Energy Levels of Light Nuclei
$A = 13$

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Abstract: An evaluation of $A = 13$–15 was published in *Nuclear Physics* A152 (1970), 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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^{13}Be

The light nuclei observed, by particle-identification techniques, to be emitted in the 5.5 GeV proton bombardment of uranium do not include ^{13}Be. It is therefore particle unstable (1968PO04). (1966GA25) predict that ^{13}Be is unbound with respect to ^{12}Be + n by 2.70 MeV.

^{13}B

(Figs. 1, 2 and 4)

GENERAL:

See (1960TA1C, 1966MO1E). See also (1969AR13).

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

The ratio of the half-life of ^{13}B to that of ^{12}B is 0.86 ± 0.02 (1962MA19). Taking $\tau_{1/2}$(^{12}B) $= 20.41 \pm 0.06$ msec (see (1968AJ02)), $\tau_{1/2}$(^{13}B) $= 17.6 \pm 0.4$ msec (1962MA19). (1968CH28) have observed delayed neutrons decaying with $\tau_{1/2} = 16 \pm 1$ msec. The branching ratios to various ^{13}C states are shown in Table 13.2 (1962MA19, 1969JO21): they indicate $J^\pi = \frac{1}{2}^-$ or $\frac{3}{2}^-$ for ^{13}B(0). See also (1959AJ76).

2. ^{7}Li(^{7}Li, p)^{13}B $\quad Q_{\rm m} = 5.964$

Proton groups have been observed to five states of ^{13}B: see Table 13.3 (1959MO12, 1963CA09). Angular distribution measurements have been reported by (1969CA1A) in the range E(^{7}Li) $= 2.1$ to 5.8 MeV (p_0, p_{1+2}, p_{3+4}, p_5, p_7). The lifetimes of ^{13}B*(3.53, 3.71, 4.13) are, respectively, > 0.3, < 0.38 and 0.062 ± 0.050 psec: $E_\gamma = 3536.3 \pm 4.2$ and 4133.4 ± 7.8 keV (1969TH01). See also (1962BE24), (1959AJ76) and ^{14}C.

3. ^{11}B(t, p)^{13}B $\quad Q_{\rm m} = -0.233$

$Q_0 = -0.233 \pm 0.004$ MeV (1960MU07).

At $E_{\rm t} = 11$ MeV, proton groups are observed to ten states of ^{13}B: see Table 13.3. Angular distributions have been analyzed for seven of the ^{13}B levels (1964MI04). The ground state is formed by $L = 0$ transfer, leading to an unambiguous assignment of $J^\pi = \frac{3}{2}^-$. See also (1960JA17, 1962MA19, 1967BA1E, 1968CH28, 1969BA1Z, 1969JO21).

Table 13.1: Energy levels of ^{13}B

E_x (MeV $\pm$ keV)	$J^\pi; T$	τ or Γ	Decay	Reactions
0	$\frac{3}{2}^-; \frac{3}{2}$	$\tau_{1/2} = 18.6 \pm 0.5$ msec	β^-	1, 2, 3
3.483 ± 5	$(\frac{1}{2}, \frac{3}{2}, \frac{5}{2})^+$		γ	2, 3
3.535 ± 3	$(\frac{1}{2}, \frac{5}{2}, \frac{7}{2})^-$	$\tau_m > 0.3$ psec	γ	2, 3
3.681 ± 5	$(\frac{1}{2}, \frac{3}{2}, \frac{5}{2})^+$		γ	2, 3
3.712 ± 5	$(\frac{1}{2}, \frac{5}{2}, \frac{7}{2})^-$	$\tau_m < 0.38$ psec	γ	2, 3
4.132 ± 6	$(\frac{1}{2}, \frac{5}{2}, \frac{7}{2})^-$	$\tau_m = 0.062 \pm 0.050$ psec	γ	2, 3
4.82 ± 10				2, 3
5.01 ± 10	$(\frac{1}{2}, \frac{3}{2}, \frac{5}{2})^+$			2, 3
5.38 ± 10		$\Gamma = 15 \pm 5$ keV		2, 3
6.17 ± 20				3

Table 13.2: Beta decay of ^{13}B

Decay to ^{13}C* (MeV)	J^π	Branch [a] (%)	Branch [b] (%)	log ft
0 [c]	$\frac{1}{2}^-$	93 ± 1.5	92.1 ± 0.8	4.02 ± 0.02 [b]
3.09	$\frac{1}{2}^+$	≤ 0.7		≥ 5.7 [a]
3.68	$\frac{3}{2}^-$	7 ± 1.5	7.6 ± 0.8	4.47 ± 0.05 [b]
3.85	$\frac{5}{2}^+$	≤ 0.7		≥ 5.5 [a]
7.55	$\frac{5}{2}^-$		0.094 ± 0.020 [d]	5.37 ± 0.09 [b]
8.86	$\frac{1}{2}^-$		0.16 ± 0.03 [d]	4.63 ± 0.08 [b]

[a] (1962MA19).
[b] (1969JO21).
[c] E_{β^-}(max) $= 13.4 \pm 0.2$ MeV (1962MA19).
[d] See also (1962MA19, 1965PO03, 1968CH28).

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

^{7}Li(^{7}Li, p)^{13}B	^{11}B(t, p)^{13}B		
(1959MO12, 1963CA09)	(1964MI04)		
E_x (MeV $\pm$ keV)	E_x (MeV $\pm$ keV)	L	J^π
0	0	0 [d]	$\frac{3}{2}^-$
	3.483 ± 5	1	$\frac{1}{2}^+, \frac{3}{2}^+, \frac{5}{2}^+$
3.50 ± 50 [a]			
	3.533 ± 5	2	$\frac{1}{2}^-, \frac{5}{2}^-, \frac{7}{2}^-$
	3.681 ± 5	1	$\frac{1}{2}^+, \frac{3}{2}^+, \frac{5}{2}^+$
3.70 ± 50 [b]			
	3.712 ± 5	2	$\frac{1}{2}^-, \frac{5}{2}^-, \frac{7}{2}^-$
4.16 ± 50 [c]	4.13 ± 10	2	$\frac{1}{2}^-, \frac{5}{2}^-, \frac{7}{2}^-$
	4.82 ± 10		
5.05 ± 80	5.01 ± 10	1	$\frac{1}{2}^+, \frac{3}{2}^+, \frac{5}{2}^+$
5.5 ± 100	5.38 ± 10 [e]		
	6.17 ± 20		

[a] The decay is by γ-emission to ^{13}B(0).

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

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

[d] See also (1960MU07).

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

^{13}C

(Figs. 2 and 4)

GENERAL:

Model calculations: (1959BR1E, 1960PH1A, 1960TA1C, 1960ZE1B, 1961BA1G, 1961BA1E, 1961KU17, 1961KU1C, 1961NE1B, 1962EA01, 1963BO1G, 1963MA1E, 1963PE04, 1963SE19, 1963TR02, 1964AM1D, 1964NA1D, 1964ST1B, 1965CO25, 1965MA1T, 1965ME1C, 1965NE1C, 1965WE1D, 1966EL08, 1966GU08, 1966HA18, 1966MA1P, 1966NO1B, 1966RI12, 1966WI1E, 1967BA12, 1967CO32, 1967FA1A, 1967HU1C, 1967KU1E, 1967PO1J, 1967RI1B, 1967WA1C, 1968FI1F, 1968HO1H, 1968RE1G, 1969KU1J, 1969VA1C, 1970KU1K).

Other: (1962BA1K, 1964LI1B, 1965BO1M, 1966HE1C, 1966OL1C, 1968RI1H, 1968TA1C, 1968WI1B, 1969AL1G, 1969AR1G, 1969AU1D, 1969BA2V, 1969CH1C, 1969HA1G, 1969HE1N, 1969MC1C, 1969OC1A).

Ground state: $\mu = +0.702381 \pm 0.000002$ nm (1964LI14). See also (1958LA04, 1963BE36, 1964BE24, 1967CO1D, 1967SH14, 1968PE16, 1968RO1E, 1969FU11, 1969NO1E, 1969VA1C).

1. (a) ^{6}Li(^{7}Li, n)^{12}C	$Q_{\rm m} = 20.924$	$E_{\rm b} = 25.871$
(b) ^{6}Li(^{7}Li, p)^{12}B	$Q_{\rm m} = 8.337$	
(c) ^{6}Li(^{7}Li, 2n)^{11}C	$Q_{\rm m} = 2.204$	
(d) ^{6}Li(^{7}Li, d)^{11}B	$Q_{\rm m} = 7.192$	
(e) ^{6}Li(^{7}Li, t)^{10}B	$Q_{\rm m} = 1.994$	
(f) ^{6}Li(^{7}Li, α)^{9}Be	$Q_{\rm m} = 15.220$	

Differential and total cross sections have been measured for $E(^{7}{\rm Li}) = 3.8$ to 6.0 MeV for the proton groups to ^{12}B*(0, 0.95, 1.67, $2.6 + 2.7$, 3.4), the deuteron groups to ^{11}B*(0, 2.14, 4.44, 5.02, $6.74 + 6.79$, 7.30), the triton groups to ^{10}B*(0, 0.72, 1.74) and the α group to ^{9}Be(0). The dominant reaction appears to be transfer of an α-particle. The total cross sections generally increase smoothly with energy without showing any structure (1967KI03). See also ^{9}Be and ^{10}B in (1966LA04) and ^{11}B and ^{12}B in (1968AJ02). The ^{11}C yield has been measured for $E(^{6}{\rm Li}) = 1.2$ to 3.6 MeV by (1961NO05). See also (1957NO17, 1963GA15, 1963HU02, 1963KA1E, 1964GA1E, 1965BE1X).

2. ^{7}Li(^{7}Li, n)^{13}C	$Q_{\rm m} = 18.619$

See (1957NO17, 1962BE24).

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

E_x (MeV $\pm$ keV)	$J^\pi; T$	τ_m or Γ (keV)	Decay	Reactions
0	$\frac{1}{2}^-$		—	2, 3, 4, 9, 10, 12, 13, 14, 15, 16, 21, 22, 23, 24, 25, 32, 33, 34, 35, 36, 37, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 60, 61, 62, 63, 64, 65, 66
3.086 ± 3	$\frac{1}{2}^+$	$\tau_m = 1.5 \pm 0.16$ fsec	γ	9, 12, 13, 14, 22, 24, 32, 33, 38, 43, 45, 46, 50, 51, 55, 56, 60, 61, 63
3.68415 ± 0.11	$\frac{3}{2}^-$	1.5 ± 0.15 fsec	γ	3, 9, 12, 13, 14, 22, 24, 26, 32, 33, 35, 37, 38, 40, 42, 45, 46, 50, 51, 52, 53, 55, 56, 60, 61, 63
3.854 ± 1	$\frac{5}{2}^+$	10.8 ± 1 psec	γ	3, 9, 12, 13, 14, 22, 24, 32, 33, 45, 46, 50, 51, 55, 56, 60, 61, 63
6.864 ± 3	$\frac{5}{2}^+$	$\Gamma = 6$ keV	n	9, 14, 22, 24, 27, 32, 42, 45, 55, 56, 60, 61
7.492 ± 10		< 5		9, 14, 22, 24, 32, 46, 51, 55, 56, 61
7.549 ± 9	$\frac{5}{2}^-$	< 5		9, 14, 22, 24, 32, 37, 42, 45, 46, 51, 55, 56, 60, 61
7.677 ± 12	$\frac{3}{2}^+$	72 ± 10	n	9, 14, 22, 24, 27, 32, 38, 46, 56, 61
8.25 ± 80	$\frac{3}{2}^+$	1000 ± 100	n	27, 32
8.858 ± 14	$\frac{1}{2}^-$	161 ± 18	n	22, 24, 27, 37, 38, 42, 45, 55, 56, 60, 61
9.499 ± 4	$(\frac{3}{2}^-)$	≤ 5	n	14, 22, 24, 27, 28, 32, 45, 55, 56, 60, 61
9.899 ± 5	$\frac{3}{2}^-$	28	n	14, 22, 24, 27, 28, 32, 42, 56, 61
10.46		200	n	14, 28
10.753 ± 5	$\frac{7}{2}^-$	≈ 50	n	22, 27, 28, 32, 56
10.809 ± 20		< 30	n	22, 27, 28, 39, 56
11.000 ± 20	$(\frac{1}{2}^+)$	37	n, α	5, 22, 27, 28, 39, 56

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

E_x (MeV $\pm$ keV)	$J^\pi; T$	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
11.078 ± 20	$(\frac{1}{2}^-)$	< 4	n, α	5, 14, 22, 27, 28, 42, 56, 60
11.721 ± 30	$(\frac{3}{2}^-)$	125 ± 20	γ, n	27, 28, 39, 42, 56
11.97	$(\frac{7}{2}^-)$	≈ 150	n, α	5, 8, 14, 28, 55, 56
12.104 ± 8	$(> \frac{7}{2})$	125 ± 30	n, α	5, 14, 22, 27, 28, 56
12.42 ± 50	$(\frac{1}{2}, \frac{7}{2})^-$	≈ 200	n, α	5, 27, 28, 31, 60
12.81 ± 100				22
13.3		5000 ± 1000	γ, n	39
13.41		60	n, α	5, 8, 14
13.55		≈ 500	n, α	5, 27, 28
13.76		≈ 350	n, α	5, 42
14.13		≈ 200	n, α	5, 8
14.39 ± 100		260	n, α	5
14.63		210	n, α	5, 8
14.95 ± 50		380	n, α	5
15.1087 ± 2.5	$\frac{3}{2}^-; \frac{3}{2}$	5.9 ± 0.9	γ, n, α	4, 5, 22, 42, 45, 52, 60
15.29	$\geq \frac{3}{2}$	450	n, α	5, 27
15.53 ± 50		220	n, α	5
16.02		210	n, α	5, 14
16.16 ± 50		230	n, α	5, 14, 27
16.96 ± 50		330	n, α	5
17.37 ± 100		190	n, α	5
17.72 ± 50		170	n, α	5
(17.99)		40	n, α	5
18.30 ± 50		300	n, α	5
18.504 ± 25	$T = \frac{3}{2}$			22
18.648 ± 15	$T = \frac{3}{2}$	≈ 35		22
18.679 ± 20	$T = \frac{3}{2}$			22
18.76 ± 30		70	n, α	5
19.123 ± 10	$T = \frac{3}{2}$	≈ 35	α	22, 42
19.5	$(\frac{1}{2}, \frac{3}{2}^-)$	≈ 460	n, d	17, 27, 28
19.90		≈ 600	n, p, d	17, 18

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

E_x (MeV ± keV)	$J^\pi; T$	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
20.25		≈ 200	n, d, α	17, 20
20.54 ± 10		116 ± 10	n, p, d, α	5, 17, 18
21.30 ± 15		159 ± 15	n, p, d	17, 18
21.84 ± 20		114 ± 20	n, d	17
22.28		broad	n, p, d	17, 30
23.0 ± 200		≈ 1000	n, d	17, 27
23.5		≈ 3000	γ, p	40
26.9			n, d	17
27.5			n, d	17

[a] See also Tables 13.8, 13.17 and 13.18.

