

Energy Levels of Light Nuclei $A = 13$

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Abstract: An evaluation of $A = 13$ – 15 was published in *Nuclear Physics A449* (1986), p. 1. This version of $A = 13$ differs from the published version in that we have corrected some errors discovered after the article went to press. Figures and introductory tables have been omitted from this manuscript. [Reference](#) key numbers have been changed to the NNDC/TUNL format.

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¹³He

(Not illustrated)

¹³He has not been observed. See also (1983ANZQ; theor.).

¹³Li

(Not illustrated)

¹³Li has not been observed. The calculated value of its mass excess is 60.34 MeV [see (1981AJ01)]: ¹³Li would then be unstable with respect to ¹¹Li + 2n by 3.26 MeV. (1980BO31) have not observed ¹³Li in the bombardment of ¹²⁴Sn by 6.7 GeV protons but state that the statistics were poor in the region of interest and that it is not excluded that ¹³Li may be stable. See also (1983ANZQ; theor.).

¹³Be

(Not illustrated)

¹³Be is reported in the ¹⁴C(⁷Li, ⁸B) reaction at $E(^7\text{Li}) = 82$ MeV: the atomic mass excess of ¹³Be is 35.0 ± 0.5 MeV. It is then unstable with respect to breakup into ¹²Be + n by 1.9 MeV (1983AL20). See also (1981AJ01), (1984BE1C) and (1981SE06, 1982KA1D, 1983ANZQ, 1984VA06; theor.).

¹³B

(Reactions on which no new work is reported are not always discussed.)

(Figs. 1 and 4)

GENERAL: (See also (1981AJ01).)

Model calculations: (1981SE06, 1984VA06).

Complex reactions involving ¹³B: (1983EN04, 1983MA06, 1983OL1A, 1983WI1A, 1984HI1A).

Muon and neutrino capture and reactions: (1984KO1U).

Pion capture and reactions (See also reactions 4 and 5.): (1981OS04, 1982CH16, 1983LI15).

Hypernuclei: (1983FE07).

Other topics: (1981SE06, 1981WA1J, 1982NG01, 1984PO11).

Ground-state properties of ¹³B: (1980FU1G, 1982NG01, 1983ANZQ, 1984KU07).

Mass of ¹³B: From the Q_0 of the ¹¹B(t, p)¹³B reaction [-233.4 ± 1.0 keV], the atomic mass excess of ¹³B is 16561.3 ± 1.4 keV.

$$Q = 0.0478 (46) \text{ b (1978LEZA),}$$

$$\mu = +3.17778 (51) \text{ nm (1978LEZA).}$$

$$1. \text{}^{13}\text{B}(\beta^-)^{13}\text{C} \quad Q_m = 13.436$$

The half-life of ^{13}B is 17.36 ± 0.16 msec: see (1981AJ01). The branching ratios to various ^{13}C states are shown in Table 13.2: they indicate $J^\pi = \frac{1}{2}^-$ or $\frac{3}{2}^-$ for $^{13}\text{B}_{\text{g.s.}}$. See also (1981KO27; theor.).

$$2. \text{}^7\text{Li}(\text{}^7\text{Li}, \text{p})^{13}\text{B} \quad Q_m = 5.963$$

Observed proton and γ -ray groups are shown in Table 13.3. See also ^{14}C .

$$3. \text{}^{11}\text{B}(\text{t}, \text{p})^{13}\text{B} \quad Q_m = -0.2324$$

$$Q_0 = -233.36 \pm 1.00 \text{ keV (1983AN1Q).}$$

Observed proton groups are displayed in Table 13.3.

$$4. \text{}^{13}\text{C}(\gamma, \pi^+)^{13}\text{B} \quad Q_m = -153.004$$

Differential cross sections have been measured to $^{13}\text{B}_{\text{g.s.}}$ ($E_{\pi^+} = 18, 29, 42$ MeV) and the unresolved structure at $E_x \approx 3.5 - 3.7$ MeV ($E_{\pi^+} = 42$ MeV) (1982LE26) and to $^{13}\text{B}_{\text{g.s.}}$ (1983SH01; $E_\gamma = 194$ MeV, $E_{\pi^+} \approx 40$ MeV) [see the latter for a discussion of the comparison of the results with DWIA]. At $E_e = 195$ MeV the ^{13}B E_x region to 12 MeV has been studied by (1983MI06): they find that the photopion reaction predominantly excites M2 states at low q and M4 states at high q . Fits to the data are obtained by assuming the excitation of $^{13}\text{B}_{\text{g.s.}}$ and $^{13}\text{B}^*(3.5, 6.4, 9.0)$ [the latter are clearly due to unresolved groupings of levels]. Comparisons are made with the $^{13}\text{C}(e, e')$ work in the analog region in ^{13}C (1983MI06). [For $T = \frac{3}{2}$ states see Table 13.6.] See also reaction 43 in ^{13}C and the ‘‘General’’ section here.

$$5. \text{}^{13}\text{C}(\text{n}, \text{p})^{13}\text{B} \quad Q_m = -12.654$$

See (1985FO1C, 1985FO1D).

Table 13.1: Energy levels of ^{13}B

E_x (MeV \pm keV)	$J^\pi; T$	τ or $\Gamma_{\text{c.m.}}$ (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, 10
3.4828 ± 4.5	^a		(γ)	3, 6
3.5346 ± 3.1	^a	$\tau_m > 0.3$ psec	γ	2, 3, 6
3.6810 ± 4.5	^a		(γ)	3, 6, 8
3.7126 ± 4.5	^a	$\tau_m < 0.38$ psec	γ	2, 3, 6, 8
4.131 ± 6		$\tau_m = 0.062 \pm 0.050$ psec	γ	2, 3
4.829 ± 6			(γ)	2, 3
5.024 ± 6				2, 3
5.106 ± 10		$\Gamma = 60 \pm 10$ keV		3
5.388 ± 6		10 ± 10		2, 3
(5.557 ± 7)				2
6.167 ± 6				2, 3, 4
6.425 ± 7		36 ± 5		2, 3, 4, 6
6.934 ± 9	^a	55 ± 15		2, 3, 4, 6
(7.516 ± 8)				2, 6
(7.859 ± 20)				2, 6
8.133 ± 7		100 ± 15		2, 3
8.683 ± 7		89 ± 20		2, 3
9.44 ± 30		81 ± 25		3, 4
10.22 ± 20		210 ± 20		3, 6
10.89 ± 20				3
(11.80)				3

^a See Table 13.3 and reaction 5.

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

Decay to $^{13}\text{C}^*$ (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	$\frac{5}{2}^-$	0.094 ± 0.020	5.33 ± 0.08
8.86	$\frac{1}{2}^-$	0.16 ± 0.03	4.60 ± 0.08
9.90	$\frac{3}{2}^-$	0.022 ± 0.007	4.95 ± 0.12

^a For references see Table 13.2 in (1981AJ01).

^b Log ft shown here are based on $\tau_{1/2} = 17.33 \pm 0.17$ msec.

6. $^{13}\text{C}(\pi^-, \gamma)^{13}\text{B}$ $Q_m = 126.131$

Gamma rays have been observed which are associated with the ^{13}B ground state; an unresolved doublet at $E_x \approx 3.5 - 3.7$ MeV; sharp states at $E_x \approx 6.5$ and 7.6 MeV; a broad level (or unresolved levels) at ≈ 10.2 MeV (1983MA16; see for radiative capture branching ratios). The analogs of the peaks at $E_x = 6.5, 7.6$ and 10.2 MeV, calculated to be at $^{13}\text{C}^*(21.6, 22.7, 25.3)$, are attributed to a $\Delta L = 1, \Delta S = 1, \Delta T = 1$ spin-isospin giant dipole resonance of ^{13}C (1983MA16). See also the “General” section here.

7. $^{13}\text{C}(^7\text{Li}, ^7\text{Be})^{13}\text{B}$ $Q_m = -14.298$

See (1982AL1G, 1984GL1G; $E(^7\text{Li}) = 78$ MeV).

8. $^{14}\text{C}(\text{d}, ^3\text{He})^{13}\text{B}$ $Q_m = -15.337$

See (1981AJ01).

9. $^{14}\text{C}(\text{t}, \alpha)^{13}\text{B}$ $Q_m = -1.016$

At $E_t = 23$ 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.

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

${}^7\text{Li}({}^7\text{Li}, p){}^{13}\text{B}$	${}^{11}\text{B}(t, p){}^{13}\text{B}$				
	A			B	
	E_x (MeV \pm keV)	L	J^π	E_x (MeV \pm keV)	$\Gamma_{\text{c.m.}}$ (keV)
0	0	0	$\frac{3}{2}^-$	0	
	3.483 ± 5	1	$(\frac{1}{2}, \frac{3}{2}, \frac{5}{2})^+ \text{ }^g$	3.482 ± 10	
3.5363 ± 4.2 ^b	3.533 ± 5	2	$(\frac{1}{2}, \frac{5}{2}, \frac{7}{2})^- \text{ }^g$	3.531 ± 10	
	3.681 ± 5	1	$(\frac{1}{2}, \frac{3}{2}, \frac{5}{2})^+ \text{ }^g$	3.681 ± 10	
^c	3.712 ± 5	2	$(\frac{1}{2}, \frac{5}{2}, \frac{7}{2})^- \text{ }^g$	3.715 ± 10	
4.1334 ± 7.8 ^{b,d}	4.13 ± 10	2	$(\frac{1}{2}, \frac{5}{2}, \frac{7}{2})^- \text{ }^g$	4.128 ± 10	
4.833 ± 10 ^e	4.82 ± 10			4.834 ± 10	
5.033 ± 8	5.01 ± 10	1	$(\frac{1}{2}, \frac{3}{2}, \frac{5}{2})^+ \text{ }^g$	5.023 ± 10	
				5.106 ± 10	60 ± 10
5.391 ± 8	5.38 ± 10 ^f			5.393 ± 10	10 ± 10
5.557 ± 8				^h	
6.169 ± 8	6.17 ± 20			6.164 ± 10	
6.419 ± 8				6.434 ± 10	36 ± 5
6.939 ± 15				6.932 ± 10 ⁱ	55 ± 15
7.516 ± 8				^h	
7.859 ± 20				^h	
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: $E_t = 11$ MeV.

B: $E_t = 23$ MeV.

^a For references see (1981AJ01).

^b $E_\gamma; \tau_m > 0.3$ psec.

^c The decay is primarily by γ_0 : the upper limit to the cascade via ${}^{13}\text{B}^*(3.5)$ is 10%; $\tau_m < 0.38$ psec.

^d The γ -decay is (75 \pm 10)%, (25 \pm 10)% and $< 10\%$, respectively to ${}^{13}\text{B}^*(0, 3.5, 3.7)$; $\tau_m = 62 \pm 50$ fsec.

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

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

^g See, however, (1978AJ02), p. 1289.

^h Not observed.

ⁱ $L \geq 4$.

10. $^{18}\text{O}(\text{d}, ^7\text{Be})^{13}\text{B}$

$$Q_m = -19.976$$

See (1984NE1A).

¹³C
(Figs. 2 and 4)

GENERAL: (See also (1981AJ01)).

Nuclear models: (1982KU1B, 1983JA09, 1983SH38, 1983VA31, 1984VA06, 1984ZW1A).

Special states: (1980RI06, 1981KO1Q, 1981LI19, 1983AU1B, 1983GO1R, 1983MI08, 1983VA31, 1984GO1M, 1984RO05, 1984VA06, 1984ZW1A, 1985HA1J, 1985WE02).

Electromagnetic transitions: (1980BA54, 1980RI06, 1981KN06, 1981KO1Q, 1981LI19, 1982AW02, 1983AD1B, 1983MI08, 1984KU07, 1984MA2J, 1984MO1D, 1984SC09).

Astrophysical questions: (1980AU1D, 1980GA1Q, 1980WA1M, 1981CR1B, 1981GU1D, 1981LA1L, 1981SC1M, 1981SN1B, 1981WA1N, 1981WA1Q, 1981WI1G, 1982IB1B, 1982JO1B, 1982NO1D, 1983AL1M, 1983BO1F, 1983IB1A, 1983SW1A, 1984HA1R, 1984HA1Z, 1984LA1J, 1984LI1L, 1984TR1C, 1984WE1C, 1985GU1A).

Applied work: (1980SE1E, 1981DE2B, 1981FR1D, 1982FR1L, 1982ST1C, 1982ZA1C, 1983AM1A, 1983DO1H, 1983GI1E, 1983JU1B, 1983SC1B, 1983SU1C, 1984AR1C, 1984BO1T, 1984DE1T, 1984DO1B, 1984GI1K, 1984GI1M, 1984HO1E, 1984LE1G, 1984NA1R, 1984RA1J, 1984SH2A, 1984SU1H, 1984SU1J, 1985AR1N).

Complex reactions involving ¹³C: (1980GR10, 1980RI06, 1981FR02, 1981GR08, 1981ME13, 1981OL1C, 1982LY1A, 1982TA02, 1983CH23, 1983EN04, 1983FR1A, 1983GA01, 1983JA05, 1983MA06, 1983OL1A, 1983SA06, 1983VO04, 1983WI1A, 1984GR08, 1984HI1A, 1984HO23, 1984VO06, 1985GU1A, 1985MO08, 1985ST1J, 1985UT1B).

Muon and neutrino capture and reactions: (1981MU1E, 1981PH1C, 1982SC11, 1982WE02, 1983GM1A, 1984AA1B, 1984KO1U, 1985MI1P).

Pion capture and reactions (See also reactions 8, 28 and 44): (1978MO01, 1979BA16, 1979ME2A, 1980BA27, 1980BU15, 1980DE1X, 1980EI01, 1980GO1M, 1980LE17, 1981AU1C, 1981BA1J, 1981CR1A, 1981FE2A, 1981GI1A, 1981GO1G, 1981HA1L, 1981HI06, 1981KE1A, 1981LI02, 1981LI1B, 1981LO1B, 1981MO11, 1981NI1B, 1981OS04, 1981PE1C, 1981PO10, 1981SI1D, 1981WH01, 1982AS05, 1982BE51, 1982BE1D, 1982CH16, 1982CO07, 1982CO1Z, 1982DE1K, 1982DO01, 1982DO02, 1982DO10, 1982FE1A, 1982FR02, 1982GI1B, 1982GR1F, 1982GR1K, 1982HO1C, 1982IN1A, 1982IQ1A, 1982KE1D, 1982KI1D, 1982LE26, 1982LI1K, 1982LO1K, 1982MA1F, 1982MA1U, 1982NA1K, 1982SO1B, 1982THZZ, 1982WA1G, 1983CH54, 1983GE12, 1983GM1A, 1983KA19, 1983LI1M, 1983LI1Q, 1983LI15, 1983LI1X, 1983MA16, 1983MA40, 1983MI06, 1983PE14, 1983SH01, 1983THZZ, 1983TI1A, 1983TO17, 1983TR1J, 1983ZE1C, 1984AN11, 1984BA2Y, 1984COZY, 1984GO1F, 1984GR27, 1984KE02, 1984LI1U, 1984MI1K, 1984SA1H, 1984ST16, 1984TI02).

Kaon capture and reactions: (1979LI1A, 1981BA1H, 1981DA1C, 1981MA27, 1981MI1F, 1982BA1R, 1982BE1U, 1982DO1C, 1982DO1M, 1982MA1Y, 1982ZH1C, 1983AU1A, 1983FE07, 1983LI1Q, 1983PO1D, 1984GI1E, 1984MI1C, 1984SI13).

