.547 ± 4	$\frac{5}{2}^+$	47 ± 7	p	2, 8, 10, 11, 14, 19, 20, 22, 25, 27, 30, 31, 32, 37, 39, 44
6.364 ± 9	$\frac{5}{2}^+$	11	p	9, 11, 14, 20, 31, 39, 44
6.886 ± 8	$\frac{3}{2}^+$	115 ± 5	p	9, 11, 14, 20, 39
7.155 ± 5	$\frac{7}{2}^+$	9 ± 0.5	p	9, 11, 14, 20, 31, 39
7.376 ± 9	$\frac{5}{2}^-$	75 ± 5	p	9, 10, 11, 14, 20, 31, 34, 37, 38, 39, 44
7.9	$\frac{3}{2}^+$	≈ 1500	p	14, 20, 39
8.918 ± 11	$\frac{1}{2}^-$	230	p	11, 14, 31, 34, 37, 38, 39, 44
9.00	$(\frac{9}{2}^+)$	280 ± 30		9, 38
9.476 ± 8	$\frac{3}{2}^-$	30	p	9, 11, 14, 31, 34, 38
10.25 ± 150	$(\frac{1}{2}^+)$	≈ 280	γ, p	13
10.36	$\frac{5}{2}^-$	30	p	9, 11, 14, 20, 34
10.36	$\frac{7}{2}^-$	76	p	9, 14, 20
10.833 ± 9	$(\frac{1}{2}^-)$			9, 11, 31, 44
11.530 ± 12	$\frac{5}{2}^+$	430 ± 35	p	9, 11, 14
11.70 ± 30	$\frac{5}{2}^-$	115 ± 30	p	14
11.74 ± 40	$\frac{3}{2}^+$	240 ± 30	γ, p	13, 14
11.74 ± 50	$\frac{3}{2}^-$	530 ± 80	p	14
11.878 ± 12	$(\frac{3}{2}^-)$	380 ± 50	p	10, 11, 14, 31, 37, 38, 39, 44
12.13 ± 50	$\frac{7}{2}^-$	250 ± 30	p	14, 20, 46
12.558 ± 23		> 400		11
12.937 ± 24		> 400		11
13.5 ± 200	$\frac{3}{2}^+$	≈ 6500	γ, p	13, 14
14.05 ± 20	$\frac{3}{2}^+; \frac{1}{2}$	165 ± 20	γ, p, α	13, 14, 17
15.0645 ± 1.0 [a]	$\frac{3}{2}^-; \frac{3}{2}$	0.86 ± 0.12	γ, p, α	11, 13, 14, 17, 31, 44

Table 13.18: Energy levels of ^{13}N (continued)

E_x (MeV ± keV)	$J^\pi; T$	Γ_{cm} (keV)	Decay	Reactions
15.3 ± 200	$(\frac{3}{2}^+)$	350 ± 150	γ, p	13
15.99 ± 30	$\frac{7}{2}^+; \frac{1}{2}$	135 ± 90	p, α	14, 17, 31
16.0		≈ 500	p	14
17.5			γ, p	13, 14
18.15 ± 30	$\frac{3}{2}^+; \frac{1}{2}$	320 ± 80	p	14
18.17 ± 20	$\frac{1}{2}^-; \frac{1}{2}$	225 ± 50	p, α	14, 17
18.406 ± 5	$\frac{3}{2}^+; \frac{3}{2}$	66 ± 8	p, α	11, 14, 17
18.961 ± 10	$\frac{3}{2}^-$ or $\frac{7}{2}^+; \frac{3}{2}$	23 ± 5	p, α	11, 14, 17
19.83	$\frac{5}{2}^-; \frac{1}{2}$	1000	p, α	14, 17
19.88	$\frac{7}{2}^+; \frac{1}{2}$	750	p	14
20.2	$\frac{5}{2}^-$	1000	p	14
20.9 ± 300	$\frac{1}{2}^+$	1200	γ, p	13, 14
21.4	$\frac{5}{2}^-$	750	p	14
21.7	$\frac{3}{2}^+$		p	14
22.4 ± 500	$\frac{1}{2}^+$		p	14
23			γ, p	13
23.3		400	p, ^{3}He	4
23.83 ± 50		350 ± 50	p, ^{3}He	4, 13
24.4		700	p, ^{3}He	4, 13, 14
(24.6)		120	p, ^{3}He	4
25.6 ± 100	$(\frac{3}{2})^-$	240 ± 80	p, ^{3}He	4, 14
25.9		1000	(n), p, d, ^{3}He, α	3, 4, 7, 14
26.84			p	14
28			(γ), p, ^{3}He, (α)	2, 4, 7
(31)			p	14
32		≈ 2000	γ, d, ^{3}He, α	2, 5, 7, 13

[a] See also Table 13.7.

The $90°$ cross sections for γ_0 and γ_{2+3} have been measured for $E(^3\text{He}) = 4.8$ to 14 MeV: no pronounced structures are observed (1972BE05). See also (1976AJ04) and (1974LO1B).

3. ^{10}B(^{3}He, n)^{12}N $\quad Q_m = 1.574 \quad E_b = 21.637$

Activation cross sections have been reported for $E(^3\text{He}) = 1$ to 30.6 MeV: there is some evidence of broad structures. See (1976AJ04), (1974LO1B) and ^{12}N in (1980AJ01).

Table 13.19: Structure in $^{10}B + ^{3}He$

E_{res} (MeV ± keV)	Γ (keV)	Res. in	$^{13}N^*$ (MeV)	Refs.
2.1 [a]	500	p_0, (p_1)	23.3	(1956SC01, 1966PA10)
2.85 ± 50	450 ± 50	$\gamma_{15.1}$	23.83	(1964KU09)
3.6 [a]	700	p_0, p_1	24.4	(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 [b]	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, α_0	25.9	(1965PA05, 1972BE05, 1972BE56)
8.5	[e]	(γ_0), p_0, $\gamma_{12.7}$, $\gamma_{15.1}$, (α_0)	28	(1972BE05, 1972BE56)
13.5 [c]	≈ 2000	(γ_0), d_{4+5}, α_1	32	(1972BE05, 1972BE56)

[a] See, however, (1964KU09).
[b] See, however, (1966BA01, 1966PA10).
[c] This may correspond to more than one state (1972BE56).
[d] $J \geq \frac{3}{2}$ (1965PA10, 1966PA10).
[e] $J \geq \frac{7}{2}$ (1966PA10).

