Energy Levels of Light Nuclei
$A = 13$

F. Ajzenberg-Selove [a] and T. Lauritsen [b]

[a] *University of Pennsylvania, Philadelphia, Pennsylvania 19104-6396*
[b] *California Institute of Technology, Pasadena, California*

Abstract: An evaluation of $A = 5$–24 was published in *Nuclear Physics* 11 (1959), 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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Table 13.1: Energy levels of ^{13}B

E_x (MeV)	$J^\pi; T$	$\tau_{1/2}$ (sec)	Decay	Reactions
0	$(\frac{3}{2}^-); \frac{3}{2}$	$(35 \pm 15) \times 10^{-3}$	β^-	1, 2

^{13}B
(Not illustrated)

GENERAL:

Mass of ^{13}B: The mass excess of ^{13}B is 20.40 ± 0.05 MeV from the Q of the reaction ^{7}Li(^{7}Li, p)^{13}B (1957NO14), and Wapstra's masses (1955WA1A) for ^{7}Li and ^{1}H. ^{13}B is then stable by 4.88 MeV to decay into ^{12}B + n, by 11.00 MeV to decay into ^{10}Be + t and by 11.3 MeV to decay into ^{9}Li + α.

1. ^{13}B(β^-)^{13}C $Q_m = 13.44$

The half-life of ^{13}B is $(35 \pm 15) \times 10^{-3}$ sec (1956NO1A). Attempts to observe delayed neutrons from the decay of neutron-unstable states of ^{13}C have been unsuccessful (1953HU1C, 1956NO1A). It is pointed out by (1957NO14) that transitions to such states are unlikely if ^{13}B has the expected $J = \frac{3}{2}^-$. See also (1948SN1A, 1952SH44).

2. ^{7}Li(^{7}Li, p)^{13}B $Q_m = 5.97$
$Q_0 = 5.97 \pm 0.05$ (1957NO14).

This reaction has been observed for $E(^7\text{Li}) = 1.4$ to 2.0 MeV (1956AL1F, 1957NO14, 1958LI42). At $E(^7\text{Li}) = 2$ MeV, no proton groups have been observed corresponding to excited states of ^{13}B below $E_x = 2.9$ MeV (1958LI42). See also ^{14}C.

3. ^{11}B(t, p)^{13}B $Q_m = 0.24$

Not reported.

^{13}C
(Fig. 22)

GENERAL:

Theory: See (1955AU1A, 1955LA1A, 1956DA1G, 1956DE1C, 1956KU1A, 1957BA1H, 1958FR1C, 1958SK1A).

1. (a) ^{6}Li(^{7}Li, p)^{12}B $Q_{\rm m} = 8.338$ $E_{\rm b} = 25.876$
   (b) ^{6}Li(^{7}Li, n)^{12}C $Q_{\rm m} = 20.931$
   (c) ^{6}Li(^{7}Li, 2n)^{11}C $Q_{\rm m} = 2.209$

See (1957NO17).

2. ^{7}Li(^{7}Li, n)^{13}C $Q_{\rm m} = 18.624$

See (1957NO17).

3. ^{9}Be(α, γ)^{13}C $Q_{\rm m} = 10.654$

At $E_\alpha = 1.60$ MeV, the capture cross section is less than 30 μb (1955AL16).

4. ^{9}Be(α, n)^{12}C $Q_{\rm m} = 5.709$ $E_{\rm b} = 10.654$

Resonances for neutrons and for γ-rays from ^{12}C*(4.4) are given in Table 13.3. Absolute cross sections for several resonances are reported by (1956BO61, 1959GI47). For the prominent 1.9 MeV resonance, dσ/dΩ (90°) for 4.4 MeV γ-rays is given as 12 mb/sr (lab) by (1956BO61) and as 26 mb/sr by (1955TA28). For $E_\alpha = 2.5$ to 8.2 MeV, absolute neutron yields have been measured by (1958MA1J, 1959GI47).

Separate excitation curves (at $0°$) for ground state neutrons (n$_0$) and for neutrons to the 4.4 MeV state (n$_1$) are reported by (1957RI38) in the range $E_\alpha = 1.7$ to 4.8 MeV (n$_0$) and 3.1 to 4.8 MeV (n$_1$). The n$_0$ yield curves show broad maxima at $E_\alpha = 1.9$, 2.0, 2.6, 4.2 and 4.5 MeV. The sharp 3.98 MeV resonance is strong for n$_1$, but quite weak for n$_0$. Angular distributions of ground-state neutrons suggest two broad resonances in the region $E_\alpha = 3.9$ to 4.6 MeV, probably $J = \frac{3}{2}^+$ and $\frac{5}{2}^+$ (1957RI38).

Table 13.2: Energy levels of ^{13}C

E_x (MeV $\pm$ keV)	J^π	τ_m or Γ (keV)	Decay	Reactions
0	$\frac{1}{2}^-$	–	stable	2, 9, 15, 17, 23, 29, 30, 32, 34, 35, 37, 40, 41
3.085 ± 5	$\frac{1}{2}^+$	$\tau_m < 3 \times 10^{-13}$ sec	γ	9, 15, 18, 23, 29, 32, 40
3.680 ± 7	$\frac{3}{2}^-$	$\tau_m < 3 \times 10^{-13}$ sec	γ	9, 15, 17, 23, 29, 32, 34, 40
3.850 ± 10	$\frac{5}{2}^+$	$\tau_m > 3 \times 10^{-13}$ sec	γ	9, 15, 23, 32, 40
5.51 ± 50				15
6.10 ± 50				15
6.86 ± 10	$\frac{5}{2}^+$	$\Gamma = 6$	n	15, 18, 23, 40
7.470 ± 20				23, 40
7.533 ± 20				15, 23, 40
7.641 ± 20	$\frac{3}{2}^+$	55 ± 15	n	18, 23, 40
8.33 ± 100	$\frac{3}{2}^+$	1000 ± 250	n	18, 23, 35
8.82 ± 40			n	15, 18, 40
9.50 ± 20			n	15, 18, 23, 40
9.90 ± 20	> 0		n	15, 18, 23, 40
10.76 ± 20			n	18, 19, 23
10.94 ± 100			n	15, 18, 19
11.02 ± 30	$(\frac{1}{2}^+)$	50	α, n	4, 15
11.08 ± 30		sharp	α, n	4, 15
11.97 ± 15	$(\frac{7}{2}^-)$	70	α, n	4, 15, 18, 19
12.21 ± 30		≈ 140	α, n	4, 15, 18, 19
12.44 ± 30	$(\frac{1}{2}^-)$	≈ 140	α, n	4, 19
12.81 ± 100				15
13.41 ± 30		50	α, n	4
13.77 ± 30		≈ 280	α, n	4
14.1 ± 100		≈ 210	α, n	4
14.64 ± 30			α, n	4
16.1 ± 100			α, n	4
20.52 ± 20		115 ± 10	d, n	10
21.28 ± 20		160 ± 15	d, n	10