3. ^{7}Li(^{11}B, αn)^{13}C $\quad Q_m = 9.954$

The ΔE for the 3.85 and 3.68 MeV transitions is 169.63 ± 0.23 keV (1969TH01). See also (1963HO1E).

4. ^{9}Be(α, γ)^{13}C $\quad Q_m = 10.651$

At $E_\alpha = 6.446 \pm 0.004$ MeV, corresponding to the excitation of the first $T = \frac{3}{2}$ state in ^{13}C ($E_x = 15.114 \pm 0.005$ MeV, $\Gamma \leq 7$ keV), $\Gamma_\alpha \Gamma_\gamma / \Gamma \approx 2$ eV for the ground state transition. Capture radiation has also been observed to one of the three states ^{13}C*(3.1, 3.7, 3.9) (1966MI1K). (1968SN1B) find $E_x = 15.107 \pm 0.003$ MeV, $\Gamma = 6.7 \pm 1.7$ keV. See also (1969MC1C).

5. ^{9}Be(α, n)^{13}C $\quad Q_m = 5.704 \quad E_b = 10.651$

Resonances for neutron groups to the ground and first excited states of ^{12}C, for γ-rays from ^{12}C*(4.4, 12.7, 15.1) and resonances in the total neutron cross section are given in Table 13.5 (1959AJ76, 1963SE04, 1965GI02, 1965GR22, 1966MI12, 1968DA05, 1968SN1B). See also ^{12}C in (1968AJ02) and (1959SM98, 1959BR75, 1967FO1B, 1968DA1D, 1968OB1B, 1968VE06). The yield of neutrons to ^{12}C*(7.65) has been measured for $E_\alpha = 1.7$ to 6.4 MeV (1968OB1B, 1970WE1L) and 6 to 10.1 MeV (1966MI12). Angular distributions of ground-state neutrons suggest two broad resonances in the region $E_\alpha = 3.9$ to 4.6 MeV, probably $J^\pi = \frac{3}{2}^+$ and $\frac{5}{2}^+$ (1957RI38). At the threshold for formation of the $T = \frac{3}{2}$ state at 15.11 MeV, weak interference anomalies are observed in the n_0 and n_1 yields (1966MI1K).

Polarization measurements have been carried out for $E_\alpha = 1.9$ to 4.5 MeV by (1965LI09; n_0, n_1) and for 4.5 to 5.9 MeV by (1966DO1E, 1967DE1U; n_0, n_1). See also (1962GO1J, 1963GO1J, 1965CL1B, 1965TS1A, 1966DA1B, 1966DE1M, 1968ST1R).

6. ^{9}Be(α, p)^{12}B $Q_m = -6.884$ $E_b = 10.651$

See ^{12}B.

7. ^{9}Be(α, d)^{11}B $Q_m = -8.028$ $E_b = 10.651$

See ^{11}B.

8. (a) ^{9}Be(α, α)^{9}Be $E_b = 10.651$
(b) ^{9}Be(α, α'n)^{8}Be $Q_m = -1.665$
(c) ^{9}Be(α, n)^{4}He^{4}He^{4}He $Q_m = -1.570$

A number of excitation functions have been measured for elastically scattered α particles (reaction (a)) for $E_\alpha = 1.7$ to 20 MeV: these show considerable resonance structure with the variations being most prominent below 10 MeV but persisting up to 20 MeV. Angular distributions have been analyzed by the optical model: see (1965TA1C, 1969GO1P). See also ^{9}Be in (1966LA04) and (1967FU08). For reactions (b) and (c), see (1952AJ38) and ^{8}Be in (1966LA04). See also (1963IG01).

9. (a) ^{9}Be(^{6}Li, d)^{13}C $Q_m = 9.178$
(b) ^{9}Be(^{7}Li, t)^{13}C $Q_m = 8.183$

At $E(^7\text{Li}) = 3.2$ MeV, triton groups are observed to the first eight states of ^{13}C (not all resolved). No triton groups are observed to the previously reported states at 5.51 and 6.10 MeV (1964CA05)† . For reaction (a) see reaction 3 (1969TH01). See also (1968OG1A).

† Angular distributions for the triton groups to ^{13}C*(0, 3.09, 3.68+3.85, 6.86) have been measured at $E(^7\text{Li}) = 5.6$, 5.8, 6.0, 6.2 MeV (1969SN02).

Table 13.5: Resonances in ^{9}Be(α, n)^{12}C

E_{α} [a] (MeV)	E_{α} [b] (MeV)	E_{α} [c] (MeV)	Γ_{cm} (keV)	J^{π}	^{13}C* [d] (MeV)	Refs.
0.52	0.52		≈ 55 [e]	$(\frac{1}{2}^{+})$	11.01	(1956JA28, 1968DA05)
0.60	0.60		< 4 [e]		11.06	(1968DA05)
1.9	1.905	1.92	130	$(\frac{7}{2}^{-})$	11.97	(1953TA06, 1954BE08, 1955TA28, 1956BO61, 1956JA28, 1965GI02)
2.24		2.25	280		12.20	(1956BO61, 1965GI02)
2.58	2.6	2.58	≈ 200	$(\frac{1}{2}^{-})$	12.44	(1953TA06, 1956BO61, 1956JA28, 1965GI02, 1965GR22)
4.00	3.98	4.00	60		13.41	(1956BO61, 1959GI47, 1963SE04, 1965GI02, 1965GR22)
4.18			570		13.55	(1957RI38, 1965GR22)
4.50	4.47	4.50	≈ 350		13.76	(1956BO61, 1959GI47, 1963SE04, 1965GI02, 1965GR22)
5.0	5.02	5.0	≈ 200		14.13	(1956BO61, 1963SE04, 1965GI02)
5.40 ± 0.10	5.3		260		14.39 ± 0.10	(1963SE04, 1965GR22, 1966MI12)
	5.75	5.75	210		14.63	(1959GI47, 1963SE04, 1965GI02, 1965GR22, 1966MI12)
6.20 ± 0.05			380		14.95 ± 0.05	(1965GR22, 1966MI12)
		(6.7)	broad		(15.29)	(1965GI02)
7.10 ± 0.05	7.00		220		15.53 ± 0.05	(1963SE04, 1965GR22, 1966MI12)
	7.75	7.8	210		16.02	(1959GI47, 1963SE04, 1965GI02, 1965GR22)
7.95 ± 0.05			230		16.16 ± 0.05	(1965GR22, 1966MI12)
9.10 ± 0.05		9.1	330		16.96 ± 0.05	(1965GI02, 1965GR22, 1966MI12)
9.7 ± 0.10	9.70		190		17.37 ± 0.1	(1965GR22, 1966MI12)
10.2 ± 0.05			170		17.72 ± 0.05	(1965GR22, 1966MI12)
(10.60)			40		(17.99)	(1965GR22)
11.05 ± 0.05			300		18.30 ± 0.05	(1965GR22, 1966MI12)
11.70 ± 0.03	11.60		70		18.76 ± 0.03	(1965GR22, 1966MI12)
14.25 [f]			≈ 120		20.52	(1968SN1B)

[a] Resonances in neutron yield.

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

[c] Resonances in total cross section.

[d] Not corrected for effects of Coulomb barrier penetration.

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

[f] Resonance in yield of 12.7 and 15.1 MeV γ-rays.

10. ^{9}Be(^{14}N, ^{10}B)^{13}C $\quad Q_m = -0.963$

See (1965GR1F, 1966EL1D, 1969BR1D).

11. (a) ^{10}B(t, p)^{12}B $\quad Q_m = 6.343 \quad E_b = 23.878$
(b) ^{10}B(t, d)^{11}B $\quad Q_m = 5.199$
(c) ^{10}B(t, α)^{9}Be $\quad Q_m = 13.227$

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

12. ^{10}B(α, p)^{13}C $\quad Q_m = 4.063$
$Q_0 = 4.0634 \pm 0.0024$ (1967OD01).

Proton groups have been observed to the first four states of ^{13}C: see (1959AJ76) and (1962ED01). Angular distributions of ground state protons have been measured at $E_\alpha = 4.9$ to 8.1 MeV (1957VO25), 12.1 to 16.0 MeV (1967IV1B), 22 MeV (1963YA1C), 25.9 MeV (1963TE1A), 27.5 and 33.1 MeV (1961YA02) and at 30.4 MeV (1959HU19). See also (1965NI1B).

A study of γ rays from this reaction and from ^{12}C(d, p)^{13}C shows three lines with $E_\gamma = 0.1695 \pm 0.0004$, 3.844 ± 0.015 and 3.69 ± 0.02 MeV. The lifetime of ^{13}C*(3.85) is $(9.0^{+2.5}_{-1.5})$ psec (1968RI16). (1968FO1F) find $\tau_m = 10.8 \pm 1$ psec. See also (1959DI46). The 3.69 MeV line shows approximately the maximum possible Doppler shift ($\tau < 0.3$ psec): see also Table 13.16. The 170 keV line is due to the cascade transition between the 3.85 and 3.68 MeV states; the internal conversion coefficient is consistent with E1, although M1 cannot be excluded. The probability of this cascade decay of 3.85 MeV state is 0.24 ± 0.05 (1956MA1Q, 1956MA52). The cascade decay via the 3.09 MeV state has a strength relative to all other decays of $(9.3 \pm 2.0) \times 10^{-3}$. This branching ratio is of the order expected for an E2 transition of single-particle (proton) strength (1960PI09)[‡] . The angular distributions and p-γ correlations for the 3.8 MeV radiation indicate $J^\pi = \frac{5}{2}^+$ for the 3.84 MeV state. If the 170 keV line is due to an E1 transition, the J^π of the 3.68 MeV state is then $\frac{3}{2}^-$ ($J^\pi = \frac{1}{2}^-, \frac{3}{2}^-$ follows from ^{12}C(d, p)^{13}C); the angular distribution of the 3.68 MeV radiation is consistent with M1 (1954ST20): $\Gamma_\gamma = 0.40$ to 0.75 eV (1960KA13). The 3.68 MeV state also decays via the 3.09 MeV state with a probability of $(6.5 \pm 1.0) \times 10^{-3}$ (1960KA13). See also reaction 31, (1960EL1C), (1969GA01) and ^{14}N.

[‡] The intensity ratio for the transitions $(3.85 \to 3.68)/(3.85 \to 0)$ is 0.55 ± 0.03. The cascade decay via ^{13}C*(3.09), relative to the g.s. decay, is $(2.5 \pm 0.5) \times 10^{-2}$, $E_\gamma = 3854 \pm 1$ keV (1969LI07).

13. ^{10}B(^{6}Li, ^{3}He)^{13}C $Q_{\rm m} = 8.085$

The first four states of ^{13}C have been observed at $E(^{6}$Li$) = 4.89$ MeV (1966MC05). See also (1965CA05).

14. ^{10}B(^{7}Li, α)^{13}C $Q_{\rm m} = 21.410$

At $E(^{7}$Li$) = 5.20$ MeV, angular distributions have been measured for the α-particles to ^{13}C*(0, 3.1, $3.7 + 3.9$, 6.9). Alpha groups have also been observed to ^{13}C*($7.5 + 7.7$, 9.5, 9.9, 10.5, 11.1, 12, 13.5, 16.1) (1966MC05). See also (1963MI02, 1963MO1B, 1965CA05).

15. (a) ^{10}B(^{14}N, ^{11}C)^{13}C $Q_{\rm m} = 1.143$
(b) ^{10}B(^{19}F, 4α)^{13}C $Q_{\rm m} = -2.257$

For reaction (a) see (1966CO27); for reaction (b) see (1963HO1E).

16. ^{11}B(d, γ)^{13}C $Q_{\rm m} = 18.679$

See (1961SU17, 1963SU1C, 1966SU05).

17. ^{11}B(d, n)^{12}C $Q_{\rm m} = 13.732$ $E_{\rm b} = 18.679$

The yield of neutrons has been measured for $E_{\rm d} = 0.2$ to 11 MeV: observed resonant structure is displayed in Table 13.6 (1965AL17). See also (1959AJ76, 1959NE1A, 1965CL02, 1965SI12, 1966HU1H). The yield of 15.1 MeV γ-rays shows 4 resonances for $E_{\rm d} = 1.5$ to 5.5 MeV: see Table 13.6 (1958KA31, 1964KU09). See also (1963KI02, 1967LE1J). Polarization of neutrons has been studied at $E_{\rm d} = 1.4$ to 1.9 (1966MA21; n_0, n_1), 2 (1967MI1E, 1969MI20; n_0, n_1, n_2, n_3, n_7), 2.8 (1964CH1F; n_0, n_1), 2.8 to 4.0 (1967ME1L; n_0, n_1), 3.0 (1966BR1E; n_0) and 12.3 MeV (1964SM05; n_0, n_1). See also (1959BR75) and ^{12}C.

18. ^{11}B(d, p)^{12}B $Q_{\rm m} = 1.144$ $E_{\rm b} = 18.679$

Table 13.6: Resonant structure in ^{11}B + d

Resonant structure in yield of (MeV ± keV)							$\Gamma_{c.m.}$ (keV)	E_x (MeV)
n_0 [a]	n_1 [a]	n_2 [a]	n_3 [a]	$\gamma_{15.1}$ [b]	p	α [d]		
	1.2							19.7
1.45					1.5 [f]		≈ 600	19.90
1.6	1.8 [e]					1.84	≈ 200	20.25
	2.2 [e]			2.180 ± 10	2.2 [c,f]		116 ± 10	20.54
				3.080 ± 15	3.0 [f]		159 ± 15	21.30
3.6				3.71 ± 20			114 ± 21	21.84
4.23	4.1	4.1		4.4			broad	22.28
	(5.2)							(23.1)
9.6	9.6	9.6	9.6					26.9
10.4		10.4	10.4					27.5

[a] (1965AL17, 1967DI01).
[b] (1958KA31, 1964KU09).
[c] Yield of p_0, p_1 and p_2 (1964BR1A).
[d] Yield of α_0, α_1, α_2, α_3. (1964DU1C, 1969FR03); $\Gamma_{cm} \approx 200$ keV.
[e] (1965AL17) report a resonance at 1.8 MeV while (1967DI01) report one at 2.2 MeV, in addition to a sharper structure at 1.2 MeV.
[f] Resonances in polarization of ^{12}B recoils (1967PF02).

It is reported that the thin-target yield rises smoothly from E_d = 0.3 to 3.1 MeV with no evidence of resonances (1949HU41, 1958KA31, 1963RO22, 1965SA15). However, (1964BR1A) reports a strong resonance at $E_d = 2.3$ MeV in the p_0, p_1 and p_2 yield. Analysis of yield curves of 0.95 and 1.67 MeV γ-rays (1968CH05) also suggest a broad resonance at $E_d \approx 2.1$ MeV. See also (1963SE1F). The polarization of ^{12}B recoils has been studied for $E_d = 0.9$ to 3.2 MeV: resonances in the recoil polarization are observed at $E_d = 1.5$, 2.1 and 3.0 MeV (see Table 13.6) (1967PF02). See also (1963KE06, 1967BE10). See also ^{12}B and (1964TI03, 1967BO17, 1967TI1A).

19. ^{11}B(d, d)^{11}B $\qquad E_b = 18.679$

See ^{11}B and (1963NE1H).