4. $^{10}B(^{3}He, p)^{12}C$ $Q_m = 19.6940$ $E_b = 21.637$

Observed resonances in the yields of proton groups and of 12.7 and 15.1 MeV γ-rays are displayed in Table 13.19. For polarization measurements see (1970AJ04) and (1976LA1F). See also (1974LO1B) and ^{12}C in (1980AJ01).

5. $^{10}B(^{3}He, d)^{11}C$ $Q_m = 3.197$ $E_b = 21.637$

Activation cross sections (1976GA27) and excitation functions have been measured for $E(^{3}He) =$ 1 to 19 MeV: for resonances see Table 13.19. See also (1974LO1B) and ^{11}C in (1980AJ01).

6. (a) $^{10}B(^{3}He, t)^{10}C$ $Q_m = -3.670$ $E_b = 21.637$
(b) $^{10}B(^{3}He, ^{3}He)^{10}B$

See (1976AJ04) and ^{10}B and ^{10}C in (1979AJ01).

7. ^{10}B(^{3}He, α)^{9}B $\qquad Q_m = 12.142 \qquad E_b = 21.637$

Excitation functions for α_0 and α_1 have been measured for $E(^3\text{He}) = 2$ to 19 MeV. Observed resonances are displayed in Table 13.19. See also (1974LO1B) and ^{9}B in (1979AJ01).

8. ^{10}B(α, n)^{13}N $\qquad Q_m = 1.060$

Angular distributions have been measured for $E_\alpha = 1.5$ to 4.6 MeV (n_0) and ≈ 4.6 MeV (n_1, n_{2+3}) (1973VA25), and at 18.0, 19.0 and 20.2 MeV (1976DU08; n_0, n_1). See also ^{14}N and (1976EP1A; astrophys.).

9. ^{10}B(^{6}Li, t)^{13}N $\qquad Q_m = 5.843$

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}N*(7.9, 8.92). In addition, evidence is presented for a ^{13}N state at $E_x = 9.00$ MeV with $\Gamma_{cm} = 280 \pm 30$ keV: it is very strongly excited and its angular distribution is similar to that for ^{13}C*(9.50) in the mirror reaction (^{6}Li, ^{3}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 14 of ^{13}C. The widths of ^{13}N*(6.89, 7.38) are, respectively, 120 ± 30 and 70 ± 30 keV (1974HO06). See also (1970AJ04).

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

At $E(^{10}\text{B}) = 100$ MeV, angular distributions are reported for the transitions to ^{13}N*(0, 3.5, 7.4, 11.9) (1975NA15). See also (1976NA09, 1977MO1A) and (1976AJ04).

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

Neutron groups have been observed to a number of states of ^{13}N: see Table 13.20. The parameters of the first $T = \frac{3}{2}$ state at $E_x = 15.06$ MeV are displayed in Table 13.7 where they are compared with the corresponding quantities for ^{13}C*(15.11) (1973AD02, 1975MA21, 1977MA16, 1979AD01). Angular distributions for n_0 have recently been reported at $E(^3\text{He}) = 1.70$ and 1.90 MeV (1979OS10) and 5.2 to 12 MeV (1977DA18). See also ^{14}N and (1977OS08; theor.).

12. ^{11}B(^{11}B, ^{9}Li)^{13}N $\qquad Q_m = -12.965$

Table 13.20: States of ^{13}N from ^{11}B(^{3}He, n)^{13}N

E_x [a] (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	L [a]	J^{π} [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 ± 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 13.21: Resonances in ^{12}C(p, γ)^{13}N [a]

E_p (MeV ± keV)	Γ_{cm} (keV)	Γ_{γ_0} (eV)	^{13}N* (MeV)	Res. in yield of	J^π	Refs.
0.4568 ± 0.5	33.7 ± 0.9 [b]	0.45 ± 0.05 [c]	2.3648 ± 0.0011	γ_0	$\frac{1}{2}^+$	[a]
1.699 ± 2	62 ± 4	0.64 [j]	3.511	γ_0	$\frac{3}{2}^-$	[a], (1974RO29)
9.01 ± 150	≈ 280	[d]	10.25	γ_0	$(\frac{1}{2}^+)$	(1976BE28)
10.62 ± 120	200 ± 50	≈ 4.2 [e]	11.74	γ_0	$\frac{3}{2}^+$	(1973ME12)
12.5 ± 200	6500	≥ 1100	13.5	γ_0	$\frac{3}{2}^+$	(1973ME12)
13.12 ± 90	160 ± 20	3.7 ± 1.0 [f]	14.04	γ_0	$\frac{3}{2}^+$	(1973ME12)
14.2	[see Table 13.7]		15.0	γ_0, γ_{2+3}	$\frac{3}{2}^-; T = \frac{3}{2}$	(1968DI04, 1975MA21, 1977MA16)
14.5 ± 200 [g]	350 ± 140	≥ 0.5	15.3	γ_1	$(\frac{3}{2}^+)$	(1973ME12)
16.9			17.5	γ_0		(1976BE28)
20 [h]			20	γ_1, γ_{2+3}		(1976BE28)
20.5 [i]	≈ 3700		20.8	γ_0		(1963FI07, 1976BE28, 1976FE1C)
23			23	γ_0		(1976BE28)
24.5			24.5	γ_{2+3}		(1963FI07)
32.5	broad		31.9	γ_0, γ_{2+3}		(1963FI07, 1976FE1C)

[a] See also Table 13.26 in (1976AJ04) and (1980BA54; theor.).
[b] Weighted mean of values from (1968RI16, 1974BL06).
[c] (1968RI16).
[d] See (1973ME12).
[e] A value of 0.30 ± 0.05 is assumed for Γ_{p_0}/Γ: see Table 13.22.
[f] A value of 126 keV is taken for Γ_{p_0} (1969LE18).
[g] This peak may be due to an unresolved doublet.
[h] Giant resonance for γ_1.
[i] Main dipole strength is concentrated in this peak (1976BE28).
[j] Recalculated on basis of total $\Gamma_{lab} = 67 \pm 4$ keV. I am indebted to Prof. F.C. Barker for his comments [see (1980BA54)].