Table 13.3: Resonances in ^{9}Be(α, n)^{12}C

E_{α} ^{a} (MeV)	E_{α} ^{b} (MeV)	Γ (keV)	J^{π}	^{13}C* (MeV)	Refs.
0.53	0.53	70	$(\frac{1}{2}^{+})$ [j]	11.02	c
0.61	0.61	sharp		11.08	c
1.9	1.905	180	$(\frac{7}{2}^{-})$ [j]	11.97 [k]	d
2.24		≈ 200		12.21 [k]	e
2.58	2.6	≈ 200	$(\frac{1}{2}^{-})$ [j]	12.44 [k]	f
4.00	3.98	70		13.41	h,i
(4.2)		(≈ 300)		(13.6)	g
4.50	4.4	≈ 400		13.77 [k]	h,i
5.0	5.0	≈ 300		14.1 [k]	h
5.75				14.64	i
7.8				16.1	i

[a] Resonances in neutron yield.
[b] Resonances for 4.4 MeV γ-rays.
[c] (1954BE08).
[d] (1953TA06, 1954BE08, 1954TR09, 1955TA28, 1956BO61), $\Gamma_{n}/\Gamma_{\alpha} > 12$ (1955TA28).
[e] (1954TR09, 1956BO61).
[f] (1953TA06, 1954TR09, 1956BO61, 1958MA1J).
[g] (1957RI38).
[h] (1956BO61).
[i] (1958MA1J, 1959GI47).
[j] (1956JA28).
[k] Not corrected for effects of Coulomb barrier penetration.

Extensive angular distribution studies have been made for $E_{\alpha} < 2$ MeV by (1955TA28, 1956JA28). According to (1956JA28), the best fit to the distributions in the range $E_{\alpha} = 0.4$ to 1.3 MeV is obtained from the assignments $J = \frac{1}{2}^{+}, \frac{7}{2}^{-}, \frac{1}{2}^{-}$ for the 0.5, 1.9 and 2.6 (?) MeV resonances (see also (1955TA28)). The angular correlation of neutrons and 4.4 MeV gamma-rays is isotropic at $E_{\alpha} = 1.2$ and 2.8 MeV, indicating that stripping plays only a minor role at these energies (1958TA05). See also (1955MA1J; theor.) and (1956BE98).

5. ^{9}Be(α, p)^{12}B $\qquad Q_{m} = -6.884 \qquad E_{b} = 10.654$

See ^{12}B.

6. ^{9}Be(α, d)^{11}B $\quad Q_{\rm m} = -8.022 \quad E_{\rm b} = 10.654$

See ^{11}B.

7. (a) ^{9}Be(α, α')^{9}Be* $\quad E_{\rm b} = 10.654$
(b) ^{9}Be(α, α'n)^{8}Be $\quad Q_{\rm m} = -1.667$
(c) ^{9}Be(α, n)^{4}He^{4}He^{4}He $\quad Q_{\rm m} = -1.572$

For reaction (a) see ^{9}Be and (1955TA28). For reactions (b) and (c), see (1952AJ38).

8. ^{10}B(t, α)^{9}Be $\quad Q_{\rm m} = 13.210 \quad E_{\rm b} = 23.882$

See ^{9}Be.

9. ^{10}B(α, p)^{13}C $\quad Q_{\rm m} = 4.070$
$Q_0 = 4.064 \pm 0.012$ (W.J. Fader, quoted in (1957VA11)).
$Q_0 = 4.08 \pm 0.03$ (1956PI1A).
$Q_0 = 4.10 \pm 0.03$ (1956PA1B).

Four proton groups are observed, corresponding to the ^{13}C levels at 0, 3.09, 3.68 and 3.85 MeV (1953SH64, 1954FA1A, 1954FA1B, 1956PI1A). Additional groups are reported by (1957RO1F). The relative intensities depend strongly on bombarding energy (see ^{14}N, (1953SH64)). See also (1955AJ61).

A study of gamma 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 3.85 MeV γ-ray exhibits no Doppler shift and therefore has a lifetime greater than 3×10^{-13} sec; the 3.69 MeV line shows approximately the maximum possible Doppler shift ($\tau < 3 \times 10^{-13}$ sec). The 170 keV line is due to the cascade transition between the 3.84 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 the 3.84 MeV state is 0.24 ± 0.05. Cascade transitions to the 3.1 MeV excited state have not been observed. Their intensities are less than 3% of the ground state transitions (1956MA1Q, 1956MA52): see Fig. 23. (For earlier work see (1953SH64) and (1954ST20)). The angular distributions and p-γ correlations for the 3.8 MeV radiation contain terms in ($\cos^4\theta$), indicating $J = \frac{5}{2}^+$ for the 3.84 MeV state (1954ST20: see ^{12}C(d, p)^{13}C). 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 3.7 MeV radiation is consistent with M1 (1954ST20).

Angular distributions of the grounds state protons are reported at $E_{\alpha} = 4.9$, 6.0, 7.0 and 8.1 MeV (1957VO25) and at $E_{\alpha} = 30.5$ MeV (1957HU1E): in both cases direct interaction appears to be involved. See also (1957BA1K) and (1955BR1A).

10. ^{11}B(d, n)^{12}C $Q_{\mathrm{m}} = 13.731$ $E_{\mathrm{b}} = 18.677$

The yield of neutrons has been measured for $E_{\mathrm{d}} = 0.2$ to 5.4 MeV. The total cross section for ground state neutrons in the 0.5 to 1.15 MeV range rises from 0.5 to 30 mb; both direct and exchange stripping processes seem to be involved (1956PA23, 1957AM48). The yield of the excited-state group, ^{12}C*(4.4) rises smoothly from $E_{\mathrm{d}} = 0.5$ to 1.1 MeV and is essentially flat from $E_{\mathrm{d}} = 1.1$ to 2.0 MeV (1959NE1A). At $E_{\mathrm{d}} = 600$ keV, angular distributions indicate that stripping is important for the ground-state group. For the excited-state group (^{12}C*(4.4)), the interpretation is less clear; the observed distribution can be accounted for by p-wave formation of a $J = \frac{7}{2}^{+}$ level in ^{13}C (1955WA30). (1959NE1A) find evidence of strong "heavy-particle" stripping for this group in the range $E_{\mathrm{d}} = 0.5$ to 2.0 MeV. The cross section for emission of neutrons in the forward direction is ≈ 270 mb/sr at $E_{\mathrm{d}} = 5.4$ MeV (1955MA76). For $E_{\mathrm{d}} = 1.6$ to 3.2 MeV, the yield of 15.1 MeV γ-rays shows resonances at $E_{\mathrm{d}} = 2.180 \pm 0.010$ and 3.080 ± 0.015 MeV, corresponding to ^{13}C*(20.52, 21.28) with $\Gamma_{\mathrm{c.m.}} = 115 \pm 10$ and 160 ± 15 keV, respectively; the cross section at $E_{\mathrm{d}} = 2.2$ MeV is 29 ± 7 mb (1958KA31). See also (1954BU06, 1955RI1B) and ^{12}C.