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

E_x in ^{13}C (MeV \pm keV)	$J^\pi; T$	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
g.s.	$\frac{1}{2}^-; \frac{1}{2}$		stable	5, 6, 7, 8, 10, 12, 13, 14, 18, 19, 20, 21, 22, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84
3.089443 ± 0.020	$\frac{1}{2}^+$	$\tau_m = 1.55 \pm 0.15$ fsec ^b	γ	6, 7, 10, 12, 18, 20, 22, 28, 29, 30, 32, 33, 34, 36, 43, 44, 45, 46, 47, 48, 49, 53, 64, 65, 66, 68, 69, 71, 72, 73, 74, 75, 77
3.684507 ± 0.019	$\frac{3}{2}^-$	1.59 ± 0.13 fsec ^b	γ	5, 6, 7, 8, 12, 13, 18, 20, 22, 28, 29, 30, 32, 33, 34, 39, 43, 44, 45, 46, 47, 48, 49, 53, 64, 65, 66, 68, 69, 70, 71, 72, 74, 75, 77, 78
3.853807 ± 0.019	$\frac{5}{2}^+$	12.4 ± 0.2 psec ^c	γ	6, 7, 12, 18, 20, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 44, 45, 46, 47, 48, 49, 53, 64, 65, 66, 68, 71, 72, 75, 77
6.864 ± 3	$\frac{5}{2}^+$	$\Gamma = 6$	γ, n	5, 6, 7, 11, 12, 18, 20, 23, 28, 29, 43, 46, 48, 49, 71, 72, 74
7.492 ± 10	$(\frac{7}{2}^+)$	< 5		5, 7, 11, 13, 18, 20, 29, 36, 48, 49, 70, 71, 72

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

E_x in ^{13}C (MeV \pm keV)	$J^\pi; T$	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
7.547 ± 3	$\frac{5}{2}^-$	1.2 ± 0.3	γ, n	5, 7, 13, 18, 20, 23, 29, 36, 39, 43, 44, 46, 48, 49, 70, 71, 72, 74
7.686 ± 6	$\frac{3}{2}^+$	70 ± 5	γ, n	18, 20, 23, 29, 40, 48, 49, 68, 72
8.2 ± 100	$\frac{3}{2}^+$	1000 ± 300	γ, n	7, 23, 29, 40
8.860 ± 20	$\frac{1}{2}^-$	150 ± 30	γ, n	18, 23, 29, 39, 40, 43, 44, 46, 48, 49, 68, 71, 72, 74
9.4997 ± 0.1	$\frac{9}{2}^+$	5	$(\gamma), n$	5, 7, 11, 18, 23, 28, 29, 44, 46, 48, 49, 71, 72, 74
9.897 ± 5	$\frac{3}{2}^-$	26 ± 3	γ, n	5, 11, 18, 23, 29, 39, 40, 43, 46, 48
10.46		200	n	23
10.753 ± 4	$\frac{7}{2}^-$	55 ± 2	n	11, 18, 23, 29, 46, 48, 72
10.818 ± 5	$(\frac{5}{2}^-)$	24 ± 3	n	5, 7, 11, 18, 23, 29, 48, 72
10.996 ± 6	$\frac{1}{2}^+$	37 ± 4	γ, n, α	2, 18, 23, 29, 40, 72
11.080 ± 5	$\frac{1}{2}^-$	< 4	γ, n, α	2, 18, 23, 29, 40, 43, 46, 48, 49, 72, 74
11.748 ± 10	$\frac{3}{2}^-$	110 ± 15	n	13, 18, 23, 29, 72
11.851 ± 5	$(\frac{3}{2}^-)$	68 ± 4	n	13, 29, 44, 46, 49, 68, 70, 71, 74
11.95 ± 40	$\frac{5}{2}^+$	500 ± 80	n, α	2, 23, 29
12.106 ± 5	$\frac{3}{2}^+$	540 ± 70	$(\gamma), n, (\alpha)$	2, 23, 29, 40, 72
12.13 ± 50	$\frac{5}{2}^-$	80 ± 30	n, (α)	2, 23
12.14 ± 70	$\frac{1}{2}^+$	430 ± 70	n, (α)	2, 23
12.27 ± 70	$\frac{3}{2}^-$	190 ± 50	n, (α)	2, 23
12.438 ± 12	$\frac{7}{2}^-$	140 ± 30	n, α	2, 23, 74
13.0 ± 1000		broad	γ, n	40

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

E_x in ^{13}C (MeV \pm keV)	$J^\pi; T$	τ_m or $\Gamma_{\text{c.m.}}$ (keV)	Decay	Reactions
(13.28)	$(\frac{3}{2}^-)$	340	α	4
13.41	$(\frac{9}{2}^-)$	35 ± 3	n, α	2, 4
13.57	$\frac{7}{2}^-$	620 ± 50	n, α	2, 4, 23
13.76	$(\frac{5}{2}, \frac{3}{2})^+$	≈ 300	n, α	2, 4
14.13	$\frac{3}{2}^-$	≈ 150	n, α	2, 4, 23
14.390 ± 15	$(\frac{1}{2}, \frac{5}{2})^-$	280 ± 70	n, α	2, 46
14.582 ± 10		230 ± 50	n, α	2
14.983 ± 10	$\frac{7}{2}^-$	380 ± 60	n, α	2, 23
$15.1082 \pm 1.2^{\text{d}}$	$\frac{3}{2}^-; \frac{3}{2}$	5.49 ± 0.25	γ , n, α	2, 4, 5, 18, 40, 43, 46, 48, 66, 74
15.27	$\frac{9}{2}^+$		n	23
15.526 ± 11	$(\frac{3}{2}^-)$	150 ± 30	n, α	2, 23
16.080 ± 7	$(\frac{7}{2}^+)$	150 ± 15	(γ) , n, α	2, 23, 43, 44, 48
16.15 ± 50	$(\frac{5}{2}^-)$	230	n, α	2, 23, 46
16.95 ± 50		330	n, α	2
17.36 ± 100		190	n, α	2
17.699 ± 5		170	n, α	2
(17.92 \pm 50)				44
18.30 ± 50		300	n, α	2
18.699 ± 5		100 ± 15	γ , n, p, α	2, 41
19.5		≈ 450	n, d	15, 23
19.9		≈ 600	n, p, d	15, 16
20.021 ± 13		230 ± 30	(γ) , n, (p), d, α	15, 17
20.429 ± 8		116 ± 10	(γ) , n, p, d	14, 15, 16
(20.52 \pm 70)		510 ± 70	γ , n, p	22, 40, 41
(21.1 \pm 600)		4200 ± 400	γ , n, p	22, 40, 41, 42
21.28 ± 15		159 ± 15	n, p, d	15, 16, 44
21.466 ± 8		270 ± 20		44, 46
21.81 ± 20		114 ± 21	n, d	15
22		≈ 1000	(γ) , n, (p), d	14, 15, 41

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

E_x in ^{13}C (MeV \pm keV)	$J^\pi; T$	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
23		≈ 1000	$(\gamma), n, (p)$	23, 29, 41
24		≈ 4000	γ, n, p	29, 40, 41, 43
(26)		broad	γ, p	41
26.8			n, d	15
27.5		≈ 1000	n, p, d, t	9, 15
30			γ, n	40

^a See also Table 13.5.

^b From Table 13.5 in (1981AJ01).

^c Weighted mean of values displayed in Table 13.5 in (1981AJ01) and in (1981RU04).

^d See Table 13.6.

Antiproton reactions: (1981YA1C).

Hypernuclei: (1980IW1A, 1980ZH1C, 1981AU05, 1981DA1C, 1981MA27, 1981MI1A, 1981MI1F, 1981RA18, 1981WA1J, 1981ZH1B, 1982BE1U, 1982DO1C, 1982DO1M, 1982GR1P, 1982JO1C, 1982KA1U, 1982KA1D, 1982MA1Y, 1982PI1J, 1982RA1L, 1982SH1P, 1982ZH1C, 1983AU1A, 1983BA2K, 1983CH1T, 1983DO1B, 1983FE07, 1983GA17, 1983JO1E, 1983KO1V, 1983KO1D, 1983LI1Q, 1983MA1F, 1983PO1D, 1983SH1E, 1984AS1D, 1984BA2Y, 1984BA1N, 1984BO1A, 1984CH1G, 1984DA03, 1984DA1D, 1984MI1C, 1984SH1J, 1985AH1A, 1985BA2N).

Other topics: (1979LI1A, 1980BA54, 1981AU05, 1981PL03, 1982AW02, 1982HU1D, 1982LU02, 1982NG01, 1983CO09, 1983GO1R, 1983GU09, 1984PO11).

Ground state of ^{13}C : (1980BA54, 1981AV02, 1982LO13, 1982NG01, 1983AD1B, 1983ANZQ, 1983AU1A, 1983AU1B, 1983BU07, 1983CO09, 1983VA31, 1984FR13, 1984KA25, 1984KU07, 1984WE04, 1985HA18, 1985FA01).

$$\mu = +0.702411 (1) \text{ nm (1978LEZA),}$$

$$\langle r^2 \rangle^{1/2} = 2.4795 (20) \text{ fm (1982SC11). See also (1984AA1B).}$$

Natural abundance: $(1.10 \pm 0.03)\%$ (1984DE53).

The neutron rms radius is 2.35 (3) fm (1979JO08). See also (1981AJ01).

$^{13}\text{C}^*(3.85)$: g is negative (1976DY05). From the γ -ray due to the transition $^{13}\text{C}^*(3.85 \rightarrow 3.68)$, $\Delta E_x = 169.356 \pm 0.020 \text{ keV (1984SC09)}$. See, however, footnote ^c in Table 13.11.

Table 13.5: Summary of results on the total radiation widths of low-lying levels of ^{13}C - ^{13}N ^a

$J_i^\pi \rightarrow J_f^\pi$	$^{13}\text{C}^*$ (MeV)	Γ_γ (eV)	$^{13}\text{N}^*$ (MeV)	Γ_γ (eV)
$\frac{1}{2}^+ \rightarrow \frac{1}{2}^-$	3.09 ^b	0.43 ± 0.04	2.37	0.64 ± 0.07
$\frac{3}{2}^- \rightarrow \frac{1}{2}^-$	3.68 ^c	0.41 ± 0.04	3.51 ^f	0.70
$\frac{5}{2}^+ \rightarrow \frac{1}{2}^-$	3.85 ^d	$(5.32 \pm 0.09) \times 10^{-5}$ ^e	3.55	$< 2 \times 10^{-3}$

^a See also Tables 13.12 and 13.17. For references see Table 13.6 in (1981AJ01).

^b $E_x = 3089.443 \pm 0.020$ keV, $E_\gamma = 3089.049 \pm 0.020$ keV* (1980WA24): here, and in footnote ^d, measured values are asterisked; the others are derived.

^c Branching ratio for cascade via $^{13}\text{C}^*(3.09)$ is $0.75 \pm 0.04\%$ (1980WA24), $(0.74 \pm 0.05)\%$ (1982MU14). $E_x = 3684.482 \pm 0.023$ keV, $E_\gamma = 3683.921 \pm 0.023$ keV. $\delta(E2/M1) = -0.094 \pm 0.009$. E_γ for the transition to $^{13}\text{C}^*(3.09)$ is 595.013 ± 0.011 keV (1980WA24).

^d Branching ratios for cascades via $^{13}\text{C}^*(3.68, 3.09)$ are $(36.3 \pm 0.6)\%$ and $(1.20 \pm 0.04)\%$, respectively (1980WA24). $E_x = 3853.783 \pm 0.022$ keV, $E_\gamma = 3853.170 \pm 0.022$ keV; E_γ for the transitions to $^{13}\text{C}^*(3.09, 3.68)$ are 764.316 ± 0.010 keV* and 169.300 ± 0.004 keV* (1980WA24) [169.356 ± 0.020 keV (1984SC09)].

^e The ground-state branching ratio is $(62.5 \pm 0.6)\%$ (1980WA24) and $\delta(E3/M2) = +0.12 \pm 0.03$ (1966PO11).

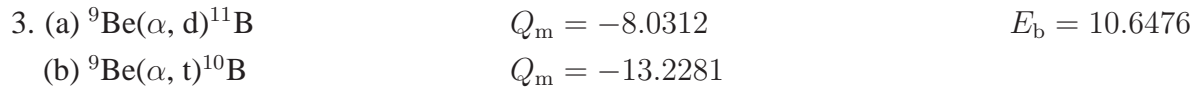
^f Branching ratio for cascade via $^{13}\text{N}^*(2.37)$ is $(8 \pm 1)\%$ (1974RO29). See also footnote ^g in Table 13.17.

1. (a) $^6\text{Li}(^7\text{Li}, \gamma)^{13}\text{C}$	$Q_m = 25.867$	
(b) $^6\text{Li}(^7\text{Li}, n)^{12}\text{C}$	$Q_m = 20.921$	$E_b = 25.867$
(c) $^6\text{Li}(^7\text{Li}, p)^{12}\text{B}$	$Q_m = 8.334$	
(d) $^6\text{Li}(^7\text{Li}, d)^{11}\text{B}$	$Q_m = 7.189$	
(e) $^6\text{Li}(^7\text{Li}, t)^{10}\text{B}$	$Q_m = 1.992$	
(f) $^6\text{Li}(^7\text{Li}, \alpha)^9\text{Be}$	$Q_m = 15.220$	

The yield curves for $d_0(E(^6\text{Li}) = 4 \text{ to } 14 \text{ MeV})$, $t_0(E(^7\text{Li}) = 5 \text{ to } 14 \text{ MeV})$ and $\alpha_0(E(^6\text{Li}) = 4 \text{ to } 14 \text{ MeV})$ show broad, uncorrelated structures. Energy-averaged differential cross sections are also reported for a number of ^{12}B , ^{11}B and ^{10}B states. Total cross-section measurements have been measured for $E(^7\text{Li}) = 3.8 \text{ to } 6.0 \text{ MeV}$ for $p_0 \rightarrow p_2, p_{3+4}, p_5$; $d_0 \rightarrow d_3, d_{4+5}, d_6$; $t_0 \rightarrow t_2$; and α_0 : the total cross sections generally increase smoothly with energy without showing any structure: see (1981AJ01). For reaction (b) see (1981NO1E). See also (1983KAZF).

2. (a) $^9\text{Be}(\alpha, n)^{12}\text{C}$	$Q_m = 5.7013$	$E_b = 10.6476$
(b) $^9\text{Be}(\alpha, 2n)^{11}\text{C}$	$Q_m = -13.020$	

Resonances for n_0 and n_1 , for γ -rays from $^{12}\text{C}^*(4.4, 12.7, 15.1)$ and resonances in the total neutron cross section are given in Table 13.7. In addition the yield of neutrons to $^{12}\text{C}^*(7.65, 9.64)$ has been measured in the range $E_\alpha = 2.9 - 6.4$ MeV. 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 $E_x = 15.11$ MeV: see Tables 13.6 and 13.7 (1978HI06). The thick-target yield of neutrons has been measured for $E_\alpha = 3.0$ to 9.0 MeV by (1979BA48). Polarization measurements have been reported for E_α to 100 MeV: see (1981AJ01). Reaction (b) has been studied at a number of energies for $E_\alpha = 17$ to 44 MeV [see (1981AJ01)] and at $E_\alpha = 19.5$ to 32.1 MeV (1981AN16). See also (1982WE16; applied).



Excitation curves have been measured for $E_\alpha = 15$ to 27.5 MeV for reaction (a) [involving d_0 , d_1 and at the higher energies d_2 , d_3 , d_{4+5} , d_6] and at 26.0 to 27.5 MeV for reaction (b) [t_0 , t_1 , t_3]: no structures are observed. See (1981AJ01).



A number of excitation functions have been measured for elastically scattered α -particles 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 excitation functions are displayed in Table 13.8: see the footnotes to that table for a summary of the most important caveats. 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 $E_x = 15.11$ MeV: see Table 13.6 for the parameters of that state (1978HI06). For inclusive cross sections see (1985AB02). See also (1981FR1T, 1985SR01; theor.).



A number of ^{13}C states have been studied at $E(^6\text{Li}) = 23.8$ MeV: see (1981AJ01).



Angular distributions for t_0 , t_1 , t_{2+3} , t_4 are reported at $E(^7\text{Li}) = 5.6$ to 6.2 MeV: see (1976AJ04).

Table 13.6: Parameters of the first $T = \frac{3}{2}$ states in ^{13}C and ^{13}N ^a

	$^{13}\text{C}^*(15.11)$	$^{13}\text{N}^*(15.06)$
E_x (MeV)	15.1082 ± 0.0012	15.06457 ± 0.0004
J^π	$\frac{3}{2}^-$	$\frac{3}{2}^-$
$\Gamma_{\text{c.m.}}$ (keV)	5.49 ± 0.25	0.932 ± 0.028
Γ_{γ_0} (eV)	22.4 ± 1.5 (M1), 0.6 ± 0.1 (E2)	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
Γ_{γ_0}/Γ (%)	0.396 ± 0.030 b	
$\Gamma_{p_0}\Gamma_{\gamma_0}/\Gamma$ (eV)		5.79 ± 0.20
$\Gamma_{\gamma_0}/\Gamma_{p_0}$ (%)		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 For references see Table 13.7 in (1981AJ01).

^b The decay width to $^{13}\text{C}^*(7.55)$ is < 0.9 eV.

^c Widths for $^{13}\text{C}^*(15.11) \rightarrow ^{12}\text{C}_{\text{g.s.}} + n_0$ or $^{13}\text{N}^*(15.06) \rightarrow ^{12}\text{C}_{\text{g.s.}} + p_0$ [$n_1, p_1; n_2, p_2$; and p_3 and p_5 refer to the decays to $^{12}\text{C}^*(4.4, 7.7, 9.6, 10.8)$ respectively].

^d Widths for $^{13}\text{C}^*(15.11) \rightarrow ^9\text{Be}_{\text{g.s.}} + \alpha_0$ or $^{13}\text{N}^*(15.06) \rightarrow ^9\text{B}_{\text{g.s.}} + \alpha_0$ [α_1 and α_2 refer to the decays to $^9\text{B}^*((1.6), 2.4)$].

^e $\delta = -0.15 \pm 0.07$ (1978HI06). Here $\delta = B(^{13}\text{C})/B(^{13}\text{N}) - 1$.

^f $\delta = 1.0 \pm 0.6$ (1978HI06).

^g $\delta \geq 0.83 \pm 0.29$.

^h $\delta = -0.04 \pm 0.14$.

ⁱ Based on measured branching ratios and on $\Gamma_{\text{c.m.}} = 0.932 \pm 0.028$ keV. See also footnote ^d in Table 13.18.

^j The decay width to $^{12}\text{C}^*(12.71)$ is < 0.13 keV. It is expected to be ≈ 0.03 keV. The sum of the branching ratios for all measured decays of $^{13}\text{N}^*(15.06)$ is $(92 \pm 8)\%$. It is apparent from the character of the decay modes of this state that 2s1d shell isospin admixtures are important.

Table 13.7: Resonances in ${}^9\text{Be}(\alpha, n){}^{12}\text{C}$ ^a

E_α ^b (MeV)	E_α ^c (MeV)	E_α ^d (MeV)	$\Gamma_{\text{c.m.}}$ (keV)	J^π	${}^{13}\text{C}^*$ ^e (MeV)
0.52	0.52		≈ 55 ^f	$(\frac{1}{2}^+)$	11.01
0.60	0.60		< 4 ^f		11.06
1.9	1.905	1.92	130	$(\frac{7}{2}^-)$	11.97
2.24		2.25	280		12.20
2.58	2.6	2.58	≈ 200	$(\frac{1}{2}^-)$	12.43
4.00	3.98	4.00	35 ± 3 ^g		13.41
4.18			570	$(\frac{3}{2}^+)$	13.54
4.50	4.47	4.50	≈ 350	$(\frac{5}{2}^+)$	13.75
5.0	5.02	5.0	≈ 200		14.12
5.40 ± 0.10	5.3		260	$(\frac{1}{2}^-, \frac{5}{2}^-)$	14.39 ± 0.1
	5.75	5.75	210		14.63
6.20 ± 0.05			380	$(\frac{3}{2}^+)$	14.94 ± 0.05
	6.44 ^h			$\frac{3}{2}^-; T = \frac{3}{2}$	15.1086
7.10 ± 0.05	7.00		220		15.56 ± 0.05
	7.75	7.8	210		16.01
7.95 ± 0.05			230		16.15 ± 0.05
9.10 ± 0.05		9.1	330		16.95 ± 0.05
9.7 ± 0.10	9.70		190		17.36 ± 0.1
10.2 ± 0.05			170		17.71 ± 0.05
11.05 ± 0.05			300		18.30 ± 0.05
11.70 ± 0.03	11.60		70		18.75 ± 0.03

^a For references see (1981AJ01).