20. ^{11}B(d, α)^{9}Be $\qquad Q_m = 8.028 \qquad E_b = 18.679$

The excitation function for α-particles to the ground state increases monotonically for $E_{\rm d}$ = 0.39 to 1.05 MeV (1963RO22, 1965SA15); that for the α-particles to ^{9}Be*(2.43) increases monotonically for $E_{\rm d} = 0.39$ to 0.70 MeV (1965SA15). At $E_{\rm d} = 1.83$ MeV, a pronounced resonance is observed in the α_0, α_1, α_2 and α_3 yields: $\Gamma_{\rm cm} \approx 200$ keV (1964DU1C, 1969FR03). Some gross structure is observed in these yields for $E_{\rm d} = 1.0$ to 3.2 MeV (1964BR1A, 1969FR03). See also (1966DR04, 1968CO31, 1969MC1C) and ^{9}Be in (1966LA04).

21. ^{11}B(t, n)^{13}C $\qquad Q_{\rm m} = 12.422$

See ^{14}C.

22. ^{11}B(^{3}He, p)^{13}C $\qquad Q_{\rm m} = 13.185$

$Q_0 = 13.1854 \pm 0.0040$ (1967OD01); see also (1964MA57).

Levels derived from reported proton groups are listed in Table 13.7.

The proton groups thought to correspond to ^{13}C levels at $E_{\rm x} = 5.51$ and 6.10 MeV (1958MO99) come instead from the proton decay of ^{13}N*(9.48, 10.37) fed in the reaction ^{11}B(^{3}He, n)^{13}N (1966CH18). See also (1963GA03). At $E(^{3}{\rm He}) = 8$ to 12 MeV, proton groups are observed to the first five $T = \frac{3}{2}$ states of ^{13}C: see Table 13.7 (1965HE1C, 1966HE1F). The angular distribution of the protons to the first $T = \frac{3}{2}$ state at $E_{\rm x} = 15.106$ MeV is consistent with $J^{\pi} = \frac{3}{2}^{-}$ (the known character of ^{13}B$_{\rm g.s.}$) (1965HE1C). The neutron and γ-widths of ^{13}C*(15.10) are displayed in Table 13.8 where they are compared with the corresponding quantities for ^{13}N*(15.07) (1968CO27, 1969AD01). Comparison of the reduced widths for the particle decays to ^{12}C(0) and ^{12}C*(4.4) show that the form of the isospin impurity in the 15.1 MeV, $T = \frac{3}{2}$ state, depends in $T_{\rm Z}$ (1969AD01). Preliminary results for the branching ratios for the α-decay to ^{9}B(0) are $(1.9 \pm 0.5)\%$ for ^{13}C*(15.10) and $(6.5 \pm 1.5)\%$ for ^{13}C*(19.12) (1969NE1G). Other angular distributions have been measured at $E(^{3}{\rm He}) = 4.5$ MeV (1957HO61; p_0, p_1, $(p_2 + p_3)$), 8.6, 9.6 and 10.3 MeV (1963MA24; p_0) and 10 and 12 MeV (1968LI1K, 1969AD1C; p_0, p_1, p_2, p_4, p_6, p_7, p_{10}, p_{11}). The parity of ^{13}C*(9.90) is odd (1969AD1C). See also (1959AL96, 1963CL1A, 1969BA1Z, 1969MC1C).

23. ^{11}B(α, d)^{13}C $\qquad Q_{\rm m} = -5.168$

Differential cross sections of deuterons corresponding to ^{13}C(0) have been measured at E_{α} = 23 and 25 MeV (1967AL16). See also (1968ZE1B).

24. ^{11}B(^{6}Li, α)^{13}C $\qquad Q_{\rm m} = 17.207$

Table 13.7: Levels of ^{13}C from ^{11}B(^{3}He, p)^{13}C

E_x (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Refs.
0		(1955BI26, 1958MO99, 1963GA03)
3.09		(1955BI26, 1958MO99, 1963GA03)
3.68	< 5	(1955BI26, 1958MO99, 1963GA03)
3.86	< 5	(1958MO99, 1963GA03)
6.871 ± 12	< 10	(1959YO25, 1963GA03)
7.500 ± 12	< 5	(1959YO25, 1963GA03)
7.554 ± 12	< 5	(1959YO25, 1963GA03)
7.694 ± 14	75 ± 15	(1959YO25, 1963GA03)
8.869 ± 36	175 ± 50	(1959YO25)
9.509 ± 12	< 10	(1959YO25)
9.896 ± 12	< 10	(1959YO25)
10.9 ± 150		(1957GA01)
11.1 ± 150		(1957GA01)
12.08 ± 100		(1957GA01)
12.81 ± 100		(1957GA01)
15.106 ± 10 [a]	≤ 5	(1965HE1C)
18.504 ± 25 [a]		(1966HE1F)
18.648 ± 15 [a]	$\approx 30 - 40$	(1966HE1F)
18.679 ± 20 [a]		(1966HE1F)
19.123 ± 10 [a]	$\approx 30 - 40$	(1966HE1F)

[a] It is suggested that these states have $T = \frac{3}{2}$ (1965HE1C, 1966HE1F).

Table 13.8: Parameters of the first $T = \frac{3}{2}$ state in ^{13}C and ^{13}N

	^{13}C*(15.11)	^{13}N*(15.07)	Refs.
J^π	$\frac{3}{2}^-$	$\frac{3}{2}^-$	
Γ (keV)	6.2 ± 1.1	1.17 ± 0.21	(1969AD01)
	4.7 ± 1.6	1.13 ± 0.3	(1968CO27)
	6.7 ± 1.7		(1968SN1B)
Γ_{n_0} or Γ_{p_0} (keV) [a]	0.40 ± 0.11	0.24 ± 0.05	(1969AD01)
Γ_{n_1} or Γ_{p_1} (keV) [b]	1.55 ± 0.35	0.14 ± 0.03	(1969AD01)
Γ_{γ_0} (eV)	25 ± 7 [c]	27 ± 5	(1969AD01)
$\Gamma_{\gamma_1}/\Gamma_{\gamma_0}$	0.25 ± 0.10	< 0.20	(1968CO27)
$\Gamma_{\gamma_{2+3}}/\Gamma_{\gamma_0}$	0.79 ± 0.10	0.81 ± 0.12	(1968CO27)

[a] Widths for ^{11}B(^{3}He, p)^{13}C(15.11) $\rightarrow$ n_0 + ^{12}C and ^{11}B(^{3}He, n)^{13}N(15.07) $\rightarrow$ p_0 + ^{12}C.
[b] Widths for ^{13}C(15.11) $\rightarrow$ n_1 + ^{12}C* and ^{13}N(15.07) $\rightarrow$ p_1 + ^{12}C*.
[c] 22.7 ± 2.6 eV (1969WI22).

Angular distributions have been measured at $E(^6\text{Li}) = 4.72$ MeV to the ^{13}C ground state and to ^{13}C*(3.1, 3.8 [u], 6.9, 7.5 [u]) [u = unresolved]. The ^{13}C states at 8.86, 9.50 and 9.90 MeV have also been observed (1966MC05). See also (1963MO1B, 1965CA05).

25. ^{11}B(^{16}O, ^{14}N)^{13}C $\qquad Q_m = -2.057$

See (1968OK06).

26. ^{12}C(n, γ)^{13}C $\qquad Q_m = 4.947$

$Q_0 = 4.94603 \pm 0.00015$ (1968SP01);
$Q_0 = 4.94647 \pm 0.00017$ (1967PR10);
$Q_0 = 4.947 \pm 0.001$ (1965JA09).

The thermal capture cross section is 3.4 ± 0.3 mb (1964ST25), 3.8 ± 0.8 mb (1963MO1C). Reported γ-transitions are listed in Table 13.9. See also (1963MA60, 1964FO1A, 1967FO1B, 1968RO1H).

27. ^{12}C(n, n)^{12}C $\qquad E_b = 4.947$

Table 13.9: Neutron capture γ-rays in ^{13}C

E_γ (MeV ± keV)	Transition	Intensities [a]				
		(1967TH05)	(1968SP01)	(1953BA18)	(1958GR01)	(1961JA19)
4.9458 ± 0.6	capt. → g.s.		68 ± 1			
4.94546 ± 0.17 [b]	capt. → g.s.					
4.948 ± 8 [c]	capt. → g.s.			70		
4.950 ± 15	capt. → g.s.				75	
4.946	capt. → g.s.	66 ± 3				69
3.68428 ± 0.14	3.68 → g.s.		32 ± 1			
3.68394 ± 0.17 [b]	3.68 → g.s.					
3.68 ± 50	3.68 → g.s.			30		
3.68 ± 20	3.68 → g.s.				25	
3.684	3.68 → g.s.	34 ± 2				31
1.26176 ± 0.07	capt. → 3.68		32 ± 1			
1.26192 ± 0.06 [b]	capt. → 3.68					
1.260 ± 15	capt. → 3.68				25	
1.27	capt. → 3.68					30
1.262	capt. → 3.68	34 ± 2				

[a] Gamma rays per 100 captures.
[b] (1967PR10).
[c] $E_\gamma = 4.946 \pm 1$ (1965JA09).

The total cross section data up to 164 MeV is summarized in (1964ST25). Table 13.11 lists recent cross section measurements: see also ^{12}C in (1968AJ02), (1964ST25) and (1959HA06, 1966DE1M, 1968HA1V). Angular distributions are summarized in (1963GO1M). See also (1966GA1M, LA67Q). The coherent scattering length (thermal, bound) is 6.656 ± 0.004 fm (1967HO1J, 1967KO1M). See also (1961WI1A, 1963SE13, 1966DA1B, 1969BA1P). An effective range theory analysis ascribes the s-wave scattering to the (bound) 3.09 MeV state: $\theta^2(E_n = 0) = 0.20 \pm 0.02$ (1963SE13).

In the region $E_n = 0$ to 20 MeV a number of resonances have been reported: see Table 13.10 (1960TS02, 1961LA1A, 1961FO07, 1966LI03, 1964HA1G, 1965HA21, 1968BO34, 1968CI1A, 1968DA1F, 1968SC1G, 1969DA13), and (1959AJ76) for a listing of the earlier references.

Polarization measurements have been carried out with E_n up to 24 MeV: see Table 13.12 for recent references and (1959AJ76) for earlier ones. See (1963HA1G, 1966DA1B, 1966RO1B) for a general discussion of $^{12}C + n$ polarization.

See also (1958HA1A, 1959MA1C, 1959PR65, 1960PE02, 1960SA25, 1963KU1F, 1965AN1A, 1965DE1G, 1965FR1B, 1967CH42, 1967MA1K, 1968EN1A, 1969AN1E, 1969CR1C) and (1959KE1A, 1959WI1C, 1960HO14, 1960MI1B, 1960TO1B, 1962CA1C, 1962KA1D, 1963ED1B, 1963KA27,

Table 13.10: Resonances in ^{12}C(n, n)^{12}C [a]

E_{res} (MeV ± keV)	Γ_{cm} (keV)	^{13}C* (MeV)	l_n	J^π	θ^2	Refs. [a]
		3.09			0.20 ± 0.02	(1963SE13)
2.077 ± 3	6	6.864	2	$\frac{5}{2}^+$		(1961LA1A, 1963PI03, 1968DA1F)
2.82	≈ 5	7.55				(1968CI1A, 1968SC1G)
2.95	80	7.67	2	$\frac{3}{2}^+$		(1958WI36)
3.58 ± 80	1000 ± 100	8.25	2	$\frac{3}{2}^+$	0.35	(1960TS02, 1961FO07, 1966LI03, 1969GA1U)
4.26 ± 30	185 ± 40	8.88	1	$\frac{1}{2}^-$	0.03	(1960TS02, 1961FO07, 1966LI03, 1969GA1U)
4.935 ± 4	≤ 5 [e]	9.499	1	$(\frac{1}{2}, \frac{3}{2})^-$		(1960TS02, 1961FO07, 1969DA13, 1969GA1U)
5.368 ± 5	28 [b,e]	9.899	1	$\frac{3}{2}^-$		(1961FO07, 1968GA1L, 1969DA13, 1969GA1U)
6.294 ± 5	60 [b,e]	10.753	3	$\frac{7}{2}^-$		(1961FO07, 1968GA1L, 1969DA13, 1969GA1U)
6.5 [b]		10.9				(1961FO07)
6.559 [b]	37 [e]	11.03	(0)	$(\frac{1}{2}^+)$		(1961FO07 [c], 1968GA1L, 1969GA1U)
6.7		11.1				(1961FO07)
(7.4)	(250)	(11.8)		$(\geq \frac{5}{2})$		(1961FO07)
7.759 ± 8	(200)	12.104		$(> \frac{7}{2})$		(1961FO07, 1969DA13)
(8.1)	(150)	(12.4)				(1961FO07)
9.3	370	13.5				(1961FO07)
11.1	450	15.2		$(\geq \frac{3}{2})$		(1961FO07)
12.1	230	16.1				(1961FO07)
15.8 [d]	≈ 460	19.5	1	$(\frac{1}{2}, \frac{3}{2})^-$		(1968BO34)
19.6 ± 0.2	≈ 1000	23.0	1	$(\frac{1}{2}, \frac{3}{2})^-$		(1964HA1G, 1965HA21, 1968BO34)

[a] See (1959AJ76) for earlier references; see also (1964ST25).
[b] See (1961FO07).
[c] I am indebted to J.C. davis and H.H. Barschall for sending me this revised value based on a change in the calibration of the analyzing magnet used by (1961FO07).
[d] Resonance in elastic scattering: see also Table 13.13.
[e] (1968CI1A): see (1969GA1U).

1963LU10, 1963MC1B, 1964CR1B, 1965SL1B, 1966AG1A, 1966JA08, 1966LE1M, 1966LO1M, 1966SE1E, 1967BE1F, 1967PI02, 1967RO1J, 1967SC1H, 1967TA1B, 1968CH35, 1968KO1A, 1968RE1G, 1968TI1B, 1969PU05).

Table 13.11: ^{12}C + n total cross-section measurements [a]

E_n (MeV)	Refs.	E_n (MeV)	Refs.
0.003 – 10 eV	(1960WA07)	3.3 – 5.0	(1960TS02)
0.3 – 400 eV	(1967HO1J)	3.4 – 16	(1961FO07)
1.1 – 6.2 eV	(1969HO1Y)	5.6	(1960BR13)
1.44 eV	(1965RA15)	7.0 – 14.3	(1964MA46)
0.003 – 0.66	(1963SE13)	13.7 – 14.6	(1968HU17)
0.01 – 0.50	(1966MO09)	15 – 120	(1961BO06)
0.15 – 0.2	(1959BI19)	17 – 21	(1964HA1G, 1965HA21)
0.18 – 0.70	(1961WI02)	17.8, 20.6, 25.3, 28.3, 29.1	(1960PE25)
0.2 – 140	(1966LA1M)	88 – 151	(1966ME14)
0.50 – 1.35	(1960HU02)		
0.7 – 4.0	(1968SC1G)		
1.92 – 6.40	(1968CI1A)		
2.61 – 2.83	(1965SO1A)		
3 – 8	(1969DA13)		
3.10 – 15	(1963GL1E)		

[a] See (1959AJ76) and (1964ST25) for earlier references.