See (1974AN36).

13. (a) ^{12}C(p, γ)^{13}N $\qquad Q_m = 1.9434$

(b) ^{12}C(p, γp$'$)^{12}C

$Q_0 = 1943.31 \pm 0.32$ keV (1977FR20);
$Q_0 = 1944.01 \pm 0.22$ keV (1977HE26).

Resonances for capture radiation are displayed in Table 13.21. No resonance is observed at $E_p = 1.73$ MeV [^{13}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 first two resonances, direct radiative capture is observed. 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}N*(2.36). The cascade decay ^{13}N*($3.51 \rightarrow 2.36$) has an intensity of 8 ± 1% (1974RO29). Extrapolating the cross section to $E_{cm} = 25$ keV yields a cross section factor $S = 1.45 \pm 0.20$ keV · b (1974RO29). A reanalysis of the data by (1980BA54) suggests $S = 1.54^{+0.15}_{-0.10}$ keV · b. For other discussions of astrophysical questions see (1976AJ04) and (1975ZI1A, 1976BR1H, 1976RO1Q).

At $E_p = 14.2$ MeV, capture radiation from the first $T = \frac{3}{2}$ state, ^{12}N*(15.06), is reported: see Table 13.7 for the parameters and the decay modes of this state (1968DI04, 1975MA21, 1977MA16). The angular distributions of the γ-rays determine $J = \frac{3}{2}$ for ^{13}N*(15.06) (1968DI04).

Exciation functions for γ-rays have also been measured at $E_p = 8.7$ to 24.4 MeV (γ_0) and 19.9 to 24.4 MeV (γ_1, γ_{2+3}) (1976BE28) and at 16 to 37 MeV (γ_0) and 23 to 37 MeV (γ_{2+3}) (1976FE1C). Angular distributions of γ_0 are reported for $16.5 < E_p < 27.0$ MeV by (1980WO1A; prelim.). At $E_p = 40$ to 100 MeV most of the γ strength is due to transitions to ^{13}N*(3.5), probably to ^{13}N*(3.55) [$J^\pi = \frac{5}{2}^+$] because of its single particle character. Transitions to higher states may also be indicated (1979KO05, 1979AR1G). Differential cross sections for the transitions to the ground state have been measured for $E_{\overline{p}} = 10$ to 17 MeV. The total E2 capture cross section are ≈ 0.2 μb and no resonance effects are observed. The E2 energy-weighted sum rule depleted over this energy range is (8.5 ± 3.3)% (1980HE04). The interference between the M1(E2) $T = \frac{3}{2}$ resonance (^{13}N*(15.06)) and the E1 GDR has been studied by (1980SN01): the E1 capture is found to be predominantly d-wave (1980SN01). At $E_{\overline{p}} = 28.5$ MeV, the capture is dominated by γ_{2+3} but γ_0 and a transition to ^{13}N*(8.1) are also observed (1980BL1B).

See also reaction 14, (1976AJ04), (1976TS1B, 1977TS1A, 1979BL1F), (1974LO1B, 1979SN1A), (1977YO1F, 1978GO1F, 1979RO1C; applications) and (1977AL18, 1977BA29, 1979JO1E; theor.).

14. (a) ^{12}C(p, p)^{12}C $\qquad E_b = 1.9434$

(b) ^{12}C(p, 2p)^{11}B $\qquad Q_m = -15.9569$

(c) ^{12}C(p, pα)^{8}Be $\qquad Q_m = -7.3667$

(d) ^{12}C(p, 3p)^{10}Be $\qquad Q_m = -27.1857$

(e) ^{12}C(p, π^+)^{13}C $\qquad Q_m = -135.403$

Table 13.22: ^{13}N levels from ^{12}C(p, p), ^{12}C(p, p′) and ^{12}C(p, α) [a]

E_p (MeV $\pm$ keV)	^{13}N* (MeV)	Γ_{cm} (keV)	l_p	J^π		Refs.
					[d]	
0.461 ± 3	2.369 [b]	31 [b]	0	$\frac{1}{2}^+$	$\theta^2 = 0.54$	A, (1979KR18)
1.686 ± 6	3.499 [b,c]	63 [b]	1	$\frac{3}{2}^-$	0.031	A
1.734 ± 6	3.543 [b,c]	74 [b]	2	$\frac{5}{2}^+$	0.21	A
4.808 ± 10	6.378	11	2	$\frac{5}{2}^+$	0.0031	A
5.370 ± 10	6.896	115 ± 5	2	$\frac{3}{2}^+$	0.13	A
5.65 ± 10	7.155	9 ± 0.5	4	$\frac{7}{2}^+$	0.016	A
5.891	7.38	75 ± 5	3	$\frac{5}{2}^-$	0.069	A
6.5	7.9	≈ 1500	2	$\frac{3}{2}^+$	0.14	A
7.54	8.90	230	1	$\frac{1}{2}^-$	0.02	A
8.18	9.49	30	1	$\frac{3}{2}^-$	0.001	A
9.13	10.36	30	3	$\frac{5}{2}^-$		A
9.13	10.36	76	3	$\frac{7}{2}^-$		A
					$\Gamma_p/\Gamma =$	
10.35 ± 50	11.49	430 ± 35	2	$\frac{5}{2}^+$	0.70 ± 0.05	A
10.58 ± 30	11.70	115 ± 30	3	$\frac{5}{2}^-$	0.60 ± 0.04	A
10.62 ± 40	11.74	250 ± 30	2	$\frac{3}{2}^+$	0.30 ± 0.05	A
10.62 ± 50	11.74	530 ± 80	1	$\frac{3}{2}^-$	0.55 ± 0.05	A
10.75 ± 40	11.86	380 ± 50	0	$\frac{1}{2}^+$	0.35 ± 0.05	A
11.05 ± 50	12.13	250 ± 30	3	$\frac{7}{2}^-$	0.30 ± 0.05	(1973ME03)
12.5	13.5	≈ 500				(1961NA02)
13.13 ± 20	14.05	180 ± 35	2	$\frac{3}{2}^+; T = \frac{1}{2}$	0.29 ± 0.07	(1976ME18, 1969LE18)