^b Resonances in total neutron yield.

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

^d Resonances in total cross section.

^e Not corrected for effects of Coulomb barrier penetration.

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

^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 13.6 for parameters of 15.11 MeV state (1978HI06).

Table 13.8: Resonances in ${}^9\text{Be}(\alpha, \alpha_0)$ ^a

E_α (MeV)	$\Gamma_{\text{c.m.}}$ (keV)	l_α	J^π	${}^{13}\text{C}^*$ (MeV)
3.80	343	0, 2	$\frac{3}{2}^-$ ^b	13.28
4.00	58	(4, 6)	$(\frac{9}{2}^-)$	13.42
4.20	685	1, 3	$\frac{5}{2}^+$ ^c	13.56
4.50	247	1, 3	$\frac{3}{2}^+$ ^c	13.76
5.00	75	2, 4	$\frac{5}{2}^-$ ^d	14.11
5.075	73	3, 5	$\frac{7}{2}^+$ ^d	14.161
(5.50)	400	(1, 3)	$(\frac{5}{2}^+)$	(14.46)
6.44	^e		$\frac{3}{2}^-; T = \frac{3}{2}$	15.11

^a (1973GO15): from analysis in the single-level approximation. This assumes the J^π ordering suggested by (1965LI09). See also (1981AJ01).

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

^c The ordering of these two J^π values is not clear.

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

^e Weak anomaly at $E_\alpha = 6443.5 \pm 2.0$ keV: see Table 13.6 for parameters of 15.11 MeV state, and reaction 2 (1978HI06).

$$7. {}^9\text{Be}({}^{12}\text{C}, {}^8\text{Be}){}^{13}\text{C} \quad Q_{\text{m}} = 3.2810$$

Angular distributions have been measured at $E({}^{12}\text{C}) = 12$ and 15 MeV and at $E({}^9\text{Be}) = 20$ MeV [see (1981AJ01)] and at $E({}^{12}\text{C}) = 10.5, 12.0$ and 13.5 MeV (1982TA21; ${}^{13}\text{C}_{\text{g.s.}}$). In the earlier work the neutron spectroscopic factors for the first four states of ${}^{13}\text{C}$ are 1.15, 0.95, 0.20, 1.02. At $E({}^9\text{Be}) = 50$ MeV several higher states are also populated. For yield measurements see (1981AJ01) and (1982HU06, 1982TA21). See also (1983DEZW; theor.).

$$8. {}^{10}\text{B}({}^3\text{He}, \pi^+){}^{13}\text{C} \quad Q_{\text{m}} = -115.710$$

At $E({}^3\text{He}) = 260$ and 280 MeV ${}^{13}\text{C}_{\text{g.s.}}$ and an unresolved group at $E_{\text{x}} \approx 3.6$ MeV are observed. The cross section for this reaction at $\theta_{\text{lab}} = 20^\circ$ has been measured (1984WI06).

$$9. \text{(a) } {}^{10}\text{B}(\text{t}, \text{p}){}^{12}\text{B} \quad Q_{\text{m}} = 6.342 \quad E_{\text{b}} = 23.8757$$

- (b) $^{10}\text{B}(t, d)^{11}\text{B}$ $Q_m = 5.1969$
(c) $^{10}\text{B}(t, \alpha)^9\text{Be}$ $Q_m = 13.2281$

Yields have been measured for $E_t = 0.5$ to 2.0 MeV: there is no evidence of resonance behavior (1981AJ01). The yield of protons for $E_t = 3$ to 12 MeV shows a structure at $E_t = 5.4$ MeV ($\Gamma \approx 1$ MeV) which may be connected with a state at ≈ 28 MeV (1984GU1F). See also (1980BO1T; theor.).

10. $^{10}\text{B}(\alpha, p)^{13}\text{C}$ $Q_m = 4.0617$

Angular distributions of p_0 have been measured at many energies up to $E_\alpha = 30.4$ MeV [see (1970AJ04)] and at 31.2 MeV (1984KO1Q; also p_{1+2+3}), and for p_1 at $E_\alpha = 2.58$ to 3.06 MeV (1983CS03). For γ -decay measurements see Table 13.6 (1980WA24). See also ^{14}N .

11. $^{10}\text{B}(^6\text{Li}, ^3\text{He})^{13}\text{C}$ $Q_m = 8.0800$

Comparisons of the relative intensities of the ^3He groups in this reaction and of the triton groups in the mirror reaction (see reaction 7 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 in ^{13}N]: see (1981AJ01).

12. $^{10}\text{B}(^7\text{Li}, \alpha)^{13}\text{C}$ $Q_m = 21.4076$

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: see (1981AJ01).

13. $^{10}\text{B}(^{14}\text{N}, ^{11}\text{C})^{13}\text{C}$ $Q_m = 1.139$

At $E(^{10}\text{B}) = 100$ MeV angular distributions are reported for the transitions to $^{13}\text{C}^*(0, 3.68, 7.5, 11.8)$: see (1981AJ01).

14. $^{11}\text{B}(d, \gamma)^{13}\text{C}$ $Q_m = 18.6788$

Table 13.9: Resonant structure in $^{11}\text{B} + \text{d}$ ^a

Resonant structure in yield of (MeV \pm keV)							$\Gamma_{\text{c.m.}}$ (keV)	E_x (MeV)
γ_0	n_0	n_1	n_2	n_3	$\gamma_{15.1}$	α^b		
2.0 ± 100^c		1.2						19.7 ^d
		1.45					≈ 600	19.90
		1.6	1.8				≈ 200	20.24
			2.2			2.180 ± 10	116 ± 10	20.4
4.0 ± 100^c					3.080 ± 15		159 ± 15	20.52
		3.6			3.71 ± 20		114 ± 21	21.28
		4.23	4.0	4.1	4.4		≈ 1000	21.81
			(5.2)					22.1
								(23.1)
	9.6	9.6	9.6	9.6				26.8
	10.4		10.4	10.4				27.5

^a For references see Table 13.10 in (1981AJ01).

^b Yield of $\alpha_0, \alpha_1, \alpha_2, \alpha_3$.

^c (1981KA16): part of the GDR.

^d $J^\pi = \frac{5}{2}^-$ is suggested.

The $90^\circ \gamma_0$ excitation curve measured for $E_d = 1.0$ to 12.0 MeV shows resonant structure at $E_d = 2.0 \pm 0.1$ and 4.0 ± 0.1 MeV, $\Gamma \approx 0.6$ and ≈ 1 MeV, corresponding to states at $E_x = 20.4$ and 22.1 MeV: see Table 13.9. The results are consistent with the hypothesis of the isospin splitting of the giant dipole resonance in ^{13}C (1981KA16). See also (1981AJ01, 1984WO05).

$$15. \text{ (a) } ^{11}\text{B}(\text{d}, \text{n})^{12}\text{C} \quad Q_m = 13.7325 \quad E_b = 18.6788$$

$$\text{ (b) } ^{11}\text{B}(\text{d}, 2\text{n})^{11}\text{C} \quad Q_m = -4.989$$

The yield of neutrons and 15.1 MeV γ -rays has been measured in the range $E_d = 0.2$ to 11 MeV: see Table 13.9. For polarization measurements see (1981AJ01). The thick-target yield in reaction (b) has been measured for $E_d = 7.00$ to 16.01 MeV (1981AN16). See also (1981NO1G; applied.).

$$16. \text{ (a) } ^{11}\text{B}(\text{d}, \text{p})^{12}\text{B} \quad Q_m = 1.145 \quad E_b = 18.6788$$

(b) $^{11}\text{B}(\text{d}, \text{d})^{11}\text{B}$

The results from the measurements of the proton and γ -ray yields are not consistent: see reaction 19 and Table 13.10 in (1981AJ01). An activation analysis is reported by (1984GU1F) for $E_{\text{d}} = 3$ to 12 MeV. See also (1980HU1D, 1981HU1G). For reaction (b) see (1981AJ01).

17. $^{11}\text{B}(\text{d}, \alpha)^9\text{Be}$ $Q_{\text{m}} = 8.031$ $E_{\text{b}} = 18.6788$

At low energies the excitation functions for α_0 and α_1 increase monotonically: see (1970AJ04). Then at $E_{\text{d}} = 1.85$ MeV a pronounced resonance is observed in the $\alpha_0, \alpha_1, \alpha_2$ and α_3 yields: see Table 13.9. Some gross structure is also observed in these yields for $E_{\text{d}} = 1.0$ to 3.2 MeV: see (1981AJ01). See also ^9Be in (1984AJ01).

18. $^{11}\text{B}(^3\text{He}, \text{p})^{13}\text{C}$ $Q_{\text{m}} = 13.1853$

Levels derived from proton groups are displayed in Table 13.11 of (1981AJ01). [The only level parameters included in the values of Table 13.4 are $E_{\text{x}} = 7500 \pm 12$ keV and $\Gamma_{\text{c.m.}} < 5, 70 \pm 10$ and 150 ± 30 keV for $^{13}\text{C}^*(7.49, 7.69, 8.86)$.] The neutron decay of $^{13}\text{C}^*(6.86, 9.90, 11.75)$ are to $^{12}\text{C}_{\text{g.s.}}$ (99 ± 9)% and (100 ± 20)% for the first two states, and to $^{12}\text{C}^*(0, 4.4)$ (67 ± 16)% and (33 ± 8)% for the third (1973AD02). The decay parameters for the first $T = \frac{3}{2}$ state, $^{13}\text{C}^*(15.11)$, are shown in Table 13.6. The reduced asymmetries $B(^{13}\text{C})/B(^{13}\text{N}) - 1$ are $-0.07 \pm 0.13, 0.82_{-0.6}^{+1.2}, \geq 0.83 \pm 0.29$ and -0.04 ± 0.14 for the $\gamma_0(\text{M1}), \gamma_0(\text{E2}), \gamma_1(\text{E1})$ and $\gamma_2(\text{M1})$ 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 13.5. See, however, (1980BA54).

19. $^{11}\text{B}(\alpha, \text{d})^{13}\text{C}$ $Q_{\text{m}} = -5.1679$

Angular distributions of the d_0 group have been measured at $E_{\alpha} = 15.1$ to 25.2 MeV [see (1981AJ01)], at 29.5 MeV (1983VA28) and at 31.2 MeV (1984KO1Q; also d_{1+2+3}). See also (1983BE1Q; theor.).

20. $^{11}\text{B}(^6\text{Li}, \alpha)^{13}\text{C}$ $Q_{\text{m}} = 17.2037$

Angular distributions have been reported at $E(^6\text{Li}) = 4.72$ MeV for $\alpha_0, \alpha_1, \alpha_{2+3}, \alpha_4, \alpha_{5+6+7}$: see (1981AJ01).

21. $^{11}\text{B}(^{14}\text{N}, ^{12}\text{C})^{13}\text{C}$ $Q_m = 8.4064$

See ^{12}C in (1985AJ01) and (1984CL09; theor.).

22. $^{12}\text{C}(n, \gamma)^{13}\text{C}$ $Q_m = 4.94634$

$$Q_0 = 4946.362 \pm 0.021 \text{ keV (1981VA1P, 1980WA24).}$$

$$Q_0 = 4946.336 \pm 0.014 \text{ keV [see (1983CO09)].}$$

The thermal capture cross section is 3.53 ± 0.07 mb (1982JU01). See also (1981PR04, 1982MU14). The capture is $(67.47 \pm 0.92)\%$, $(0.16 \pm 0.01)\%$ and $(32.36 \pm 0.44)\%$ via $^{13}\text{C}^*(0, 3.09, 3.68)$ (1982MU14). (1982JU01) report $(68.6 \pm 0.9)\%$ and $(31.0 \pm 0.4)\%$ via $^{13}\text{C}^*(0, 3.68)$. (1981VA1P; prelim.) find recoil-corrected $\text{C} \rightarrow 0$, $\text{C} \rightarrow 3.68$ and $3.68 \rightarrow 0$ energies of 4946.397 ± 0.031 , 1261.854 ± 0.006 and 3684.516 ± 0.030 keV. Folding in the (1980WA24) value for $3.85 \rightarrow 0$ (see Table 13.11) leads to weighted mean adjusted energies for these three transitions of 4946.362 ± 0.021 , 1261.855 ± 0.006 and 3684.507 ± 0.019 keV [E.K. Warburton, private communication]. Other recent E_γ measurements of ground-state transitions are 3089.3 ± 0.3 and 3684.6 ± 0.1 keV (1982MU14; see also for cascade γ -rays). The branching ratios for the decay of $^{13}\text{C}^*(3.68)$ to $^{13}\text{C}^*(0, 3.09)$ are $(99.3 \pm 2.0)\%$ and $(0.74 \pm 0.05)\%$, respectively (1982MU14).

(1984WO05) have determined the angular distributions and analyzing powers of γ_0 for $E_\pi = 12.0$ to 18.8 MeV. The data were used to analyze results from the $^{13}\text{C}(\gamma, n_0)^{12}\text{C}$ reaction. These can be understood in terms of two doorway states at $E_x = 21.1 \pm 0.6$ and 20.52 ± 0.07 MeV with $\Gamma = 4.2 \pm 0.4$ and 0.51 ± 0.07 MeV, respectively (1984WO05). See also (1981AJ01) for the earlier work, (1981MUZQ, 1983SH2K) and (1983HO17, 1985HO1M; theor.).

23. (a) $^{12}\text{C}(n, n)^{12}\text{C}$ $E_b = 4.94634$

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

(c) $^{12}\text{C}(n, n')^4\text{He}^4\text{He}^4\text{He}$ $Q_m = -7.27476$

The coherent scattering length (thermal, bound) $a_{\text{coh}} = 6.6535 \pm 0.0014$ fm; $\sigma_{\text{scatt}} = 4.7456 \pm 0.0020$ b (1979KO26).

Total cross sections have been measured in the range 1 keV to 273 GeV/c [see (1981AJ01)] and at $E_n = 24$ keV (1983AI01; isotopic C), 0.509, 1.024 and 2.003 MeV (1982PO05; to $\pm(0.2 - 0.4)\%$), 2.5 to 40 MeV (1980KE1L and R.B. Schwartz, private communication; isotopic C; to $\pm(1 - 3)\%$) and 200 to 600 MeV (1980FR1K; prelim.). Differential cross sections are reported to the 4.4 MeV γ -ray to $E_n \approx 200$ MeV and for the 15.1 MeV γ -ray to $E_n = 36$ MeV (1985WE1D; prelim.). Integrated cross sections for n_1 and n_2 are reported at $E_n = 14.7$ MeV

(1981GU12). Total non-elastic cross sections have been measured at $E_n = 40.3$ and 50.4 MeV (1981ZA03). See also (1983CI1E) and see (1981AJ01) for the earlier work. (1983DA22) report elastic differential cross sections for $E_n = 9$ to 15 MeV for isotopic carbon and derive predictions for σ_R and σ_T . Polarization measurements have been reported for $E_n = 1.5$ to 15.9 MeV [see (1976AJ04, 1981AJ01)] and at $E_n = 8.9$ to 14.9 MeV (1983WO02; n_0, n_1) and 16.34 MeV (1984BE1X; n_0), and at $E_n = 15.85$ MeV (1980TH07; n_0, n_1) and 15.95 MeV (1981TO1E; n_0). See also (1983ANZY).

Observed resonances are displayed in Table 13.10 here, and in Table 13.13 in (1981AJ01) [the latter for $(n, n'\gamma_{4.4})$]. In Table 13.10 the newer work comes from phase-shift analyses ($\sigma(\theta)$ and analyzing power) in the range $E_n = 7.0$ to 12.0 MeV by (1983TO19, 1985TO02). A multilevel-multichannel R -matrix analysis is also reported by (1982KN02).

Table 13.10: Resonances in $^{12}\text{C}(n, n)^{12}\text{C}$ ^a

E_{res} (MeV \pm keV)	$\Gamma_{\text{c.m.}}$ (keV)	$^{13}\text{C}^*$ (MeV)	J^π	Γ_n/Γ
2.079 ± 3	6	6.864	$\frac{5}{2}^+$	
2.819 ± 3	1.2 ± 0.3	7.546		
2.94 ± 10	124 ± 7	7.66	$\frac{3}{2}^+$	
3.472 ± 15	1000 ± 50	8.149	$\frac{3}{2}^+$	
4.259 ± 15	210 ± 15	8.874	$\frac{1}{2}^-$	1.00
4.93707 ± 0.07^b	1.9 ± 0.15^b	9.4997	$(\frac{9}{2}^+)^c$	1.00
5.368 ± 5	26 ± 3	9.897	$\frac{3}{2}^-$	0.70 ± 0.10
6.294 ± 5	53 ± 4	10.751	$\frac{7}{2}^-^c$	0.70 ± 0.10
6.5		10.9		
6.558 ± 8	37 ± 4	10.994	$(\frac{1}{2}^+)$	0.40 ± 0.10
6.7		11.1		
7.35 ± 50^d	129 ± 40	11.72	$\frac{3}{2}^-$	0.80 ± 0.08
7.62 ± 90^d	494 ± 80	11.97	$\frac{5}{2}^+$	0.51 ± 0.06
7.78 ± 80^d	538 ± 65	12.12	$\frac{3}{2}^+$	0.28 ± 0.05
7.79 ± 50^d	77 ± 30	12.13	$\frac{5}{2}^-$	0.43 ± 0.06
7.80 ± 70^d	426 ± 70	12.14	$\frac{1}{2}^+$	0.50 ± 0.07
7.94 ± 70^d	186 ± 50	12.27	$\frac{3}{2}^-$	0.73 ± 0.08
8.12 ± 50^d	114 ± 40	12.43	$\frac{7}{2}^-$	0.42 ± 0.06
9.35	619 ± 50	13.57	$\frac{7}{2}^-$	0.18 ± 0.03
9.96		14.13	$\frac{3}{2}^-$	
10.88	450	14.98	$\frac{7}{2}^-$	

Table 13.10: Resonances in $^{12}\text{C}(n, n)^{12}\text{C}$ ^a (continued)

E_{res} (MeV \pm keV)	$\Gamma_{\text{c.m.}}$ (keV)	$^{13}\text{C}^*$ (MeV)	J^π	Γ_n/Γ
11.20		15.27	$\frac{9}{2}^+$	
11.40		15.46	$\frac{3}{2}^-$	
12.1	230	16.1	$(\frac{5}{2}^- + \frac{7}{2}^+)$	
15.8	≈ 460	19.5	$(\frac{1}{2}, \frac{3}{2})^-$	
19.6 ± 200	≈ 1000	23.0		

^a For earlier references and additional information see Tables 13.10 in (1970AJ04), 13.16 in (1976AJ04) and 13.12 in (1981AJ01). See the discussion in (1985TO02). See also (1982KN02) for an R -matrix analysis to $E_n \approx 9$ MeV.

