Energy Levels of Light Nuclei
$A = 15$

F. Ajzenberg-Selove

University of Pennsylvania, Philadelphia, Pennsylvania 19104-6396

Abstract: An evaluation of $A = 13$–15 was published in *Nuclear Physics A*152 (1970), p. 1. This version of $A = 15$ 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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^{15}B

^{15}B has been identified in the 5.3 GeV proton bombardment of uranium. It is particle stable (1966PO09). See also (1960ZE03, 1961BA1C, 1966GA25).

^{15}C

(Figs. 9 and 12)

GENERAL:

See (1960TA1C, 1962TA1E, 1964LI1B, 1964ST1B, 1967LO03). See also (1969AR13).

1. ^{15}C(β^-)^{15}N $\quad Q_m = 9.773$

The half-life is 2.25 ± 0.05 sec (1956DO37), 2.49 ± 0.07 sec (1964NE09). The β-spectrum is complex. Transitions have been observed both to the ground state and to the upper of the 5.3 MeV levels of ^{15}N: the latter transition is clearly allowed: see Table 15.2 (1959AL06, 1966AL12, 1969GA05). The ground state transition of ^{15}N*(5.3) has $E_\gamma = 5.29903 \pm 0.00043$ MeV (1967CH19); J^π for this state is $\frac{1}{2}^+$ (see Table 15.4). Thus $J^\pi(^{15}\text{C}) = \frac{1}{2}^+$ or $\frac{3}{2}^+$ (1959AL06, 1964AL21: see also (1965WA03)). See also (1963KI1B, 1968ZH1B) and ^{15}N.

2. ^{9}Be(^{6}He, α)^{11}Be $\quad Q_m = 6.343 \quad E_b = 19.076$

^{9}Be was irradiated with 14 MeV neutrons and the decay of ^{11}Be was observed [^{9}Be(n, α)^{6}He, followed by the above reaction]: the cross section (which is determined for a large ^{6}He energy spread) is 11 ± 10 mb (1967ST21).

3. ^{9}Be(^{7}Li, p)^{15}C $\quad Q_m = 9.095$

Observed proton groups are listed in Table 15.3 (1957MU99, 1964CA05). τ_m for ^{15}C*(0.75) is (3.77 ± 0.11) nsec (1968ME08: delayed coincidence technique). Angular distributions of the protons to ^{15}C*(0, 0.75) are reported at $E(^{7}\text{Li}) = 5.6$, 5.8, 6.0, 6.2 MeV by (1969SN02).

4. ^{14}C(d, p)^{15}C $\quad Q_m = -1.006$

Table 15.1: Energy levels of ^{15}C

E_x (MeV $\pm$ keV)	$J^\pi; T$	τ	Decay	Reactions
g.s.	$\frac{1}{2}^+; \frac{3}{2}$	$\tau_{1/2} = 2.33 \pm 0.08$ sec	β^-	1, 3, 4
0.747 ± 7	$\frac{5}{2}^+; \frac{3}{2}$	$\tau_m = 3.76 \pm 0.10$ nsec	γ	3, 4
(2.48 ± 50)				3
3.08 ± 40				3, 4
4.21 ± 30				3, 4
(4.60)				3
5.93 ± 30				3, 4
6.38 ± 30				3, 4
6.58 ± 40				3
(6.84)				3
(7.06)				3
7.32 ± 30				3, 4
(7.69)				3
(8.00)				3
8.12 ± 60				3
(8.47)				3

Table 15.2: Beta decay of ^{15}C (1959AL06, 1966AL12, 1969GA05)

Decay to ^{15}N* (MeV)	J^π	Branch (%)	$\log ft$ [a] (exp)	$\log ft$ [b] (theor)
g.s.	$\frac{1}{2}^-$	32 ± 2	5.96 ± 0.03	5.8
5.30	$\frac{1}{2}^+$	68 ± 2	4.04 ± 0.02	4.80
7.30	$\frac{1}{2}^+, \frac{3}{2}^+$	$(0.8 \pm 0.2) \times 10^{-2}$	6.82 ± 0.13	6.49
8.31	$\frac{1}{2}^+, \frac{3}{2}^+$	$(5.0 \pm 0.6) \times 10^{-2}$	5.06 ± 0.06	4.51
8.58	$\frac{1}{2}^+, \frac{3}{2}^+$	$\leq 2.8 \times 10^{-2}$	≥ 5.0	
9.05	$\frac{1}{2}^+, \frac{3}{2}^+$	$(3.5 \pm 0.5) \times 10^{-2}$	3.99 ± 0.07	

[a] Using $\tau_m = 2.25 \pm 0.05$ sec.
[b] See (1959AL97).

Table 15.3: Proton groups from ^{9}Be(^{7}Li, p)^{15}C and ^{14}C(d, p)^{15}C

E_x (MeV $\pm$ keV)		E_x (MeV)
(1957MU99)	(1959MO1B)	(1964CA05) [c]
0	0	0
0.62 ± 60 [a]	0.75 ± 30	0.74
2.48 ± 50 [b]		
3.08 ± 40	3.09	3.08
4.26 ± 40	4.21	4.16
		4.60
5.93 ± 40	5.94	5.81
	6.38	6.39
6.58 ± 40		6.58
		6.84
		7.06
	7.32	7.31
		7.69
		8.00
8.16 ± 60		8.08
		8.47

[a] (1957NO14) reports $E_x = 0.70 \pm 0.05$ MeV.

[b] Not observed by (1964CA05).

[c] $\pm$30 keV (private communication).

Identification of ^{15}C$_{\text{g.s.}}$ with ^{15}N*(11.62), $T = \frac{3}{2}$, $J^{\pi} = \frac{1}{2}^{+}$, is suggested by (1956BA16). At $E_d = 14.9$ MeV, proton groups are observed to the ground state of ^{15}C and to the levels at 0.75, 3.09, 4.21, 5.94, 6.38 and 7.32 MeV ($\pm$30 keV) (1959MO1B). The angular distribution of ground state protons implies $l_n = 0$, $J^{\pi} = \frac{1}{2}^{+}$ (1959MO1B: see also (1961PU1B) and ref. [9] there, (1964AL21)); for the first excited state, $l_n = 2$. $\theta^2 = 0.093$ and 0.032 (1959MO1B), 0.16 and 0.063 (1966GL01) for the ground state and the first excited state, respectively. See also (1967NE06).