11. ^{11}B(d, p)^{12}B $Q_{\mathrm{m}} = 1.138$ $E_{\mathrm{b}} = 18.677$

The thin-target yield rises smoothly from $E_{\mathrm{d}} = 0.3$ to 3.1 MeV with no evidence of resonances (1949HU41, 1958KA31). At $E_{\mathrm{d}} = 1.5$ MeV, $\sigma \approx 0.38$ b (1958KA31: see, however, (1949HU41)). See also ^{12}B and (1957JA37).

12. ^{11}B(d, d)^{11}B $E_{\mathrm{b}} = 18.677$

See ^{11}B.

13. ^{11}B(d, α)^{9}Be $Q_{\mathrm{m}} = 8.022$ $E_{\mathrm{b}} = 18.677$

Some absolute cross sections are given by (1958KA31). See also ^{9}Be.

14. ^{11}B(t, n)^{13}C $Q_{\mathrm{m}} = 12.419$

Table 13.4: Levels of ^{13}C from ^{11}B(^{3}He, p)^{13}C

E_x [a] (MeV ± keV)	E_x [b] (MeV)
0	0
3.09	3.08
3.68	3.77
3.86	
5.51 ± 50	
6.10 ± 50	
6.87	6.89
7.55 ± 40	7.63
8.87 ± 50	8.96
9.52 ± 60	
9.91 ± 50	10.00
10.9 ± 150 [c]	10.99
11.1 ± 150 [c]	
	11.67
12.08 ± 100 [c]	
12.81 ± 100 [c]	

[a] (1958MO99): $E(^3\text{He}) = 1.23$ MeV.
[b] (1955BI26): $E(^3\text{He}) = 0.9$ MeV; values are ± 100 keV.
[c] (1957GA01): $E(^3\text{He}) = 1.25$ MeV.

Not reported.

15. ^{11}B(^{3}He, p)^{13}C $\qquad Q_m = 13.184$

Levels derived from reported proton groups are listed in Table 13.4. The levels at 5.5 and 6.1 MeV have not been observed in any other reaction. From the fact that they do not appear in ^{12}C(n, n)^{12}C, an upper limit of $\Gamma = 10$ keV is estimated; the mirror levels in ^{13}N must be assumed to have $\theta^2_p < 0.02$ (1958MO99).

Angular distributions have been measured for the p_0, p_1 and ($p_2 + p_3$) groups at $E(^3\text{He}) = 4.5$ MeV. The p_0 group appears to be peaked in both the forward and the backward direction. The other groups do not exhibit a strong angular variation (1957HO61). At $E(^3\text{He}) = 6.05$ MeV the p_0 group is strongly peaked forward ((1958SW63), and D.R. Sweetman, private communication).

16. ^{11}B(α, d)^{13}C $\qquad Q_m = -5.167$

Not reported.

17. ^{12}C(n, γ)^{13}C $\qquad Q_m = 4.946$

The thermal capture cross section is 3.3 ± 0.2 mb (1958HU18). In addition to the 4.95 MeV ground state transition ($E_\gamma = 4948 \pm 8$ keV), a γ-ray is reported with an energy of 3.68 ± 0.05 MeV and an intensity of 0.3 γ/capture. If 3.1 and 3.9 MeV γ-rays occur, their intensities are less than 0.10 and 0.06 γ/capture, respectively (1953BA18).

18. ^{12}C(n, n)^{12}C $\qquad E_b = 4.946$

The cross section is approximately constant to 160 keV, then decreases monotonically to $E_n = 2$ MeV. There follows a region of resonances to 8.5 MeV, followed by a smooth variation of the cross section to $E_n = 100$ MeV (1958HU18). (1958CO07) finds a minimum of 1.3 b at $E_n = 14$ MeV, followed by a rise to 1.5 b at $E_n = 15.5$ MeV: see also ^{12}C(n, p)^{12}B. The average total cross section in the range $E_n = 14$ to 10000 eV is 4.69 ± 0.10 b (1956BR99).

The parameters of observed resonances are displayed in Table 13.5. A careful search for resonances in the region $E_n = 20$ to 1360 keV with 10 and 22 keV resolution revealed no deviation $> 5\%$ from a smooth monotonic decrease in σ_t (1950MI1A) (see, however, ^{11}B(^{3}He, p)^{13}C). The course of the cross section in this region can be accounted for by the broad $s_{1/2}$ state at ^{13}C*(3.09) (1952TH1D). A similar search, with 5 keV resolution, in the range $E_n = 2.73$ to 2.80 MeV revealed no deviations > 0.2 b from a smooth function (1958WI01: see ^{12}C(d, p)^{13}C).

Below $E_n = 4.0$ MeV, three d-wave resonances occur, at 2.08, 2.95, and 3.67 MeV. The total cross section and angular distributions establish the first as $D_{\frac{5}{2}}$ (1958WI36); phase shift analyses of angular distributions yield $D_{\frac{3}{2}}$ for the other two. The s-wave phase shift is everywhere negative and decreases slowly with energy: the behavior for $E_n = 0$ to 4 MeV can be accurately reproduced by a static potential well with a diffuse boundary (1958WI36). See also (1954HU1A). The $p_{1/2}$ and $p_{3/2}$ phase shifts are negative and small, not inconsistent with hard-sphere scattering (1954ME95, 1955BU56, 1958WI36). Polarization of scattered neutrons is discussed in these three papers and in (1956MC70, 1957MC1B). Other angular distribution studies in this range are reported by (1957LA14: $E_n = 0.06$ to 1.8 MeV), (1955WI25: $E_n = 0.55$ to 1.5 MeV), (1956MU96: $E_n = 1.66$ MeV), (1955LI50: $E_n = 2.7$ MeV), (1955WA27: $E_n = 4.1$ MeV).