^b Derived from a lorentzian probability plot (1980CI03).

^c See (1982KN02).

^d (1983TO19).

For reaction (c) see (1983AN02, 1984BR19) and (1984HA48). See also ^{12}C in (1985AJ01) and (1980SA34, 1980WE1F, 1982GOZZ, 1984MA2D), (1979CO1B, 1982DI1E, 1983AF01, 1983HA1U, 1985BA2R; applied), (1980LI1M, 1981IN1B, 1981MUZQ, 1981WA1G, 1982FU1F, 1982HA1A, 1983GO1H, 1983SH2K, 1985HO1J) and (1979OL1A, 1979ZH1B, 1980DM1A, 1980RI05, 1981DM1A, 1981FL04, 1981SH1A, 1982AZ01, 1982PL1A, 1983HO17, 1983KO44, 1983OL04, 1985MA1U; theor.).

$$24. \ ^{12}\text{C}(n, 2n)^{11}\text{C} \quad Q_m = -18.721 \quad E_b = 4.94634$$

Excitation functions for $E_n = 22.8$ to 33.6 MeV are reported by (1981AN16). See also (1981AJ01), (1981WE1B) and (1979CO1B; applied).

$$25. \ ^{12}\text{C}(n, p)^{12}\text{B} \quad Q_m = -12.587 \quad E_b = 4.94634$$

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 $E_n = 50$ MeV [see (1981AJ01)] and 18 MeV (1982DE16). For proton emission at $E_n \approx 545$ MeV see (1985FR07). See also ^{12}B in (1985AJ01), (1983SU07), (1983SH2K) and (1981OL1B; theor.).

26. (a) $^{12}\text{C}(\text{n}, \text{d})^{11}\text{B}$ $Q_{\text{m}} = -13.732$ $E_{\text{b}} = 4.94634$
 (b) $^{12}\text{C}(\text{n}, \text{t})^{10}\text{B}$ $Q_{\text{m}} = -18.9293$
 (c) $^{12}\text{C}(\text{n}, ^3\text{He})^{10}\text{Be}$ $Q_{\text{m}} = -19.4670$

For deuteron and triton emission at $E_{\text{n}} \approx 545$ MeV see (1985FR07). See also (1983SU07) and (1981AJ01, 1983SH2K).

27. $^{12}\text{C}(\text{n}, \alpha)^9\text{Be}$ $Q_{\text{m}} = -5.7013$ $E_{\text{b}} = 4.94634$

The cross section for the α_0 group shows a broad structure at $E_{\text{n}} \approx 8$ MeV: see (1981AJ01). For cross sections for α_0 and total α -emission at $E_{\text{n}} = 14.1$ MeV see (1984HA48). See also (1982KN02) in reaction 23, (1983SU07) and (1983SH2K).

28. $^{12}\text{C}(\text{p}, \pi^+)^{13}\text{C}$ $Q_{\text{m}} = -135.4033$

At $E_{\text{p}} = 156.4$ to 200 MeV angular distributions are reported to $^{13}\text{C}^*(0, 3.09, 3.68, 3.85, 6.86, 9.5)$. The energy dependence of the angular distributions and of the cross sections are different for the single-particle states [$^{13}\text{C}^*(0, 3.09, 3.85)$] and the 2p2h states [$^{13}\text{C}^*(3.68, 6.86, 9.5)$] (1981SO04). At $E_{\text{p}} = 200$ to 250 MeV the analyzing-power angular distributions for $^{13}\text{C}^*(0, 3.09 + 3.68 + 3.85, 6.86 + 7.50, 9.50 + 9.90)$ are found to be energy dependent (1982LO03). Angular distributions have also been measured at $E_{\text{p}} = 147$ to 159 MeV (1981SJ02) and $E_{\text{p}} = 185$ MeV [see (1981AJ01)], 200 MeV (1980HO20; to $^{13}\text{C}^*(0, 3.09, 3.68, 3.85)$) and 200 to 250 MeV (1982LO03, 1984LO13; to $^{13}\text{C}^*(0, 3.09 + 3.68 + 3.85)$ and A_{y}). Polarization measurements have also been reported at $E_{\text{p}} = 147$ to 159 MeV (1981SJ02; $^{13}\text{C}^*(0, 3.09, 3.68+3.85)$) and 170, 183 and 190 MeV (1982GRZY). See (1981AJ01) for the earlier work. See also (1980SO05, 1981NA1C, 1982GR1M), (1983VI01) and the ‘‘General’’ section here.

29. (a) $^{12}\text{C}(\text{d}, \text{p})^{13}\text{C}$ $Q_{\text{m}} = 2.7218$
 (b) $^{12}\text{C}(\text{d}, \text{np})^{12}\text{C}$ $Q_{\text{m}} = -2.2246$

Measurements of proton groups and γ -rays are summarized in Table 13.11. Angular distributions have been studied at many energies to $E_{\text{d}} = 80.2$ MeV [see (1981AJ01)] and more recently in the range $E_{\text{d}} = 0.56$ to 2.5 MeV (1980HA1X; $p_{0 \rightarrow 3}$), 17.7 MeV (1984PE24; to $^{13}\text{C}^*(9.50)$) and at $E_{\text{d}} = 16$ MeV to $^{13}\text{C}^*(3.09)$ [$J^{\pi} = \frac{1}{2}^{+}$] and to ($^{12}\text{C} + \text{n}$) with zero relative energy (1983WI1D) [the two angular distributions are very similar] as well as at $E_{\text{d}} = 56$ MeV (1984HA26; $p_0 \rightarrow p_3$). See also (1982SA29) and ^{14}N .

Table 13.11: Levels of ^{13}C from $^{12}\text{C}(\text{d}, \text{p})^{13}\text{C}$ ^a

^{13}C (MeV \pm keV)	$\Gamma_{\text{c.m.}}$ (keV)	l_n	J^π	S ^b
0		1	$\frac{1}{2}^-$	0.58 ± 0.04
3.089443 ± 0.020 ^c		0	$\frac{1}{2}^+$	0.36 ± 0.02
3.684482 ± 0.023 ^c		1	$\frac{3}{2}^-$	0.10
3.853783 ± 0.022 ^c		2	$\frac{5}{2}^+$	1.1
6.86		2	$\frac{5}{2}^+$	0.04
7.470 ± 20				
7.533 ± 20				
7.641 ± 20	70 ± 15			
8.4 ± 300	1100 ± 300	2	$\frac{3}{2}^+$	1.0
8.86		1	$\frac{1}{2}^-$	0.5
9.500 ± 20		(1)	$(\frac{3}{2}^-)^f$	
9.897 ± 20		1	$\frac{3}{2}^-$	0.1
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 ^d	≈ 260			
12.108 ± 5	81 ± 8			
22.3 ± 200 ^{d,e}	200 ± 50	(1)	$(\frac{3}{2}^-)$	
23.1 ± 200 ^{d,e}	500 ± 100			
23.8 ± 200 ^{d,e}	120 ± 40			

^a For references and additional information see Table 13.14 in (1981AJ01).

^b Preliminary values at $E_d = 17.7$ MeV are 0.50, 0.21, 0.50, 0.16, 0.54 for $^{13}\text{C}^*(0, 3.68, 8.9, 9.9, 11.1)$ (1984PEZW).

^c (1980WA24): E_γ for the $3.85 \rightarrow 3.68$ transition is 169.300 ± 0.004 keV. Using $E_x = 3684.507 \pm 0.019$ keV [see reaction 22] and this value for E_γ , E_x for the higher state is 3853.807 ± 0.019 keV, which we adopt. I am indebted to Dr. E.K. Warburton for his comments. See also Table 13.5 and the ‘‘General’’ section here.

^d May correspond to unresolved states.

^e (1983SA1M; preliminary): $E_d = 56$ and 60 MeV.

^f Known to be $\frac{9}{2}^+$.

(1981RU04) determine $|g| = 0.558 \pm 0.015$ and $\tau_m = 12.2 \pm 0.4$ psec for $^{13}\text{C}^*(3.85)$. For other τ_m measurements see Table 13.5, and for γ -decay see Table 13.6. For reaction (b) see (1981AJ01). For a fragmentation study at 9.1 GeV/c see (1985AB1J). See also ^{14}N , (1983JI04, 1981OZ1A), (1981OS1H) and (1980BA54, 1982GO05, 1982TA19, 1982TH02, 1982TH06; theor.).

$$30. \ ^{12}\text{C}(t, d)^{13}\text{C} \quad Q_m = -1.3109$$

See (1981AJ01).

$$31. \ ^{12}\text{C}(^3\text{He}, 2p)^{13}\text{C} \quad Q_m = -2.7718$$

See (1981AJ01).

$$32. \ ^{12}\text{C}(\alpha, ^3\text{He})^{13}\text{C} \quad Q_m = -15.6314$$

Angular distributions of the ^3He particles to the first three states of ^{13}C have been measured in the range $E_\alpha = 56$ to 139 MeV. The ground-state distributions in this, and in the mirror reaction $^{12}\text{C}(\alpha, t)^{13}\text{N}$, have also been compared: see (1981AJ01).

$$33. \ ^{12}\text{C}(^7\text{Li}, ^6\text{Li})^{13}\text{C} \quad Q_m = -2.304$$

Angular distributions at $E(^7\text{Li}) = 48$ MeV to $^{13}\text{C}^*(0, 3.09, 3.68, 3.85)$ have been analyzed and yield spectroscopic factors of 0.80, 0.44, 0.17 and 0.74, respectively: see (1981AJ01). An angular distribution and TAP measurements are reported at $E(^7\vec{\text{Li}}) = 21.1$ MeV (1984MO06). See also (1980BA54; theor.).

$$34. \ ^{12}\text{C}(^9\text{Be}, ^8\text{Be})^{13}\text{C} \quad Q_m = 3.2810$$

Excitation curves involving $^{13}\text{C}^*(0, 3.09, 3.68 + 3.85)$ have been studied by (1983JA09). See also (1980HU1E) and (1983KA17; theor.).

$$35. \ ^{12}\text{C}(^{12}\text{C}, ^{11}\text{C})^{13}\text{C} \quad Q_m = -13.775$$

Angular distributions have been reported at $E(^{12}\text{C}) = 93.8$ MeV [to $^{13}\text{C}^*(0, 3.85)$] [see (1981AJ01)] and at 72.5 MeV to $^{13}\text{C}_{\text{g.s.}}$ (1981CH1R).

36. (a) $^{12}\text{C}(^{14}\text{N}, ^{13}\text{N})^{13}\text{C}$ $Q_{\text{m}} = -5.6071$
 (b) $^{12}\text{C}(^{14}\text{N}, \text{p})^{12}\text{C}^{13}\text{C}$ $Q_{\text{m}} = -7.5506$

Angular distributions have been reported in the range $E(^{14}\text{N}) = 28$ to 154.8 MeV involving $^{13}\text{C}^*(0, 3.09, 3.85, 7.3 \pm 0.3)$: see (1981AJ01). For a study of fragmentation at $E(^{14}\text{N}) = 48$ MeV, see (1983QU02). See also (1980BA54, 1980IZ1B, 1980TA1K, 1983OS08; theor.).

37. $^{12}\text{C}(^{16}\text{O}, ^{15}\text{O})^{13}\text{C}$ $Q_{\text{m}} = -10.7176$

See (1981AJ01).

38. (a) $^{12}\text{C}(^{17}\text{O}, ^{16}\text{O})^{13}\text{C}$ $Q_{\text{m}} = 0.8027$
 (b) $^{12}\text{C}(^{18}\text{O}, ^{17}\text{O})^{13}\text{C}$ $Q_{\text{m}} = -3.098$

See (1981AJ01).

39. $^{13}\text{B}(\beta^-)^{13}\text{C}$ $Q_{\text{m}} = 13.436$

See ^{13}B and Table 13.2.

40. (a) $^{13}\text{C}(\gamma, \text{n})^{12}\text{C}$ $Q_{\text{m}} = -4.94634$
 (b) $^{13}\text{C}(\gamma, 2\text{n})^{11}\text{C}$ $Q_{\text{m}} = -23.668$

The main features of the cross section is a sharp peak corresponding to the $T = \frac{3}{2}$ state $^{13}\text{C}^*(15.11)[\Gamma_{\gamma_0} = 19.7 \pm 2.0$ eV], the broad pigmy resonance at $E_{\text{x}} = 13$ MeV [on which peaks are superimposed at $E_{\text{x}} = 11.0, 13.8, 16.5$ and 17.8 MeV] and the giant resonance at $E_{\text{x}} = 24$ MeV ($\sigma_{\text{max}} = 9.5$ mb) [surrounded by shoulder resonances at $E_{\text{x}} = 20.8$ 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. A study of the angular distributions of n_0 suggests states at $E_{\text{x}} = 7.70$ ($\frac{3}{2}^+$), 7.95 ($\frac{3}{2}^+$), 8.95 ($(\frac{1}{2}^-)$), 10.0 ($(\frac{3}{2}^-)$), 11.0 ($(\frac{1}{2}^+)$) and 12.05 MeV ($(\frac{3}{2}^+)$). See (1981AJ01) for references and for additional information. See also (1982JU03) and (1980JO1E, 1982KI1H; theor.).

41. $^{13}\text{C}(\gamma, p)^{12}\text{B}$ $Q_m = -17.534$

The integrated cross section for $E_\gamma = 17.5$ (threshold) to 28 MeV is 36 ± 5 MeV · mb. Resonances are observed at $E_x = 18.6, (19.7), 20.7, (22), 23.5, 24.5$ and (26) MeV. [σ_{max} at $E_x \approx 23$ MeV is 8 mb]. Below ≈ 18 MeV the cross section is dominated by transitions involving $T_<$ states. The states at 18.6 and 20.7 MeV have a significant $T_>$ component. The two isospin components of the GDR appear to be split by 6.8 MeV (1983ZU02). For the earlier work see (1981AJ01).

42. $^{13}\text{C}(\gamma, \gamma)^{13}\text{C}$

See (1981AJ01).

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

The elastic scattering has been studied for $E_e = 120$ to 750 MeV [see (1981AJ01)] and 80 to 338 MeV (1982HI07). The form factor for M1 elastic scattering is enhanced above $q \approx 2$ fm⁻¹ (1982HI07). See also (1983SI11) and (1985SI05; theor.). A number of inelastic groups are seen: see Table 13.12. [The data (1980SO1B) shown in Table 13.16 of (1981AJ01) have not been published.] A distinct splitting of the giant resonance into two large peaks near $E_x = 20.5$ and 24.5 MeV, with widths of ≈ 3 and ≈ 4 MeV, respectively, is observed. It is suggested that these are groupings of narrower peaks. The $E_x = 20.5$ and 24.5 MeV resonances are probably $T = \frac{1}{2}$ and $T = \frac{3}{2}$, although the 4 MeV splitting is somewhat smaller than expected: see (1981AJ01). For reaction (b) see (1981AJ01). See also (1981SI1B, 1982DE1K, 1984DO20, 1984LI25, 1985HI04) and (1981DE07, 1981DE1U, 1981IS11, 1981LI13, 1981SU03, 1981SU08, 1982CH16, 1982LIZW, 1983CH15, 1983CH1N, 1983GM1A, 1984SA1H; theor.).

44. (a) $^{13}\text{C}(\pi^-, \pi^-)^{13}\text{C}$
 (b) $^{13}\text{C}(\pi^+, \pi^+)^{13}\text{C}$

Angular distributions have been measured at $E_\pi = 20$ to 180 MeV: see (1981AJ01) and Table 13.13. At $E_{\pi^\pm} = 162$ MeV angular distributions have been measured to many states (or groups of states) of ^{13}C with E_x up to 22 MeV [see Table 13.13]. Enhanced in π^- scattering are $^{13}\text{C}^*(0, 3.09, 3.85, 9.50, 21.60 \pm 0.05)$, the latter very strongly but with a large uncertainty. Enhanced in π^+ scattering are $^{13}\text{C}^*(3.68, 7.55, 8.86, 11.82, 16.05 \pm 0.05, 17.92 \pm 0.05, 21.37 \pm 0.05)$. The data for $^{13}\text{C}^*(9.50, 21.60, 16.05, 21.37)$ indicate pure neutron particle-hole excitations for the first two states and pure proton excitation for the latter two, however with large uncertainties except

Table 13.12: Electromagnetic transitions ^a in ¹³C from ¹³C(e, e')¹³C

E_x (MeV \pm keV)	J^π	Mult.	Γ_{γ_0} (eV)	$\Gamma_{\gamma_0}/\Gamma_W$ (W.u.)
3.08 \pm 30 ^b	$\frac{1}{2}^+$	C1	0.68 \pm 0.23	0.062
3.69 \pm 20	$\frac{3}{2}^-$	C2	$(3.61 \pm 0.40) \times 10^{-3}$	3.52
		M1	0.358 \pm 0.047	0.339
6.85 \pm 60	$\frac{5}{2}^+$	M2	$(6.9 \pm 3.6) \times 10^{-5}$	0.055
7.54 \pm 20	$\frac{5}{2}^-$	M3	(1.01×10^{-5})	(35)
		C2	0.115 \pm 0.007 ^d	3.15
8.86 \pm 20 ^c	$\frac{1}{2}^-$	M1	3.36 \pm 0.47 ^e	0.230
		E0	2.09 ^f	
9.50 ^b	$\frac{9}{2}^+$			
9.90 \pm 30	$\frac{3}{2}^-$	C2	$(6.3 \pm 1.1) \times 10^{-3}$	0.045
		M1	0.324 \pm 0.038	0.0159
11.07 \pm 20	$\frac{1}{2}^-$	M1	1.02 \pm 0.12	0.0359
		E0	2.62 ^f	
	$\frac{3}{2}^-$	C2	0.256 \pm 0.047	1.03
		M1	0.172 \pm 0.020	0.006
15.11 \pm 20	$\frac{3}{2}^-$	C2	0.6 \pm 0.1	0.50
		M1	22.4 \pm 1.5	0.31
16.1 ^b				

^a For references see Table 13.15 in (1981AJ01). See also (1984MO1D) and Tables 13.4 and 13.5.