The 0.75 MeV level has a mean life of 3.73 ± 0.23 nsec (1962LO02); $E_{\gamma} = 750 \pm 7$ keV. The angular distribution of the γ-rays requires $J \geq \frac{5}{2}$. Since the $l_n = 2$ stripping requires $J^{\pi} = \frac{3}{2}^{+}$ or $\frac{5}{2}^{+}$, $J^{\pi} = \frac{5}{2}^{+}$ is established (1962CH14). The observed lifetime excludes $J > \frac{5}{2}$ (1962LO02). See also (1964NE09, 1965WA03, 1966AL12, 1967CH19).

5. ^{14}C(n, γ)^{15}C $\quad Q_{\rm m} = 1.218$

The capture cross section is $< 1\ \mu$b (1951YA1A).

6. ^{18}O(n, α)^{15}C $\quad Q_{\rm m} = -5.009$

See (1966BA1F).

The following reactions leading to ^{15}C have not been reported:

^{13}C(t, p)^{15}C	$Q_{\rm m} = 0.912$
^{14}C(t, d)^{15}C	$Q_{\rm m} = -5.039$
^{14}C(α, ^{3}He)^{15}C	$Q_{\rm m} = -19.360$
^{15}N(n, p)^{15}C	$Q_{\rm m} = -8.990$

^{15}N

(Figs. 10 and 12)

GENERAL:

Model calculations: (1957HA1E, 1959BR1E, 1959FE1B, 1960TA1C, 1961BA1E, 1963BU1C, 1963KU1B, 1964MA1G, 1965CO25, 1965FA1B, 1965GR1H, 1965GU1A, 1965ZA1B, 1966EL08, 1966SO05, 1967CO32, 1967EL03, 1967PA05, 1968EL1A, 1968HO1H, 1968MA2B, 1968SH08, 1968WA04, 1968ZH05, 1969CH1R, 1969EL1B).

General calculations and reviews: (1964EV1A, 1965BE1B, 1966OL1C, 1966WI1E, 1967FA1A, 1967LO03, 1968BI1C, 1968ZH1B, 1969HA1G, 1969IW1B).

Electromagnetic transitions: (1965RO1N, 1966HA31, 1966PO11, 1966RO1P, 1966RO1U, 1966WA1E, 1967KU1E, 1967PO1J, 1967WA1C, 1968BI1C, 1968SH08, 1968YA1E, 1968ZH06, 1968ZH1B, 1969KH1C, 1969ZH1A).

Meson interactions: (1969KA1R).

Other: (1961BA05, 1964VA1D).

Ground state: $\mu = -0.28309$ nm (1962BA63, 1964LI14, 1967CO1D).

See also (1961BR13, 1964ST1B, 1965IC1A, 1965MA1T, 1966MA1V, 1966WI1E, 1967SH14, 1968PE16, 1968RO1E, 1969CH1R, 1969FU11).

1. (a) ^{9}Be(^{6}Li, p)^{14}B	$Q_{\rm m} = 15.130$	$E_{\rm b} = 25.339$
(b) ^{9}Be(^{6}Li, α)^{11}B	$Q_{\rm m} = 14.347$	
(c) ^{9}Be(^{6}Li, 2n)^{13}N	$Q_{\rm m} = 3.951$	
(d) ^{9}Be(^{6}Li, ^{8}Be)^{7}Li	$Q_{\rm m} = 5.587$	
(e) ^{9}Be(^{6}Li, ^{5}He)^{10}B	$Q_{\rm m} = 1.933$	

The yield of p_0 and p_1 (reaction (a)) for $E(^{6}\text{Li}) = 3.84$ to 6.40 MeV shows some broad structure: analysis in terms of Ericson fluctuation theory gives a value of ≈ 0.4 MeV for the average level width at $E_{\rm x} = 28$ MeV in ^{15}N (1967SE08). The excitation functions for α_0, α_1 and α_{2+3} (reaction (b)) [$E(^{6}\text{Li}) = 2$ to 4 MeV: (1961LE01)] and the yield of ^{13}N (reaction (c)) [$E(^{6}\text{Li}) = 1.5$ to 3.5 MeV: (1961NO05)] show a smooth increase in the cross section with energy. For reactions (d) and (e) see (1962MC12). See also (1963BA1Q).

2. ^{9}Be(^{7}Li, n)^{15}N $\qquad Q_{\rm m} = 18.086$

At $E(^7\text{Li}) = 2.9$ MeV, γ-rays are observed which are assigned to the ground state decay of ^{15}N*(9.05, 9.83, 10.80) (1964CA18). See also (1957NO17).

Table 15.4: Energy levels of ^{15}N [a]

E_x (MeV ± keV)	$J^\pi; T$	τ_m (psec) or Γ (keV)	Decay	Reactions
0	$\frac{1}{2}^-$		stable	2, 3, 4, 8, 9, 10, 12, 13, 14, 21, 22, 23, 24, 25, 26, 29, 30, 32, 39, 40, 41, 42, 43, 44, 45, 46, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66
5.27055 ± 0.25	$\frac{5}{2}^+$	$\tau_m = 2.9 \pm 0.5$	γ	3, 4, 8, 12, 13, 21, 22, 23, 26, 29, 30, 32, 39, 42, 52, 53, 55, 58, 59, 62
5.29921 ± 0.25	$\frac{1}{2}^+$	< 0.01	γ	3, 4, 8, 12, 13, 21, 22, 23, 26, 29, 30, 32, 39, 46, 52, 53, 55, 58, 59
6.3235 ± 0.4	$\frac{3}{2}^-$	< 0.040	γ	3, 4, 8, 10, 12, 13, 21, 22, 26, 29, 30, 32, 39, 49, 52, 53, 55, 57, 58, 59, 62
7.1550 ± 0.4	$\frac{5}{2}^+$	< 0.018	γ	3, 4, 8, 12, 21, 22, 26, 29, 32, 39, 52, 53, 62
7.3010 ± 0.5	$\frac{3}{2}^+$	< 0.025	γ	3, 4, 8, 12, 13, 21, 26, 29, 32, 39, 46, 52, 53, 55, 62
7.566 ± 3	$\frac{7}{2}^+$	0.06 ± 0.02	γ	3, 4, 8, 12, 13, 21, 22, 29, 39, 52, 53, 62
8.3126 ± 0.7	$\frac{1}{2}^+$	< 0.010	γ	3, 4, 8, 21, 26, 29, 32, 39, 46, 52, 53, 55, 62
8.576 ± 2	$\frac{3}{2}^+$		γ	3, 4, 8, 13, 21, 22, 26, 32, 39, 52, 53, 62
9.053 ± 2	$\frac{1}{2}^+$		γ	2, 3, 4, 8, 21, 26, 29, 32, 39, 46, 55
9.1518 ± 0.5	$\frac{3}{2}^-$		γ	3, 4, 8, 13, 21, 22, 29, 32, 39, 52, 53
9.1549 ± 0.5	$(\frac{5}{2})$	< 0.010	γ	3, 4, 8, 13, 21, 22, 29, 32, 39, 52, 53
9.225 ± 3.5	$\frac{3}{2}$ or $\frac{1}{2}$ [b]	< 0.1	γ	21, 29, 39, 55
9.762 ± 3.5	$\frac{5}{2}^-$		γ	21, 39, 52, 53
9.829 ± 3	$\frac{7}{2}$	< 0.19	γ	2, 3, 4, 8, 21, 22, 29, 52, 53
9.929 ± 4	$(\frac{1}{2}, \frac{3}{2})^+$		γ	21, 39