28. (a) ^{12}C(n, n′)^{12}C* $E_b = 4.947$

(b) ^{12}C(n, n′)^{4}He^{4}He^{4}He $Q_m = -7.274$

From threshold to $E_n = 19$ MeV, twelve resonances are observed in the yield of 4.4 MeV γ-rays: see Table 13.13 (1959HA13, 1968BO34). Cross sections have also been measured for various of the elastic transitions for $E_n = 5.5$ to 15.6 MeV by (1959HA06, 1959SI79, 1960BE24, 1963BO15, 1964CL05, 1964PE20, 1964ST30, 1965WI17, 1967BR23, 1968HA1V, 1969MA39). See (1959AJ76) for a listing of the earlier references. See also (1959GA1D, 1968GA1L, 1969GA1U) and ^{12}C.

For reaction (b) see ^{12}C and (1959AJ76).

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

E_n (MeV)	Neutron groups	Refs.
0.4 – 2.4	n_0	(1962EL01)
0.5 – 2.0	n_0	(1969LA30)
0.8, 1.24	n_0	(1963BE15)
1.06 – 2.24	n_0	(1968AS1C)
2 – 4	n_0	(1959BU95)
2.4, 2.7	n_0	(1964SA05)
2.8	n_0	(1962IY01)
2.8 – 4.7	n_0	(1965WE1C)
3.2	n_0	(1959ST1A)
3.2 – 4.2	n_0	(1969MI04)
3.5	n_0	(1962OT01)
4	n_0	(1964GO1L, 1967GO36)
4.4 – 8.5	n_0	(1965KE07)
14.7	n_0, n_1	(1965BR1E, 1967ZO1A)
15.85	n_0, n_1	(1967MA1L, 1968MA24, 1968ME11)
24	n_0	(1962WO08)

[a] See (1959AJ76) for earlier references. See also (1960DU03).

29. $^{12}C(n, 2n)^{11}C$ $\qquad Q_m = -18.720 \qquad E_b = 4.947$

See (1961BR1A, 1952BR61, 1958AS63, 1969MA39).

30. (a) $^{12}C(n, p)^{12}B$ $\qquad Q_m = -12.588 \qquad E_b = 4.947$
(b) $^{12}C(n, np)^{11}B$ $\qquad Q_m = -15.957$

The cross section for reaction (a) has been measured from threshold to $E_n = 22$ MeV (1959KR69, 1968RI02). It exhibits a strong resonance with a peak cross section of 19 mb at $E_x \approx 22$ MeV in ^{13}C and another weaker resonance corresponding to $E_x \approx 20.5$ MeV (1968RI02). See also (1959AL83, 1963LE1D, 1966JE1B).

For reaction (b) see (1962AU1A).

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

E_n (MeV)	$\Gamma_{c.m.}$ (keV)	E_x in ^{13}C (MeV)
4.96	< 80	9.52
5.42	< 80	9.95
5.98	200	10.46
6.35	120	10.79
6.57	< 80	11.01
6.65	< 80	11.08
7.50	260	11.87
7.81	180	12.15
8.14	220	12.46
9.31	500	13.54
15.8	≈ 450	19.5
≈ 19		22.5

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

31. ^{12}C(n, α)^{9}Be $\quad Q_m = -5.704 \quad E_b = 4.947$

The cross section for the transition to ^{9}Be(0) shows a broad structure at $E_n \approx 8$ MeV (1963DA12). See also (1963AL10, 1963CH1C, 1966HU1J, 1967KO27, 1969KI02) and ^{9}Be in (1966LA04).

32. (a) ^{12}C(d, p)^{13}C $\quad Q_m = 2.722$
(b) ^{12}C(d, np)^{12}C $\quad Q_m = -2.225$

$Q_0 = 2.725 \pm 0.005$ (1961LO1C);
$Q_0 = 2.7223 \pm 0.00061$ (1967OD01).

Measurements on the proton groups are summarized in Table 13.14. In addition to a number of relatively sharp states, the proton spectrum exhibits a conspicuous broad structure attributed to a ^{13}C level at $E_x = 8.4$ MeV, $\Gamma = 1.1 \pm 0.3$ MeV. [It seems probable that this level is to be identified with the $D_{3/2}$ level of similar width observed in ^{12}C(n, n)^{12}C at $E_x = 8.25$ MeV: see Table 13.10].

Angular distributions have been studied at many energies, and analyzed by PWBA and DWBA. A listing of the early work is given in (1959AJ76). Recent experiments are listed in Table 13.15. See also (1965GA1A). A DWBA stripping description of the direct reaction interaction part of the

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

^{13}C* (MeV ± keV)				l_n	J^π	θ_n^2 (%) [f]
(1951ST19, 1951VA1A)	(1954SP01)	(1956DO41, 1961JA23)	(1955MC75)			
0	0		0	1 [d]	$\frac{1}{2}^-, \frac{3}{2}^-$	2.6 [g]
3.086 ± 6	3.090 ± 10	3.093 ± 6	3.09 [a]	0 [d]	$\frac{1}{2}^+$	14 [h]
3.686 ± 11	3.684 ± 10	$[3.681 \pm 3]$	3.68 [a]	1 [d]	$\frac{1}{2}^-, \frac{3}{2}^-$	0.7
	3.855 ± 7	$[3.851 \pm 3]$	3.84 [a]	2 [d]	$\frac{3}{2}^+, \frac{5}{2}^+$	4.7
			6.87 [a]	(0, 2) [e]	$(\leq \frac{5}{2}^+)$	
			7.470 ± 20			
			7.533 ± 20			
			7.641 ± 20 [b]			
			8.4 ± 300 [c]			
			9.500 ± 20			
			9.897 ± 20			
			10.759 ± 20			

[a] Energies given for identification only.
[b] $\Gamma = 70 \pm 15$ keV.
[c] $\Gamma = 1.1 \pm 0.3$ MeV.
[d] See (1959AJ76) for early references.
[e] (1955MC75).
[f] PWBA and DWBA analyses: $E_d = 8$ and 12 MeV (1966GL01).
[g] 3.7 ± 0.3 (1961HA19), 3.5 (1964SC12); see also (1966KA05).
[h] 15.7 (1964SC12).

reaction almost certainly will require the use of spin dependent potentials. There is pronounced compound nucleus formation even up to $E_{\rm d} = 11$ MeV (1963EV04, 1967SC29). See also (1969PE09, 1969PE1L) and ^{14}N.

Observed gamma rays are listed in Table 13.16. The cascade decay of the 3.85 MeV state (via ^{13}C*(3.68)) occurs in $37 \pm 4\%$ of the decays; the direct transition occurs in $62 \pm 4\%$ of the events (1966GO15). The mixing ratio for the transition $3.68 \rightarrow 0$ χ(E2/M1) $= -(0.096^{+0.030}_{-0.021})$, while the transition $3.85 \rightarrow 0$, χ(E3/M2) $= +(0.12 \pm 0.03)$ (1966PO11). Angular correlation measurements at $E_{\rm d} = 2.8$ to 3.7 MeV show Γ(E2)/$\Gamma_\gamma \lesssim 5\%$ for ^{13}C*(3.68) and Γ(E3)/$\Gamma_\gamma \lesssim 2\%$ for ^{13}C*(3.85) (1962FL06). See also (1966KA05, 1966PR1B, 1967TI1A, 1968GO14). The lifetime of ^{13}C*(3.09) is < 10 fsec (1968RI16), < 15 fsec (1968AL03) [see also (1967ME02)]; $\tau_{\rm m}$ for ^{13}C*(3.68) < 26 fsec (1968RI16); $\tau_{\rm m}$ for ^{13}C*(3.85) $= 7.5^{+3}_{-2}$ psec (1962SI08): see also Table 13.17.

A study with polarized deuterons at $E_{\rm d} = 7$ and 10 MeV is reported by (1968YU01; p_0, p_1). For other polarization measurements see ^{14}N, (1959AJ76) and (1961GO1K). For reaction (b), see (1963PI04, 1968BO02, 1969SA1K).

See also (1958AR1B, 1959LO59, 1960AL35, 1960BA26, 1961GO27, 1961GO28, 1961PU1B, 1961ST10, 1962AL1D, 1962GR10, 1963NE16, 1963NE09, 1963SE1G, 1963VA1E, 1964RI1C, 1965HE1B, 1965ZI1A, 1966BE31, 1966GO1L, 1967WA1C, 1968FO1E) and (1959AM1B, 1959BO1C, 1959HO1D, 1960BE1B, 1960BU1D, 1960LU1B, 1960NE1C, 1961GI04, 1961RO1G, 1962JO1C, 1963GL1C, 1963SM05, 1963TA1A, 1964VA1F, 1964ZA1B, 1965BA1T, 1965ST1E, 1966HO1D, 1966PE1F, 1967LE1F, 1967MO1N, 1968BE1Z, 1968ED1C, 1968EL1G, 1968ST1T).

33. ^{12}C(t, d)^{13}C $\qquad\qquad$ $Q_{\rm m} = -1.311$

At $E_{\rm t} = 12$ MeV, DWBA fits have been made of the angular distributions of the deuterons to ^{13}C*(0, 3.09, 3.68, 3.85) (1966GL01). See also (1960MU07, 1961BA10, 1969GL1C, 1969LI1D).

34. ^{12}C(^{3}He, 2p)^{13}C $\qquad\qquad$ $Q_{\rm m} = -2.771$

See (1965DO1H, 1967FO1E, 1967HE1E, 1969ST1L).

35. ^{12}C(α, ^{3}He)^{13}C $\qquad\qquad$ $Q_{\rm m} = -15.631$

At $E_\alpha = 56$ MeV, angular distributions of the ^{3}He particles to ^{13}C*(0, $3.68 + 3.85$) have been analyzed by DWBA (1968GA1C, 1968LE1G, 1969GA11). A detailed comparison has been made between the angular distributions of the ground state ^{3}He particles and of tritons from the mirror reaction ^{12}C(α, t)^{13}N (1969GA11).

Table 13.15: $^{12}C(d, p)^{13}C$ angular distribution studies [a]

E_d (MeV)	Distributions of proton groups	Refs.
0.7 − 1.7	p_0	(1965WI11)
0.9 − 1.75	p_0, p_1	(1966KL05, 1967PO01)
0.9 − 2.0	p_0	(1969BO32)
1.2 − 4.5	p_0	(1966GA09)
1.7, 2.7, 3.1, 4.0	p_0, p_1, p_2, p_3	(1965FI05)
2.1 − 2.9	p_1, p_2, p_3	(1966KA05)
2.1 − 3.1	p_0	(1959SE1A)
2.8 − 3.7	p_2, p_3	(1966GE03)
4	p_1	(1960SE13)
4.7 − 13.3	p_0	(1960ZA04, 1960ZA06)
5.0 − 8.4	p_0, p_1, p_2, p_3	(1969CO02)
6.6	p_0, p_1	(1962ZH01)
7 − 11	p_0, p_1	(1963EV04)
8, 12	p_0, p_1, p_2, p_3	(1966GL01)
9.2 − 13.9	p_0, p_1	(1966BA2M, 1968BA2P)
10.2, 12.4, 14.8	p_0, p_1	(1959HA29, 1961HA19)
11, 13	p_0, p_1, p_2, p_3	(1966SC09)
11.8	p_0, p_1	(1964SC12)
12	p_0, p_2	(1967SC29)
12.1, 13.3	p_1, p_2, p_3	(1960ZA04, 1960ZA06)
12.35 − 14.68	p_0, p_2	(1968HO23)
13.3	p_0	(1966MA2A)
14.6	$p_0 - p_{11}$	(1968HO23)
14.9 − 19.6	p_0, p_1, p_2, p_3	(1960MO05)
14.5	p_0, p_2, p_5	(1968KA1J)
25.9	p_0, p_1	(1963VA23)
27.7	p_0, p_2	(1962SL04)
28	p_0, p_1, p_{2+3}	(1968LE1G)
51.5	p_0	(1969BR1E)

[a] See (1959AJ76) for earlier references. See also ^{14}N.

Table 13.16: Gamma radiation from ^{12}C(d, p)^{13}C [a]

E_γ [b] (MeV $\pm$ keV)	E_γ [c] (MeV $\pm$ keV)	Refs.
3.86 ± 20	(3.84 ± 30)	(1955BE62)
3.844 ± 15		(1956MA1Q, 1956MA52)
3.863 ± 15		(1961GO29)
0.1695 ± 0.4 [d]		(1956MA1Q, 1956MA52; see also (1960CH12))
0.16925 ± 0.04		(1969AL17)
(3.76 ± 20) [e]	3.74 ± 30	(1955BE62)
(3.69 ± 20) [e]	3.675 ± 15 [f]	(1956MA1Q, 1956MA52)
(3.687 ± 15) [e]		(1961GO29)
(3.097 ± 5) [e]	3.082 ± 7	(1952TH24)
(3.110 ± 12) [e]		(1961GO29)

[a] See also ^{10}B(α, p)^{13}C.

[b] Uncorrected for Doppler shift.

[c] Corrected for Doppler shift.

[d] From the proton groups $\Delta E = 170 \pm 3$ keV (1954SP01) and 170 ± 1.5 keV (1956DO41).

[e] Doppler shift correction is not required for the 3.86 MeV radiation, but is required for the 3.09 and 3.68 MeV radiation (1952TH24, 1956MA1Q, 1956MA52): see Table 13.17.

[f] Value obtained by subtraction: $3.844 - 0.170$ (1956MA1Q, 1956MA52).

Table 13.17: Summary of results on the total radiation widths of the low-lying levels of ^{13}C–^{13}N [a]

^{13}C* [b] (MeV)	Γ_γ (eV)	Method [c]	Refs.	^{13}N* (MeV)	Γ_γ [d] (eV)	Refs.
3.09	0.44 ± 0.05	(γ, γ)	(1968RO02)	2.37	0.45 ± 0.05	(1968RI16)
	> 0.066	DS	(1968RI16)		0.67	see (1959AJ76)
3.68	> 0.025	DS	(1968RI16)	3.51	0.53	(1963YO06)
	0.44 ± 0.04	(γ, γ)	(1969RA20)		0.69	see (1959AJ76)
3.86	$(7.3 \pm 1.6) \times 10^{-5}$	DS	(1968RI16)	3.56	$< 200 \times 10^{-5}$	(1963YO06)
	$(8.8 \pm 3.0) \times 10^{-5}$	DS	(1962SI08)			
	$(4.4 \pm 0.6) \times 10^{-5}$	DS	(1968AL03)			
	$(6.1 \pm 0.7) \times 10^{-5}$	RD	(1968FO1F)			

[a] (1968RI16).

[b] See also Table 13.18.

[c] DS = Doppler shift; RD = recoil distance.

[d] Obtained from ^{12}C(p, γ)^{13}N.

36. (a) ^{12}C(^{11}B, ^{10}B)^{13}C $Q_m = -6.509$
(b) ^{12}C(^{14}N, ^{13}N)^{13}C $Q_m = -5.606$
(c) ^{12}C(^{19}F, ^{18}F)^{13}C $Q_m = -5.483$

For reaction (a) see (1963SA1E, 1967PO13, 1969BR1D). For reaction (b), see (1965GA1B, 1967BI1F, 1969BR1D, 1969DO07). For reaction (c), see (1968GA1K).