Table 13.22: ^{13}N levels from ^{12}C(p, p), ^{12}C(p, p′) and ^{12}C(p, α) [a] (continued)

E_p (MeV ± keV)	^{13}N* (MeV)	Γ_{cm} (keV)	l_p	J^π		Refs.
[a]						
14.23075 ± 0.2	15.06447 [e]	0.932 ± 0.028 [l]	1	$\frac{3}{2}^-; T = \frac{3}{2}$		A, Table 13.7, (1980TH05)
15.24 ± 40 [f]	15.99	135 ± 90	4	$\frac{7}{2}^+; T = \frac{1}{2}$	0.05 ± 0.04	(1976ME18, 1969LE18)
15.2	16.0	≈ 500				A
16.8	17.4				[f]	(1976BE28)
17.58 ± 30	18.15	322 ± 75	2	$\frac{3}{2}^+; T = \frac{1}{2}$	0.08 ± 0.02	(1976ME18)
17.60 ± 20	18.17	225 ± 50	1	$\frac{1}{2}^-; T = \frac{1}{2}$	0.24 ± 0.06	(1976ME18, 1969LE18)
17.857 ± 5	18.406	66 ± 8	2	$\frac{3}{2}^+; T = \frac{3}{2}$	[g]	A, (1976BE28, 1969LE18)
[a]						
18.460 ± 10	18.961	23 ± 5		$\frac{3}{2}^-$ or $\frac{7}{2}^+; T = \frac{3}{2}$	[g]	A, (1976BE28, 1969LE18)
[a]						
19.40 [j]	19.83	1000	3	$\frac{5}{2}^-; T = \frac{1}{2}$		A, (1969LE18)
19.46	19.88	750	4	$\frac{7}{2}^+; T = \frac{1}{2}$		A, (1979GA13)
19.8	20.2	1000		$\frac{5}{2}^-$	[g]	(1976BE28, 1979GA13)
20.6 ± 300	20.9	1200		$\frac{1}{2}^+$	[f,g]	(1973ME12, 1976BE28, 1979GA13) [i]
21.1	21.4	750		$\frac{5}{2}^-$		(1979GA13)
21.4	21.7			$\frac{3}{2}^+$		A, (1979GA13)
22.2 ± 500	22.4	≈ 1000		$\frac{1}{2}^+$		A, (1979GA13)
[k]						
24.0	24.1	$\lesssim 500$				A
25.7	25.6			$(\frac{3}{2})^-$		A
27.02	26.84					A

Table 13.22: ^{13}N levels from ^{12}C(p, p), ^{12}C(p, p′) and ^{12}C(p, α) [a] (continued)

E_p (MeV $\pm$ keV)	^{13}N* (MeV)	Γ_{cm} (keV)	l_p	J^π		Refs.
32	31				[j]	(1976FE1C)

A: See references listed in Table 13.27 in (1976AJ04).

[a] See also Tables 13.25 in (1970AJ04) and 13.27 in (1976AJ04).

[b] An R-matrix analysis by (1976ME22) leads to $E_x = 2.367$, 3.501 and 3.547 MeV, and $\Gamma_{cm} = 33$, 55 and 50 keV for these states. (1976ME22) also find that $^{13}N_{g.s.}$ has an appreciable effect on the low energy scattering.

[c] See also (1976MA55).

[d] A dispersion analysis leads to a spectroscopic factor of 0.53 ± 0.08 for $^{13}N_{g.s.}$ (1977ME05).

[e] See also (1976IK01).

[f] Resonance in yield of 12.7 MeV γ-rays (1976BE28).

[g] Reosnance in yield of 15.1 MeV γ-rays (1976BE28).

[h] See however (1976BE28).

[i] See also (1976FE1C).

[j] Resoance in yield of 4.4 MeV γ-rays (1976FE1C).

[k] A $\frac{3}{2}^+$ state is indicated in this region by the work of (1976GA27).

[l] $\Gamma_p = 263 \pm 15$ eV (1980TH05).

Yield curves for elastic protons, protons inelastically scattered to ^{12}C*(4.4, 7.7, 9.6, 12.7, 15.1) and for γ-rays from ^{12}C*(4.4, 12.7, 15.1) have been studied at many energies: see Table 13.22 for a display of the characteristics of the observed structure. Recent yield measurements include those of (1976ME22; $E_{\rm p} = 0.3$ to 2.0 MeV), (1976BE28; $13.8 \rightarrow 24.4$ MeV (12.7 MeV γ), $16.4 \rightarrow 24.4$ MeV (15.1 MeV γ)), (1976FE1C; $16 \rightarrow 37$ (4.4 MeV γ), $16 \rightarrow 31$ (12.7 MeV γ), $17 \rightarrow 37$ MeV (15.1 MeV γ)) and 22 to 27 MeV (1980HO07; (12.7 and 15.1 MeV γ)).