Table 15.4: Energy levels of ^{15}N [a] (continued)

E_x (MeV $\pm$ keV)	$J^\pi; T$	τ_m (psec) or Γ (keV)	Decay	Reactions
10.070 ± 3	$\frac{3}{2}^+$		γ	13, 21, 39, 52, 53
10.451 ± 1	$\frac{3}{2} \rightarrow \frac{7}{2}$		γ, p	21, 22, 26, 39
10.536 ± 1	$\frac{5}{2}^{(+)}$		γ, p	21, 26, 39
10.700 ± 1	$\frac{3}{2}^+$		γ, p	21, 22, 26, 27, 39, 52
10.800 ± 1	$\frac{3}{2}^{(-)}$		γ, p	2, 3, 4, 8, 13, 21, 26, 39
(10.94 ± 30)				21
11.236 ± 5	$\geq \frac{3}{2}$	$\Gamma = 3.3$	n	33
11.2943 ± 1	$\frac{1}{2}^-$	7.9 ± 0.3	γ, n, p	26, 27, 28, 33, 52
11.438 ± 1	$\frac{1}{2}^+$	41.4 ± 1.1	γ, n, p, α	5, 26, 27, 28, 33, 35
11.615 ± 4	$\frac{1}{2}; \frac{3}{2}$	404.9 ± 6.3	γ, n, p	26, 27, 28
11.764 ± 3	$\frac{3}{2}^+$	40 ± 3	n, p, α	5, 28, 33, 35
11.877 ± 3	$\frac{3}{2}^-$	21 ± 4	n, p, α	5, 28, 33, 35, 52
11.943 ± 6	$(\frac{9}{2}^-)$	≤ 3	n	22, 33, 52
11.965 ± 3	$\frac{1}{2}^-$	17 ± 5	n, p, α	5, 28, 33, 35
12.097 ± 4	$\frac{5}{2}^+$	14 ± 5	γ, n, p, α	5, 6, 27, 28, 33, 35, 38
12.145 ± 3	$\frac{3}{2}^-$	47 ± 7	γ, n, p, α	5, 6, 27, 28, 33, 35, 39
12.326 ± 4	$\frac{5}{2}^{(+)}$	22	n, p	22, 28, 33, 35
12.493 ± 4	$\frac{5}{2}^+; \frac{1}{2}$	42	γ, n, p, α	5, 6, 28, 33, 35, 38, 52
12.52 ± 10	$\frac{5}{2}^+; \frac{3}{2}$	80	p	27, 52
12.921 ± 4	$\frac{3}{2}^-$	67 ± 8	n, p, α	5, 6, 28, 33, 35, 38
12.93	$\frac{7}{2}^-$	30	p, α	6
13.028 ± 20	$(\frac{11}{2}^-)$			22
13.14		< 3	n, p, α	5, 6, 38
13.19		6	n, p, α	5, 6, 28, 38
13.36	$\frac{3}{2}^-$	29 ± 8	n, p, α	5, 6, 28, 38
13.40	$\frac{5}{2}^+$	≈ 60	n, p, α	6, 28, 35
(13.52)			n, p	28
13.60	$(\frac{5}{2}, \frac{7}{2})^-$	15 ± 4	n, p, α	5, 6, 28, 33, 35, 38
13.67	$\frac{1}{2}^+$	≈ 80	n, p, α	6, 28
13.71		≈ 40	n, p, α	5, 35, 38
13.75			n, α	5
13.84		≈ 40	n, p, α	28, 35, 38
13.89			n, α	5

Table 15.4: Energy levels of ^{15}N [a] (continued)

E_x (MeV $\pm$ keV)	$J^\pi; T$	τ_m (psec) or Γ (keV)	Decay	Reactions
14.03			p, α	6
14.06			n, α	5
14.11		105	n, p, α	5, 28, 35, 38, 52
14.17	$\frac{3}{2}^{(+)}$	30 ± 5	n, p, α	5, 28, 35, 38
14.18			n, α	5
14.23			n, α	5
14.4		≈ 2000	n, p, α	33, 35, 38
14.46		≈ 180	p, α	6
14.51		130	n, p	28
14.64		50 ± 3	n, p, α	5, 35, 38
14.7		≈ 280	n, p, α	35, 38
14.81		99	n, p	28
14.90		37	n, p, α	5, 28, 38
15.00			n, p, α	5, 28
15.11			n, p, α	5, 28, 38, 52
15.29			n, α	5
15.37			n, t, α	5, 11
15.52			n, α	38
15.61			n, α	5
15.74			p, t, α	11
15.83		< 3	n, p, t, α	5, 6, 11
15.89 ± 20		< 3	n, t, α	5, 11
15.96 ± 20			n, t, α	5, 11
15.99			n, α	5
16.03			n, p, t, α	5, 6, 11, 38
16.08			n, p, t, α	5, 6, 11, 38
16.17 ± 40			n, p, t, α	5, 6, 11
16.29			n, p, t, α	5, 6, 11
16.33 ± 20			n, p, t, α	5, 6, 11, 38
16.43 ± 20			n, p, t, α	5, 6, 11, 38
16.49 ± 30			n, p, d, t, α	5, 6, 11, 16
16.59 ± 25		70	n, p, t, α	5, 6, 11, 38
16.67 ± 30		100	n, p, d, t, α	5, 6, 11, 15, 16, 33, 38