37. ^{13}B(β^-)^{13}C $Q_m = 13.437$

^{13}B decays to ^{13}C*(0, 3.68, 7.55, 8.86): see ^{13}B and Table 13.2 (1962MA19, 1969JO21).

38. ^{13}C(γ, γ)^{13}C

By means of nuclear resonant scattering of bremsstrahlung, τ_m of ^{12}C*(3.09) $= 1.5 \pm 0.2$ fsec (1968RO02), τ_m of ^{12}C*(3.68) $= 1.5 \pm 0.15$ fsec (1969RA20): see Table 13.17.

39. ^{13}C(γ, n)^{12}C $Q_m = -4.947$

The cross section appears to exhibit structure at ≈ 7.8, 8.9, 10.9 and 11.6 MeV (1965BE1A), at 13.3 ± 1 ($\Gamma = 5 \pm 1$ MeV) and at ≈ 22 MeV ($\Gamma \approx 7$ MeV) (1957CO57). For analyses of the work done on this reaction, see (1963HA1E, 1965ME1C). See also (1960ED01, 1964GR40) and (1959FU1A, 1960FR1B, 1961BA1G, 1964FR1C, 1964SH1C, 1969AU06, 1969AU1D, 1969OC1A).

40. ^{13}C(γ, p)^{12}B $Q_m = -17.535$

(1964DE12) report structures at $E_\gamma = 18.5$, 20.0, 23.5, 26.0 and 29.0 MeV. The main part of the cross section is in the 23.5 MeV peak which has $\Gamma \approx 3$ MeV. A broad maximum near 25.5 MeV has been reported by (1956CO72, 1957CO57). See also (1965ME1C) and (1962NE14, 1964KO09).

41. ^{13}C(γ, α)^{9}Be $Q_m = -10.651$

See (1953MI31, 1964GR08).

42. ^{13}C(e, e′)^{13}C*

From a study at $E_e = 250$ MeV, the ratio of the rms radius of the charge distribution for ^{13}C to that of ^{12}C is found to be 0.96 ± 0.01 (1967CR1C). See also (1968RA1B). Inelastic spectra show strong excitation of the negative parity states ^{13}C*(3.68, 7.55, 8.86, 11.7, 13.76, 15.1, 19.12) (1969CA1C, 1969WI22). Excitation of ^{13}C*(3.09, 3.85) has also been reported (1969CR1D, 1969WI22). See Table 13.18. See also (1967KA1A, 1969TO05).

Table 13.18: Electromagnetic transitions [a] in ^{13}C from ^{13}C(e, e′)^{13}C [b]

E_x (MeV ± keV)	J^π	Mult.	$\Gamma_{\gamma 0}$ (eV)	$\Gamma_{\gamma 0}/\Gamma_W$ (W.u.)
3.69 ± 20	$\frac{3}{2}^-$	E2	$(3.61 \pm 0.39) \times 10^{-3}$	3.52
		M1	0.358 ± 0.045	0.339
6.85 ± 60	$\frac{5}{2}^+$	M2	$(6.9 \pm 3.6) \times 10^{-5}$	0.055
7.54 ± 20	$\frac{5}{2}^-$	E2	0.1150 ± 0.0062	3.15
8.86 ± 20	$\frac{1}{2}^-$	M1	3.36 ± 0.46	0.230
		E0	2.09 ± 0.38 [c]	
9.90 ± 30	$\frac{3}{2}^-$	E2	$(6.3 \pm 2.1) \times 10^{-3}$	0.045
		M1	0.324 ± 0.050	0.0159
11.07 ± 20	$(\frac{1}{2}^-)$	M1	1.02 ± 0.20	0.0359
		E0	2.62 ± 0.26 [c]	
	$(\frac{3}{2}^-)$	E2	0.256 ± 0.026	1.03
15.11 ± 20	$\frac{3}{2}^-$	E2	0.59 ± 0.11	0.50
		M1	22.7 ± 2.6	0.313

[a] See also Tables 13.8 and 13.17.

[b] (1969WI22).

[c] Monopole matrix element in fm^2.

43. ^{13}C(p, p′)^{13}C*

Angular distributions of the 3.09 MeV γ-rays are isotropic for E_p up to 5 MeV consistent with the assignment $J = \frac{1}{2}$ (1960BA35). The elastic differential cross section has been studied for $E_p = 1.37$ to 2.38 MeV (1966GE03), 7 MeV (1969GU02), and at $E_p = 32.9$ MeV (1969MA2D). See also (1961RO1G, 1968RI1Q, 1969WA11). The Doppler-shift method leads to lifetime limits of $\tau < 10$ fsec and $\tau < 26$ fsec for ^{13}C*(3.09, 3.68) (1968RI16): see Table 13.16.

44. ^{13}C(d, d)^{13}C

Angular distributions of elastically scattered deuterons have been measured at $E_{\rm d} = 4.7$, 5.0 and 5.3 MeV (1968CO04) and 15 MeV (1965DI1C). See also ^{15}N.

45. ^{13}C(^{3}He, ^{3}He$'$)^{13}C*

Angular distributions of elastically scattered ^{3}He have been studied at $E(^3{\rm He}) = 12$, 15 and 18 MeV (1966KE08) and at 40 MeV (1969BA06). Angular distributions at $E(^3{\rm He}) = 40$ MeV have also been reported to ^{13}C states at $E_{\rm x} = 3.09$, 3.68, 3.85, 6.87, 7.55 ± 0.03, 8.86 ± 0.03 and 11.84 ± 0.03 MeV. ^{3}He groups to ^{13}C*(9.50 ± 0.03) and (15.11) are also reported, the latter only weakly (1968BA1E, 1969BA06). See also (1967AR17, 1969AR10, 1969ZU02).

46. ^{13}C(α, α')^{13}C*

Angular distributions of scattered α-particles have been studied at $E_\alpha = 33.4$ MeV (1967AR17; ^{13}C*(0, 3.68, 7.5)) and 40.5 MeV (1966HA19; ^{13}C*(0, 3.09, 3.68+3.85, 7.5)). See also (1959FU62, 1968FA1A, 1969BA06).

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

Angular distributions of elastically scattered ^{6}Li and ^{7}Li ions have been measured at $E({\rm Li}) =$ 20 MeV (1969BE90).

48. (a) ^{13}C(^{12}C, ^{12}C)^{13}C
(b) ^{13}C(^{16}O, ^{16}O)^{13}C

Angular distributions of elastically scattered ^{12}C and ^{16}O ions have been studied for $E = 10$ to 30 MeV (1968GO1H).

49. ^{13}N(β^+)^{13}C $\qquad Q_{\rm m} = 2.221$

See ^{13}N.

50. ^{14}C(p, d)^{13}C $\qquad Q_m = -5.952$

At $E_p = 12$ MeV, the angular distribution of the deuterons to ^{13}C(0) is PWBA-fitted with $l = 1$: $\theta^2 = 0.038$ (1966GL01). At $E_p = 18.5$ MeV, angular distributions have also been obtained for ^{13}C*(3.09, 3.68, 3.85) (1961LE1A, 1963LE03). See also (1969CU1D).

51. ^{14}C(d, t)^{13}C $\qquad Q_m = -1.919$

At $E_d = 12$ MeV, angular distributions of the tritons to ^{13}C*(0, 3.09, 3.68, 3.85) have been PWBA fitted: $\theta^2 = 14.5$, 0.43 and 5.76 for the three most energetic triton groups. The group to ^{13}C*(3.85) does not show a stripping pattern (1966GL01). See also (1958MO97, 1959KU1C).

52. ^{14}C(^{3}He, α)^{13}C $\qquad Q_m = 12.402$

Angular distributions of the α particles to ^{13}C(0) have been determined at $E(^3\text{He}) = 2$, 6, 8, 10 (1964DU1A) and 44.8 MeV (1966BA13). At the highest energy, the differential cross sections to ^{13}C*(3.68) and to the $T = \frac{3}{2}$ state at 15.11 MeV have also been measured (1966BA13). See also (1966GO1J).

53. ^{14}N(n, d)^{13}C $\qquad Q_m = -5.325$

Angular distributions of ground state deuterons have been determined at $E_n = 14.1$ to 14.7 MeV (1963ZA01, 1967AN08, 1967FE06, 1968MI02). Excitation of ^{13}C*(3.68) is also reported (1957CA07, 1963ZA01, 1967FE06). Gamma rays with energies of 3.686 ± 0.003 and 3.853 ± 0.003 MeV are reported by (1969NY1A). See also (1959HA1G, 1963MO04, 1964MO1D).

54. (a) ^{14}N(p, 2p)^{13}C $\qquad Q_m = -7.550$
(b) ^{14}N(e, ep)^{13}C $\qquad Q_m = -7.550$

At $E_p = 460$ MeV, the summed proton spectrum shows three peaks with binding energies 7.5 ± 0.5, 15.3 ± 0.5 and 19.8 ± 0.6 MeV ($^{13}\text{C}^* = 0$, 7.8 and 12.3 MeV) corresponding to the ejection of $p_{1/2}$ protons in the case of the ground state and $p_{3/2}$ protons in the case of the two excited states. There is also some indication of other structure (1966TY01). See also (1961CL09, 1962MA1L, 1963CL1B, 1965DE1P, 1965DE21, 1966BE1B), and (1962BA1J, 1962BA1A, 1963EL1C, 1965BA21). For reaction (b) see (1969BA1F).

55. $^{14}N(d, ^3He)^{13}C$ $Q_m = -2.056$

At $E_d = 52$ MeV, angular distributions have been measured for the ^{3}He particles to ^{13}C*(0, 3.09, 3.68, 6.87, 7.5, 8.85, 9.51, 11.9 ± 0.15) and analyzed by DWBA: $J^\pi = \frac{5}{2}^-, \frac{1}{2}^-, \frac{3}{2}^-$ and $\frac{3}{2}^-$, respectively, are assigned to ^{13}C*(7.5, 8.85, 9.51, 11.9) (1968HI01). See also (1969KA1A, 1969KA1W). As expected, angular distributions of ^{3}He and of tritons (from ^{14}N(d, t)^{13}N) to analog states are identically the same: this has been shown for the ground state ^{3}He and triton groups (1966DE1C, 1968GA13; $E_d = 28.5$ MeV) and for the groups to ^{13}C*($8.9 + 9.5$) and ^{13}N*(9.2) (1968HI01; $E_d = 52$ MeV). See also (1968BA2J).

56. $^{14}N(t, \alpha)^{13}C$ $Q_m = 12.264$

Observed particle groups at $E_t = 2.6$ MeV are displayed in Table 13.19 (1962SI08). See also (1964SC09) and ^{16}O.

57. $^{14}N(p, p\alpha)^{13}C$ $Q_m = -7.546$

This sequential reaction has been studied at $E_\alpha = 22.9$ MeV (1968KU1C, 1969BA17).

58. (a) $^{14}N(^{12}C, ^{13}N)^{13}C$ $Q_m = -5.606$
(b) $^{14}N(^{14}N, ^{15}O)^{13}C$ $Q_m = -0.257$

For reaction (a) see (1969VO01) and ^{13}N. For reaction (b) see (1966GA04).

59. $^{15}N(n, t)^{13}C$ $Q_m = -9.903$

Not reported.

60. $^{15}N(p, ^3He)^{13}C$ $Q_m = -10.667$

At $E_p = 43.7$ MeV, ^{3}He groups have been observed to eleven states of ^{13}C: see Table 13.19 (1966CE02, 1968FL03). Angular distributions of the ^{3}He particles to these states are generally found to be in agreement with DWBA predictions, using intermediate coupling wave functions to obtain the two-nucleon structure factors (1968FL03). Detailed comparisons are made with the

Table 13.19: Energy levels of ^{13}C from ^{14}N(t, α)^{13}C (1962SI04) and from ^{15}N(p, ^{3}He)^{13}C (1968FL03)

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

[a] From ^{14}N(t, α)^{13}C (1962SI04).

[b] From ^{15}N(p, ^{3}He)^{13}C (1968FL03).

[c] Observed but E_x not determined.

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

[e] (1966CE02).

Table 13.20: ^{13}C states from ^{15}N(d, α)^{13}C

E_x (MeV $\pm$ keV) (1951MA08)	E_x (MeV $\pm$ keV) (1961JA23)	E_x (MeV $\pm$ keV) [a] (1957WA01)
0	0	0
3.083 ± 5	3.100 ± 20	3.09
3.677 ± 5	3.695 ± 10	3.68
		3.85
		6.87
		7.47, 7.53, 7.64 [b]
		8.80 ± 40
		9.5
		9.9

[a] Level energies for identification purposes only except for ^{13}C* $= 8.80$ MeV.

[b] Not resolved.

results of the mirror reaction ^{15}N(p, t)^{13}N: the (p, t) transitions are generally stronger than expected relative to the mirror (p, ^{3}He) transitions. This may arise from interference effect terms due to a spin-orbit interaction on the optical potential, or to interference terms between direct-reaction and core-excitation (1968FL02, 1968FL03). See also (1969VA1C).

61. ^{15}N(d, α)^{13}C $\qquad Q_m = 7.687$

$Q_0 = 7.675 \pm 0.009$ (1961LO10).

Observed α-particle groups are displayed in Table 13.20 (1951MA08, 1957WA01, 1961JA23). Angular distributions of α-particles have been measured at $E_d = 1.0$ to 1.2 MeV (1966ST16; α_0), 20.9 MeV (1968PR04; α_0, α_1) and 21 MeV (1959FI30; α_0). See also (1961LO02, 1965MA59).

62. ^{15}N(α, ^{6}Li)^{13}C $\qquad Q_m = -14.688$

At $E_\alpha = 42$ MeV, the angular distribution of the ^{6}Li particles to ^{13}C(0) has been measured (1968MI05).

63. ^{16}O(n, α)^{13}C $\qquad Q_m = -2.215$

At $E_n = 14.1$ to 18.8 MeV angular distributions of α-particles have been measured: see (1961CI01, 1966MC14, 1968LE11; α_0), (1967HS04; α_0, α_1, $\alpha_2 + \alpha_3$), (1968MA10; α_0, $\alpha_1 + \alpha_2$), (1968SI06; α_0, $\alpha_1 + \alpha_2 + \alpha_3$). See also (1959AJ76, 1962RO1G, 1963DA12, 1963MO04, 1963SE08, 1964MA1N, 1964MO1D, 1965CH13, 1965FU1E, 1966CI1A, 1966FA1B, 1967FU1K, 1967SI1E).

64. ^{17}O(d, ^{6}Li)^{13}C $\qquad Q_m = -4.885$

See (1966DE09).

65. ^{18}O(d, ^{7}Li)^{13}C $\qquad Q_m = -5.678$

See (1963DR1B, 1967DE03).

66. ^{20}Ne(n, 2α)^{13}C $\qquad Q_m = -6.944$

See (1966PE08).