A phase shift analysis of the elastic scattering analyzing power for $E_{\overline{\rm p}} = 11.5$ to 18.1 MeV shows four $T = \frac{1}{2}$ states with $E_{\rm x} = 14.06$, 16.00, 18.16 and 18.18 MeV, with $J^{\pi} = \frac{3}{2}^{+}, \frac{7}{2}^{+}, \frac{3}{2}^{+}, \frac{1}{2}^{-}$: see Table 13.22 (1976ME18). At $E_{\overline{\rm p}} = 19.15$ to 23.34 MeV, measurements of the elastic group and the protons to ^{12}C*(4.4, 12.7) locate $\frac{1}{2}^{+}$ (E1), $\frac{5}{2}^{-}$ (E2) and $\frac{7}{2}^{+}$ (E3) resonances below 21 MeV, $\frac{3}{2}^{+}$ (E1) and $\frac{5}{2}^{-}$ resonances with $21 < E_{\rm x} < 22$ MeV and $\frac{1}{2}^{+}$ and $\frac{3}{2}^{+}$ resonances above 22 MeV: see Table 13.22 (1979GA13). Elastic polarization measurements are also reported at $E_{\overline{\rm p}} = 0.45$ to 0.60 MeV (1979KR18; study of Mott-Schwinger interaction), $E_{\rm p} = 7.16$ to 7.43 MeV (1977ME06), $E_{\overline{\rm p}} \approx 14.2$ MeV (WI80D), 36.2 MeV (1978BE49), 39.9 to 75.0 MeV (1980KA02), 52.3 to 68.2 MeV (1977EG1A), $E_{\rm p} = 185$ MeV (1979IN01; ^{12}C*(0, 4.4, 7.7, 9.6), $E_{\overline{\rm p}} = 800$ MeV (1978HO05, 1978RA17) and $E_{\rm p} = 1$ GeV (1977AL25, 1980AL09). Polarization measurements involving ^{12}C*(4.4, 12.71, 15.11, 15.4, 16.1) are reported by (1978HO11) at $E_{\overline{\rm p}} = 50$ and 65 MeV: a marked difference in the analyzing powers for the groups to the 1^{+} states ^{12}C*(12.71, 15.11) is observed. At $E_{\overline{\rm p}} = 800$ MeV analyzing powers have been measured for ^{12}C*(12.7, 15.1, 18.3, 19.4): those to ^{12}C*(12.7, 18.3) are negative. The values of $A_{\rm y}$ appear to be charateristic of the isospin transfer (1980MO06). For other polarization measurements see (1979KA1N; $E_{\overline{\rm p}} = 65$ MeV; p_0, p_2), (1979FU1H; $E_{\overline{\rm p}} = 24.1$, 26.2, 28.0 MeV; p_1; measured spin flip probability), (1979BE44; $E_{\overline{\rm p}} = 299$, 380, 483 and 561 MeV), (1979LI03; ^{12}C*(4.4); $E_{\overline{\rm p}} = 800$ MeV), (1977NA16, 1977NA29, 1978NA18: (p, 2p); $E_{\overline{\rm p}} = 635$ MeV) and the older measurements [$E_{\rm p} = 0.5$ MeV to 3.6 GeV] listed in Tables 13.26 in (1970AJ04) and 13.28 in (1976AJ04). See also (1978SE01).

For total cross section measurements see (1976AJ04) and (1979SC07; $E_{\rm p} = 191$ to 550 MeV) and (1978JA16; $E_{\rm p} = 0.87$ GeV/c and 2.10 GeV/c). See also (1979DE31). For reaction (b) see ^{11}B in (1980AJ01) and (1979KO21). For reaction (c) see ^{8}Be in (1979AJ01). For reaction (d) see (1979KO36).

Bremsstrahlung measurements are reported by (1978TR05) near the $E_{\rm p} = 1.7$ MeV resonance and by (1976MA06, 1976MA55, 1977MU1C, 1979LE1G, 1979LE1H). See also (1979JA17, 1980LI01; theor.).

Inclusive cross sections have been measured by (1978FR12, 1979FR12, 1979KO21). For polarization measurements at $E_{\overline{\rm p}} = 316$ and 516 MeV see (1978KA08). Studies of hadron multiple production are reported by (1977AV01, 1978AR1J, 1978AZ02). Spallation measurements have been carried out by (1976RO12, 1977FO04, 1978WE1D, 1979RA20). See also (1979VD02). The production of π^{+} with $E_{\overline{\rm p}} = 200$ MeV (reaction (e)) is reported by (1978AU07).

See also ^{12}C in (1980AJ01), (1975DE26, 1976CU08, 1976PL1C, 1976WE1E, 1976WE1F, 1976WU1A, 1977BE1Y, 1977SA1B, 1978DE1Q, 1978GO05, 1979TR1D, 1980CO05, 1980WH1A), (1977AU1B, 1978DW1A, 1979RA1C; astophys.) and (1976AH09, 1976ES1B, 1976GO20, 1976JE1A,

1977BA29, 1976BR1L, 1977PH02, 1977WE1G, 1978AH04, 1978BA21, 1978BE66, 1978BH1B, 1978CA03, 1978CO1J, 1978FA04, 1978GR1D, 1978GU12, 1978RA20, 1978RE1D, 1978UC1A, 1978WU03, 1979AB13, 1979AM02, 1979DE1P, 1979ER02, 1979HE16, 1979LO12, 1979OS06, 1979PH05, 1979RA27, 1979RO1E, 1979TH1A, 1979WE1C, 1979YA1E, 1980AL12, 1980BR04, 1980CO06, 1980JA05, 1980RA1B; theor.).

15. (a) ^{12}C(p, n)^{12}N $Q_{\rm m} = -18.120$ $E_{\rm b} = 1.9434$
(b) ^{12}C(p, pn)^{11}C $Q_{\rm m} = -18.721$

The cross section for reaction (a) has been measured from threshold to $E_{\rm p} = 50$ MeV. Resonant structure is observed corresponding to $E_{\rm x} = 21$, 24 and , possibly ≈ 27 MeV (1968RI01). See also (1976RO10) and ^{12}N in (1980AJ01).