Table 15.4: Energy levels of ^{15}N [a] (continued)

E_x (MeV ± keV)	$J^\pi; T$	τ_m (psec) or Γ (keV)	Decay	Reactions
16.74			n, p, α	5, 6
16.76 ± 30			n, p, d, t, α	5, 6, 11, 15, 16
16.85 ± 30			t, α	11
16.90		≈ 350	n, p, d, t, α	5, 6, 11, 15, 33, 38
16.98			n, p, α	5, 6, 33, 38
17.05			p, t	11
17.10		broad	d, t, α	11, 19
17.16 ± 50			n, p, t, α	5, 6, 11
17.19			n, p, α	5, 6, 18
17.30		190	n, p, α	5, 6, 18, 38
17.36		350	n, p, d, t, α	5, 6, 11, 16, 18, 19
17.50			n, p, α	5, 6, 38
17.56			n, p, α	5, 6
17.81 ± 40		≈ 170	n, p, d, t, α	5, 6, 18
17.70 ± 50		≈ 500	n, d, α	15, 19
17.72 ± 10		48 ± 9	(p), d, t, α	16, 18, 19
17.81		170	n, α	33, 38
17.95			n, p, α	5, 6
18.07 ± 10		19 ± 4	(n), d, α	15, 19
18.09 ± 20		≈ 45	(n), p, d, t	15, 16, 18
18.22		160	n, α	38
18.28 ± 30		230 ± 60	n, p, d, α	15, 16, 19, 38
19.16 ± 30		≈ 130	n, d	15
19.5			γ, p	48
20.4			γ, p	48
22.7			γ, p	48
24.5			γ, p	48

[a] See also Tables 15.7 and 15.10.

[b] See (1967PH03).

3. ^{10}B(^{6}Li, p)^{15}N $\qquad Q_m = 18.751$

Table 15.5: Resonances in ^{11}B $+ \alpha$

E_α (MeV)	Γ_{lab} (keV)	Particle out	E_{x} (MeV)	J^π	Refs. [a]
0.60		n	11.43		(1954BE08) [b]
1.03		n	11.75		(1954BE08)
1.18		n	11.86		(1954BE08)
1.30		n	11.95		(1954BE08)
1.51		n, p	12.10		(1955SH46)
1.58		n, p	12.15		(1955SH46)
2.06	66	n_0, p_0	12.50	$\frac{5}{2}^+$	(1955SH46, 1956BO61, 1958HA1B, 1959LE28)
2.63	80	n_0, p_0	12.92	$\frac{3}{2}^-$	(1956BO61, 1958HA1B, 1959LE28, 1963MA28, 1966MA04)
2.64	40	p_0	12.93	$\frac{7}{2}^-$	(1959LE28, 1963MA28)
2.94	< 6	n_0, p_0	13.15		(1956BO61, 1958HA1B, 1959LE28)
2.99	8	n_0, p_0	13.18		(1956BO61, 1958HA1B, 1959LE28, 1966MA04)
3.23	29	n_0, p	13.36	$\frac{3}{2}^-$	(1956BO61, 1958HA1B, 1959LE28, 1963MA28, 1966MA04)
3.31	40	p	13.42	$\frac{5}{2}^+$	(1959LE28, 1963MA28)
3.56	20	n_0, p	13.61	$(\frac{5}{2}, \frac{7}{2})^-$	(1956BO61, 1958HA1B, 1959LE28, 1963MA28, 1966MA04)
3.64	≈ 110	p_0	13.66		(1963MA28)
3.71	40	n_0	13.71		(1956BO61, 1958HA1B, 1963MA28, 1966MA04)
3.76		n_0	13.75		(1966MA04)
3.95		n_0	13.89		(1963MA28, 1966MA04)
4.15		p_0	14.03		(1963MA28)
4.19		n_1	14.06		(1963MA28, 1966MA04)
4.24		n_0	14.10		(1963MA28, 1966MA04)
4.31	35	n_1	14.15		(1956BO61, 1958HA1B, 1963MA28, 1966MA04)
4.35		n_0	14.18		(1963MA28, 1966MA04)
4.41		n_0	14.23		(1963MA28, 1966MA04)
4.56		p_0	(14.33)		(1963MA28)

Table 15.5: Energy levels of ^{15}N [a] (continued)

E_α (MeV)	Γ_{lab} (keV)	Particle out	E_x (MeV)	J^π	Refs. [a]
4.73	≈ 250	p_0	14.46		(1963MA28)
4.96	72	n_0	14.63		(1956BO61, 1958HA1B)
5.34		n_0	14.90		(1958HA1B)
5.49		n_0	15.01		(1958HA1B)
5.58		n_0	15.08		(1958HA1B)
5.86		n_0	15.29		(1958HA1B)
5.98		n_0, n_2	15.37		(1958HA1B)
6.30		n_0, (n_2)	15.61		(1958HA1B)
6.60		n, p	15.83		(1963ED01) [c]
6.72		n_0, (n_2)	15.92		(1958HA1B)
6.74		n_0, n_2	15.93		(1958HA1B)
6.82		n_0, n_2	15.99		(1958HA1B)
6.89		n, p	16.04		(1958HA1B, 1963ED01)
6.94		n, p	16.08		(1963ED01)
7.08		n, p	16.18		(1963ED01)
7.26		n, p	16.31		(1963ED01)
7.31		n, p	16.35		(1963ED01)
7.41		n, p	16.42		(1963ED01)
7.56		n, p	16.53		(1963ED01)
7.65		n, p	16.60		(1963ED01)
7.77		n, p	16.69		(1963ED01)
7.84		n, p	16.74		(1963ED01)
7.86		n, p	16.75		(1963ED01)
8.07		n, p	16.91		(1963ED01)
8.17		n, p	16.98		(1963ED01)

Table 15.5: Energy levels of ^{15}N [a] (continued)

E_α (MeV)	Γ_{lab} (keV)	Particle out	E_x (MeV)	J^π	Refs. [a]
8.44		n, p	17.18		(1963ED01)
8.46		n, p	17.19		(1963ED01)
8.59		n, p	17.29		(1963ED01)
8.68		n, p	17.35		(1963ED01)
8.88		n, p	17.50		(1963ED01)
8.96		n, p	17.56		(1963ED01)
8.99		n, p	17.58		(1963ED01)
9.49		n, p	17.95		(1963ED01)

[a] It should be noted that (1954BE08), (1958HA1B) and (1963ED01) are unpublished. They are quoted here only because of the dearth of published information on these resonances.