^{13}N

(Figs. 3 and 4)

GENERAL:

Model calculations: (1955LA1A, 1957HU1C, 1959BA1D, 1960PH1A, 1960TA1C, 1961KU17, 1961KU1C, 1961NE1B, 1962IN02, 1962TA1E, 1963BA43, 1963BO1G, 1963SE19, 1963TR02, 1964AM1D, 1964BO1K, 1964ST1B, 1965BO1N, 1965MA1T, 1965ME1C, 1965WE1D, 1966EL08, 1966HA18, 1966NO1B, 1967BR1Q, 1967FA1A, 1967HU1C, 1967KU1E, 1967NE1D, 1967PO1J, 1967WA1C, 1968FI1F, 1968GO01, 1968HO1H, 1969VA1C, 1969ZU1B).

Other: (1967AU1B, 1967EP1A, 1968BA2N, 1968BA2F, 1968VO1C, 1969AU1D, 1969AR1G, 1969BL1G, 1969FO1D, 1969HA1G, 1969HE1N, 1969MC1C, 1969VA1C).

Ground state: $J = \frac{1}{2}$ (1961SN01). $\mu = -0.32212 \pm 0.00035$ nm (1964BE24). See also (1961PO09, 1964LI14, 1967CO1D, 1967SH14, 1968RO1E, 1969FU11, 1969NO1E, 1969SU15, 1969VA1C).

1. ^{13}N(β^+)^{13}C $\qquad Q_{\rm m} = 2.221$

Measured values of the half-life are displayed in Table 13.22. The positon spectrum shows no deviation from the allowed shape: it is concluded that the Fierz coefficient in the Fermi interaction is $< 11\%$ (1957DA08, 1958DA09, 1968DA1J). $\log ft = 3.664$ based on $Q_{\rm m}$ and $\tau_{1/2} = 9.961$ min. The positon polarization has been studied by (1957BO65, 1957HA27). The results indicate that the positons are completely polarized and hence that Fermi transitions as well as GT transitions exhibit the maximum effect of parity non-conservation. See also (1959AJ76) and (1965GA1D, 1966MI1F, 1967AM1H, 1969LE1D, 1969SU15).

2. ^{7}Li(^{6}Li, 2n)^{11}C $\qquad Q_{\rm m} = 2.204 \qquad E_{\rm b} = 23.651$

See (1960NO1A).

3. ^{9}Be(^{6}Li, 2n)^{13}N $\qquad Q_{\rm m} = 3.951$

See (1957NO17).

4. ^{10}B(^{3}He, n)^{12}N $\qquad Q_{\rm m} = 1.563 \qquad E_{\rm b} = 21.638$

Table 13.21: Energy levels of ^{13}N [a]

E_x (MeV $\pm$ keV)	$J^\pi; T$	$\tau_{1/2}$ orΓ (keV)	Decay	Reactions
0	$\frac{1}{2}^-$	$\tau_{1/2} = 9.961 \pm 0.004$ min	β^+	1, 3, 9, 10, 11, 12, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38
2.3660 ± 1.0	$\frac{1}{2}^+$	$\Gamma = 35 \pm 1$ keV	γ, p	10, 12, 15, 19, 20, 27, 29, 30, 31
3.509 ± 2	$\frac{3}{2}^-$	63 ± 5	γ, p	10, 11, 12, 15, 19, 20, 21, 22, 23, 26, 27, 29, 30, 31, 34, 37
3.547 ± 4	$\frac{5}{2}^+$	47 ± 7	p	10, 15, 19, 20, 21, 22, 23, 27, 29, 37
6.382 ± 10	$\frac{5}{2}^+$	11	p	10, 15, 27, 31, 33, 37
6.898 ± 10	$\frac{3}{2}^+$	115 ± 5	p	15, 31
7.166 ± 8	$\frac{7}{2}^+$	9 ± 0.5	p	15, 27, 31
7.387 ± 6	$\frac{5}{2}^-$	75 ± 5	p	11, 15, 27, 28, 29, 30, 31, 34, 37
7.9	$\frac{3}{2}^+$	≈ 1500	p	15
8.92 ± 30	$\frac{1}{2}^-$	230	p	15, 27, 28, 29, 30, 34
9.52 ± 20	$\frac{3}{2}^-$	30	p	11, 15, 27, 30
10.35 ± 20	$\frac{5}{2}^-$	30	p	11, 15
10.36	$\frac{7}{2}^-$	76	p	15
10.78 ± 40	$\frac{1}{2}^-$			27, 34
1.44			p	15
11.65		80	p	15
11.87 ± 30	$\frac{3}{2}^-$	130	p	11, 15, 27, 29, 30, 34
12.08		140	p	15
13.5		≈ 500	p	15
13.962	$\frac{3}{2}^+; \frac{1}{2}$	140	p, α	15, 18
14.1		≈ 500	(γ), p	12, 15
14.7		≈ 500	p	15
15.066 ± 0.4	$\frac{3}{2}^-; \frac{3}{2}$	1.16 ± 0.2	γ, p, α	11, 12, 15, 18, 27, 34
15.7		≈ 500	p	15
15.976	$\frac{7}{2}^+; \frac{1}{2}$	100	p, α	15, 18, 27
16.0		≈ 500	p	15
16.3		≈ 500	p	15

Table 13.21: Energy levels of ^{13}N (continued)

E_x (MeV ± keV)	$J^\pi; T$	Γ_{cm} (keV)	Decay	Reactions
17.2		≈ 500	p	15
17.88 ± 50		≈ 400	p	15
18.233	$\frac{1}{2}^-; \frac{1}{2}$	300	p, α	15, 18
18.419 ± 5	$\frac{3}{2}^+; \frac{3}{2}$	66 ± 8	p, α	11, 15, 18
18.5		≈ 500	p	15
18.7		≈ 500	p	15
18.973 ± 10	$\frac{3}{2}^-$ or $\frac{7}{2}^+; \frac{3}{2}$	23 ± 5	p, α	11, 15, 18
19.3		≈ 500	p	15
19.83	$\frac{5}{2}^-; \frac{1}{2}$	1000	(γ), p, α	12, 15, 18
19.88	$\frac{3}{2}^+; \frac{1}{2}$	520	(γ), p, α	12, 15, 18
20.9	$(\frac{5}{2})^+$	≈ 1500	p	15
21.69			p	15
21.99			p	15
22.6	$(\frac{5}{2})^-$	≈ 1000	γ, p	12, 15
23.3		400	p, ^{3}He	5
23.83		350 ± 50	p, ^{3}He	5
24.4		≈ 500	p, ^{3}He	5, 15
(24.8)		100	p, ^{3}He	5
(25.2)	$(\frac{3}{2})^-$	120	p, ^{3}He	5, 15
25.7	$\geq \frac{3}{2}$	≈ 1000	p, ^{3}He	5
26.1	$\geq \frac{7}{2}$	≈ 1000	d, ^{3}He, α	6, 8
26.87			p	15
27.9		broad	p, ^{3}He	5
31.9			γ, p	12

[a] See also Tables 13.8 and 13.17.

The cross section has been measured for $E(^3\text{He}) = 1$ to 6.3 MeV. There is some evidence of broad structures (1963PE10). See also (1966ZA01) and ^{12}N.

5. ^{10}B(^{3}He, p)^{12}C $\qquad Q_m = 19.695 \qquad E_b = 21.638$

Table 13.22: The half-life of ^{13}N [a]

$\tau_{1/2}$ (min)	Refs.
9.96 ± 0.03	(1958AR15)
9.96 ± 0.03	(1958DA09)
9.965 ± 0.005	(1960JA12)
9.93 ± 0.05	(1960KI02)
9.96 ± 0.02	(1965EB01)
10.05 ± 0.05	(1965BO42)
9.963 ± 0.009	(1968RI15)
9.961 ± 0.004	weighted mean

[a] See also (1955AJ61, 1959AJ76, 1961RA06).

Observed resonances in the yields of proton groups and γ-rays for $E(^3\text{He}) = 1.2$ to 12 MeV are displayed in Table 13.23 (1956SC01, 1964KU09, 1966PA10). For polarization measurements see (1965SI05, 1967SI05) and (1966MI1E). See also ^{12}C.

6. ^{10}B(^{3}He, d)^{11}C $\quad Q_{\text{m}} = 3.199 \quad E_{\text{b}} = 21.638$

Excitation functions for the ground state group have been measured for $E(^3\text{He}) = 3.5$ to 10 MeV: a resonance reported at $E(^3\text{He}) \approx 5.8$ MeV (1965PA10). See also (1965BR42, 1967HA20). See also ^{11}C.

7. ^{10}B(^{3}He, t)^{10}C $\quad Q_{\text{m}} = -3.624 \quad E_{\text{b}} = 21.638$

The excitation function for ^{10}C production has been measured from threshold to $E(^3\text{He}) = 10.5$ MeV. σ_{max} (at 10.5 MeV) $= 435 \pm 87$ μb. No detailed structure is observed (1964OS1A). See also (1966MA36).

8. ^{10}B(^{3}He, α)^{9}B $\quad Q_{\text{m}} = 12.140 \quad E_{\text{b}} = 21.638$

The excitation function for α-particles to ^{9}B(0), measured for $E(^3\text{He}) = 2$ to 10 MeV, indicates a strong resonance at $E(^3\text{He}) = 5.8$ MeV (^{13}N* $= 26.1$), $\Gamma \approx 1$ MeV. This resonance does not appear in the excitation function for alphas to ^{9}B*(2.3) measured over the same energy range.

Table 13.23: Structure in $^{10}B + ^{3}He$

E_{res} (MeV)	Γ (keV)	E_{res} (MeV)	Γ (keV)	E_{res} (MeV)	E_{res} (MeV)	Res. in	E_x in $^{13}N^*$ (MeV)
(1956SC01)		(1964KU09)		(1966PA10)	(1965PA05)		
2.0 [a,b]	500			2.2		p_0, (p_1)	23.3
		2.85 ± 50	450 ± 50			$\gamma_{15.1}$	23.83
3.7 [a]	700			3.5 [a]		p_1, p_0	24.5
4.1	120			3.7		p_0	24.8
4.6 [a]	150					p_0, (p_1)	25.2
		5.2 ± 100 [c]	240 ± 80	5.4 [d]		p_0, $\gamma_{15.1}$	25.7
						p_2, p_3	
					5.8 [f]	α_0, d_0	26.1
				8.2 [e]		p_0	27.9

[a] See, however, (1964KU09).
[b] See also (1967SI05).
[c] See, however, (1966BA01).
[d] $J \geq \frac{3}{2}$, $\Gamma \approx 1$ MeV (1966PA10).
[e] $J \geq \frac{7}{2}$ (1966PA10).
[f] $\Gamma \approx 1$ MeV. This resonance is also seen in the d_0 excitation curve (1965PA10).

Minor structure is observed in both excitation functions approximately 2 MeV (1965PA05). See also ^{9}B and (1968TA1M).

9. $^{10}B(\alpha, n)^{13}N$ $\qquad Q_m = 1.060$

See (1959AJ76) and (1959HE1B, 1960KA13, 1961RO21, 1962ED01, 1965NI1B, 1966ZA01).

10. $^{10}B(^{6}Li, t)^{13}N$ $\qquad Q_m = 5.845$

At $E(^{6}Li) = 4.9$ MeV, triton groups are observed to $^{13}N^*$(0, 2.4, 3.6 [u], 6.38) [u = unresolved] (1966MC05). See also (1963MO1B, 1965CA05).

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

Ground state angular distributions have been measured for $E(^{3}He) = 2.0$ to 5.3 MeV (1966DI04) and 4.7, 6.1 and 6.5 MeV (1969HO1F). Angular distributions at the latter energies of the neutrons corresponding to $^{13}N^*$(3.51, 7.39, 9.52, 10.36, 11.87) indicate, respectively, L = (0, 2), (2, 4), (0, 2), (2, 4), (0, 2), in agreement with the J^π assignments in Table 13.19 (1969HO1F). Work at $E(^3\text{He}) = 1.2$ to 2.0 MeV has shown tht previously reported states at $E_x = 5.51$ and 6.10 MeV in the ^{11}B(^{3}He, p)^{13}C reaction are instead due to the proton decay to ^{12}C(0) of ^{13}N states at $E_x = 9.52 \pm 0.02$ and 10.35 ± 0.02 MeV (1966CH18).

In a study with $E(^3\text{He}) = 7.0$ to 13.5 MeV, neutron groups have been observed to $T = \frac{3}{2}$ states at $E_x = 15.068 \pm 0.008$ MeV ($\Gamma < 15$ keV), 18.44 ± 0.04 MeV and 18.98 ± 0.02 MeV ($\Gamma = 40 \pm 20$ keV). J^π (determined by DWBA) for ^{13}N*(15.07) is $\frac{3}{2}^-$ (1969AD02). The proton and γ-decay widths of ^{13}N*(15.07) are displayed in Table 13.8 where they are compared with the corresponding quantities for ^{13}C*(15.11) (1968CO27, 1969AD01). Comparison of the reduced widths for the particle decays to ^{12}C(0) and ^{12}C*(4.4) show that the form of the isospin impurity in the 15.1 MeV, $T = \frac{3}{2}$, states depend on T_Z (1969AD01). See also (1964BR13, 1967TI1B, 1969MC1C).

12. (a) ^{12}C(p, γ)^{13}N $\qquad Q_m = 1.944$

(b) ^{12}C(p, γp$'$)^{12}C

Resonances for capture radiation displayed in Table 13.24. [See also Table 13.17 for a summary of the total radiation widths of low-lying levels of ^{13}C–^{13}N.] No resonance is observed at $E_p = 1.73$ MeV, corresponding to ^{13}N*(3.56) (1951SE67, 1963YO06).

No capture radiation is observed for $E_x = 5$ to 10.4 MeV: the upper limits to the (p, γ_0) cross sections are 2 mb/sr at the known (p, p) resonances (1962PA07). At $E_p = 14.2$ MeV, capture radiation from the first $T = \frac{3}{2}$ state at $E_x = 15.07$ MeV is observed. $\Gamma_p\Gamma_\gamma/\Gamma = 5.5 \pm 0.8$ eV for the ground state transition which, combined with $\Gamma_p/\Gamma = 0.20 \pm 0.025$ from (1969AD01), yields $\Gamma_\gamma = 27 \pm 5$ eV. The amplitude ratio of E2/M1 $= -0.095 \pm 0.07$. For the transitions to ^{13}N*(2.37) and ^{13}N*($3.51 + 3.56$), $\Gamma_\gamma < 4.5$ and 23 ± 5 eV, respectively. The angular distributions of the γ-rays determine $J = \frac{3}{2}$ for ^{13}N*(15.07) (1968DI04). No clear structure is observed in the ground state capture cross section for $E_p = 14$ to 19.5 MeV (1962WA31). Resonances reported by (1963FI07) in the yields of γ_0 and γ_2 are displayed in Table 13.22. See also (1964TA05).

The capture cross section at low energy is of interest in connection with stellar energy generation: see (1959AJ76) and (1959CA1A, 1964FO1A, 1966BA2P, 1967FO1B).

In the range $E_p = 1.2$ to 2.5 MeV, reaction (b) is observed, involving a γ-transition to the 2.37 MeV state. p-wave resonant capture at $E_p = 1.70$ MeV, with $\Gamma_\gamma = 0.04$ eV, interferes with direct p-wave capture (1954WO09). See also (1959DE28, 1959SU55, 1963CA09, 1964AL1J, 1965FA1E, 1965MA1H, 1966ED1A, 1968TH1K).