Cross sections for reaction (b) have been measured to 300 GeV: see (1976AJ04). At $E_{\rm p} = 800$ MeV, $\sigma = 32.0 \pm 1.0$ mb (1976HO19). See also (1976BE1K).

16. (a) ^{12}C(p, d)^{11}C $Q_{\rm m} = -16.497$ $E_{\rm b} = 1.9434$
(b) ^{12}C(p, t)^{10}C $Q_{\rm m} = -23.364$
(c) ^{12}C(p, ^{3}He)^{10}B $Q_{\rm m} = -19.6940$

For polarization measurements [reaction (a)] see (1970AJ04) and (1977HA1N; $E_{\overline{\rm p}} = 27.4$ MeV; d$_0$, d$_1$) and (1979HO1H; $E_{\overline{\rm p}} = 65$ MeV; d$_0$, d$_1$). See also ^{11}C in (1980AJ01).

Polarization measurements involving the t$_0$ and t$_1$ groups have been carried out at $E_{\rm p} = 49.5$ MeV (1970NE17). See also ^{10}B, ^{10}C in (1979AJ01).

17. ^{12}C(p, α)^{9}B $Q_{\rm m} = -7.552$ $E_{\rm b} = 1.9434$

Yield curves for α_0 have been measured over the 14.2 MeV resonance, corresponding to the first $T = \frac{3}{2}$ state at $E_{\rm x} = 15.06$ MeV, and from $E_{\rm p} = 17$ to 20 MeV. The yield for the α_1 group has been determined for $E_{\rm p} = 17$ to 21.5 MeV. Parameters of observed resonances are displayed in Table 13.22 (1969LE18). Excitation functions for α_0 have also been measured for $E_{\rm p} = 18.5$ to 44 MeV at a number of angles: they exhibit structures which are typically 1 MeV broad (1971GU23). See also ^{9}B in (1979AJ01).

18. ^{12}C(p, ^{6}Li)^{7}Be $Q_{\rm m} = -22.568$ $E_{\rm b} = 1.9434$

Excitation functions have been measured for $E_p = 36$ to 43 MeV: no structure is apparent (1971HO25). See also (1979RA20) and ^{6}Li, ^{7}Be in (1979AJ01).

19. (a) ^{12}C(d, n)^{13}N $\quad Q_m = -0.2812$
 (b) ^{12}C(d, pn)^{12}C $\quad Q_m = -2.2246$

Measurements of angular distributions of neutrons are tabulated in Table 13.27 of (1970AJ04) and in (1976AJ04). Recent measurements have been reported at $E_{\vec{d}} = 5.74$ to 9.70 MeV (1976TE03; n_0, n_1) and $E_d = 13.9$ and 15.25 MeV (1975AZ02; n_0, n_1, n_{2+3}).

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}N*($3.51 + 3.55$). At the lower energies ^{13}N*(2.36) participates also: see (1976AJ04) and (1976GE20). See also ^{14}N, (1977BA1L, 1979SI07), (1974LO1B), (1976LO1B; applications) and (1977TR09, 1978BA21; theor.).

20. (a) ^{12}C(^{3}He, d)^{13}N $\quad Q_m = -3.5501$
 (b) ^{12}C(^{3}He, pd)^{12}C $\quad Q_m = -5.4936$

Angular distributions have been studied to the first eight states of ^{13}N with $E(^3\text{He})$ up to 40 MeV: see (1970AJ04, 1976AJ04). Recent measurements are reported at $E(^3\text{He}) = 25.4$ MeV (1979SE07; d_0, d_1, d_{2+3}), $E(^3\vec{\text{He}}) = 33.3$ MeV (1976KA23; d_0, d_{2+3}) and $E(^3\text{He}) = 43.6$ MeV (1980PE13; d_0, d_1, d_{2+3} and d to ^{13}N*(6.36, 6.89, 7.16, 7.38, 8.0, 9.0, 10.78)) and 81.4 MeV (1976KO36; d to ^{13}N*(0, 2.36, $3.51 + 3.55$, $7.16 + 7.38$, 7.9, 10.36, 11.1, 12.08)). See also (1976RO1L). The spectroscopic factors derived by (1980PE13) are $S = 0.48$, 0.14, 0.53, 0.007, 0.015, < 0.009, 0.024, 0.13 and 0.064 for ^{13}N*(0, 2.37, 3.55, 6.36, 6.89, 7.16, 7.38, 8.0, 10.78); $S < 0.005$ for ^{13}N*(9.0) and evidence is presented for its $\frac{9}{2}^+$ character. For other values of S see (1976KA23, 1976KO36, 1979SE07). The energies and widths of the first three excited states are $E_x = 2368.2 \pm 2.8$, 3507.8 ± 7.6 and 3549.2 ± 5.0 keV, with $\Gamma_{cm} = 36.1 \pm 2.8$, 54.8 ± 11.5 and 46.5 ± 7.1 keV, respectively (1974BL06). Spectra obtained at $E(^3\text{He}) = 36$ MeV at forward angles show the broad $d_{3/2}$ state at $E_x = 7.9$ MeV. Interfering with it is the 120 keV $\frac{3}{2}^+$ state at 6.89 MeV. The line shape of the $\frac{5}{2}^+$ state at 6.36 MeV is said to show a pronounced interference pattern (1979FU03). For reaction (b) see (1978MA42; $E(^3\text{He}) = 70$ and 80 MeV). See also (1977BO30, 1977SA1L, 1978BA21; theor.) and ^{15}O.

21. ^{12}C(α, t)^{13}N $\quad Q_m = -17.8706$

Angular distributions of the t_0 groups have been measured at $E_\alpha = 56$ MeV (1969GA11) and 104 MeV (1972HA08).