[b] And private communication.

[c] Resonant energies listed by (1963ED01) are ± 40 keV.

At $E(^6\text{Li}) = 4.9$ MeV, thirty proton groups are observed corresponding to ^{15}N states with $E_x < 16.8$ MeV. Angular distributions have been measured for the proton groups corresponding to ^{15}N*($5.27 + 5.30$, 6.32, $7.16 + 7.30$, 7.57, 8.31, 8.58, $9.05 + 9.15$) (1966MC05). The ground-state γ-decay of ^{15}N*(9.83, 10.80) is reported by (1964CA18). See also (1963MO1B).

4. ^{10}B(^{7}Li, d)^{15}N $\quad Q_m = 13.723$

At $E(^7\text{Li}) = 5.2$ MeV, thirty deuteron groups are observed corresponding to ^{15}N states with $E_x < 15.1$ MeV. Angular distributions have been measured for the deuteron groups corresponding to ^{15}N*(0, $5.27 + 5.30$, 6.32, $7.16 + 7.30$, 7.57, 8.31, 8.58, $9.05 + 9.15$, 9.83) (1966MC05). See also (1963MO1B). The ground state γ-decay of ^{15}N*(8.31, 9.05, 9.83, 10.80) is reported by (1964CA18).

5. ^{11}B(α, n)^{14}N $\quad Q_m = 0.157 \quad E_b = 10.992$

Reported resonances are displayed in Table 15.5 (1954BE08, 1955SH46, 1956BO61, 1958HA1B, 1963ED01, 1963MA28, 1966MA04). See also (1962GO1J, 1963GO1J, 1965TS1A) and (1966WE1B). See also ^{14}N.

6. ^{11}B(α, p)^{14}C $\quad Q_m = 0.784 \quad E_b = 10.992$

Reported resonances are listed in Table 15.5 (1955SH46, 1959LE28, 1963ED01, 1963MA28). Partial widths for several resonances are listed by (1959LE28, 1963MA28). See also ^{14}C.

7. ^{11}B(α, d)^{13}C $\quad Q_m = -5.168 \quad E_b = 10.992$

The yield of ground state deuterons has been measured for $E_\alpha = 17$ to 22 MeV by (1967AL16). See also ^{13}C.

8. (a) ^{11}B(^{6}Li, d)^{15}N $\quad Q_m = 9.520$
(b) ^{11}B(^{7}Li, t)^{15}N $\quad Q_m = 8.525$

At $E(^6\text{Li}) = 4.72$ MeV and at $E(^7\text{Li}) = 5.00$ MeV, angular distributions are reported for the deuterons and the tritons corresponding to ^{15}N*(0, $5.27 + 5.30$, 6.32, $7.16 + 7.30$, 7.57, 8.31, 8.58, $9.05 + 9.15$) (1966MC05). See also (1963MO1B). Gamma rays are observed in reaction (a) which are assigned to the ground state transitions of ^{15}N*(9.15, 9.83, 10.80) (1964CA18). See also (1963HO1E) and (1964HA09).

9. ^{11}B(^{9}Be, ^{5}He)^{15}N $Q_{\rm m} = 8.464$

See (1963HO1E).

10. ^{11}B(^{16}O, ^{12}C)^{15}N $Q_{\rm m} = 3.831$

At $E(^{16}\rm O) = 27$, 30, 32.5 and 35 MeV, angular distributions corresponding to transitions to ^{15}N*(0, 6.32) have been measured by (1965BO14, 1966BO22): the ground state angular distributions show strong diffraction structure. See also (1969GO1R, 1969BR1D, 1969KA1G).

11. (a) ^{12}C(t, n)^{14}N $Q_{\rm m} = 4.015$ $E_{\rm b} = 14.850$
(b) ^{12}C(t, p)^{14}C $Q_{\rm m} = 4.641$
(c) ^{12}C(t, t)^{12}C
(d) ^{12}C(t, α)^{11}B $Q_{\rm m} = 3.858$

Reported resonances are listed in Table 15.6 (1961VA13, 1962GU01, 1962KU09, 1963NI04, 1965SE05, 1969ET01). The triton yield has been measured for $E_{\rm t} = 9$ to 13 MeV by (1965GL04). See also (1962NE1D, 1964GR1H, 1967CH35), ^{11}B and ^{12}C in (1968AJ02), and ^{14}C and ^{14}N.

12. ^{12}C(α, p)^{15}N $Q_{\rm m} = -4.965$

Angular distributions of the protons corresponding to the ground state transition have been measured at $E_{\alpha} = 13.4$ to 16.0 MeV (1967IV1B), 16.1 to 19.0 MeV (1960PR13), 19.7 to 22.1 MeV (1963YA1C), 20.6 to 22.2 MeV (1961KO04), 25 to 39 MeV (1959NO38) and at 42 MeV (1962LI07). Angular distributions are also reported for the groups to ^{15}N*($5.27+5.30$, 6.32, $7.16+7.30+7.57$) (1959NO38: 34.6 MeV) and ^{15}N*(6.32) (1962LI07: 42 MeV). See also (1962EI03, 1969GL1D), (1961KR1A, 1962HO1D, 1962TE1B, 1963DA1B, 1964DA1D, 1964KE1C, 1965NE1D, 1966HI1C, 1967RO1K; theor.) and (1959AJ76).