^b See (1984HIZX, 1985HI04).

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

^d 0.11 ± 0.015 eV (1980HO11; ¹³C(γ , n)).

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

^f Monopole matrix element in fm².

Table 13.13: Summary of recent $^{13}\text{C}(\pi, \pi)$ angular distributions

E_{π^+} (MeV)	E_{π^-} (MeV)	Angular distributions to ^{13}C	Refs.
	20, 30, 40, 50	g.s.	(1981KA1N)
48.6		g.s.	(1978DY01)
65, 80	65, 80	g.s.	(1983BL11)
100	100	g.s., 3.7, 7.6, 9.5	(1982ANZW)
162	162	g.s., 3.09, 3.68, 3.85, 7.55, 8.86, 9.5, 11.82, 16.05, 17.92, 21.37, 21.60	(1982SE04, 1983SE15)
180	180	g.s., 3.68, 7.55, 9.5, 11.7, 15.0, 17.5	(1979SC25)

for $^{13}\text{C}^*(9.5)$. Spin assignments are $\frac{9}{2}^+$ for $^{13}\text{C}^*(9.50)$; $\frac{7}{2}^+$ or $\frac{9}{2}^+$ for $^{13}\text{C}^*(16.05, 17.92, 21.37, 21.60)$; $\frac{5}{2}^+$ and/or $\frac{7}{2}^+$ for $^{13}\text{C}^*(11.82)$ [unresolved doublet?]. The π^-/π^+ asymmetry near 21.5 MeV suggests that there is isospin mixing between $T = \frac{1}{2}$ and $\frac{3}{2}$ states of $J^\pi = \frac{7}{2}^+$ and/or $\frac{9}{2}^+$ (1982SE04, 1983SE15). See also (1981AJ01), (1981SE08), (1984LI1T; theor.) and the ‘‘General’’ section here.

45. $^{13}\text{C}(n, n)^{13}\text{C}$

Angular distributions have been measured at $E_n = 4.5$ to 11 MeV (1982REZX; n_0, n_1), 5.7 to 8.25 MeV (1982REZY; n_2, n_3), 9.97, 11.96, 13.94, 15.94 and 17.92 MeV (1982DA05, 1983DA22; n_0 ; and n_1, n_{2+3} at 9.97 MeV). See also (1981AJ01), ^{14}C and (1984PEZV, 1985DI1B; theor.).

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

(b) $^{13}\text{C}(p, pn)^{12}\text{C}$ $Q_m = -4.94634$

Angular distributions have been studied at $E_p = 1.37$ MeV to 1 GeV [see (1981AJ01)] and at $E_p = 135$ MeV (1982CO08; to $^{13}\text{C}^*(0, 3.09, 3.68, 3.85, 7.55, 8.86, 9.50, 9.90, 10.75, 11.08$ [$J^\pi = \frac{1}{2}^-$], 15.11; DWBA) [see also (1982RI05)], $E_p = 200$ MeV (1981ME02; elastic; also A_y) and 547 MeV (1984SE12; $^{13}\text{C}^*(0, 3.09, 3.68, 3.85, 6.86, 7.55, 8.86, 9.50)$; also A_y). At $E_p = 135$ MeV $^{13}\text{C}^*(6.86$ [weak], 11.85, 14.39, 16.15, 21.4) are also populated (1982CO08). See also (1982PEZY). For reaction (b) see (1981AJ01). For breakup see (1983GL1D). See also ^{14}N , (1983PE14, 1983SC1G) and (1982BA14, 1984PEZV; theor.).

47. $^{13}\text{C}(d, d)^{13}\text{C}$

Angular distributions have been measured at $E_d = 0.71$ to 13.6 MeV [see (1981AJ01)], at $E_d = 17.7$ MeV (1984PE24; d_0) and at $E_d = 56$ MeV (1984HA26; d_0). See also ^{15}N .

48. $^{13}\text{C}(^3\text{He}, ^3\text{He})^{13}\text{C}$

Angular distributions of elastically scattered ^3He ions have been studied at $E(^3\text{He}) = 12$ to 41 MeV: see (1981AJ01). Angular distributions have also been reported at $E(^3\text{He}) = 43.6$ MeV for the ^3He ions to $^{13}\text{C}^*(3.09, 3.68, 3.85, 6.86, 7.49 + 7.55, 7.69, 8.86, 9.50, 9.90, 10.75 + 10.82, 11.08, 11.85, 15.11, 16.0)$ [and these have been compared to the analog states reached in the $^{13}\text{C}(^3\text{He}, t)^{13}\text{N}$ reaction] (1981PE08). See (1981AJ01) for the earlier work and (1983PE14).

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

Angular distributions have been studied at $E_\alpha = 15$ to 40.5 MeV [see (1981AJ01)] and at $E_\alpha = 35.5$ MeV (1981PE08; to $^{13}\text{C}^*(3.09, 3.68, 3.85, 6.86, 7.49 + 7.55, 7.69, 8.86, 9.50, 11.08, 11.85)$). For $^{13}\text{C}^*(7.69)$, $E_x = 7686 \pm 6$ keV, $\Gamma_{\text{c.m.}} = 70 \pm 5$ keV (1980FU04; also line shapes). $\Gamma_\gamma/\Gamma \leq 3 \times 10^{-4}$ and $(3.0 \pm 0.6) \times 10^{-4}$ for $^{13}\text{C}^*(6.86, 7.49 + 7.55)$, respectively (1984DE1U). See also (1981AJ01) for the earlier work and (1982BU1D, 1983GO27; theor.).

50. (a) $^{13}\text{C}(^6\text{Li}, ^6\text{Li})^{13}\text{C}$

(b) $^{13}\text{C}(^7\text{Li}, ^7\text{Li})^{13}\text{C}$

Angular distributions of elastically scattered Li ions have been studied at $E(\text{Li}) = 4.5$ to 34 MeV and $E(^6\text{Li}) = 28$ MeV (1980CU03), 40 MeV [see (1981AJ01)] as well as at $E(^7\text{Li}) = 34$ MeV (1983STZS). For fusion and breakup cross sections see (1982DE30, 1982TA23). See also (1983BI1A, 1984CA39, 1984HA53) and (1981ME1F, 1984AG1B; theor.).

51. $^{13}\text{C}(^9\text{Be}, ^9\text{Be})^{13}\text{C}$

The elastic scattering has been studied at $E(^{13}\text{C}) = 28.1$ and 36.2 MeV: see (1981AJ01). For total reaction cross sections see (1984DA17). See also (1981GR17; theor.).

52. (a) $^{13}\text{C}(^{10}\text{B}, ^{10}\text{B})^{13}\text{C}$

(b) $^{13}\text{C}(^{11}\text{B}, ^{11}\text{B})^{13}\text{C}$

Elastic angular distributions have been measured at $E(^{10}\text{B}) = 18, 25, 32, 39$ and 46 MeV (1982MA20) and at $42.5, 62.3$ and 80.9 MeV (1985MA10). For fusion and breakup cross sections see (1981MA18, 1982MA20, 1983DA20, 1983MA53, 1984DEZX, 1984FR1A, 1984HAZK, 1985MA10). See also (1983BI1A, 1983DU13, 1984HA53) and (1984HA43; theor.).

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

Angular distributions for reaction (a) have been reported for $E(^{12}\text{C}) = 10$ to 87 MeV and $E(^{13}\text{C}) = 12$ and 36 MeV [see (1981AJ01)] and at $E(^{13}\text{C}) = 21.7, 24.6, 27.4$ MeV (1984FR05; $^{13}\text{C}^*(0, 3.09, 3.85)$) and 260 MeV (1985BO2F; $^{12}\text{C}^*(0, 4.4)$). Elastic distributions for reactions (b) and (c) have been studied at $E(^{13}\text{C}) = 15$ to 24 MeV and at 15 MeV, respectively. See (1981AJ01) for references. At $E(^{13}\text{C}) = 32$ MeV the single and mutual inelastic excitation of $^{13}\text{C}^*(3.09)$ has been studied by (1984BA31): the mutual excitation is very much smaller than predicted using a molecular particle-core coupling model. For excitation functions, fusion and evaporation cross sections see (1981HE08, 1982CH05, 1982DA16, 1983FR04, 1983KO15, 1984BA31, 1984FR1A). For a spin-flip probability study see (1981TA21). See also ^{12}C in (1985AJ01), (1981PL1C, 1983HAZI), (1981ST1P, 1983BI1A, 1983DU13, 1983GR1M, 1983VO1J, 1984FR1A, 1984HA53) and (1980BA54, 1982LO13, 1982OH05, 1982VO1F, 1983BA49, 1983CI08, 1983DE1U, 1983FR23, 1983HU1C, 1983LA1E, 1983RO16, 1984HA43, 1984IN03, 1984MAZT, 1984SA31, 1984VO11, 1985VO01; theor.).

54. (a) $^{13}\text{C}(^{14}\text{N}, ^{14}\text{N})^{13}\text{C}$
 (b) $^{13}\text{C}(^{15}\text{N}, ^{15}\text{N})^{13}\text{C}$

Elastic angular distributions (reaction (a)) have been measured at $E(^{14}\text{N}) = 19.3$ MeV [see (1981AJ01)] and 28 and 35 MeV (1983SR01) and at $E(^{13}\text{C}) = 105$ MeV (1980PR09). For excitation curves and fusion cross sections see (1982DI13, 1983SR01). See also (1981AJ01), (1983BI1A, 1983DU13, 1984FR1A, 1984HA53) and (1983GO13; theor.).

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

Elastic angular distributions have been measured for reaction (a) at $E(^{16}\text{O}) = 10$ to 30 MeV and at $E(^{13}\text{C}) = 36$ and 105 MeV: see (1981AJ01). Those for reaction (b) are reported at

$E(^{17}\text{O}) = 29.8$ and 32.3 MeV [see (1981AJ01)] and at 85.4 , 120 and 140 MeV (1982HE07); and those for reaction (c) at $E(^{18}\text{O}) = 15$, 20 , 24 and 31 MeV [see (1981AJ01)]. For breakup yield and fusion measurements see (1980RA12, 1982HE07, 1983DA02, 1983FR17, 1984RA10) and (1981AJ01). See also (1982LE1N, 1983BI1A, 1983DU13, 1984FR1A, 1984HA53, 1985GA1M) and (1983AB08, 1983CI08, 1983PA1G, 1984AB1A, 1984HA43, 1984IN03, 1985PAZY; theor.).

56. $^{13}\text{C}(^{22}\text{Ne}, ^{22}\text{Ne})^{13}\text{C}$

See (1983DU13).

57. $^{13}\text{C}(^{24}\text{Mg}, ^{24}\text{Mg})^{13}\text{C}$

See (1980LI13, 1983CH01, 1984LI14; theor.).

58. $^{13}\text{C}(^{28}\text{Si}, ^{28}\text{Si})^{13}\text{C}$

Backward elastic angular distributions are reported at $E(^{28}\text{Si}) = 77.6$ to 94.6 MeV: see (1981AJ01). For an excitation function study see (1982CH02).

59. (a) $^{13}\text{C}(^{32}\text{S}, ^{32}\text{S})^{13}\text{C}$

(b) $^{13}\text{C}(^{36}\text{S}, ^{36}\text{S})^{13}\text{C}$

For an excitation function study (reaction (a)) see (1982CH02). For reaction (b) see (1983DU13).

60. $^{13}\text{C}(^{40}\text{Ar}, ^{40}\text{Ar})^{13}\text{C}$

See (1983DU13, 1986MO15).

61. (a) $^{13}\text{C}(^{40}\text{Ca}, ^{40}\text{Ca})^{13}\text{C}$

(b) $^{13}\text{C}(^{48}\text{Ca}, ^{48}\text{Ca})^{13}\text{C}$

See (1981AJ01, 1982HO1E) and (1980JA1C, 1980MA34, 1981KU09, 1981KU03, 1981LA04, 1984HU1Q; theor.).

62. $^{13}\text{N}(\beta^+)^{13}\text{C}$ $Q_m = 2.2205$

See ^{13}N .

63. $^{14}\text{C}(\gamma, n)^{13}\text{C}$ $Q_m = -8.1765$

See (1985KU01) and ^{14}C .

64. $^{14}\text{C}(\text{p}, \text{d})^{13}\text{C}$ $Q_m = -5.9519$

Angular distributions have been measured at $E_p = 12$ to 27 MeV: see (1981AJ01).

65. $^{14}\text{C}(\text{d}, \text{t})^{13}\text{C}$ $Q_m = -1.9192$

Angular distributions for $t_0 \rightarrow t_3$ have been studied at $E_d = 12$ and 14 MeV: see (1981AJ01).

66. $^{14}\text{C}(^3\text{He}, \alpha)^{13}\text{C}$ $Q_m = 12.4013$

Angular distributions have been measured at $E(^3\text{He}) = 3$ to 44.8 MeV: see (1981AJ01).

67. (a) $^{14}\text{C}(^{12}\text{C}, ^{13}\text{C})^{13}\text{C}$ $Q_m = -3.2301$

(b) $^{14}\text{C}(^{14}\text{C}, ^{15}\text{C})^{13}\text{C}$ $Q_m = -6.9584$

(c) $^{14}\text{C}(^{16}\text{O}, ^{17}\text{O})^{13}\text{C}$ $Q_m = -4.0329$

Angular distributions have been measured at $E(^{16}\text{O}) = 20, 25$ and 30 MeV: see (1981AJ01).
For reactions (a) and (b) see (1985KO04).

68. (a) $^{14}\text{N}(\gamma, \text{p})^{13}\text{C}$ $Q_m = -7.5506$

(b) $^{14}\text{N}(\gamma, \text{np})^{12}\text{C}$ $Q_m = -12.4970$

Angular distributions measured in the giant resonance region of ^{14}N are consistent with the proton decay of $(p_{1/2})^{-1}(2s1d)$ giant dipole states to $^{13}\text{C}_{\text{g.s.}}$ and of $(p_{3/2})^{-1}(2s1d)$ states to $^{13}\text{C}^*(3.68)$. The population of $^{13}\text{C}^*(3.09, 3.85)$ [and of $^{13}\text{C}^*(7.55)$ ([1983VA1K](#))] is also reported. For $E_{\text{bs}} = 15.5$ to 29.5 MeV a large fraction of the neutron yield appears to be associated with sequential decay to ^{12}C via $^{13}\text{C}^*(7.75, 8.86, 11.80)$: see ([1981AJ01](#)). See also ^{14}N .

$$69. \ ^{14}\text{N}(n, d)^{13}\text{C} \quad Q_{\text{m}} = -5.3260$$

Angular distributions have been determined at $E_{\text{n}} = 10.1$ to 14.7 MeV: see ([1981AJ01](#)).

$$70. \ ^{14}\text{N}(p, 2p)^{13}\text{C} \quad Q_{\text{m}} = -7.5506$$

At $E_{\text{p}} = 46$ MeV, the summed proton spectrum shows transitions to $^{13}\text{C}^*(0, 3.68, 7.5, 11.9)$; see ([1981AJ01](#)).

$$71. \ ^{14}\text{N}(d, ^3\text{He})^{13}\text{C} \quad Q_{\text{m}} = -2.0571$$

At $E_{\text{d}} = 52$ MeV, angular distributions have been measured for the ^3He particles to $^{13}\text{C}^*(0, 3.09, 3.68, 6.86, 7.5, 8.86, 9.50, 11.9 \pm 0.15)$ and analyzed by DWBA: $J^{\pi} = \frac{5}{2}^{-}, \frac{1}{2}^{-}, \frac{3}{2}^{-}$ and $\frac{3}{2}^{-}$, respectively, are assigned to $^{13}\text{C}^*(7.5, 8.86, 9.50, 11.9)$. [However $^{13}\text{C}^*(9.50)$ is known to have $J^{\pi} = \frac{9}{2}^{+}$.] As expected, angular distributions of ^3He and of tritons (from $^{14}\text{N}(d, t)^{13}\text{N}$) to analog states are closely the same: this has been shown for the ground state ^3He and triton groups as well as groups to $^{13}\text{C}^*(8.9 + 9.5)$ and $^{13}\text{N}^*(9.2)$: see ([1981AJ01](#)). Analyzing powers are reported at $E_{\text{d}} = 52$ MeV to $^{13}\text{C}^*(0, 7.55)$ ([1981MA14](#)).

$$72. \ ^{14}\text{N}(t, \alpha)^{13}\text{C} \quad Q_{\text{m}} = 12.2634$$

Observed α groups at $E_{\text{t}} = 2.6$ MeV are displayed in Table 13.22 of ([1976AJ04](#)).

$$73. \text{ (a) } \ ^{14}\text{N}(^6\text{Li}, ^7\text{Be})^{13}\text{C} \quad Q_{\text{m}} = -1.945$$

$$\text{ (b) } \ ^{14}\text{N}(^6\text{Li}, ^3\text{He } \alpha)^{13}\text{C} \quad Q_{\text{m}} = -3.5322$$

An angular distribution has been obtained at $E(^6\text{Li}) = 32$ MeV for the transition to $^{13}\text{C}_{\text{g.s.}}$ and $^7\text{Be}^*(0, 0.43)$ [for the mirror reaction see reaction 33 in ^{13}N]: the relative cross sections show a deviation from isospin symmetry which is attributed to Coulomb effects. $^{13}\text{C}^*(3.09)$ was also populated: see ([1981AJ01](#)). For reaction (b) see ([1984ET01](#)).