22. $^{12}C(^{7}Li, ^{6}He)^{13}N$ $Q_m = -8.031$

Angular distributions have been obtained at $E(^{7}Li) = 36$ MeV for the ^{6}He ions to $^{13}N^{*}(0, 3.51 + 3.55)$ (1973SC26). The spectroscopic factor for $^{13}N_{g.s.}$ is 0.72 (1979ZE01).

23. $^{12}C(^{10}B, ^{9}Be)^{13}N$ $Q_m = -4.642$

See (1976AJ04).

24. $^{12}C(^{11}B, ^{10}Be)^{13}N$ $Q_m = -9.285$

See (1974AN36). See also (1976AJ04).

25. $^{12}C(^{12}C, ^{11}B)^{13}N$ $Q_m = -14.014$

At $E(^{12}C) = 93.8$ MeV angular distributions involving $^{13}N^{*}(0, 3.51 + 3.55)$ and various ^{11}B states have been measured by (1979FU04). See also (1979HE1E) and (1976AJ04).

26. $^{12}C(^{14}N, ^{13}C)^{13}N$ $Q_m = -5.607$

Angular distributions involving $^{13}N_{g.s.}$ and various ^{13}C states [see reaction 43 in ^{13}C] have been studied at $E(^{14}N) = 28$ to 155 MeV: see (1976AJ04) and (1976BA16, 1976NA09). See also (1978MA1F) and (1977WE1H, 1978DZ1A, 1978NA15, 1978WE1F, 1979DO13; theor.).

27. $^{12}C(^{16}O, ^{15}N)^{13}N$ $Q_m = -10.184$

At $E(^{16}O) = 128$ MeV angular distributions are reported to $^{13}N^{*}(0, 2.36, 3.55)$ (1979PR07; also see for reduced widths).

28. $^{12}C(^{20}Ne, ^{19}F)^{13}N$ $Q_m = -10.901$

See (1979OR01; $E(^{20}Ne) = 150$ to 294 MeV).

29. ^{13}C(π^+, π^0)^{13}N $\quad Q_m = 2.384$

See (1979MO1N) and the "GENERAL" section here.

30. (a) ^{13}C(p, n)^{13}N $\quad Q_m = -3.0030$

(b) ^{13}C(p, pn)^{12}C $\quad Q_m = -4.9464$

Angular distributions of n_0, n_1 n_{2+3} have been measured for $E_p = 3.1$ to 50 MeV: see (1970AJ04, 1976AJ04). See also (1978WA1D). The 0° differential cross section for the n_0 group has been measured to be 4.5 ± 0.7 mb/sr at $E_p = 120$ MeV (1980GO07). In reaction (b) at $E_p = 7.9$ to 12 MeV one or both of the ^{13}N states at $E_x = 3.5$ MeV appear to be involved (1971OT02). See also (1980BA11; theor.).

31. ^{13}C(^{3}He, t)^{13}N $\quad Q_m = -2.2392$

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 2.36, 3.53 ± 0.03 (unresolved), 6.36, 7.16, 7.38, 8.92 ± 0.04, $11.85 + 0.04$ and 15.06 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}N*(7.38, 8.92, 11.85, 15.06) 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). For a comparison of the angular distribution to ^{13}N*(8.918) and ^{13}C*(9.498) at $E(^3\text{He}) = 43.6$ MeV, see reaction 57 in ^{13}C (1980PE1E).

32. ^{13}C(^{6}Li, ^{6}He)^{13}N $\quad Q_m = -5.727$

Angular distributions have been measured at $E(^6\text{Li}) = 31.8$ MeV (1970CH19; ^{13}N*(0, $3.51 + 3.55$)). See also (1979ZE01) and (1976AJ04).

33. ^{13}C(^{14}N, ^{14}C)^{13}N $\quad Q_m = -2.377$

See (1976AJ04) and (1978OS06; theor.).

34. ^{13}O(β^+)^{13}N $\quad Q_m = 17.762$

See ^{13}O.

35. ^{14}N(γ, n)^{13}N $\quad Q_m = -10.554$

See ^{14}N.

36. ^{14}N(n, 2n)^{13}N $\quad Q_m = -10.554$

See (1978RY02), (1977LE1J; applications) and ^{15}N.

37. ^{14}N(p, d)^{13}N $\quad Q_m = -8.3290$

Angular distributions have been measured for deuteron groups to ^{13}N*(0, 2.36, $3.51 + 3.55$, 7.38, 8.92, 11.88) at many energies up to $E_p = 155.6$ MeV: see (1976AJ04) and by (1977GU14; $E_p = 16.2$ and 17.7 MeV; p_0) and (1979AO02; $E_{\overline{p}} = 21$ MeV; p_0). See also (1976WA15, 1978MA34; theor.).

38. ^{14}N(d, t)^{13}N $\quad Q_m = -4.2963$

Angular distributions of the tritons to ^{13}N*(0, 3.51, 7.38, $8.92 + (9.00) + 9.48$, 11.8) have been obtained at $E_d = 52$ MeV and analyzed by DWBA. The spectroscopic factors for the ^{13}N states [and the mirror states reached in the ^{14}N(d, ^{3}He)^{13}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). For comparisons of (d, t) and (d, ^{3}He) angular distributions see reaction 80 in ^{13}C. See also ^{16}O in (1982AJ01).

39. (a) ^{14}N(^{3}He, α)^{13}N $\quad Q_m = 10.024$
(b) ^{14}N(^{3}He, pα)^{12}C $\quad Q_m = 8.0808$

Alpha particle groups have been observed to the first seven excited states of ^{13}N, including two at $E_x = 7.166$ and 7.388 MeV (1962CL12; ± 8 keV). Angular distributions have been studied at many energies up to $E(^3\text{He}) = 45$ MeV: see (1976AJ04) and (1971GU22; 4 to 10.25 MeV; α_0, α_1). Reaction (b), studied at $E(^3\text{He}) = 8$ MeV, appears to involve some states of ^{13}N, possibly ^{13}N*(7.93, 8.92, 11.87) (1969HO13). See also ^{17}F in (1982AJ01).