13. ^{12}C(^{7}Li, α)^{15}N $Q_{\rm m} = 12.382$

Angular distributions have been measured at $E(^{7}\rm Li) = 3.2$ to 4.0 MeV (1962HO06; α_0, α_{1+2}, α_3) and 30.3 MeV (1969GL07; α_0, α_{1+2}, α_3 and the α's corresponding to ^{15}N*(7.35, 7.6, 8.6, 9.2, 10.1, 10.9, 12.8, 13.5, 15.2). (1969BA2U) report the excitation of ^{15}N*(12.5, 13.3, 14.9, 15.6, 16.2, 16.8, 18.9, 19.8) and (1969GL07) also report α groups corresponding to ^{15}N*(11.8, 16.5)

Table 15.6: Resonances in ^{12}C + t

E_t (MeV ± keV)	E_x (MeV)	Particles out	Refs.
0.66	15.38	α_0	(1963NI04, 1969ET01)
1.11	15.74	p_0, t_0, α_1	(1962GU01, 1962KU09, 1963NI04, 1969ET01)
1.21	15.82	t_0	(1969ET01)
1.30 ± 20	15.89	n, α_0	(1961VA13, 1969ET01)
1.39 ± 20	15.96	n, t_0, α_0	(1961VA13, 1969ET01)
1.46	16.02	p_0	(1969ET01)
1.54	16.08	n, α_0, α_1	(1961VA13, 1969ET01)
1.65 ± 40	16.17	n, α_0	(1961VA13, 1965SE05, 1969ET01)
1.78	16.27	α_0	(1969ET01)
1.85 ± 20	16.33	n, p_0, α_0, α_1	(1961VA13, 1965SE05, 1969ET01)
1.98 ± 20	16.43	n, p_0	(1961VA13, 1969ET01)
2.05 ± 30	16.49	p_0, t_0, α_0	(1965SE05, 1969ET01)
2.18 ± 25	16.59	n, p_0, t_0, α_0, α_1	(1961VA13, 1969ET01)
2.28 ± 30	16.67	n, p_0, α_0, α_1	(1961VA13, 1965SE05, 1969ET01)
2.39 ± 30	16.76	n, t_0, α_0, α_1	(1961VA13, 1965SE05, 1969ET01)
2.50 ± 30	16.85	α_0, α_1	(1965SE05, 1969ET01)
2.60	16.93	α_0	(1969ET01)
2.75	17.05	p_0	(1969ET01)
2.82	17.10	t_0, α_0, α_1	(1969ET01)
2.89 ± 50	17.16	α_0	(1965SE05, 1969ET01)
3.14	17.36	α_1	(1969ET01)

and, possibly ^{15}N*(17.1, 18.3). The mean lifetime of ^{15}N*(9.83) $< 1.9 \times 10^{-13}$ sec (see Table 15.7): $E_\gamma = 4562.6 \pm 4.0$ keV (^{15}N*(9.83 $\rightarrow$ 5.27)) (1969TH01). See also (1960SH05) and (1969GI1B, 1969RO1G).

14. (a) ^{12}C(^{14}N, ^{11}C)^{15}N $\quad Q_m = -7.885$
    (b) ^{12}C(^{19}F, ^{16}O)^{15}N $\quad Q_m = 3.150$

For reaction (a) see (1969BR1D); for reaction (b) see (1969RO1G).

15. ^{13}C(d, n)^{14}N $\quad Q_m = 5.325 \quad E_b = 16.160$

Table 15.7: Lifetimes of some ^{15}N states

E_x (MeV)	τ_m (psec)	Reaction	Refs.
5.27	> 1	^{16}O(t, α)	(1965AL19)
	≈ 1	^{9}Be(^{14}N, ^{8}Be)	(1969NI09)
	2.9 ± 0.5	^{14}N(d, p)	(1967BI11)
5.30	< 0.01	^{14}C(p, γ)	(1968COZV)
	$(4.3 \pm 1.8) \times 10^{-2}$	^{14}N(d, p)	(1965AL19)
	$(2.2 \pm 0.7) \times 10^{-2}$	^{14}N(n, γ)	(1969WE07)
6.32	< 0.045	^{14}N(d, p)	(1968GI11)
	< 0.040	^{14}N(n, γ)	(1969WE07)
	< 0.010	^{14}C(p, γ)	(1968COZV)
7.16	< 0.018	^{14}N(d, p)	(1968GI11)
	0.115 ± 0.025	^{13}C(^{3}He, p)	(1966LI07)
	0.010 ± 0.002	^{14}C(p, γ)	(1968COZV)
7.30	< 0.025	^{14}N(d, p)	(1968GI11)
	< 0.030	^{14}N(n, γ)	(1969WE07)
	< 0.010	^{14}C(p, γ)	(1968COZV)
7.57	0.15 ± 0.05	^{13}C(^{3}He, p)	(1966LI07)
	0.06 ± 0.02	^{14}N(d, p)	(1968GI11)
8.31	< 0.021	^{14}N(d, p)	(1968GI11)
	< 0.020	^{14}N(n, γ)	(1969WE07)
	< 0.010	^{14}C(p, γ)	(1968COZV)
9.155	< 0.010	^{14}C(p, γ)	(1968COZV)
	< 0.010	^{14}N(n, γ)	(1969WE07)
9.23	< 0.1	^{16}O(γ, p)	(1969MU07)
9.83	< 0.19	^{12}C(^{7}Li, α)	(1969TH01)

Table 15.8: Resonances in ^{13}C + d

E_d (MeV)	Emitted particles	Γ_{lab} (keV)	^{15}N* (MeV)	Refs.
0.37	p		16.47	(1956VA17)
0.64	n, p_0	≈ 100	16.72	(1950CU13, 1950RI57, 1953KO42, 1956MA46, 1956VA17)
0.85	n	≈ 400	16.90	(1950RI57)
1.10	α_0	broad	17.11	(1956MA35, 1966KL06)
1.24 ± 0.04	t_0	≈ 200	17.24	(1956MA35)
1.40 ± 0.04	p_0, t_0, α_0	≈ 400	17.37	(1956MA35, 1956MA46)
1.55 [a]	n	≈ 100		(1941BE1A, 1950RI57, 1966KL06)
1.64 ± 0.04	t_0	≈ 200	17.58	(1956MA35)
1.78 ± 0.05	n, α_0	≈ 600	17.70	(1950RI57, 1955MA76, 1956MA35)
1.80 ± 0.01	(p_0), t_0, α_1	55 ± 10	17.72	(1956MA35, 1956MA46)
2.20 ± 0.01	(n), α_0, α_1	22 ± 4	18.07	(1956MA35, 1963AL21)
2.23 ± 0.02	(n), p_0, t	≈ 50	18.09	(1956MA35, 1956MA46, 1963AL21)
2.45 ± 0.03	n, p_0, α_0	270 ± 70	18.28	(1955MA76, 1956MA35, 1956MA46)
3.46 ± 0.03	n	≈ 150	19.16	(1955MA76, 1963DE19)

[a] Possibly to be identified with 1.40 MeV resonance (1956MA35).