74. $^{15}\text{N}(\text{p}, ^3\text{He})^{13}\text{C}$ $Q_m = -10.6658$

At $E_p = 43.7$ MeV ^3He groups have been observed to eleven states of ^{13}C : see Table 13.17 in (1981AJ01). See also (1976AJ04).

75. $^{15}\text{N}(\text{d}, \alpha)^{13}\text{C}$ $Q_m = 7.6874$

See (1970AJ04, 1976AJ04).

76. $^{15}\text{N}(\alpha, ^6\text{Li})^{13}\text{C}$ $Q_m = -14.6842$

At $E_\alpha = 42$ MeV, the angular distribution of the ^6Li particles to $^{13}\text{C}_{\text{g.s.}}$ has been measured: see (1981AJ01).

77. $^{16}\text{O}(\text{n}, \alpha)^{13}\text{C}$ $Q_m = -2.2156$

Angular distributions have been measured for E_n to 18.8 MeV for $\alpha_0, \alpha_1, \alpha_{2+3}$: see (1981AJ01).

78. $^{16}\text{O}(\text{p}, \text{p}^3\text{He})^{13}\text{C}$ $Q_m = -22.7934$

See (1977GR04).

79. $^{16}\text{O}(\alpha, ^7\text{Be})^{13}\text{C}$ $Q_m = -21.2058$

At $E_\alpha = 42$ MeV the angular distributions of the reaction involving $^{13}\text{C}_{\text{g.s.}}$ and $^7\text{Be}^*(0 + 0.43)$ has been measured: see (1981AJ01).

80. $^{16}\text{O}(^{14}\text{N}, ^{17}\text{F})^{13}\text{C}$ $Q_m = -6.9502$

See ^{17}F in (1982AJ01).

81. $^{16}\text{O}(^{17}\text{O}, ^{20}\text{Ne})^{13}\text{C}$ $Q_m = -1.625$

See ^{20}Ne in (1983AJ01).

$$82. \text{}^{18}\text{O}(\text{d}, \text{}^7\text{Li})\text{}^{13}\text{C} \quad Q_{\text{m}} = -5.678$$

Angular distributions at $E_{\text{d}} = 13.6$ MeV involving $^{13}\text{C}_{\text{g.s.}}$ and $^7\text{Li}^*(0, 0.48)$ are reported by (1980GA1K). See also (1984NE1A).

$$83. \text{}^{19}\text{F}(\text{d}, \text{}^8\text{Be})\text{}^{13}\text{C} \quad Q_{\text{m}} = 3.5817$$

An angular distribution involving $^{13}\text{C}_{\text{g.s.}}$ is reported at $E_{\text{d}} = 13.6$ MeV (1980GA26). See also (1984NE1A).

$$84. \text{}^{23}\text{Na}(\text{d}, \text{}^{12}\text{C})\text{}^{13}\text{C} \quad Q_{\text{m}} = 0.4794$$

At $E_{\text{d}} = 13.6$ MeV an angular distribution has been reported by (1984GO1H).

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

GENERAL: (See also (1981AJ01)).

Nuclear models: (1983SH38).

Special states: (1981KO1Q, 1983AU1B, 1983WI15, 1984RO05).

Electromagnetic transitions: (1980BA54, 1980RI06, 1981KO1Q, 1983AD1B, 1984MA2J).

Astrophysical questions: (1980BA1P, 1983LI01, 1985GI1C).

Applied work: (1982BO1N, 1982HA1V, 1982HI1H, 1982MA1T, 1982PI1H, 1982YA1C, 1983HA1W, 1983KO1Q, 1984HI1D, 1984MO1Q, 1984MO1R, 1984NI1C).

Complex reactions involving ^{13}N : (1982LY1A, 1983FR1A, 1983OL1A, 1983WI1A, 1984HI1A).

Muon and neutrino reactions: (1985MI1P).

Pion and kaon capture and reactions (See also reactions 23, 24 and 25): (1980CR03, 1980EI01, 1981HI06, 1981LI02, 1981OS04, 1981PO10, 1982BE1D, 1982IN1A, 1982LI1K, 1983JEZZ, 1983KA19, 1983TR1J, 1984AL1L, 1984GI1E, 1984MI1K, 1984SA1H, 1984SI13, 1984TI02).

Hypernuclei: (1981KO1V, 1981WA1J, 1982KA1D, 1983SH38, 1984AS1D).

Other topics: (1980BA54, 1982NG01).

Ground state of ^{13}N : (1980BA54, 1982NG01, 1983AD1B, 1983ANZQ, 1983AU1B, 1983BU07, 1984KA25, 1985HA18, 1985FA01).

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

1. $^{13}\text{N}(\beta^+)^{13}\text{C}$ $Q_m = 2.2205$

The weighted mean of $\tau_{1/2}$ measurements is 9.965 ± 0.004 min. The decay is entirely to $^{13}\text{C}_{\text{g.s.}}$: $\log ft = 3.667 \pm 0.001$. See (1981AJ01), (1980AN40), (1982KA1C; applied), (1981BA2G, 1982CO1D, 1983LI01, 1984DA1H, 1984HA1M, 1985KL1A; astrophys.) and (1980AF1A; theor.).

2. $^{10}\text{B}(^3\text{He}, \gamma)^{13}\text{N}$ $Q_m = 21.6366$

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: see (1981AJ01).

Table 13.14: Energy levels of ^{13}N

E_x (MeV \pm keV)	$J^\pi; T$	$\Gamma_{\text{c.m.}}$ (keV)	Decay	Reactions
g.s.	$\frac{1}{2}^-; \frac{1}{2}$	$\tau_{1/2} = 9.965 \pm 0.004$ min	β^+	1, 2, 6, 8, 9, 10, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 37, 38, 39
2.3649 ± 0.6	$\frac{1}{2}^+$	$\Gamma_{\text{c.m.}} = 31.7 \pm 0.8$	γ, p	6, 9, 10, 11, 15, 16, 22, 26, 27, 30, 32, 33, 35
3.511 ± 2	$\frac{3}{2}^-$	62 ± 4	γ, p	2, 6, 8, 9, 10, 11, 15, 16, 18, 20, 23, 26, 27, 28, 29, 30, 31, 32, 34, 35
3.547 ± 4	$\frac{5}{2}^+$	47 ± 7	p	2, 6, 8, 9, 11, 15, 16, 18, 20, 22, 23, 26, 27, 28, 30, 32
6.364 ± 9	$\frac{5}{2}^+$	11	p	7, 9, 11, 16, 27, 32, 34
6.886 ± 8	$\frac{3}{2}^+$	115 ± 5	p	7, 9, 11, 27, 32
7.155 ± 5	$\frac{7}{2}^+$	9 ± 0.5	p	7, 9, 11, 16, 27, 32
7.376 ± 9	$\frac{5}{2}^-$	75 ± 5	p	7, 8, 9, 11, 16, 27, 28, 29, 30, 31, 32, 34
7.9	$\frac{3}{2}^+$	≈ 1500	p	9, 11, 16, 32
8.918 ± 11	$\frac{1}{2}^-$	230	p	9, 11, 16, 29, 30, 31, 32, 34
9.00	$\frac{9}{2}^+$	280 ± 30		7, 16, 26, 27, 31
9.476 ± 8	$\frac{3}{2}^-$	30	p	7, 9, 11, 16, 27, 29, 31
10.25 ± 150	$(\frac{1}{2}^+)$	≈ 280	γ, p	10
10.36	$\frac{5}{2}^-$	30	p	7, 9, 11, 16, 27, 29
10.36	$\frac{7}{2}^-$	76	p	7, 11, 16, 27
10.833 ± 9	$\frac{1}{2}^-$			7, 9, 27, 34
11.530 ± 12	$\frac{5}{2}^+$	430 ± 35	p	7, 9, 11
11.70 ± 30	$\frac{5}{2}^-$	115 ± 30	p	11
11.74 ± 40	$\frac{3}{2}^+$	240 ± 30	γ, p	10, 11
11.74 ± 50	$\frac{3}{2}^-$	530 ± 80	p	11
11.878 ± 12	$\frac{3}{2}^-$	380 ± 50	p	8, 9, 11, 30, 34

Table 13.14: Energy levels of ^{13}N (continued)

E_x (MeV \pm keV)	$J^\pi; T$	$\Gamma_{\text{c.m.}}$ (keV)	Decay	Reactions
12.13 \pm 50	$\frac{7}{2}^-$	250 \pm 30	p	11, 16, 35
12.558 \pm 23		> 400		9
12.937 \pm 24		> 400		9
13.5 \pm 200	$\frac{3}{2}^+$	\approx 6500	γ, p	10, 11
14.05 \pm 20	$\frac{3}{2}^+; \frac{1}{2}$	165 \pm 20	γ, p, α	10, 11, 14
15.06457 \pm 0.4 ^a	$\frac{3}{2}^-; \frac{3}{2}$	0.86 \pm 0.12	γ, p, α	9, 10, 11, 14, 26, 27, 34
15.3 \pm 200	$(\frac{3}{2}^+)$	350 \pm 150	γ, p	10
15.99 \pm 30	$\frac{7}{2}^+; \frac{1}{2}$	135 \pm 90	p, α	11, 14, 27
16.0		\approx 500	p	11
17.5			γ, p	10, 11
18.15 \pm 30	$\frac{3}{2}^+; \frac{1}{2}$	320 \pm 80	p	11
18.17 \pm 20	$\frac{1}{2}^-; \frac{1}{2}$	225 \pm 50	p, α	11, 14
18.406 \pm 5	$\frac{3}{2}^+; \frac{3}{2}$	66 \pm 8	p, α	9, 11, 14
18.961 \pm 10	$\frac{3}{2}^-$ or $\frac{7}{2}^+; \frac{3}{2}$	23 \pm 5	p, α	9, 11, 14
19.83	$\frac{5}{2}^-; \frac{1}{2}$	1000	p, α	11, 14
19.88	$\frac{7}{2}^+; \frac{1}{2}$	750	p	11
20.2	$\frac{5}{2}^-$	1000	p	11
20.9 \pm 300	$\frac{1}{2}^+$	1200	γ, p	10, 11
21.4	$\frac{5}{2}^-$	750	p	11
21.7	$\frac{3}{2}^+$		p	11
22.4 \pm 500	$\frac{1}{2}^+$		p	11
23			γ, p	10
23.3		400	p, ^3He	3
23.83 \pm 50		350 \pm 50	p, ^3He	3
24.4		700	p, ^3He	3
(24.6)		120	p, ^3He	3
25.6 \pm 100	$(\frac{3}{2})^-$	240 \pm 80	p, ^3He	3, 11
25.9		1000	(n), p, d, $^3\text{He}, \alpha$	3, 4, 5
26.84			p	11

Table 13.14: Energy levels of ^{13}N (continued)

E_x (MeV \pm keV)	$J^\pi; T$	$\Gamma_{\text{c.m.}}$ (keV)	Decay	Reactions
28			$(\gamma), \text{p}, {}^3\text{He}, (\alpha)$	2, 3, 5
(31)			p	11
32		≈ 2000	$\gamma, \text{d}, {}^3\text{He}, \alpha$	2, 4, 5, 10

^a See also Table 13.7.

3. (a) $^{10}\text{B}({}^3\text{He}, \text{n})^{12}\text{N}$ $Q_{\text{m}} = 1.573$ $E_{\text{b}} = 21.6366$
 (b) $^{10}\text{B}({}^3\text{He}, \text{p})^{12}\text{C}$ $Q_{\text{m}} = 19.6931$

Activation cross sections (reaction (a)) have been reported for $E({}^3\text{He}) = 1$ to 30.6 MeV: there is some evidence for broad structures. Observed resonances in the yield of proton groups and of 12.7 and 15.1 MeV γ -rays are displayed in Table 13.15. See also (1981AJ01).

4. $^{10}\text{B}({}^3\text{He}, \text{d})^{11}\text{C}$ $Q_{\text{m}} = 3.196$ $E_{\text{b}} = 21.6366$

For resonances see Table 13.15. See also (1981AJ01).

5. $^{10}\text{B}({}^3\text{He}, \alpha)^9\text{B}$ $Q_{\text{m}} = 12.141$ $E_{\text{b}} = 21.6366$

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 13.15. See also (1981AJ01).

6. $^{10}\text{B}(\alpha, \text{n})^{13}\text{N}$ $Q_{\text{m}} = 1.0588$

Angular distributions have been measured in the range $E_{\alpha} = 1.5$ to 20.2 MeV: see (1981AJ01).

7. $^{10}\text{B}({}^6\text{Li}, \text{t})^{13}\text{N}$ $Q_{\text{m}} = 5.8410$

Table 13.15: Structures in $^{10}\text{B} + ^3\text{He}$ ^a

E_{res} (MeV \pm keV)	Γ (keV)	Res. in	$^{13}\text{N}^*$ (MeV)
2.1	500	p ₀ , (p ₁)	23.3
2.85 \pm 50	450 \pm 50	$\gamma_{15.1}$	23.83
3.6	700	p ₀ , p ₁	24.4
3.9	120	p ₀	24.6
(4.6)	150	p ₀ , (p ₁)	(25.2)
5.2 \pm 100	240 \pm 80	p ₀ , $\gamma_{15.1}$, p ₂ , p ₃	25.6
5.6	1000 ^c	(n), p ₀ , p ₂ , p ₃ , $\gamma_{12.7}$, $\gamma_{15.1}$, d ₀ , α_0	25.9
8.5	^d	(γ_0), p ₀ , $\gamma_{12.7}$, $\gamma_{15.1}$, (α_0)	28
13.5 ^b	\approx 2000	(γ_0), d ₄₊₅ , α_1	32

^a For references and comments see Table 13.19 in (1981AJ01).

^b This may correspond to more than one state.

^c $J \geq \frac{3}{2}$.

^d $J \geq \frac{7}{2}$.

At $E(^6\text{Li}) = 18$ MeV the known states of ^{13}N with $6.3 < E_x < 11.7$ MeV are observed, with the exception of $^{13}\text{N}^*(7.9, 8.92)$. In addition, evidence is presented for a ^{13}N state at $E_x = 9.00$ MeV with $\Gamma_{\text{c.m.}} = 280 \pm 30$ keV: it is very strongly excited and its angular distribution is similar to that for $^{13}\text{C}^*(9.50)$ in the mirror reaction ($^6\text{Li}, ^3\text{He}$) suggesting that these two states are analogs. Other analog assignments made on the basis of corresponding intensities in the mirror reaction are given in reaction 11 of ^{13}C . The widths of $^{13}\text{N}^*(6.89, 7.38)$ are, respectively, 120 ± 30 and 70 ± 30 keV (1974HO06).

$$8. \ ^{10}\text{B}(^{14}\text{N}, ^{11}\text{B})^{13}\text{N} \quad Q_m = 0.901$$

At $E(^{10}\text{B}) = 100$ MeV, angular distributions are reported for the transitions to $^{13}\text{N}^*(0, 3.5, 7.4, 11.9)$: see (1981AJ01).

$$9. \ ^{11}\text{B}(^3\text{He}, \text{n})^{13}\text{N} \quad Q_m = 10.1824$$

Neutron groups have been observed to a number of states of ^{13}N : see Table 13.16. The parameters of the first $T = \frac{3}{2}$ state at $E_x = 15.06$ MeV are displayed in Table 13.6 where they are compared with the corresponding quantities for $^{13}\text{C}^*(15.11)$: see (1981AJ01).

Table 13.16: States of ^{13}N from $^{11}\text{B}(^3\text{He}, \text{n})^{13}\text{N}$ ^a

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

^a For references see Table 13.20 in (1981AJ01).

^b See also Table 13.6.

10. (a) $^{12}\text{C}(\text{p}, \gamma)^{13}\text{N}$ $Q_{\text{m}} = 1.9435$
 (b) $^{12}\text{C}(\text{p}, \gamma\text{p}')^{12}\text{C}$

Resonances for capture radiation are displayed in Table 13.17. No resonance is observed at $E_{\text{p}} = 1.73$ MeV [$^{13}\text{N}^*(3.55)$]: $\omega\Gamma_{\gamma} < 0.006$ eV.

Excitation functions have been measured for $E_{\text{p}} = 150$ to 2500 keV. In addition to the first two resonances, direct radiative capture is observed. In reaction (b), studied for $E_{\text{p}} = 610$ to 2700 keV the capture γ -ray yield is dominated by a direct capture process to $^{13}\text{N}^*(2.36)$. The cascade decay $^{13}\text{N}^*(3.51 \rightarrow 2.36)$ has an intensity of $(8 \pm 1)\%$. Extrapolating the cross section to $E_{\text{c.m.}} = 25$ keV yields a cross-section factor $S = 1.45 \pm 0.20$ keV \cdot b. [A reanalysis of the data by (1980BA54) suggests $S = 1.54_{-0.10}^{+0.15}$ keV \cdot b.] See also (1984MA36, 1985LA06; theor.).

Differential cross sections for the transitions to the ground state have been measured for $E_{\text{p}} = 10$ to 17 MeV. The total E2 capture cross section is ≈ 0.2 μb and no resonance effects are observed. The E2 energy-weighted sum rule depleted over this energy range is $(8.5 \pm 3.3)\%$ (1980HE04). At $E_{\text{p}} = 14.2$ MeV, capture radiation from the first $T = \frac{3}{2}$ state, $^{12}\text{N}^*(15.06)$ is reported: see Table 13.6 for the parameters and the decay modes of this state. The angular distributions of the γ -rays determine $J = \frac{3}{2}$ for $^{13}\text{N}^*(15.06)$. The interference between the M1(E2) $T = \frac{3}{2}$ resonance ($^{13}\text{N}^*(15.06)$) and the E1 GDR has been studied by (1980SN01): the E1 capture is found to be predominantly d-wave (1980SN01). See (1981AJ01) for the earlier references.