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

$E_{\rm res}$ (MeV)	$\Gamma_{\rm lab}$ (keV)	^{13}C* (MeV)	$l_{\rm n}$	J^{π}	θ^2
2.076 ± 0.008 [a]	7 [a]	6.862	2 [a]	$\frac{5}{2}^+$ [a]	0.006 [a]
2.95 [b]	90 [g]	7.67	2 [h]	$\frac{3}{2}^+$ [h]	0.038 [a]
3.67 [b]	1690 [g]	8.33	2 [h]	$\frac{3}{2}^+$ [h]	0.51 [a]
4.4 [c]		9.0			
4.95 [d]		9.51			
5.40 [d]		9.93	> 0 [d]	$> \frac{1}{2}$ [d]	
6.3 [e]		10.8			
7.5 [f]		11.9			
7.83 [f]		12.17			

[a] (1958WI36): see also (1951BO45).
[b] See (1950RI1B, 1951BO45, 1951RI1A, 1951RI1B, 1958WI36).
[c] (1950FR61).
[d] (1956BE98).
[e] See (1953NE01, 1957BO13, 1958HU18).
[f] (1956HA1E).
[g] (1958WI36): (1954ME95) report 60 and 1200 keV.
[h] See (1950RI1B, 1951BO45, 1951RI1A, 1951RI1B, 1954ME95, 1955BU56, 1958WI36).

For $E_{\rm n} = 4$ to 8 MeV, several additional resonances are reported by (1950FR61, 1956BE98, 1956HA1E, 1957BO13): see Table 13.5 and (1958HU18). The structure above $E_{\rm n} = 7$ MeV is undoubtedly quite complex: see ^{9}Be(α, n)^{12}C and ^{12}C(n, n′)^{12}C*. Further angular distribution measurements are reported by (1955JE27: 4.4 MeV), (1958HI68: 5 MeV), (1958BR1F: 5.6 MeV), (1956BE32: 7 MeV), (1956DO1D, 1958NA09: 14 MeV), (1958CO77: 14.5 MeV) and (1957KH1B: 14.8 MeV): see also (1956HU1A). Optical model effects become apparent at the higher energies; see (1956CU1A; theor.).

In the region beyond the resolved resonances, recent measurements of the total cross section have been made by (1958BR16: $E_{\rm n} = 7$ to 14 MeV), (1958CO07: $E_{\rm n} = 13.1$ to 15.6 MeV), (1958VE15, 1958VE21: $E_{\rm n} = 13.6$ to 14.75 MeV) and (1957KH1A: $E_{\rm n} = 14.8$ MeV). For a review of the earlier work, see (1955AJ61) and (1957HU1D). Non-elastic cross section measurements are reported by (1956BE32: $E_{\rm n} = 7$ MeV), (1958BA03: $E_{\rm n} = 7$ to 14 MeV), (1955TA29: $E_{\rm n} = 12.7$ and 14.1 MeV), (1955GR21, 1956FL1B, 1957ST1F: $E_{\rm n} = 14$ MeV) and (1958MA54: $E_{\rm n} = 21$, 26 and 29 MeV): see also (1947HU03, 1955MA1G, 1957ZA1A). See also (1956LA1C) and (1956KA1B; theor.).

19. (a) ^{12}C(n, n′)^{12}C* $E_b = 4.946$

(b) ^{12}C(n, n′)^{4}He^{4}He^{4}He $Q_m = -7.281$

In the range $E_n = 4.4$ to 8 MeV, four resonances are observed in the yield of 4.4 MeV γ-rays, at $E_n = 6.30$, 6.49, 7.6, 7.87 and 8.15 MeV, corresponding to ^{13}C*(10.76, 10.94, 12.0, 12.21, 12.47). The differential cross section at $90°$ reaches a maximum of 60 mb/sr at 7.87 MeV (1956HA1E, 1958HU18). At $E_n = 6.58$ MeV, the cross section for production of 4.4 MeV γ-rays is 353 ± 59 mb (1956DA23); at 14 MeV, it is 245 ± 35 mb (1955BA95). (1955GR21) estimate 160 mb for the inelastic cross section at $E_n = 14$ MeV to ^{12}C levels at 9.6 to ≈ 13 MeV and 100 to 300 mb as the cross section to the ^{12}C states at 4.4 and 7.6 MeV. See ^{12}C(n, n)^{12}C above, for further references on non-elastic cross sections.

Reaction (b) has been studied for $E_n = 12.3$ to 20.1 MeV. The cross section is 190 ± 50 mb at 12.9 MeV. It goes through a broad maximum of $\approx 300 \pm 60$ mb at ≈ 16.5 MeV and then decreases to 240 ± 50 mb at $E_n = 20.1$ MeV (1955FR35). See also (1955BE1D, 1955BF01, 1958VA1D), (1956SA1E; theor.) and (1955AJ61).

20. ^{12}C(n, 2n)^{11}C $Q_m = -18.722$ $E_b = 4.946$

See (1952BR61, 1958AS63).

21. ^{12}C(n, p)^{12}B $Q_m = -12.593$ $E_b = 4.946$

The cross section has been measured from threshold to $E_n = 17.5$ MeV. At $E_n = 17.5$ MeV, the cross section is 29.1 ± 4 mb (1958KR65, 1959KR1B). See also (1956KR1A, 1956KR1B).

22. ^{12}C(n, α)^{9}Be $Q_m = -5.709$ $E_b = 4.946$

See (1955GR21) and ^{9}Be.

23. ^{12}C(d, p)^{13}C $Q_m = 2.719$

$Q_0 = 2.721 \pm 0.002$ (1957VA11).

Measurements on the proton groups are summarized in Table 13.6. The level assignments were obtained by analysis of angular distributions (with deuterons of energies up to 24 MeV) in terms of direct interaction theories. A careful search with $E_d = 5$ to 8.5 MeV ($\theta = 90°$) reveals no further

Table 13.6: Levels of ^{13}C from ^{12}C(d, p)^{13}C

^{13}C* (MeV $\pm$ keV)					l_n	J^π	$\sigma(\theta)$ [e]	θ_n^2 [h]
(1951ST19, 1951VA1A)	(1954SP01)	(1956DO41)	(1953KH1A, 1955KH35) [a]	(1955MC75)			(mb/sr)	(%)
0	0		0	0	1 [c]	$\frac{1}{2}^-, \frac{3}{2}^-$ [c]	26	7
3.086 ± 6	3.090 ± 10		3.107	3.09 [b]	0 [c]	$\frac{1}{2}^+$ [c]	103	25
3.686 ± 11	3.684 ± 10	$[3.681 \pm 3]$	3.699	3.68 [b]	1 [c]	$\frac{1}{2}^-, \frac{3}{2}^-$ [c]	16	2
	3.855 ± 7	$[3.851 \pm 3]$	3.869	3.84 [b]	2 [c]	$\frac{3}{2}^+, \frac{5}{2}^+$ [c]	152	10
				6.87 [b]	(0), (2) [d]	$(\leq \frac{5}{2}^+)$ [d]	36	
				7.470 ± 20			≈ 0.8	
				7.533 ± 20			9.6	
				7.641 ± 20 [f]			7.5	
				8.4 ± 300 [g]			100	
				9.500 ± 20			1.6	
				9.897 ± 20			2.2	
				10.759 ± 20			4.5	