Observed resonances are displayed in Table 15.8 (1950RI57, 1955MA76, 1963AL21, 1963DE19). Excitation functions have recently been measured for $E_d = 0.8$ to 1.3 MeV (1961JA09; n_0, n_1, n_2, n_3, n_5), 2.0 to 3.2 MeV (1963AL21: 7.03 MeV γ-ray) and 3.2 to 4.0 MeV (1963DE19; n_0). See also (1960VA11). Polarization measurements are reported for $E_d = 2.5$ to 4.0 MeV (1967ME1N; n_0, n_1, n_2) and 2.8 MeV (1965GA1G; n_3, n_4, n_5). See also ^{14}N.

16. ^{13}C(d, p)^{14}C $\quad Q_m = 5.952 \quad E_b = 16.160$

Observed resonances are displayed in Table 15.8 (1941BE1A, 1950CU13, 1953KO42, 1956MA46). Excitation functions have recently been measured for $E_d = 1$ to 3.4 MeV (1968LI1L; p_0, p_1), 3.0 to 4.0 MeV (1965LA09: ^{14}C*(6.09, 6.73, 7.34)), 3.1 to 4.1 MeV (1963DE19; p_0), and 4.1 to 6.2 MeV (1968CO04; p_1). See also (1963AL21). See also ^{14}C.

17. ^{13}C(d, d)^{13}C $\quad E_b = 16.160$

Excitation functions for elastically scattered deuterons have been measured for $E_d = 1$ to 3.4 MeV (1968LI1L) and 4.5 to 5.7 MeV (1968CO04).

18. ^{13}C(d, t)^{12}C $\quad Q_m = 1.311 \quad E_b = 16.160$

Observed resonances are listed in Table 15.8 (1956MA35). (1968LI1L) report measurement of the t_0 excitation function for $E_d = 1$ to 3.4 MeV. A polarization study has been made at $E_d = 12.3$ MeV (1969DE1H; t_0, t_1). See also ^{12}C.

19. ^{13}C(d, α)^{11}B $\quad Q_m = 5.168 \quad E_b = 16.160$

Observed resonances are listed in Table 15.8 (1956MA35). See also (1966KL06, 1966KL1F, 1968CO04, 1968LI1L).

20. ^{13}C(t, n)^{15}N $\quad Q_m = 9.903$

Not reported.

21. ^{13}C(^{3}He, p)^{15}N $\quad Q_m = 10.667$

Observed proton groups and γ-rays corresponding to ^{15}N states are listed in Table 15.9 (1959YO25, 1966GA08, 1966WA08, 1967PH03). Gamma-ray branching ratios obtained by (1965WA16, 1966PE04, 1966WA08) are displayed in Table 15.10 which also shows J^π values obtained from angular correlation measurements. The two states at $E_x = 9.16$ MeV [see reactions 32 and 39] are separated by 2.5 ± 0.5 keV (1968ST10). See also (1959BR79). The τ_m for ^{15}N*(7.16, 7.57) are 0.115 ± 0.025 psec and 0.15 ± 0.05 psec, respectively: see Table 15.7 (1966LI07). Angular distributions of the ground state protons have been measured for $E(^3\text{He}) = 8.7$ to 10.93 MeV (1962AL01). See also (1959AJ76).

See also (1967YO1C, 1968WE15), (1963CL1A, 1966PR1B) and ^{16}O in (1971AJ02).

22. ^{13}C(α, d)^{15}N $\quad Q_m = -7.687$

This reaction has been studied at $E_\alpha = 40.1$ MeV: see Table 15.9 (1969LU07).

Table 15.9: Energy levels in ^{15}N from ^{13}C(^{3}He, p)^{15}N and ^{13}C(α, d)^{15}N

E_x (MeV ± keV) [a]				
(1959YO25)	(1966GA08)	(1966WA08) [b]	(1967PH03)	(1969LU07) [c]
5.283 ± 12				5.266 ± 20
6.333 ± 12				6.336 ± 30
7.169 ± 12				7.170 ± 20
7.310 ± 12				
7.577 ± 13				7.581 ± 20
8.318 ± 12	8.323 ± 6	8.312		
8.581 ± 14	8.581 ± 5	8.570		8.587 ± 20
9.061 ± 14	9.056 ± 5	9.052	9.054 ± 4	
9.164 ± 14	9.159 ± 5			9.169 ± 30
	9.225 ± 6		9.225 ± 3	
	9.760 ± 5			
	9.827 ± 6		9.829 ± 4	9.808 ± 20
	9.929 ± 8			
	10.064 ± 7	10.074	10.072 ± 4	
	10.454 ± 6	10.452		10.451 ± 20
	10.536 ± 7			
	10.704 ± 6			10.698 ± 20
	10.805 ± 7	10.800		
		(10.94 ± 30)		[d]

[a] See also (1962SH21, 1966GO1J, 1966PH1B).

[b] E_γ, except for $E_x = 10.94$ MeV; errors for E_γ are nominal.

[c] ^{13}C(α, d)^{15}N: $E_\alpha = 40.1$ MeV.

[d] (1969LU07) also reports levels at $E_x = 11.950 \pm 0.020$ ($J^\pi = (\frac{9}{2}^-)$), 12.318 ± 0.030 and 13.028 ± 0.020 MeV ($J^\pi = (\frac{11}{2}^-)$).