Excitation functions for γ -rays have also been measured at $E_{\text{p}} = 8.7$ to 37 MeV (γ_0), 19.9 to 24.4 MeV (γ_1, γ_{2+3}) and 23 to 37 MeV (γ_{2+3}). At $E_{\text{p}} = 40$ to 100 MeV most of the γ -strength is due to transitions to $^{13}\text{N}^*(3.5)$, probably to $^{13}\text{N}^*(3.55)$ [$J^{\pi} = \frac{5}{2}^{+}$] because of its single-particle character. Transitions to higher states may also be indicated. Excitation functions, γ -ray angular distributions and analyzing powers for γ_0, γ_{2+3} are reported by (1984BL10) for $E_{\text{p}} \approx 25$ to 40 MeV. At $E_{\text{p}} = 40$ and 50 MeV analyzing powers to $^{13}\text{N}^*(0, 3.5)$ are reported by (1983NO1D, 1983NO1G, 1985EJ1A; prelim.).

See also (1980AN40, 1982KR05, 1984AN1J, 1984JEZY, 1984WA1L), (1980BA2M, 1981BA2F, 1982BA80, 1984BO1Q, 1984TR1C; astrophys.), (1981SN1A, 1982MA2C, 1984WO05, 1985BL1B) and (1980JO1E, 1980SO1D, 1981HA01, 1982DU1A, 1984SE16, 1985MA1V; theor.).

11. (a) $^{12}\text{C}(\text{p}, \text{p})^{12}\text{C}$ $E_{\text{b}} = 1.9435$
 (b) $^{12}\text{C}(\text{p}, \text{pd})^{10}\text{B}$ $Q_{\text{m}} = -25.1866$
 (c) $^{12}\text{C}(\text{p}, 2\text{p})^{11}\text{B}$ $Q_{\text{m}} = -15.9570$
 (d) $^{12}\text{C}(\text{p}, \text{pt})^9\text{B}$ $Q_{\text{m}} = -27.366$
 (e) $^{12}\text{C}(\text{p}, \text{p}^3\text{He})^9\text{Be}$ $Q_{\text{m}} = -26.2790$
 (f) $^{12}\text{C}(\text{p}, \text{p}\alpha)^8\text{Be}$ $Q_{\text{m}} = -7.36665$
 (g) $^{12}\text{C}(\text{p}, 3\text{p})^{10}\text{Be}$ $Q_{\text{m}} = -27.1859$

Yield curves for elastic protons, protons inelastically scattered to $^{12}\text{C}^*(4.4, 7.7, 9.6, 12.7, 15.1)$ and for γ -rays from $^{12}\text{C}^*(4.4, 12.7, 15.1)$ have been studied at many energies: see Table 13.18

Table 13.17: Resonances in $^{12}\text{C}(p, \gamma)^{13}\text{N}$ ^a

E_p (MeV \pm keV)	$\Gamma_{\text{c.m.}}$ (keV)	Γ_{γ_0} (eV)	$^{13}\text{N}^*$ (MeV)	Res. in yield of	J^π
0.4568 ± 0.5	31.7 ± 0.8 ^f	0.64 ± 0.07 ^h	2.3649 ± 0.0006	γ_0	$\frac{1}{2}^+$
1.699 ± 2 ^b	62 ± 4 ^g	0.64 ⁱ	3.511	γ_0	$\frac{3}{2}^-$
9.01 ± 150	≈ 280		10.25	γ_0	$(\frac{1}{2}^+)$
10.62 ± 120	200 ± 50	≈ 4.2 ^j	11.74	γ_0	$\frac{3}{2}^+$
12.5 ± 200	6500	≥ 1100	13.5	γ_0	$\frac{3}{2}^+$
13.12 ± 90	160 ± 20	3.7 ± 1.0 ^k	14.04	γ_0	$\frac{3}{2}^+$
14.2	[see Table 13.6]		15.0	γ_0, γ_{2+3}	$\frac{3}{2}^-; T = \frac{3}{2}$
14.5 ± 200 ^c	350 ± 140	≥ 0.5	15.3	γ_1	$(\frac{3}{2}^+)$
16.9			17.5	γ_0	
20 ^d			20	γ_1, γ_{2+3}	
20.5 ^e	≈ 3700		20.8	γ_0	
23			23	γ_0	
24.5			24.5	γ_{2+3}	
32.5	broad		31.9	γ_0, γ_{2+3}	

^a For references and other comments see Table 13.21 in (1981AJ01).

^b For a thick-target study see (1984PO13).

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

^d Giant resonance for γ_1 .

^e Main dipole strength is concentrated in this peak.

^f Recalculated on the basis of $\Gamma_{\text{c.m.}} = 33.3 \pm 1.8$ keV from (1974BL06) and 31.4 ± 0.9 keV from (1968RI16) [the value reported in (1968RI16) was Γ_{lab} ; I am indebted to Prof. F.C. Barker for his comments].

^g (1985BR06) have studied this resonance with polarized protons and analyzed the results with R -matrix theory: the E2/M1 mixing ratio is -0.102 ± 0.003 and the total width (lab) is calculated to be 62 keV. An extranuclear direct capture background appears to be necessary to explain the data.

^h G. Fox *et al.*: see p. 662 in (1985LA06).

ⁱ Recalculated on the basis of total $\Gamma_{\text{lab}} = 67 \pm 4$ keV. I am indebted to Prof. F.C. Barker for his comments [see (1980BA54)].

^j A value of 0.30 ± 0.05 is assumed for Γ_{p_0}/Γ : see Table 13.18.

^k A value of 126 keV is taken for Γ_{p_0} .

for a display of the observed structure. Cross sections for the 4.4 MeV γ -rays for $E_p = 5.1$ to 23 MeV have been measured by (1981DY03; see also for astrophysical considerations). A phase-shift analysis of the elastic scattering analyzing power for $E_p = 11.5$ to 18.1 MeV shows four $T = \frac{1}{2}$ states with $E_x = 14.06, 16.00, 18.16,$ and 18.18 MeV, with $J^\pi = \frac{3}{2}^+, \frac{7}{2}^+, \frac{3}{2}^+, \frac{1}{2}^-$: see Table 13.18. At $E_p = 19.15$ to 23.34 MeV, measurements of the elastic group and the protons to $^{12}\text{C}^*(4.4, 12.7)$ 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 $21 < E_x < 22$ MeV and $\frac{1}{2}^+$ and $\frac{3}{2}^+$ resonances above 22 MeV: see Table 13.18. For other polarization measurements see Tables 13.26 in (1970AJ04), 13.28 in (1976AJ04), 13.19 here, (1981AJ01) and (1984BY04, 1984BY05, 1985BAZZ).

Nuclear time delays of the order of 10^{-20} sec as a function of E_γ have been extracted from the bremsstrahlung cross section near the 1.7 MeV reonance (1982LI12, 1982TA09, 1982TA11). For other bremsstrahlung studies see (1981AJ01) and (1982LE03, 1983PEZW, 1983SU1G, 1983TR1G). Variation of the K-shell vacancy production probability as a function of energy across the 460 keV resonance is not observed (1982ME13).

For reaction (b) see (1977GR04, 1982REZZ). For reactions (d, e) see (1977GR04). For reaction (g) see (1980KO40). For inclusive data from the quasielastic peak to outgoing proton momenta of ≈ 350 MeV/c see (1984MC02; $E_p = 800$ MeV). For σ_T measurements see (1981PE01). For production of pions and other mesons see (1981AK1C, 1981AL1K, 1981NA1E, 1983AK1A, 1985DI01) and reaction 28 in ^{13}C . For hadron multiple production see (1980AK1D, 1981ER07, 1981NA1E, 1981TA03, 1982BA78, 1982FI1E, 1984BA2R, 1984BA1T, 1984BA2X).

Table 13.18: ^{13}N levels from $^{12}\text{C}(p, p), ^{12}\text{C}(p, p'), ^{12}\text{C}(p, \alpha)$ ^a

E_p (MeV \pm keV)	$^{13}\text{N}^*$ (MeV)	$\Gamma_{\text{c.m.}}$ (keV)	l_p	J^π	^b
0.461 ± 3	2.369 ^c	31 ^c	0	$\frac{1}{2}^+$	$\theta^2 = 0.54$
1.686 ± 6	3.499 ^c	60 ^c	1	$\frac{3}{2}^-$	0.031
1.734 ± 6	3.543 ^c	50 ^c	2	$\frac{5}{2}^+$	0.21
4.808 ± 10	6.378	11	2	$\frac{5}{2}^+$	0.0031
5.370 ± 10	6.896	115 ± 5	2	$\frac{3}{2}^+$	0.13
5.65 ± 10	7.155	9 ± 0.5	4	$\frac{7}{2}^+$	0.016
5.891	7.38	75 ± 5	3	$\frac{5}{2}^-$	0.069
6.5	7.9	≈ 1500	2	$\frac{3}{2}^+$	0.14
7.54	8.90	230	1	$\frac{1}{2}^-$	0.02
8.18	9.49	30	1	$\frac{3}{2}^-$	0.001
9.13	10.36	30	3	$\frac{5}{2}^-$	
9.13	10.36	76	3	$\frac{7}{2}^-$	
10.35 ± 50	11.49	430 ± 35	2	$\frac{5}{2}^+$	$\Gamma_p/\Gamma = 0.70 \pm 0.05$

Table 13.18: ^{13}N levels from $^{12}\text{C}(\text{p}, \text{p})$, $^{12}\text{C}(\text{p}, \text{p}')$, $^{12}\text{C}(\text{p}, \alpha)$ ^a (continued)

E_p (MeV \pm keV)	$^{13}\text{N}^*$ (MeV)	$\Gamma_{\text{c.m.}}$ (keV)	l_p	J^π	
10.58 \pm 30	11.70	115 \pm 30	3	$\frac{5}{2}^-$	0.60 \pm 0.04
10.62 \pm 40	11.74	250 \pm 30	2	$\frac{3}{2}^+$	0.30 \pm 0.05
10.62 \pm 50	11.74	530 \pm 80	1	$\frac{3}{2}^-$	0.55 \pm 0.05
10.75 \pm 40	11.86	380 \pm 50	0	$\frac{1}{2}^+$	0.35 \pm 0.05
11.05 \pm 50	12.13	250 \pm 30	3	$\frac{7}{2}^-$	0.30 \pm 0.05
12.5	13.5	\approx 500			
13.13 \pm 20	14.05	180 \pm 35	2	$\frac{3}{2}^+$; $T = \frac{1}{2}$	0.29 \pm 0.07
14.23075 \pm 0.2	15.06457 \pm 0.4	0.932 \pm 0.028 ^d	1	$\frac{3}{2}^-$; $T = \frac{3}{2}$	
15.24 \pm 40 ^e	15.99	135 \pm 90	4	$\frac{7}{2}^+$; $T = \frac{1}{2}$	0.05 \pm 0.04
15.2	16.0	\approx 500			
16.8 ^e	17.4				
17.58 \pm 30	18.15	322 \pm 75	2	$\frac{3}{2}^+$; $T = \frac{1}{2}$	0.08 \pm 0.02
17.60 \pm 20	18.17	225 \pm 50	1	$\frac{1}{2}^-$; $T = \frac{1}{2}$	0.24 \pm 0.06
17.857 \pm 5 ^f	18.406	66 \pm 8	2	$\frac{3}{2}^+$; $T = \frac{3}{2}$	
18.460 \pm 10 ^f	18.961	23 \pm 5		$\frac{3}{2}^-$ or $\frac{7}{2}^+$; $T = \frac{3}{2}$	
19.40 ^g	19.83	1000	3	$\frac{5}{2}^-$; $T = \frac{1}{2}$	
19.46	19.88	750	4	$\frac{7}{2}^+$; $T = \frac{1}{2}$	
19.8 ^f	20.2	1000		$\frac{5}{2}^-$	
20.6 \pm 300 ^{e,f}	20.9	1200		$\frac{1}{2}^+$	
21.1	21.4	750		$\frac{5}{2}^-$	
21.4	21.7			$\frac{3}{2}^+$	
22.2 \pm 500	22.4	\approx 1000		$\frac{1}{2}^+$	
h					
24.0	24.1	\leq 500			
25.7	25.6			$(\frac{3}{2}^-)$	
27.02	26.84				
32 ^g	31				

^a For references see Tables 13.22 in (1981AJ01) and 13.27 in (1976AJ04).

^b A dispersion analysis leads to a spectroscopic factor of 0.53 ± 0.08 for $^{13}\text{N}_{\text{g.s.}}$.

^c The older values for $^{13}\text{N}^*(3.50, 3.54)$ have been reanalyzed by (1980BA54). An R -matrix analysis had led to $E_x = 2.367, 3.501$ and 3.547 MeV, and $\Gamma_{\text{c.m.}} = 33, 55$ and 50 keV for these states. $^{13}\text{N}_{\text{g.s.}}$ appears to have an appreciable effect on the low-energy scattering: see (1981AJ01). (1984BU1P; prelim.) report $E_{\text{res}} = 1.74 \pm 0.01$ MeV, $\Gamma = 50$ keV.

^d $\Gamma_{\text{p}} = 263 \pm 15$ eV (1980TH05). See discussion in (1981BR24): if the ^{12}C nucleus were part of an atom the width of the resonance would be smeared out by an amount of the order of ≈ 0.5 keV (A.M. Lane, private communication). See also Table 13.6.

^e Resonance in yield of 12.7 MeV γ -rays.

^f Resonance in yield of 15.1 MeV γ -rays.

^g Resonance in yield of 4.4 MeV γ -rays.

^h A $\frac{3}{2}^+$ state is indicated in this region.

See also ^{12}C in (1985AJ01), (1980LE28, 1980ZU1B, 1981CH1L, 1983KOZX, 1983SEZW, 1984KOZZ, 1984ZU01), (1981DY03, 1983LE28; astrophys.), (1978AL1G, 1980KE14, 1981BA1F, 1981BA1R, 1983HA1H, 1983MO1K, 1984RE14, 1985HO1J, 1985WE1D) and (1979FO18, 1979MA48, 1980CH32, 1980DE2F, 1980DI10, 1980HA56, 1980MA06, 1980ST1K, 1981BR24, 1981CI03, 1981DE1P, 1981FR1R, 1981KH07, 1981KL1D, 1981KR15, 1981OL02, 1981SH1A, 1981WA20, 1981YA08, 1982AM1B, 1982BR1A, 1982MO18, 1982MO24, 1982NA13, 1982YE01, 1983BA1V, 1983DI1B, 1983GY1A, 1983KA37, 1983KO44, 1983OL04, 1983TZ01, 1983ZA09, 1984BE01, 1984BU1T, 1984CA1T, 1984GO04, 1984HU1P, 1984KO37, 1984KW01, 1984PH02, 1984PI05, 1984RI03, 1984SH14, 1985BA1Z, 1985CL1B, 1985DY03, 1985GO1V, 1985IN01, 1985SP03; theor.).

12. (a) $^{12}\text{C}(\text{p}, \text{n})^{12}\text{N}$	$Q_{\text{m}} = -18.120$	$E_{\text{b}} = 1.9435$
(b) $^{12}\text{C}(\text{p}, \text{pn})^{11}\text{C}$	$Q_{\text{m}} = -18.7215$	

The cross section for reaction (a) has been measured from threshold to $E_{\text{p}} = 50$ MeV. Resonant structure is observed corresponding to $E_x = 21, 24$ and, possibly, ≈ 27 MeV: see (1981AJ01). At $E_{\text{p}} = 160$ MeV A_{y} for the n_0 group is similar to that for the (p, p') group to the analog state $^{12}\text{C}^*(15.1)$ (1981GO1D; prelim.). For spin transfer coefficient, $K_{\text{y}}^{\text{y}'}(0^\circ)$, measurements at $E_{\text{p}} = 65$ MeV see (1984SA12). See also (1984BA1R, 1984SH04) and ^{12}N in (1985AJ01).

Cross sections for reaction (b) have been measured to 300 GeV: see (1981AJ01). See also (1984NA06, 1981OL1B; theor.).

13. $^{12}\text{C}(\text{p}, \text{d})^{11}\text{C}$	$Q_{\text{m}} = -16.4969$	$E_{\text{b}} = 1.9435$
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For polarization measurements see (1981AJ01), (1980HO18; $E_{\text{p}} = 65$ MeV; d_0, d_1), (1984OH06; $E_{\text{p}} = 497$ MeV; d_0) and (1981CH1L, 1981IR1A). See also ^{11}C in (1985AJ01), (1984BA1L) and (1981VE15; theor.).

14. $^{12}\text{C}(\text{p}, \alpha)^9\text{B}$

$Q_{\text{m}} = -7.5517$

$E_{\text{b}} = 1.9435$

Yield curves for α_0 have been measured over the 14.2 MeV resonance, corresponding to the first $T = \frac{3}{2}$ state at $E_{\text{x}} = 15.06$ MeV, and from $E_{\text{p}} = 17$ to 20 MeV. The yield for the α_1 group has been determined for $E_{\text{p}} = 17$ to 21.5 MeV. Parameters of observed resonances are displayed in Table 13.18. Excitation functions for α_0 have also been measured for $E_{\text{p}} = 18.5$ to 44 MeV at a number of angles: they exhibit structures which are typically 1 MeV broad: see (1981AJ01). For polarization measurements see Table 13.19.

15. (a) $^{12}\text{C}(\text{d}, \text{n})^{13}\text{N}$

$Q_{\text{m}} = -0.2811$

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

$Q_{\text{m}} = -2.2458$

Angular distributions have been measured for $E_{\text{d}} = 0.5$ to 17 MeV [see (1981AJ01)] and at $E_{\text{d}} = 7.0, 9.1$ and 13.0 MeV (1984SC04; n_0, n_1, n_{2+3}). Reaction (b) is dominated at $E_{\text{d}} = 5.0$ to 6.5 MeV and at 9.20 and 9.85 MeV by sequential decay via $^{13}\text{N}^*(3.51 + 3.55)$. At the lower energies $^{13}\text{N}^*(2.36)$ participates also: see (1976AJ04). See also ^{14}N , (1981BR1E), (1984BA2N; applied) and (1980BA54, 1983MU13, 1984PE1C; theor.).