[a] ± 10 to 50 keV.
[b] Energies given for identification only.
[c] (1951RO1B, 1951RO1C, 1952BL1B, 1953CA1B, 1954FR24, 1955MC75, 1956CA1D, 1956GR37, 1957CO68).
[d] (1955MC75).
[e] (1955MC75); differential cross sections at the first maximum or in the forward direction; $\pm 25\%$.
[f] $\Gamma = 70 \pm 15$ keV.
[g] $\Gamma = 1.1 \pm 0.3$ MeV.
[h] (1956EL1A, 1956GR37, 1958MC63).

proton proton groups corresponding to levels in the range 0 to 4.9 MeV with intensity greater than 0.5% of the ground state group (1954SP01). At $E_d = 14.8$ MeV, all groups show pronounced stripping distributions except that corresponding to ^{13}C*(9.50), for which the distribution is roughly isotropic. 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 $D_{\frac{3}{2}}$ level of similar width observed in ^{12}C(n, n)^{12}C at $E_x = 8.33$ MeV: see Table 13.5.) Only one other level has a measurable width: $E_x = 7.64$ MeV, $\Gamma_{lab} = 70 \pm 15$ keV (compare Table 13.5) (1955MC75). It is of interest that the 7.47 and 7.53 MeV levels do not appear in ^{12}C(n, n)^{12}C (1958WI01).

Angular distributions at low energies have been studied by (1954TA1A: $E_d = 0.52$ to 0.84 MeV), by (1956JU1E, 1956JU1F, 1957JU1A: $E_d = 0.60$ to 1.45 MeV), by (1955AL1D, 1955AL1E: $E_d = 1.4$ to 2.0 MeV), by (1956BE1H, 1956MC88: $E_d = 1.86$ to 2.86 MeV for the p_0 group - on and off resonances - and $E_d = 2.74$ and 2.89 MeV for the p_1 group), by (1954HO48, 1956BO08: $E_d = 3.2$ to 4.4 MeV) and by (1956KO26, 1956VA17: $E_d = 0.26$ to 0.59 MeV). In the range $E_d = 1$ to 6 MeV, the (^{12}C + d) reactions are characterized by numerous strong, overlapping resonances (see ^{14}N); the angular distributions show evidence of both stripping and compound nucleus formation, even below 1 MeV (1956JU1E, 1956KO26, 1956VA17, 1957JU1A). From $E_d = 2$ to 6 MeV, angular distributions of the p_0 group (to $^{13}C_{g.s.}$) generally show a stripping maximum near $25°$, as expected for an $l = 1$ transfer; several of the "resonances" appear most conspicuously at the angle. The p_1-group, ^{13}C*(3.09), show even stronger stripping effects, with a pronounced forward maximum (1956BO08, 1956MC88, 1958MC63). A detailed comparison of distributions for ^{12}C(d, p)^{13}C and ^{12}C(d, n)^{13}N at $E_d = 2.68$ and 3.26 MeV indicates equality of the ground-state reduced widths (1956BE1H, 1958MC63). At $E_d = 9$ MeV, a similar comparison yields $\gamma^2(^{13}\text{C})/\gamma^2(^{13}\text{N}) = 0.86$ (1956CA1D). See also (1955WI43).

Observed gamma rays are listed in Table 13.7. No γ-rays are observed with $E_\gamma = 3.9$ to 5.8 MeV with intensity $>$ 10% of the 3.85 MeV γ-ray (1955BE62). An upper limit of 3% is placed on the fraction of cascade transitions from the 3.67 and 3.84 MeV levels via the 3.1 MeV level. The internal conversion coefficient of the 170 keV radiation indicates E1, though M1 is not excluded (1956MA1Q, 1956MA52). The internal pair formation coefficient for the 3.09 MeV level indicates an E1 transition (1952TH24); the angular correlation of internal pairs also indicates E1 (1954GO1E, 1956GO1K, 1958AR1B). Polarization of protons accompanying the formation of $^{13}C_{g.s.}$ and ^{13}C*(3.1) has been studied by (1956HI1B, 1958BO67, 1958HE47, 1958HI74, 1958JU39, 1958JU42). The sense of polarization is correlated with the coupling of l_n and s_n: $P = \pm$ when $j = l \mp \frac{1}{2}$ (1958HE47). See (1954CH1C, 1957SA1C; theor.). See also (1952CA1B, 1954CA1B, 1955KH31, 1956CA1H, 1957SE1C), (1957DA1C; theor.) and ^{14}N.

Table 13.7: Gamma radiation from ^{12}C(d, p)^{13}C

E_γ [a] (MeV $\pm$ keV)	E_γ [b] (MeV $\pm$ keV)	Reference
3.86 ± 20	(3.84 ± 30) [c]	(1955BE62)
3.844 ± 15		(1956MA1Q, 1956MA52)
0.1695 ± 0.4 [f]		(1956MA1Q, 1956MA52)
(3.76 ± 20) [c]	3.74 ± 30	(1955BE62)
(3.69 ± 20) [c]	3.675 ± 15 [d]	(1956MA1Q, 1956MA52)
(3.097 ± 5) [e]	3.082 ± 7	(1952TH24)

[a] Uncorrected for Doppler shift.

[b] Corrected for Doppler shift.

[c] Doppler shift correction is not required for the 3.86 MeV radiation, but is required for the 3.67 MeV radiation (1956MA1Q, 1956MA52): see ^{10}B(α, p)^{13}C.

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

[e] Doppler shift required (1952TH24).

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

24. ^{12}C(t, d)^{13}C $\qquad Q_{\mathrm{m}} = -1.313$

Not reported.

25. ^{12}C(α, ^{3}He)^{13}C $\qquad Q_{\mathrm{m}} = -15.632$

Not reported.