13. ^{12}C(p, n)^{12}N $\qquad Q_m = -18.131 \qquad E_b = 1.944$

The cross section for this reaction has been measured from threshold to $E_p = 50$ MeV. Resonant structure is observed corresponding to $E_x = 21$, 24 and, possibly, ≈ 27 MeV (1968RI01). See also (1963VA1C, 1966SP09) and ^{12}N.

Table 13.24: Resonances in ^{12}C(p, γ_0)^{13}N

E_p (MeV ± keV)	Γ_{lab} (keV)	$\omega\Gamma_\gamma$ (eV)	^{13}N* (MeV)	Res. in yield of	Refs.
0.4568 ± 0.5	39.5 ± 1.0	0.67	2.365	γ_0	(1949FO18, 1951SE67, 1953HU18)
	36.5 ± 2.0				(1968BL1K)
	36.7 ± 1.0	0.45 ± 0.05			(1968RI16)
1.698 ± 5	72 ± 9	1.39	3.510	γ_0	(1949VA1A, 1951SE67)
	67 ± 4	1.06 [a]			(1963YO06, 1968BL1K)
13 [b]			14	γ_0	(1963FI07)
14.2	(see text) $T = \frac{3}{2}$ state		15.0	γ_0, γ_1, $\gamma_2 + \gamma_3$	(1968DI04)
20 [b]			20	γ_0	(1963FI07)
24.5			22.6	γ_2	(1963FI07)
32.5 [b]			31.9	γ_0	(1963FI07)

[a] $\omega\Gamma_\gamma$ for ^{13}N*(3.56) < 0.006 eV (1963YO06).
[b] $T = \frac{1}{2}$ dipole states (1963FI07, 1964TA05).

14. ^{12}C(p, pn)^{11}C $\qquad Q_m = -18.720 \qquad E_b = 1.944$

Cross sections have been measured to $E_p = 385$ MeV: see (1962AU1A, 1963CU05, 1964KA31, 1966ME01, 1968AN02) and (1959AJ76). See also (1963VA1C, 1969KO1P).

15. (a) ^{12}C(p, p)^{12}C $\qquad E_b = 1.944$
(b) ^{12}C(p, p′)^{12}C*
(c) ^{12}C(p, 2p)^{11}B $\qquad Q_m = -15.957$

Yield curves for elastic protons, protons inelastically scattered to ^{12}C*(4.4, 7.7, 9.6, 12.7, 15.1), and for γ-rays from ^{12}C*(12.7) and (15.1) have been studied at many energies up to $E_p = 48.5$ MeV: see Table 13.25 for a display of the characteristics of the observed structure.

Total reaction cross section measurements have been made at $E_p = 10 - 19$ MeV (1968DI1D), 16.4 (1965PO07), 16.2 to 28 (1965MA26), 20 and 42 (1964GI05), 24.5 to 46.1 (1967MC1E), 28 (1964MA59), 34 (1959GO90), 45 (1967CA1K), 60 (1969ME08), 61 (1960ME16), 142 (1961TA06), 180 MeV (1961JO17) and 1 GeV (1967IG1A). Non-elastic cross sections have been measured at $E_p = 9.9$ and 10.2 MeV (1962IG1A, 1963WI12) and at 77, 95, 113 and 133 MeV (1962GO02).

Table 13.25: ^{13}N levels from ^{12}C(p, p)^{12}C, ^{12}C(p, p′)^{12}C* and ^{12}C(p, α)^{9}B

E_{res} (MeV $\pm$ keV)	^{13}N* (MeV)	$\Gamma_{c.m.}$ (keV)	l_p	J^π	θ^2_p	Refs.
0.461 ± 3	2.370	31	0	$\frac{1}{2}^+$	0.54	(1953JA1B, 1954MI05)
1.686 ± 6	3.502	63	1	$\frac{3}{2}^-$	0.031	(1953JA1B, 1966AR03)
1.734 ± 6	3.547	74	2	$\frac{5}{2}^+$	0.21	(1953JA1B, 1966AR03)
4.808 ± 10	6.382	11	2	$\frac{5}{2}^+$	0.0031	(1956RE39, 1964ME1C, 1967BA1C)
5.370 ± 10	6.898	115 ± 5	2	$\frac{3}{2}^+$	0.13	A
5.65 ± 10	7.16	9 ± 0.5	4	$\frac{7}{2}^+$	0.016	(1960YO01, 1963BA36, 1963BA43, 1963NI05)
5.891	7.379	75 ± 5	3	$\frac{5}{2}^-$	0.069	B
6.5	7.9	≈ 1500	2	$\frac{3}{2}^+$	0.14	C
7.54	8.90	230	1	$\frac{1}{2}^-$	0.02	D
8.17	9.48	30	1	$\frac{3}{2}^-$	0.001	D and (1966SW04)
9.13 [a]	10.36	30	3	$\frac{5}{2}^-$		E
9.13 [a]	10.36	76	3	$\frac{7}{2}^-$		E
(10.31)	(11.44)					(1960BO19, 1961MC16)
10.52	11.65	80				(1959BR1J, 1960BO19, 1961AD04, 1961MC16, 1968DI1D)
10.74	11.85	130				(1961AD04)
10.99	12.08	140				(1959BR1J, 1960BO19, 1961AD04, 1961MC16)
12.5	13.5	≈ 500				(1961NA02)
13.035	13.962	140	2	$\frac{3}{2}^+; T=\frac{1}{2}$		(1969LE18)
13.2	14.1	≈ 500				(1961NA02, 1969FA04)
13.8	14.7	≈ 500				(1961NA02, 1964DA03)
14.231 ± 4	15.065	1.16 ± 0.2	1	$\frac{3}{2}^-; T=\frac{3}{2}$		F
14.9	15.7	≈ 500				(1964DA03)
15.220	15.976	100	4	$\frac{7}{2}^+; T=\frac{1}{2}$		(1969LE18)
15.2	16.0	≈ 500				(1961NA02, 1964DA03, 1967KU02)
15.6	16.3	≈ 500				(1964DA03)
16.5	17.2	≈ 500				(1964DA03)
17.27 ± 50	17.88	≈ 400				(1968SN1B)

Table 13.25: ^{13}N levels from ^{12}C(p, p)^{12}C, ^{12}C(p, p′)^{12}C* and ^{12}C(p, α)^{9}B (continued)

$E_{\rm res}$ (MeV ± keV)	^{13}N* (MeV)	$\Gamma_{\rm c.m.}$ (keV)	$l_{\rm p}$	J^{π}	$\theta^2_{\rm p}$	Refs.
17.670	18.233	300	1	$\frac{1}{2}^-; \frac{1}{2}$		(1964DA03, 1967KU02, 1969LE18)
17.857 ± 5	18.419	66 ± 8	2	$\frac{3}{2}^+; T = \frac{3}{2}$		(1967KU02, 1968SN1B, 1969LE18)
17.9	18.5	≈ 500				(1964DA03)
18.2	18.7	≈ 500				(1964DA03)
18.460 ± 10	18.973	23 ± 5	1	$\frac{3}{2}^-$ or $\frac{7}{2}^+; T = \frac{3}{2}$		(1967KU02, 1968SN1B, 1969LE18)
18.8	19.3	≈ 500				(1964DA03)
19.40	19.83	1000	3	$\frac{5}{2}^-; T = \frac{1}{2}$		(1964DA03, 1969LE18)
19.46	19.88	520	2	$\frac{3}{2}^+; T = \frac{1}{2}$		(1963ME04, 1965MA26, 1966LO16, 1967SC11)
20.5	20.9	≈ 1500		$(\frac{5}{2})^+$		
21.41	21.69					(1963DI16, 1964WA11, 1966CR04)
21.73	21.99					(1963DI16, 1964WA11, 1966CR04)
22.4	22.6	≈ 1000		$(\frac{5}{2}^-)$		(1963ME04, 1966LO16, 1967SC11)
24.2	24.3	≤ 500				(1963ME04, 1966LO16)
25.5	25.5			$(\frac{3}{2})^-$		(1967SC11)
27.02	26.87					(1963DI16, 1964WA11, 1966CR04)

[a] The resonant energies probably do not differ by more than 2 keV (1968BE31).

A: (1956RE39, 1961AD04, 1962SH22, 1963BA36, 1963BA43, 1963NI05, 1964ME1C, 1966BA35, 1967BA1C, 1967DU1A, 1968BE31; see also 1960BO19, 1965BE12).

B: (1956BR27, 1961AD04, 1962SH22, 1963BA36, 1963BA43, 1963NI05, 1964ME1C, 1966BA35, 1966SH10, 1968BE31; see also 1960BO19).

C: (1956SC29, 1960BO19, 1961NA02, 1962SH22, 1964ME1C, 1966BA35).

D: (1961AD04, 1962SH22, 1966BA35; see also 1960BO19, 1961MC16).

E: (1961AD04, 1962SH22, 1966BA35, 1966SW04, 1967SW1A, 1968BE31; see also 1960BO19, 1961MC16, 1961NA02).

F: (1966BR1Z, 1966BR2A, 1967KU02, 1967TE1A, 1968TE1C, 1969LE18).

Table 13.26: Summary [a] of $^{12}C(p, p)^{12}C$ polarization measurements

E_p (MeV)	^{12}C states	References
1 – 3	g.s.	(1968SL01)
1.2 – 2.4	g.s.	(1965BO1L)
1.5 – 3.0	g.s.	(1967TR08)
1.5 – 5.0	g.s.	(1959PH37)
1.7 – 1.9	g.s.	(1966BA2Q)
2.3 – 4.3	g.s.	(1960EV02)
2.4 – 3.4	g.s.	(1965BE1L)
2.9	g.s.	(1966HS1A)
3.0	g.s.	(1962NE17)
3.8 – 4.8	g.s.	(1962GO26, 1964DR01, 1964DR03, 1964DR04)
4.4 – 10	g.s.	(1968BE31, 1968TE05)
4.5	g.s.	(1964BO18)
4.6 – 5.5	g.s.	(1961GO26)
4.6 – 7.2	g.s.	(1965TE1B)
4.65 – 5.0	g.s.	(1960TO09)
4.7 – 11.3	g.s.	(1965MO15)
5.0 – 10.5	g.s.	(1961EV03)
5.1 – 6.8	g.s.	(1959WA07)
5.4 – 19.7	g.s.	(1962RO14)
6.0	g.s.	(1965BO31)
6.0 – 6.8	g.s.	(1964BE1H, 1964BE20)
6.2	g.s.	(1965CL1D)
6.3	g.s.	(1962MA1N)
6.5	g.s.	(1962BE1E)
6.7	g.s.	(1964BE29)
6.8	g.s.	(1960PA07)
6.9	g.s.	(1969GU02)
8.6	g.s.	(1961RO13)
9.2	g.s.	(1961HO09)
9.4	g.s.	(1960ST09)
10.4 – 19.9	g.s., 4.4	(1969FA04)

Table 13.26: Summary [a] of ^{12}C(p, p)^{12}C polarization measurements (continued)

E_p (MeV)	^{12}C states	References
10.8, 12.7	g.s.	(1963SA1D)
11.7	g.s.	(1961RO05)
12.8 – 13.4	g.s.	(1966ST05)
14.5	g.s., 4.4	(1962RO20, 1962ST11, 1965RO22)
16.5	g.s., 4.4	(1966DA1G)
16.6, 19.3	g.s., 4.4	(1962BO05)
17.7	g.s., 4.4	(1959BR1K)
17.8	g.s., 4.4	(1965BA54)
19.3	9.6	(1962BO05)
19.7	9.6	(1962RO14)
20 – 28	g.s.	(1966LO16)
20.2 – 28.3 [b]	g.s., 4.4	(1966CR04)
21	g.s.	(1966BE1M)
29, 49	g.s., 4.4	(1963CR03, 1966CR14)
32.9	g.s.	(1968GR1K, 1969MA2D)
38	g.s., 4.4	(1963HW01)
40 [b]	g.s., 4.4	(1966BL19, 1967FR20)
43.5	g.s.	(1966CA01)
50	g.s.	(1967FA06)
57	g.s.	(1962YA04)
75, 152	g.s.	(1966RO08)
80	g.s.	(1966MA1Z)
139	g.s.	(1963HE1B)
140	g.s.	(1966JA03, 1966JA08, 1966JA1F)
141	g.s.	(1965PO05)
143		(1964ST16)
145	g.s., 4.4, 9.6, 14, 18.5	(1966EM01)
150	g.s., 4.4, 7.7, 9.6	(1962SA05, 1965TA1F)
155	g.s., 4.4	(1957AL79)
173	g.s., 4.4, 9.6, 15.1	(1957HI98, 1957TY1B)

Table 13.26: Summary [a] of ^{12}C(p, p)^{12}C polarization measurements (continued)

E_p (MeV)	^{12}C states	References
424	g.s.	(1957HE51)
725	g.s.	(1965MC04)
2000, 3600		(1967BA2F)

[a] See also (1963AZ01, 1963AZ1C, 1965AZ1A, 1966LE1N).

[b] See also (1969KO13).

The (p, 2p) cross section has been determined at E_p = 120 to 150 MeV (1962AU1A) and that of the ^{12}C(p, p′)^{4}He^{4}He^{4}He at 90 MeV (1961GA07). See also (1962WA31, 1966KI1D, 1967BE2D, 1967WA1H).

A summary showing the energies at which polarization measurements have been made is presented as Table 13.26. Reviews of the experimental evidence are given by (1959PH37, 1962RO14, 1966DA1B, 1966RO1R, 1966RO1B). See also (1959AJ76) and (1966KI1D).

The polarization and asymmetry in the elastic scattering of 32.9 MeV protons are equal to within ≈ 1%: therefore no violation of time-reversal invariance is observed in that part of the nuclear force which flips the spin of the proton (1968GR1K, 1969MA2D).

The following is a list of recent theoretical papers bearing on these reactions: (1955DE50, 1958BE1B, 1959BA24, 1959KE1A, 1959PU1A, 1959RI1A, 1959WI1C, 1960NI02, 1960SA1E, 1960SA1G, 1961SA1B, 1962MA1M, 1962NO04, 1962NO03, 1962NO1D, 1962RO1F, 1962VO04, 1963BA43, 1963HO1D, 1963LO1A, 1963LU1C, 1963RO1G, 1963SC1C, 1964CR1B, 1964GR1E, 1964IY1A, 1964TA1E, 1964VE1A, 1965BA1M, 1965BE1K, 1965CL1E, 1965FA1E, 1965HA28, 1965PE1F, 1965SA1H, 1966BA2N, 1967BA1C, 1967MC1H, 1967SA1C, 1967TA1B, 1967WO1E, 1968BA1K, 1968CH35, 1968FA1H, 1968KO26, 1968TA1U, 1968TI1B, 1969HA2C, 1969KO1J, 1969PA1H, 1969TA1D).

See also (1959BU97, 1960DE1C, 1961JO18, 1961MC11, 1962PA07, 1963AZ1B, 1963DE35, 1964FI1B, 1965CL1C, 1965GR1N, 1965VA23, 1966HA1F, 1966MA1Y, 1966RE1D, 1967AR1D, 1967VO1C, 1969BR1D, 1969EW01).