16. (a) $^{12}\text{C}(^3\text{He}, \text{d})^{13}\text{N}$

$Q_{\text{m}} = -3.5500$

(b) $^{12}\text{C}(^3\text{He}, \text{pd})^{12}\text{C}$

$Q_{\text{m}} = -5.49353$

Angular distributions have been studied at $E(^3\text{He})$ to 81.4 MeV [see (1981AJ01)] and at 13 MeV (1984CA06; d_0, d_1, d_{2+3}) and 43.6 MeV (1980PE13). The spectroscopic factors derived by (1980PE13) for $^{13}\text{N}^*(0, 2.36, 3.55, 6.36, 6.89, 7.16, 7.38, 8.0, 8.92, 9.0, 9.48, 10.36, 10.78)$ are $S = 0.48, 0.14, 0.53, 0.007, 0.015, < 0.009, 0.024, 0.13, < 0.005, < 0.005, < 0.002, < 0.001, 0.064$, respectively. Evidence is presented for the assignment of $J^{\pi} = \frac{9}{2}^+$ to $^{13}\text{N}^*(9.0)$ (1980PE13). For other values of S , see (1981AJ01) and (1984CA06). The energies and widths for the first three excited states are $E_{\text{x}} = 2368.2 \pm 2.8, 3507.8 \pm 7.6$ and 3549.1 ± 5.0 keV, with $\Gamma_{\text{c.m.}} = 36.1 \pm 2.8, 54.8 \pm 11.5$ 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 $E_{\text{x}} = 7.9$ 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 the inclusive deuteron spectra at $E(^3\text{He}) = 52$ MeV see (1984AA01). For reaction (b) see (1983CA07, 1983DR06). See also (1983PE07) and (1980BA54, 1982CO20, 1983MU13; theor.).

17. $^{12}\text{C}(\alpha, \text{t})^{13}\text{N}$

$Q_{\text{m}} = -17.8705$

Table 13.19: Polarization measurements in $^{12}\text{C}(\text{p}, \text{p})$ and $^{12}\text{C}(\text{p}, \alpha)$ ^a

$E_{\bar{p}}$ (MeV)	A_y to $^{12}\text{C}^*$ (MeV) or ^9B	Refs.
24.1, 26.2, 28.7	4.4 ^b	(1981FU12, 1983FU1J)
25, 35	g.s.	(1984BAZZ)
65	g.s., 4.4, 7.7	(1985KA10)
65	12.7, 15.1	(1983HO1L)
65	continuum	(1980SA20)
72	inclusive (p, α)	(1981KO33)
72	continuum (p, α)	(1980LE19, 1982LE21)
95 \rightarrow 571	g.s.	(1983AP1A)
107 \rightarrow 754	inclusive	(1982RA20)
120	0, 4.4, 11.8, 12.7, 15.1, 16.1, 16.6	(1981CO20, 1981CO21)
122, 160	g.s.	(1983ME02)
122, 160, 200	4.4	(1983HU06)
150	12.7, 15.1	(1982CA08)
159.4	g.s., 4.4	(1983TA12)
200	g.s.	(1981ME02)
200	12.7, 15.1	(1981CO10)
200	4.4, 7.7, 9.6, 10.8, 11.8, 12.7, 13.4, 14.1, 15.1, 15.4, 16.1, 16.6, 18.4, 19.2, 19.7, 20.5	(1982CO21)
398, 597, 698	18.3, 19.4 ^c	(1983JO08)
500	12.7, 15.1 ^d	(1984MC1A)
800	inclusive	(1984MC04)
1 GeV	inclusive	(1983BE16)

^a See also (1981AJ01) and Tables 13.26 in (1970AJ04) and 13.28 in (1976AJ04) for the earlier work. See also (1979ZH1A).

^b Also studied polarization and spin-flip asymmetry.

^c Also angular distribution of the spin-flip probability at 398 MeV.

^d Measured all the polarization transfer observables.

Angular distributions of the t_0 group have been measured at $E_\alpha = 56$ and 104 MeV: see (1981AJ01).

$$18. {}^{12}\text{C}({}^7\text{Li}, {}^6\text{He}){}^{13}\text{N} \quad Q_m = -8.031$$

Angular distributions have been obtained at $E({}^7\text{Li}) = 36$ MeV for the ${}^6\text{He}$ ions to ${}^{13}\text{N}^*(0, 3.51 + 3.55)$. The spectroscopic factor for ${}^{13}\text{N}_{\text{g.s.}}$ is 0.72: see (1981AJ01). See also (1980BA54; theor.).

$$19. {}^{12}\text{C}({}^{10}\text{B}, {}^9\text{Be}){}^{13}\text{N} \quad Q_m = -4.6424$$

See (1976AJ04) and (1980BA54; theor.).

$$20. {}^{12}\text{C}({}^{12}\text{C}, {}^{11}\text{B}){}^{13}\text{N} \quad Q_m = -14.0135$$

At $E({}^{12}\text{C}) = 93.8$ MeV angular distributions involving ${}^{13}\text{N}^*(0, 3.51 + 3.55)$ and various ${}^{11}\text{B}$ states have been measured by (1979FU04). For an excitation function see (1980CO10). See also (1981CH1R) and (1981XU1A; theor.).

$$21. {}^{12}\text{C}({}^{14}\text{N}, {}^{13}\text{C}){}^{13}\text{N} \quad Q_m = -5.6071$$

See ${}^{13}\text{C}$.

$$22. {}^{12}\text{C}({}^{16}\text{O}, {}^{15}\text{N}){}^{13}\text{N} \quad Q_m = -10.1841$$

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

$$23. {}^{13}\text{C}(\gamma, \pi^-){}^{13}\text{N} \quad Q_m = -141.7878$$

Differential cross sections were measured for 48 MeV pions for ${}^{13}\text{N}^*(0, 3.5)$ (1984ST16). See also (1982LE06).

$$24. \ ^{13}\text{C}(\pi^+, \pi^0)^{13}\text{N} \quad Q_m = 2.384$$

The angular distribution of the IAS group is reported by (1982DO10). See also (1980BA27, 1982DO02).

$$25. \ ^{13}\text{C}(\pi^+, \gamma)^{13}\text{N} \quad Q_m = 137.3468$$

Differential cross sections for γ_0 have been measured at $E_{\pi^+} = 115.5$ MeV: no evidence is observed for nascent pion condensation (1984MA45).

$$26. \text{ (a) } \ ^{13}\text{C}(\text{p}, \text{n})^{13}\text{N} \quad Q_m = -3.0028$$

$$\text{ (b) } \ ^{13}\text{C}(\text{p}, \text{pn})^{12}\text{C} \quad Q_m = -4.94634$$

Angular distributions of the n_0 , n_1 and n_{2+3} groups have been measured for $E_p = 3.1$ to 50 MeV [see (1981AJ01)], 10.1 to 16.75 MeV (1981BY01), 35 MeV (1985OR1H; n_1 : prelim.) and 800 MeV (1984JEZZ, 1983KI1B, 1985KI1L; not n_1). (1984TA07) have measured the transverse spin-transfer coefficient [$D_{\text{NN}}(0^\circ)$] at 160 MeV for the groups to $^{13}\text{N}^*(0, 3.51)$. [$^{13}\text{N}^*(15.1)$ is also populated (1984TA07) as is $^{13}\text{N}^*(9.0)$ (1982PEZY; $E_p = 26$ MeV).] The major $\frac{1}{2} \rightarrow \frac{3}{2}$ transition is significantly more quenched than the $\frac{1}{2} \rightarrow \frac{1}{2}$ transition, as is also the case in the $^{15}\text{N}(\text{p}, \text{n})$ reaction (1985GO02; $E_p = 160$ MeV). 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: see (1981AJ01). See also ^{14}N , (1984HE20), (1982GO1C, 1982TA03, 1983PE14, 1984TAZS, 1985OR1G), and (1982BA14, 1983KR10; theor.).

$$27. \ ^{13}\text{C}(^3\text{He}, \text{t})^{13}\text{N} \quad Q_m = -2.2391$$

At $E(^3\text{He}) = 43.6$ MeV angular distributions are reported to $^{13}\text{N}^*(0, 2.36, 3.51 + 3.55, 6.36, 6.89, 7.16, 7.38, 9.0, 9.48, 10.36, 10.83, 11.8, 15.07, 16.02)$. The results are compared with the analog reaction $^{13}\text{C}(^3\text{He}, ^3\text{He})^{13}\text{C}$ [see reaction 48 in ^{13}C]; they are consistent with $J^\pi = \frac{9}{2}^+$ for one of the unresolved states at $E_x = 9.0$ MeV and with $\frac{1}{2}^-$ and $\frac{7}{2}^+$ for $^{13}\text{N}^*(10.83, 16.02)$ (1981PE08). [Earlier work (see (1981AJ01)) had assigned $L = 2$ [$J^\pi = \frac{5}{2}^-, \frac{1}{2}^-, \frac{3}{2}^-, \frac{3}{2}^-$] for the transitions to $^{13}\text{N}^*(7.38, 8.92, 11.85, 15.07)$.] See also ^{16}O in (1982AJ01, 1986AJ04), (1983EL05) and (1983PE14).

$$28. \text{ (a) } \ ^{13}\text{C}(^6\text{Li}, ^6\text{He})^{13}\text{N} \quad Q_m = -5.727$$

$$\text{ (b) } \ ^{13}\text{C}(^7\text{Li}, ^7\text{He})^{13}\text{N} \quad Q_m = -13.42$$

Angular distributions to $^{13}\text{N}^*(0, 3.51 + 3.55)$ have been measured at $E(^6\text{Li}) = 31.8$ MeV: see (1981AJ01). These two reactions have been studied at $E(^6\text{Li}) = 93$ MeV and $E(^7\text{Li}) = 78$ MeV by (1984GL06): $^{13}\text{N}^*(0, 3.5, 7.3)$ are most intensely populated.

$$29. \ ^{13}\text{O}(\beta^+)^{13}\text{N} \quad Q_m = 17.765$$

See ^{13}O .

$$30. \ ^{14}\text{N}(\text{p}, \text{d})^{13}\text{N} \quad Q_m = -8.3289$$

Angular distributions have been measured for deuteron groups to $^{13}\text{N}^*(0, 2.36, 3.51 + 3.55, 7.38, 8.92, 11.88)$ at many energies up to $E_p = 155.6$ MeV [see (1981AJ01)] and at $E_{\bar{p}} = 21$ MeV (1982AO05; $\text{d}_0, \text{d}_{2+3}$). See also (1982MA1H).

$$31. \ ^{14}\text{N}(\text{d}, \text{t})^{13}\text{N} \quad Q_m = -4.2962$$

Angular distributions of the tritons to $^{13}\text{N}^*(0, 3.51, 7.38, 8.92 + (9.00) + 9.48, 11.8)$ 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 $^{14}\text{N}(\text{d}, ^3\text{He})^{13}\text{C}$ reaction] are in good agreement with theory and are additional evidence for the J^π assignments of $\frac{1}{2}^-$, $\frac{3}{2}^-$, $\frac{5}{2}^-$, $\frac{1}{2}^-$, $\frac{3}{2}^-$ and $\frac{3}{2}^-$ to these states: see (1981AJ01).

$$32. \text{ (a) } ^{14}\text{N}(^3\text{He}, \alpha)^{13}\text{N} \quad Q_m = 10.0243$$

$$\text{ (b) } ^{14}\text{N}(^3\text{He}, \text{p}\alpha)^{12}\text{C} \quad Q_m = 8.0808$$

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 [± 8 keV]. Angular distributions have been studied at many energies up to $E(^3\text{He}) = 45$ MeV: see (1981AJ01). Reaction (b), studied at $E(^3\text{He}) = 8$ MeV, appears to involve some states of ^{13}N , possibly $^{13}\text{N}^*(7.93, 8.92, 11.87)$: see (1981AJ01).

$$33. \text{ (a) } ^{14}\text{N}(^6\text{Li}, ^7\text{Li})^{13}\text{N} \quad Q_m = -3.303$$

$$\text{ (b) } ^{14}\text{N}(^6\text{Li}, \text{t}\alpha)^{13}\text{N} \quad Q_m = -5.7713$$

An angular distribution has been measured at $E(^6\text{Li}) = 32$ MeV for the transition to $^{13}\text{N}_{\text{g.s.}}$ and $^7\text{Li}^*(0, 0.48)$. $^{13}\text{N}^*(2.36)$ was also populated: see (1981AJ01). For reaction (b) see (1984ET01).

$$34. \text{}^{15}\text{N}(\text{p}, \text{t})\text{}^{13}\text{N} \quad Q_{\text{m}} = -12.9049$$

At $E_{\text{p}} = 43.7$ 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]. Detailed comparisons have been made with the (p, ^3He) reaction to the mirror states in ^{13}C : see (1981AJ01) for references and other information.

$$35. \text{}^{16}\text{O}(\text{p}, \alpha)\text{}^{13}\text{N} \quad Q_{\text{m}} = -5.2184$$

Angular distributions of the α_0 , α_1 and α_2 groups have been measured for E_{p} to 54.1 MeV: see (1970AJ04, 1976AJ04). In addition the distribution of the α -particles to a state with $E_{\text{x}} = 12.13 \pm 0.06$ MeV, $\Gamma_{\text{c.m.}} \approx 300$ keV [$J^{\pi} = \frac{7}{2}^{-}$] is reported at 54.1 MeV: see (1981AJ01). (1983PE07) have compared $(\text{d}\sigma/\text{d}\Omega)_{\text{max}}$ for the groups observed at $E_{\text{p}} = 54.1$ MeV in this reaction and at $E(^3\text{He}) = 19.6$ MeV in the $^{12}\text{C}(^3\text{He}, \text{d})^{13}\text{N}$ reaction. Groups strongly populated in one reaction are weakly populated in the other. See also (1980KO1Q).

$$36. \text{}^{16}\text{O}(\text{p}, \text{pt})\text{}^{13}\text{N} \quad Q_{\text{m}} = -25.0325$$

See (1978GO14, 1983GO10; theor.).

$$37. \text{}^{16}\text{O}(^3\text{He}, ^6\text{Li})\text{}^{13}\text{N} \quad Q_{\text{m}} = -9.2368$$

Ground-state angular distributions have been reported at $E(^3\text{He}) = 30$ and 40.7 MeV: see (1981AJ01).

$$38. \text{}^{16}\text{O}(\alpha, ^7\text{Li})\text{}^{13}\text{N} \quad Q_{\text{m}} = -22.5644$$

The angular distribution for the transition to $^{13}\text{N}_{\text{g.s.}} + ^7\text{Li}_{\text{g.s.}+0.48}$ has been measured: see (1981AJ01).

$$39. \text{}^{16}\text{O}(^{14}\text{N}, ^{17}\text{O})\text{}^{13}\text{N} \quad Q_{\text{m}} = -6.4098$$

See (1981AJ01) and (1980IZ1B; theor.).

Table 13.20: Energy levels of ^{13}O

E_x in ^{13}O (MeV)	$J^\pi; T$	$\tau_{1/2}$ (msec) or Γ (MeV)	Decay	Reactions
g.s.	$(\frac{3}{2}^-); \frac{3}{2}$	$\tau_{1/2} = 8.90 \pm 0.20$	β^+	1, 2, 3, 4
2.75 ± 0.04				2, 3
4.21				3
6.02 ± 0.08^a				3
		$\Gamma = 1.2 \text{ MeV}$		

^a Corresponds to broad or unresolved states.

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

GENERAL: (See also (1981AJ01).)

(1982NG01, 1983ANZQ, 1983AU1B, 1983FR1A, 1983OL1A).

Mass of ^{13}O : We adopt the 1984 Wapstra atomic mass excess of $23111 \pm 10 \text{ keV}$. ^{13}O is then bound with respect to $^{12}\text{N} + \text{p}$ and $^{11}\text{C} + 2\text{p}$ by 1.516 and 2.117 MeV, respectively. See also (1981AJ01).

1. $^{13}\text{O}(\beta^+)^{13}\text{N}$ $Q_m = 17.765$

The half-life of ^{13}O is $8.90 \pm 0.20 \text{ msec}$. ^{13}O decays to a number of states of ^{13}N some of which subsequently decay to $^{12}\text{C}^*(0, 4.4)$: see Table 13.21 (1970ES03). See also (1981AJ01) and (1981KO27; theor.).

2. $^{12}\text{C}(\text{p}, \pi^-)^{13}\text{O}$ $Q_m = -155.389$

At $E_p = 613 \text{ MeV}$ the ground state of ^{13}O and an excited state at $E_x = 2.82 \pm 0.24 \text{ MeV}$ are observed in addition to unresolved structures (1978CO15). [See Fig. 4 for analog region in ^{13}B .] The angular distribution of the π^- to $^{13}\text{O}_{\text{g.s.}}$ has been measured at $E_p = 200 \text{ MeV}$ (1980HO20), as has A_y at $E_p = 205 \text{ MeV}$ (1982JA05). See also (1981AU1C, 1982GR1K, 1982HO1C, 1982WA1G, 1984JA1F) and (1981CO1M; theor.).

3. $^{13}\text{C}(\pi^+, \pi^-)^{13}\text{O}$ $Q_m = -19.986$

Table 13.21: Beta decay of ^{13}O ^a

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

^a (1970ES03). In addition there is some evidence for weak proton groups with $E_p = 3.44$ and 6.28 MeV (± 0.05 MeV).

^b The ground-state ft was taken to be 1.15 times that for ^{13}B (1970ES03).

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

^d Includes a calculated relative intensity of (3.4 ± 1.4) to $^{12}\text{C}^*(4.4)$. I am indebted to Prof. F.C. Barker for this observation.

At $E_{\pi^+} = 164$ MeV excited states are reported at $E_x = 2.75 \pm 0.04$ and 4.21 MeV, as is a broad [$\Gamma = 1.2$ MeV] structure corresponding to one or more states at $E_x = 6.02 \pm 0.08$ MeV. At $E_{\pi^+} = 292$ MeV these states are not observed. Angular distributions have been studied at $E_{\pi^+} = 164$ and 292 MeV to $^{13}\text{O}_{\text{g.s.}}$ and at 164 MeV to $^{13}\text{O}^*(4.21)$ (1984SE15). See also (1980BU15).

4. $^{16}\text{O}(^3\text{He}, ^6\text{He})^{13}\text{O}$ $Q_m = -30.509$

See (1981AJ01).

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

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

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