40. ^{14}N(^{6}Li, ^{7}Li)^{13}N $\qquad Q_{\rm m} = -3.303$

An angular distribution has been measured at $E(^{6}{\rm Li}) = 32$ MeV for the transition to ^{13}N$_{\rm g.s.}$ and ^{7}Li*(0, 0.48). ^{13}N*(2.36) was also populated (1971GR44). See also (1976AJ04) and reaction 83 in ^{13}C.

41. ^{14}N(^{9}Be, ^{10}Be)^{13}N $\qquad Q_{\rm m} = -3.741$

See (1976AJ04).

42. ^{14}N(^{10}B, ^{11}B)^{13}N $\qquad Q_{\rm m} = 0.902$

See (1976NA09).

43. ^{14}N(^{14}N, ^{15}N)^{13}N $\qquad Q_{\rm m} = 0.280$

See (1976SW02). See also (1976AJ04).

44. ^{15}N(p, t)^{13}N $\qquad Q_{\rm m} = -12.9050$

At $E_{\rm p} = 43.7$ MeV, angular distributions have been obtained for the tritons corresponding to the ground state of ^{13}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 15.06 $(\frac{3}{2}^{-}; T = \frac{3}{2})$ MeV [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}He) reaction to the mirror states in ^{13}C (1968FL02, 1968FL03, 1974MA12): see reaction 87 in ^{13}C. Angular distributions have also been measured for the triton groups to ^{13}N*(0, $3.51 + 3.55$, 7.38) at several energies in the range $E_{\rm p} = 24.0$ to 43.5 MeV (1974PI05, 1975MI01). See also ^{16}O in (1982AJ01).

45. ^{16}O(γ, t)^{13}N $\qquad Q_{\rm m} = -25.033$

See ^{16}O in (1982AJ01).

46. (a) ^{16}O(p, α)^{13}N $\quad Q_{\rm m} = -5.2185$

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

Angular distributions of the α_0, α_1 and α_2 groups have been measured for $E_{\rm p}$ to 54.1 MeV: see (1970AJ04, 1976AJ04). In addition, (1972MA21) have measured the distribution of the α group to a state with $E_{\rm x} = 12.13 \pm 0.06$ MeV, $\Gamma_{\rm cm} \approx 300$ keV [$J^{\pi} = \frac{7}{2}^-$] at $E_{\rm p} = 54.1$ MeV. See also (1976AJ04) and ^{17}F in (1982AJ01).

47. ^{16}O(^{3}He, ^{6}Li)^{13}N $\quad Q_{\rm m} = -9.239$

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

48. ^{16}O(α, ^{7}Li)^{13}N $\quad Q_{\rm m} = -22.566$

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

49. ^{16}O(^{14}N, ^{17}O)^{13}N $\quad Q_{\rm m} = -6.409$

This reaction has been studied at $E(^{14}{\rm N}) = 79$ MeV (1976MO03) and 155 MeV (1975NA15, 1976NA09).

50. ^{18}O(d, ^{7}Li)^{13}N $\quad Q_{\rm m} = -7.901$

See (1970AJ04).

51. ^{24}Mg(^{12}C, ^{23}Na)^{13}N $\quad Q_{\rm m} = -9.747$

See (1978NO02).

^{13}O
(Fig. 4)

GENERAL (See also (1976AJ04).):

Theoretical and review papers: (1975BE56, 1976AB04, 1977CE05, 1978GU10, 1979BE1H).

Mass of ^{13}O: From the Q-value of the ^{16}O(^{3}He, ^{6}He)^{13}O reaction [$Q_0 = -30.508 \pm 0.010$ MeV] (see reaction 4) the atomic mass excess of ^{13}O is determined to be 23.108 ± 0.010 MeV. ^{13}O is then bound with respect to ^{12}N + p and ^{11}C + 2p by 1.519 and 2.120 MeV, respectively.

1. ^{13}O(β^+)^{13}N $\qquad$ $Q_m = 17.762$

The half-life of ^{13}O is 8.90 ± 0.20 msec: see (1970ES03) and (1976AJ04). ^{13}O decays to a number of states of ^{13}N some of which subsequently decay to ^{12}C*(0, 4.4): see Table 13.24 (1970ES03). See also (1978RA2A) and (1977MA16, 1977RI08, 1979DE15; theor.).

2. ^{12}C(p, π^-)^{13}O $\qquad$ $Q_m = -155.386$

At $E_p = 613$ MeV the ground state of ^{13}O and an excited state at $E_x = 2.82 \pm 0.24$ MeV are observed in addition to unresolved structures (1978CO15) [see Fig. 4 for analogue region in ^{13}B]. See also (1979HO1F).

3. ^{13}C(π^+, π^-)^{13}O $\qquad$ $Q_m = -19.983$

See (1979GR1K).

4. ^{16}O(^{3}He, ^{6}He)^{13}O $\qquad$ $Q_m = -30.508$
$Q_0 = -30.506 \pm 0.013$ (1971TR03);
$Q_0 = -30.513 \pm 0.015$ (1970ME11); recalculated on basis of ^{9}C mass excess of 28.912 MeV (see (1979AJ01)).

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

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

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

Table 13.23: Energy levels of ^{13}O

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, 4
2.82 ± 0.24				2

Table 13.24: Beta decay of ^{13}O [a]

Decay to		E_p(cm) (MeV) to		Relative intensity	% of all β-decays	log ft
^{13}N* (MeV)	J^π	^{12}C*(g.s.)	^{12}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
			2.56 ± 0.05	1.5 ± 0.3		
9.48	$\frac{3}{2}^-$	observed		0.8 ± 0.1		
					0.13 ± 0.04	5.18 ± 0.14
			3.12 ± 0.05	0.43 ± 0.15		
10.36	$\frac{5}{2}^-$	observed		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 6.28 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.

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(Closed 01 August 1980)

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