26. ^{13}C(γ, n)^{12}C $\qquad Q_{\mathrm{m}} = -4.946$

The cross section for neutron production has been determined to 38 MeV. The (γ, n) cross section exhibits two peaks at 13.3 ± 1 MeV ($\Gamma = 5 \pm 1$ MeV, $\sigma = 3.3$ mb) and at ≈ 22 MeV ($\sigma \approx 6$ mb, $\Gamma \approx 7$ MeV). The total absorption cross section, $\sigma(\gamma,\ x\mathrm{n}) + \sigma(\gamma,\ \mathrm{p})$ shows maxima at $E_{\gamma} = 13.5$ and 25 MeV. The lower resonance is much too large to be explained on a single-particle model (1957CO57). Se also (1949SE1B, 1953GO13, 1956CO72).

27. ^{13}C(γ, p)^{12}B $\qquad Q_{\mathrm{m}} = -17.539$

The yield of β-particles from the ^{12}B decay has been determined to 45 MeV. The cross section shows a broad maximum of 8.8 mb near 25.5 MeV (1956CO72, 1957CO57).

28. ^{13}C(γ, α)^{9}Be $\qquad Q_{\mathrm{m}} = -10.654$

See (1953MI31).

29. ^{13}C(p, p$'$)^{13}C*

Angular distributions of the 3.09 MeV γ-rays are isotropic for $E_{\mathrm{p}} = 3.7$ to 4.2 MeV, consistent with the assignment $J = \frac{1}{2}$ to ^{13}C*(3.09). Angular distributions of the 3.68 MeV radiation have also been studied near the $E_{\mathrm{p}} = 4.5$ MeV resonance (1957BA29). See also (1952CO1C).

30. ^{13}N(β^{+})^{13}C $\qquad Q_{\mathrm{m}} = 2.222$

See ^{13}N.

31. ^{14}C(p, d)^{13}C $Q_{\rm m} = -5.947$

Not reported.

32. ^{14}C(d, t)^{13}C $Q_{\rm m} = -1.915$

At $E_{\rm d} = 14.8$ MeV, triton groups have been observed leading to the ^{13}C states at 0, 3.09, 3.68 and 3.85 MeV (1958MO97). See ^{14}C.

33. ^{14}C(^{3}He, α)^{13}C $Q_{\rm m} = 12.404$

Not reported.

34. ^{14}N(n, d)^{13}C $Q_{\rm m} = -5.319$

At 14 MeV, deuteron groups to the 0 and 3.68 MeV (but not to the 3.09 and 3.84 MeV) states of ^{13}C have been observed (1957CA07). See also (1952LI24) and ^{14}N.

35. ^{14}N(p, 2p)^{13}C $Q_{\rm m} = -7.546$

At $E_{\rm p} = 185$ MeV, the summed proton spectrum shows two peaks, corresponding to ejection of $p_{1/2}$ and $p_{3/2}$ protons, with binding energies of ≈ 7 and ≈ 15 MeV, ^{13}C* $= 0$ and ≈ 8 MeV (1958MA1B, 1958TY49).

36. ^{14}N(d, ^{3}He)^{13}C $Q_{\rm m} = -2.052$

Not reported.

37. ^{14}N(t, α)^{13}C $Q_{\rm m} = 12.267$

Table 13.8: ^{13}C states from ^{15}N(d, α)^{13}C

(1951MA08)	(1957WA01)	
^{13}C* (MeV $\pm$ keV)	^{13}C* (MeV $\pm$ keV) [a]	dσ/dΩ ($\theta_{\rm lab} = 12.6°$) (mb/sr)
0	0	0.85 ± 0.09
3.083 ± 5	3.09	0.18 ± 0.03
3.677 ± 5	3.68	2.4 ± 0.3
	3.85	< 0.3
	6.87	1.3 ± 0.2 [c]
	7.47, 7.53, 7.64 [b]	1.1 ± 0.2
	8.80 ± 40	0.56 ± 0.11
	9.5	0.15 ± 0.04
	9.9	0.26 ± 0.06

[a] Level energies for identification purposes only except for ^{13}C*(8.80).
[b] Not resolved.
[c] Measured at $\theta = 18°$.

This reaction has been observed at $E_{\rm t} = 1.9$ MeV (1958JA06).

38. ^{15}N(n, t)^{13}C $\qquad Q_{\rm m} = -9.903$

Not reported.

39. ^{15}N(p, ^{3}He)^{13}C $\qquad Q_{\rm m} = -10.668$

Not reported.

40. ^{15}N(d, α)^{13}C $\qquad Q_{\rm m} = 7.683$

Observed alpha particle groups are displayed in Table 13.8 (1951MA08, 1957WA01). The broad level at 8.4 MeV observed in ^{12}C(d, p)^{13}C does not appear in the present reaction; it is suggested that the direct (d, α) transition is forbidden by the nature of the configurations involved

(1957WA01). The angular distribution of the ground-state alpha particles at $E_d = 21$ MeV shows a maximum at $70°$ (c.m.) (1958FI27).

41. ^{16}O(n, α)^{13}C $\qquad$ $Q_m = -2.203$

See (1951HU1A, 1952LI24) and ^{17}O.

^{13}N
(Fig. 24)

GENERAL:

Theory: See (1955LA1A, 1956DA1G, 1958FR1C, 1958HA1D, 1958SK1A).

1. ^{13}N(β^+)^{13}C $\qquad$ $Q_m = 2.222$

Recent determinations of the half-life give 10.05 ± 0.03 min (1953CH34), 10.08 ± 0.04 min (1955WI43), 10.07 ± 0.06 min (1957NO17), 9.96 ± 0.03 min (1958AR15), 9.96 ± 0.03 min (1958DA09); see also (1957DE22). E_β(max) $= 1.202 \pm 0.005$ MeV (1950HO01), 1.185 ± 0.025 MeV (1954GR66), 1.190 ± 0.003 MeV (1958DA09). The positron spectrum shows no deviation from the allowed shape; it is concluded that the Fierz coefficient in the Fermi interaction is $< 11\%$. Log $ft = 3.66$ (1957DA08, 1958DA09). The positron polarization has been studied by (1957BO65, 1957HA27). The results indicate that the positrons are completely polarized and hence that Fermi transitions as well as G-T transitions exhibit the maximum effect of parity nonconservation.

2. ^{9}Be(^{6}Li, 2n)^{13}N $\qquad$ $Q_m = 3.952$

See (1957NO17).

3. ^{10}B(^{3}He, n)^{12}N $\qquad$ $Q_m = 1.46$ $\qquad$ $E_b = 21.642$

At $E(^3\text{He}) = 2.54$ MeV, the cross section for formation of the ground state is $5.2^{+2.1}_{-1.6}$ mb. At $E(^3\text{He}) = 3.60$ MeV, the differential cross section for formation of the ground state at $\theta = 0°$ is 0.73 ± 0.30 mb/sr (1957AJ71).