For discussion of spallation measurements, see (1965ZO1A, 1967AU1A, 1967GR1K, 1967LI1B, 1968JA1M, 1968JU1B, 1969DA1M, 1969DA1N).

See also ^{12}C in (1968AJ02).

16. ^{12}C(p, d)^{11}C $\quad Q_m = -16.495 \quad E_b = 1.944$

The yield has been measured for E_p = 18 to 19.8 MeV: no structure is observed (1962WA31). Polarization measurements are reported by (1960CO05, 1967CH15, 1968IN02, 1969IN1C). See also ^{11}C in (1968AJ02) and (1969BO1J, 1969ED02, 1969KO1P).

Table 13.27: ^{12}C(d, n)^{13}N angular distribution studies

E_d (MeV)	Distribution of neutron groups	Refs.
$0.5 - 0.8$	n_0	(1969CH04)
$1.5 - 3.0$	n_0	(1959EL44, 1963HO1G)
$2.7 - 3.2$	n_0	(1966GU04)
$2.8 - 4.2$	n_0	(1966SA05)
$3.8 - 4.2$	n_0	(1967FU03)
$3.8 - 4.2$	n_1	(1966SA05)
$4.1 - 5.0$	n_0, n_1	(1966HO11)
9	n_0, n_1, n_{2+3}	(1957CA02)
11.8	n_0, n_1, n_2, n_3	(1969VE1D)
12, 15, 17	n_0	(1969GA1T) [a]
13	n_0, n_1, n_{2+3}	(1963KO24)

[a] Angular distributions of recoils in coincidence with neutrons.

17. ^{12}C(p, t)^{10}C $\quad Q_m = -23.319 \quad E_b = 1.944$

See (1967CO23, 1967ME23) and ^{10}C in (1966LA04).

18. ^{12}C(p, α)^{9}Be $\quad Q_m = -7.554 \quad E_b = 1.944$

Yield curves for α_0 have been measured over the 14.2 MeV resonance, corresponding to the first $T = \frac{3}{2}$ state at $E_x = 15.07$ MeV, and from $E_p = 17$ to 20 MeV. The yield for the α_1 group has been determined for $E_p = 17$ to 21.5 MeV. Parameters of observed resonances are displayed in Table 13.25 (1969LE18). See also (1963VA1C, 1964BA29, 1966BA35, 1966RE1D, 1968TE1C) and ^{9}B in (1966LA04).

19. (a) ^{12}C(d, n)^{13}N $\quad Q_m = -0.281$
(b) ^{12}C(d, pn)^{12}C $\quad Q_m = -2.225$

Measurements of angular distributions of neutrons are tabulated in Table 13.27. See also ^{14}N.

In the range $E_d = 2.8$ to 3.7 MeV, a single neutron threshold is observed at $E_d = 3.09 \pm 0.02$ MeV, corresponding to ^{13}N* $= 2.36\ (5) \pm 0.02$ MeV (1955MA76).

At $E_d = 4.7$ to 5.5 MeV, broad proton groups are reported from the sequential decay $^{12}C + d \rightarrow {}^{14}N^* \rightarrow {}^{13}N^* + n \rightarrow {}^{12}C + n + p$ via $^{13}N^*(3.51, 3.56)$ (1963PI04). The proximity scattering associated with this process is charaterized by a mean lifetime for the intermediate state of 0.7×10^{-20} sec (1965LA08, 1965LA1F, 1966LA18). See also (1968BO02, 1969SA1K).

See also (1959AJ76), (1960MA21, 1961KE1C, 1961LE1E, 1961YA05, 1961YN02, 1963KN04, 1964CA1F, 1965GA1G, 1965JO09, 1965SI13, 1966HO1D, 1967OG1A) and (1961HO1D, 1963SM05, 1963TR1A, 1964SH1C, 1965MA1K, 1966ST1L, 1968HU1G).

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

(b) $^{12}C(^3He, pd)^{12}C$ $\quad Q_m = -5.494$

Angular distributions of deuterons to $^{13}N(0)$ have been measured at $E(^3He) = 6.0$, 8.8, 9.4 and 10.1 MeV (1960HI07; d_0), at 13.9 MeV (1960PR12; d_0), at 16, 17 and 18 MeV (1969FO02; d_0, d_1, d_{2+3}), at 19 MeV (1969FO02; d_4, d_5, d_6, d_7), at 21.6 and 24.7 MeV (1960WE04; d_0, d_1, d_{2+3}), and at 29 MeV (1962GA17; d_0, d_1, d_{2+3}). See also (1952FR1A, 1961YN02, 1966EC1B, 1966HA1Q, 1967HA21, 1967HO14, 1969FO02). For reaction (b) see (1969FO02).

21. $^{12}C(\alpha, t)^{13}N$ $\quad Q_m = -17.870$

Angular distributions have been measured at $E_\alpha = 43$ MeV (1967DE1K; t_0), 46 MeV (1969FO1C; $t_2 + t_3$) and at 56 MeV (1968GA1C, 1969GA11; t_0). At $E_\alpha = 56$ MeV a detailed comparison is made with the ^3He distribution from the mirror reaction $^{12}C(\alpha, {}^3He)^{13}C$ (1969GA11). See also (1961YN02, 1963TR1A, 1964SH1C).

22. $^{12}C(^{10}B, {}^9Be)^{13}N$ $\quad Q_m = -4.644$

At $E(^{10}B) = 105$ MeV, the ground state of ^{13}N and $^{13}N^*$(3.5 [u]) are observed (1965SA07). See also (1963GR1H, 1965GR1F, 1969BR1D).

23. $^{12}C(^{11}B, {}^{10}Be)^{13}N$ $\quad Q_m = -9.285$

At $E(^{11}B) = 116$ MeV, the ground state of ^{13}N and $^{13}N^*$(3.5 [u]) are observed (1965SA07, 1967PO13). See also (1965DA1E, 1965GR1F, 1969BR1D).

24. $^{12}C(^{12}C, {}^{11}B)^{13}N$ $\quad Q_m = -14.013$

See (1962CH01, 1969BR1D).

25. ^{12}C(^{14}N, ^{13}C)^{13}N $\qquad Q_{\mathrm{m}} = -5.606$

See (1967BI1F, 1969BR1D, 1969DO07).

26. ^{13}C(p, n)^{13}N $\qquad Q_{\mathrm{m}} = -3.003$

$$E_{\mathrm{thresh.}} = 3.2353 \pm 0.0015 \text{ (1961BE13)};$$
$$E_{\mathrm{thresh.}} = 3.2371 \pm 0.0016 \text{ (1961BE13): see (1964BO10)};$$
$$E_{\mathrm{thresh.}} = 3.2354 \pm 0.0024 \text{ (1966BO20)};$$
$$E_{\mathrm{thresh.}} = 3.2357 \pm 0.0007 \text{ (recommended by (1966MA60))}.$$

Angular distributions of ground state neutrons have been measured at $E_{\mathrm{p}} = 3.1$ to 5.3 MeV (1961AL07), 3.39 to 12.86 MeV (1961DA09), 5.0 to 13.3 MeV (1961WO03) and 18.5 MeV (1964AN1B). See also (1962PA07, 1964ST1C, 1965VA23) and (1959BL1B, 1963EL1B, 1964CA1F, 1964SA1D, 1966PA1H).

Two thresholds are observed at $E_{\mathrm{p}} = 3.235$ and 6.965 MeV (± 10 keV), corresponding to ^{13}N(0) and ^{13}N*(3.464) (1966RI09). The neutron group corresponding to ^{13}N*(2.3) is very weak compared to the groups to ^{13}N(0) and ^{13}N*(3.5) at the energies studied (1961DA09). See also (1959AJ76), (1959BO14, 1966UN1A, 1968AT1A, 1968LI1G, 1968RI1Q, 1968WO1D, 1969PA1J) and ^{14}N.

27. ^{13}C(^{3}He, t)^{13}N $\qquad Q_{\mathrm{m}} = -2.239$

At $E(^{3}\mathrm{He}) = 39.6$ MeV, angular distributions have been obtained for the tritons corresponding to the ground state of ^{13}N and to the excited states at 2.37, 3.53 ± 0.03 [u], 6.38, 7.17, 7.39, 8.92 ± 0.04, 11.85 ± 0.04 and 15.07 MeV. States at $E_{\mathrm{x}} = 9.5$, 10.78 ± 0.04 and 15.98 ± 0.05 MeV were also populated, the first of these weakly. The transitions to ^{13}N*(7.39, 8.92, 11.85, 15.07) are $L = 2$ [$J^{\pi} = \frac{5}{2}^{-}, \frac{1}{2}^{-}, \frac{3}{2}^{-}, \frac{3}{2}^{-}$, respectively] (1968BA1E, 1969BA06). See also (1966EC1B).

28. ^{14}N(γ, n)^{13}N $\qquad Q_{\mathrm{m}} = -10.553$

See (1963FU06) and ^{14}N.

29. (a) ^{14}N(p, d)^{13}N $\quad Q_{\rm m} = -8.329$
    (b) ^{14}N(p, pn)^{13}N $\quad Q_{\rm m} = -10.553$

Angular distributions have been determined at $E_{\rm p} = 14$ MeV (1969CU1D; d$_0$), 18.5 MeV (1961BE12; d$_0$, d$_1$, d$_{2+3}$), 30.3 MeV (1967KO08; d$_0$, d$_2$, and the deuterons to ^{13}N*(7.38, 8.93, 11.80)), 45 MeV (1966MA2B; d$_0$, d$_1$, d$_{2+3}$, and the deuterons to ^{13}N*(7.4 ± 0.1, 11.8 ± 0.2)) and 155.6 MeV (1966BA44; d$_0$, d$_{2+3}$, and the deuterons to ^{13}N*(7.4, 9.0, 11.9)). See also (1964EL1B, 1967OG1A, 1969DO08, 1969TO1A). For reaction (b), see (1962BA1A). See also ^{14}N.

30. ^{14}N(d, t)^{13}N $\quad Q_{\rm m} = -4.296$

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

31. (a) ^{14}N(^{3}He, α)^{13}N $\quad Q_{\rm m} = 10.025$
    (b) ^{14}N(^{3}He, pα)^{12}C $\quad Q_{\rm m} = 8.081$
    $Q_0 = 10.015 \pm 0.010$ (1959YO25).

Alpha-particle groups have been observed to the ground state of ^{13}N and to excited states at 2.358 ± 0.010, 3.471 ± 0.015 MeV (1960TA12), 6.38, 6.91, 7.166 ± 0.008 and 7.388 ± 0.008 MeV (1962CL12). See also (1963GA03). Angular distributions have been studied at $E(^3\text{He}) = 4.5$, 5.5 and 7.0 MeV (1967KN1B; α_0, α_1, α_{2+3}), 13.9 MeV (1968LU03; α_0, α_1, α_{2+3}, α_4, α_{6+7}), 17.4 to 36.6 MeV (1965AR07; α_0, α_1, α_{2+3}, α_{5+6} and the alphas to ^{13}N*(11.4)), 29 MeV (1962SE13; α_0), and at 40–45 MeV (1967BA2G). For reaction (b) see (1967DE1T). See also (1964EL1B, 1965BO1N, 1966BO1U, 1967BE22, 1967OG1A, 1968ZE1B, 1969DO08).

32. ^{14}N(^{12}C, ^{13}C)^{13}N $\quad Q_{\rm m} = -5.606$

As expected from isospin conservation the angular distributions (at $E(^{14}\text{N}) = 78$ MeV) of ^{13}N and ^{13}C are symmetric about 90° (1969VO01).

33. ^{14}N(^{14}N, ^{15}N)^{13}N $\quad Q_m = 0.282$

See (1968NA1F, 1969BR1D, 1969KA1G).

34. ^{15}N(p, t)^{13}N $\quad Q_m = -12.906$

At $E_p = 43.7$ 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 15.07 ($\frac{3}{2}^-$; $T = \frac{3}{2}$) MeV states [J^π values in parentheses, as determined by DWBA analyses using intermediate-coupling wave functions to obtain the twwo-nucleon structure factors] (1968FL03). Detailed comparisons have been made with the (p, ^{3}He) reaction to the mirror states in ^{13}C (1968FL02, 1968FL03). See also (1966CE02, 1966CE05) and (1969VA1C).

35. ^{16}O(γ, t)^{13}N $\quad Q_m = -25.032$

See (1965BU1F, 1968BU1D).

36. (a) ^{16}O(p, α)^{13}N $\quad Q_m = -5.218$

(b) ^{16}O(p, pα)^{12}C $\quad Q_m = -7.161$

$Q_0 = -5.206 \pm 0.010$ (1960WH03).

Angular distributions of the ground state α-particles have been measured at $E_p = 7.9$ to 10.2 MeV (1964DA02), 13.5 to 18.1 MeV (1961MA15) and 38 MeV (1969GA03, 1967AC01). See also (1962VA1A, 1964CE1D), (1957CH1A, 1961WI1F, 1964HO1D) and ^{17}F. For reaction (b), see (1967CH04).

37. ^{16}O(^{3}He, ^{6}Li)^{13}N $\quad Q_m = -9.239$

At $E(^3\text{He}) = 65.3$ MeV, ^{6}Li groups are observed to ^{13}N*(0, 3.6 [u], 6.4, 7.4) (1966CE02). See also (1969OH1B).

38. ^{18}O(d, ^{7}Li)^{13}N $\quad Q_m = -7.899$

See (1966DA1C).

^{13}O

(Fig. 4)

^{13}O has been produced in the reaction ^{16}O(^{3}He, ^{6}He)^{13}O at $E(^{3}\text{He}) = 65$ MeV; the mass excess of ^{13}O is 23.11 ± 0.07 MeV (1966CE02). ^{13}O is then bound with respect to ^{12}N+p by 1.54 MeV. A computation using three other members of the $T = \frac{3}{2}$ quartet predicts $M - A(^{13}\text{O}) = 23.10 \pm 0.05$ (1966CE02).

^{13}O has also been reported in the ^{14}N(p, 2n)^{13}O reaction initiated by 50 MeV protons: $\tau_{1/2} = 8.7 \pm 0.4$ msec. ^{13}O is a delayed proton emitter decaying via ^{13}N*(8.92, 9.52) to ^{12}C + p. The relative intensities are 100:24; on this scale the intensities of possible transitions to ^{13}N*(7.39; $\frac{5}{2}^{-}$) is < 15, $\log ft > 5.5$ (1965MC09). On the basis of charge symmetry, and the ^{13}B β^{-} decay, the half-life of ^{13}O should be 7.7 ± 0.8 msec and the β^{+} branching to ^{13}N*(0, 3.51, 7.39, 8.92, 9.52) should be, respectively, (89 $\pm$ 11)%, (10 $\pm$ 2)%, (0.24 $\pm$ 0.06)%, (0.57 $\pm$ 0.12)% and $<$ 0.2% (1969JO21).

See also (1960GO1B, 1960ZE03, 1961BA1C, 1963BA63, 1963VL1B, 1964GO1G, 1965JA1C, 1966GO1B, 1966KE16, 1969GA1P).

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(Closed 31 December 1969)

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