Table 13.9: Energy levels of ^{13}N

E_x (MeV $\pm$ keV)	J^π	$\tau_{1/2}$ or Γ (keV)	Decay	Reactions
0	$(\frac{1}{2})^-$	$\tau_{1/2} = 10.02 \pm 0.02$ min	β^+	1, 2, 7, 9, 15, 16, 18, 19, 20, 21, 22
2.365 ± 3	$\frac{1}{2}^+$	$\Gamma = 32 \pm 2$	p, γ	7, 9, 12, 15, 22
3.507 ± 7	$\frac{3}{2}^-$	63 ± 6	p, γ	7, 9, 12, 15, 22
3.555 ± 10	$\frac{5}{2}^+$	61	p	12, 15, 22
6.379 ± 10	$\frac{5}{2}^+$	11	p	12
6.908 ± 10	$\frac{3}{2}^+$	115	p	12
7.415 ± 10	$(\frac{5}{2}^+)$	≈ 85	p	12
(8.08)	$(\frac{3}{2}^+)$	(350)	p	12
22.7 ± 300		≈ 1400	p	12
23.2		400	p, ^{3}He	4
24.5		550	p, ^{3}He	4
24.8		90	p, ^{3}He	4
25.2		120	p, ^{3}He	4

4. ^{10}B(^{3}He, p)^{12}C $\quad Q_m = 19.702 \quad E_b = 21.642$

The yields of the protons to the ground and 4.4 MeV excited states of ^{12}C have been measured for $E(^3\text{He}) = 1.3$ to 5 MeV. Resonances are observed at 2.0, 3.7, 4.1 and 4.6 MeV, with widths of 0.5, 0.7, 0.12 and 0.15 MeV, respectively, corresponding to ^{13}N*(23.2, 24.5, 24.8, 25.2). Angular distributions taken at six energies in the above range tend to be more asymmetric at the higher energies (1956SC01). See also (1956JO1B).

5. ^{10}B(^{3}He, d)^{11}C $\quad Q_m = 3.206 \quad E_b = 21.642$

See ^{11}C.

6. ^{10}B(^{3}He, α)^{9}B $\quad Q_m = 12.139 \quad E_b = 21.642$

See ^{9}B.

Table 13.10: Resonances in ^{12}C(p, γ)^{13}N

E_p (keV)	Γ_{lab} (keV)	σ_{res} (mb)	$\omega\Gamma_\gamma$ (eV)	^{13}N* (MeV)	References
456.8 ± 0.5	39.5 ± 1.0			2.363	(1953HU18)
456 ± 2	35				(1949FO18)
450	35	127	0.67		(1951SE1B, 1951SE67)
1697 ± 12	74 ± 9			3.507	(1949VA1A)
1698 ± 5	70 ± 10	35	1.39		(1951SE1B, 1951SE67)

7. ^{10}B(α, n)^{13}N $\qquad Q_m = 1.065$

Measurements at $E_\alpha = 8$ MeV with a proton recoil telescope and a neutron threshold detector are reported to indicate ^{13}N states at 2.4 ± 0.3, 3.6 ± 0.3, (4.3 ± 0.3) and 5.0 ± 0.3 MeV (1956QU1A). See also (1957BA1K) and ^{14}N.

8. ^{11}B(^{3}He, n)^{13}N $\qquad Q_m = 10.179$

Not reported.

9. (a) ^{12}C(p, γ)^{13}N $\qquad Q_m = 1.941$
(b) ^{12}C(p, γp$'$)^{12}C

Two resonances for capture radiation are reported, at $E_p = 0.46$ and 1.70 MeV (Table 13.10). The resonance at $E_p = 1.75$ MeV observed in ^{12}C(p, p)^{12}C does not appear in the γ-excitation curve (1951SE67). The displacement of the lower level (^{13}N*(2.37), $J = \frac{1}{2}^+$) from its mirror in ^{13}C*(3.09) is ascribed to the large reduced width (1951EH1A, 1952TH1D). The angular distribution of the ground-state radiation from the upper resonance (^{13}N*(3.51), $J = \frac{3}{2}^-$) has the form $W(\theta) = 1 - 0.52\cos^2\theta$ (1951DA1A, 1951DA1B).

The capture cross section at low energy is of interest in connection with stellar energy generation. Measurements have been reported in the range $E_p = 80$ to 360 keV by (1950BA89, 1950HA78, 1957DE22, 1957LA15). At 80 keV, $\sigma = (1.4 \pm 0.4) \times 10^{-5}$ μb; from 80 to 126 keV, the course of the cross section is reasonably well accounted for by extrapolation of the $E_p = 0.46$ MeV resonance (1957LA15: see also (1957DE22)).

From $E_p = 5$ to 11 MeV, the cross section for formation of ^{13}N changes only from 2.5 to 1.8 mb; this small change strongly indicates the predominance of direct capture in this region

(1955CO57). According to (1956RE39), however, the $90°$ differential cross section for formation of ^{13}N is < 1 μb/sr at $E_p = 4.8$ MeV. See also (1956CH1D).

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. Excitation functions at $\theta = 0°$ and $90°$ indicate interference between p-wave resonant capture at $E_p = 1.70$ MeV, with $\Gamma_\gamma = 0.04$ eV, and direct p-wave capture (1954WO09). The angular distributions at $E_p = 1.37$ and 1.58 MeV have the form $W(\theta) = (0.02 \pm 0.02) + \sin^2\theta$ (1955HE1F).

10. ^{12}C(p, n)^{12}N $Q_m = -18.24$ $E_b = 1.941$

See (1957ST1D, 1958TA03) and ^{12}N.

11. ^{12}C(p, pn)^{11}C $Q_m = -18.722$ $E_b = 1.941$

See (1947CH1A, 1948MC1A, 1958WH34).

12. (a) ^{12}C(p, p)^{12}C $E_b = 1.941$
(b) ^{12}C(p, p′)^{12}C*

Elastic scattering studies indicate a number of pronounced resonances in the range $E_p = 0$ to 6 MeV: see Table 13.11. The first five excited states correspond in character and approximately in reduced width to those of ^{13}C: see ^{12}C(d, p)^{13}C and ^{12}C(n, n)^{12}C. The relatively large reduced widths of the first and third ($s_{1/2}$ and $d_{5/2}$) excited states indicate a single-particle character (1953JA1B). The small and roughly equal widths of ^{13}N*(6.4, 6.9) suggest that they may comprise a doublet, built upon ^{12}C*(4.4) + p (1956RE39: see also (1953BL1A, 1953MA1D, 1956SC29)). Angular distribution measurements above $E_p = 10$ MeV generally show direct interaction effects: see ^{12}C. Some form of resonance structure may exist near 23 MeV (1955KI43). See also (1956KL55).

The yields of 4.4 MeV gamma rays and inelastic protons from ^{12}C*(4.4) show resonances at $E_p = 5.39$ and 5.93 MeV (1953MA1D, 1956BR27, 1957LI1B). Angular distributions of inelastic protons at $E_p = 6.1$ to 6.9 MeV do not fit direct interaction theory and suggest the effects of still higher compound nucleus levels (1956BR27).

Polarization studies for $E_p < 6$ MeV are reported by (1956GA66, 1956SO1C, 1958WA1D): see also ^{12}C. See also (1955DE50, 1956ER1A, 1956NI1B, 1957GL58; theor.) and (1957GO1D).

13. ^{12}C(p, d)^{11}C $Q_m = -16.495$ $E_b = 1.941$

Table 13.11: ^{13}N levels from ^{12}C(p, p)^{12}C and ^{12}C(p, p′)^{12}C*

E_{res} (MeV ± keV)	^{13}N* (MeV)	$\Gamma_{c.m.}$ (keV)	l_p	J^π	θ_p^2
0.461 ± 3 [a]	2.367	31	0	$\frac{1}{2}^+$	0.54
1.698 [b]	3.508	55	1	$\frac{3}{2}^-$	0.031
1.748 [b]	3.555	61	2	$\frac{5}{2}^+$	0.21
4.808 [c]	6.379	11	2	$\frac{5}{2}^+$	0.0031
(5.05) [e]		(75)	(0)	$(\frac{1}{2}^+)$	(0.014)
5.381 ± 7 [d]	6.908	115	2	$\frac{3}{2}^+$	0.012
5.930 ± 7 [f]	7.415	≈ 85	2	$\frac{5}{2}^+$	
6.65 [g]	(8.08)	(350)	(2)	$(\frac{3}{2}^+)$	(0.11)

[a] (1953JA1B). (1954MI05) finds $E_{res} = 0.462$ MeV, $\Gamma = 32$ keV.
[b] (1953JA1B).
[c] (1956RE39).
[d] (1956RE39): parameters estimated from elastic scattering; $\theta^2_{p'} = 0.2$. E_{res} from ^{12}C(p, p′)^{12}C* (1957LI1B). See also (1956SC29).
[e] (1956SC29): $E_p = 4.8$ MeV, $J = \frac{5}{2}^+$ level not observed.
[f] ^{12}C(p, p′)^{12}C* (1957LI1B). (1956BR27) finds $E_{res} = 5.891$ MeV, $\Gamma_{lab} = 59$ keV. See also (1956SC29).
[g] (1956SC29). See, however, (1956BR27).

See ^{11}C.

14. ^{12}C(p, α)^{9}B $\quad Q_m = -7.563 \quad E_b = 1.941$

See ^{9}B.

15. ^{12}C(d, n)^{13}N $\quad Q_m = -0.286$

Neutron groups have been observed corresponding to excited states of ^{13}N at 2.29 ± 0.12 (1949GR1A), 2.38 ± 0.05 MeV (1953MI10) and 3.48 ± 0.12 (1949GR1A), 3.74 ± 0.05 (1957GR1A), 3.53 ± 0.05 MeV (1953MI10). The angular distributions of the ground state group and the groups corresponding to the 2.37 and (3.51 ± 3.56) MeV states at $E_d = 9.0$ MeV are consistent with $l_p = 1$, 0 and 2. The dimensionless reduced widths of the ground and (3.56) MeV states are respectively 0.056 and 0.19 (1957CA02: see also (1953MI10)). (1958MC63) finds that the reduced widths of the ground states of ^{13}C and ^{13}N are the same, 0.09 ± 0.035 (see also (1956BE1H, 1956CA1D, 1958KA16) and ^{12}C(d, p)^{13}C). In the range $E_{\rm d} = 2.8$ to 3.7 MeV, a single neutron threshold is observed, at $E_{\rm d} = 3.09 \pm 0.02$ MeV, corresponding to ^{13}N*(2.36 ± 0.02); the slow rise above threshold is attributed to p-wave neutron emission (1955MA76).

Polarization of neutrons has been studied for $E_{\rm d} = 2.5$ to 3.6 MeV by (1957HA1J). See also (1956BO1F, 1956BO43, 1956DE1D).

16. ^{12}C(^{3}He, d)^{13}N $\quad Q_{\rm m} = -3.553$

See (1952FR1A, 1958WE1E).

17. ^{12}C(α, t)^{13}N $\quad Q_{\rm m} = -17.872$

Not reported.

18. ^{13}C(p, n)^{13}N $\quad Q_{\rm m} = -3.005$

$E_{\rm thresh.} = 3.2372 \pm 0.0016$ (1958BO76).

See also (1950RI59, 1955MA84, 1958BI1B) and ^{14}N.

19. ^{13}C(^{3}He, t)^{13}N $\quad Q_{\rm m} = -2.240$

See (1952FR1A).

20. ^{14}N(γ, n)^{13}N $\quad Q_{\rm m} = -10.551$

See ^{14}N.

21. ^{14}N(p, d)^{13}N $\quad Q_{\rm m} = -8.324$

See ^{14}N.

22. ^{14}N(d, t)^{13}N $\qquad Q_{\rm m} = -4.292$

At $E_{\rm d} = 14.8$ MeV, triton groups are observed corresponding to the states at 0, 2.37 and (3.51 ± 3.56) MeV. The cross section for the transition to the 2.37 MeV state is two orders of magnitude smaller than that for the ground state transition. Transitions to ^{13}N*(2.37, 3.56) are shell-model forbidden (1957WA01).

23. ^{14}N(^{3}He, α)^{13}N $\qquad Q_{\rm m} = 10.027$

Not reported.

24. ^{15}N(p, t)^{13}N $\qquad Q_{\rm m} = -12.908$

Not reported.

25. ^{16}O(p, α)^{13}N $\qquad Q_{\rm m} = -5.208$

See (1958WH34).

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(Closed 1 December 1958)

References are arranged and designated by the year of publication followed by the first two letters of the first-mentioned author's name and then by two additional characters. Most of the references appear in the National Nuclear Data Center files (Nuclear Science References Database) and have NNDC key numbers. Otherwise, TUNL key numbers were assigned with the last two characters of the form 1A, 1B, etc. In response to many requests for more informative citations, we have, when possible, included up to ten authors per paper and added the authors' initials.

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