Table 15.10: Radiative decays in ^{15}N

E_i (MeV)	J_i^π	E_f (MeV)	J_f^π	Branch (%)	Refs.
5.27	$\frac{5}{2}^+$	0	$\frac{1}{2}^-$	100	
5.30	$\frac{1}{2}^+$	0	$\frac{1}{2}^-$	100	
6.32	$\frac{3}{2}^-$	0	$\frac{1}{2}^-$	100	(1965WA16, 1966PE04, 1969SI04)
		5.27	$\frac{5}{2}^+$	< 1	(1965WA16)
				< 3	(1966PE04)
		5.30	$\frac{1}{2}^+$	< 3	(1966PE04)
				< 1	(1965WA16)
7.16	$\frac{5}{2}^+$	0	$\frac{1}{2}^-$	< 5	(1965WA16)
				< 3	(1969SI04)
				< 12	(1968GI11)
				< 4	(1966HA30)
		5.27	$\frac{5}{2}^+$	100	(1965WA16, 1966PE04, 1968GI11)
				> 97	(1969SI04)
				< 95	(1967TH05)
		5.30	$\frac{1}{2}^+$	< 4	(1966AL18)
				< 4	(1968GI11)
				< 5	(1966PE04)
				5	(1967TH05)
		6.32	$\frac{3}{2}^-$	< 0.5	(1965WA16)
7.30	$\frac{3}{2}^+$	0	$\frac{1}{2}^-$	100	(1966PE04, 1969SI04)
				98 ± 1	(1965WA16, 1968GI11)
		5.27	$\frac{5}{2}^+$	2 ± 1	(1965WA16)
				< 1.5	(1968GI11)
		5.30	$\frac{1}{2}^+$	2 ± 1	(1968GI11)
		6.32	$\frac{3}{2}^-$	< 3	(1966PE04)
				< 0.25	(1965WA16)
7.57	$\frac{7}{2}^+$	0	$\frac{1}{2}^-$	< 2	(1965WA16)
				< 4	(1966HA30)
				< 3	(1966PE04)
		5.27	$\frac{5}{2}^+$	100	(1965WA16, 1966PE04, 1968GI11)
		5.30	$\frac{1}{2}^+$	< 5	(1965WA16)
				< 4	(1966AL18)
				< 6	(1968GI11)

Table 15.10: Radiative decays in ^{15}N (continued)

E_i (MeV)	J_i^π	E_f (MeV)	J_f^π	Branch (%)	Refs.
		6.32	$\frac{3}{2}^-$	< 0.6	(1965WA16)
8.31	$\frac{1}{2}^+$	0	$\frac{1}{2}^-$	80 ± 3	(1965WA16)
				77 ± 3	(1966WA08)
				70 ± 4	(1966PE04)
				79.1 ± 1.9	(1967PH03)
		5.27	$\frac{5}{2}^+$	< 3	(1965WA16)
		5.30	$\frac{1}{2}^+$	10 ± 2	(1965WA16)
		$5.27 + 5.30$		12 ± 2	(1966WA08)
				12 ± 3	(1966PE04)
				10.9 ± 1.3	(1967PH03)
		6.32	$\frac{3}{2}^-$	7.8 ± 2	(1965WA16)
				12 ± 3	(1966PE04)
				4.4 ± 1.0	(1967PH03)
		7.16	$\frac{5}{2}^+$	< 1	(1965WA16)
				≤ 6	(1966PE04)
				1.2 ± 0.6	(1967PH03)
		7.30	$\frac{3}{2}^+$	2.2 ± 0.4	(1965WA16)
				4.4 ± 0.7	(1967PH03)
8.58	$\frac{3}{2}^+$	0 [c]	$\frac{1}{2}^-$	34 ± 4	(1965WA16)
				32 ± 3	(1966WA08)
				27 ± 4	(1966PE04)
				33.4 ± 2.0	(1967PH03)
		5.27	$\frac{5}{2}^+$	63 ± 4	(1965WA16)
				65 ± 3	(1966WA08)
		5.30	$\frac{1}{2}^+$	< 12	(1965WA16)
		$5.27 + 5.30$		66 ± 4	(1966PE04)
				61.6 ± 2.0	(1967PH03)
		6.32	$\frac{3}{2}^-$	3 ± 1	(1965WA16)
				≤ 7	(1966PE04)
				1.4 ± 0.6	(1967PH03)
		7.16	$\frac{5}{2}^+$	< 5	(1965WA16)
				< 4	(1966WA08)
				3.6 ± 0.5	(1967PH03)

Table 15.10: Radiative decays in ^{15}N (continued)

E_i (MeV)	J^π_i	E_f (MeV)	J^π_f	Branch (%)	Refs.
		7.30	$\frac{3}{2}^+$	< 0.7	(1965WA16)
				< 3	(1966WA08)
		7.57	$\frac{7}{2}^+$	< 3	(1965WA16, 1966WA08)
9.05	$\frac{1}{2}^+$	0	$\frac{1}{2}^-$	92 ± 3	(1965WA16)
				92 ± 4	(1966WA08)
				91.6 ± 0.9	(1967PH03)
		5.27	$\frac{5}{2}^+$	3.8 ± 1	(1965WA16)
				3.5 ± 1	(1966WA08)
				4.7 ± 0.7	(1967PH03)
		6.32	$\frac{3}{2}^-$	3 ± 2	(1965WA16)
				4.5 ± 1	(1966WA08)
				3.7 ± 0.5	(1967PH03)
		7.16	$\frac{5}{2}^+$	< 10	(1965WA16)
		7.30	$\frac{3}{2}^+$	1.2 ± 0.4	(1965WA16)
		7.57	$\frac{7}{2}^+$	< 2	(1965WA16)
		8.31	$\frac{1}{2}^+$	< 0.5	(1965WA16)
		$7.16 + 7.30 + 7.57$		< 1	(1967PH03)
9.152 [a]	$\frac{3}{2}^-$	0	$\frac{1}{2}^-$	97	(1968ST10)
				100	(1969SI04)
		$5.27 + 5.30$		3	(1968ST06)
9.155 [a]	$(\frac{5}{2})$	0	$\frac{1}{2}^-$	$0 \to 17$	(1968ST10)
				17	(1967TH05)
		5.27	$\frac{5}{2}^+$	8	(1967TH05)
		5.30	$\frac{1}{2}^+$	10	(1967TH05)
		$5.27 + 5.30$		$14 \to 17$	(1968ST10)
				23	(1969SI04)
		6.32	$\frac{3}{2}^-$	$18 \to 22$	(1968ST10)
				19	(1969SI04)
				20	(1967TH05)
		7.16	$\frac{5}{2}^+$	$44 \to 52$	(1968ST10)
				58	(1969SI04)
				45	(1967TH05)
		7.30	$\frac{3}{2}^+$	$7 \to 9$	(1968ST10)

Table 15.10: Radiative decays in ^{15}N (continued)

$E_{\rm i}$ (MeV)	$J^{\pi}_{\rm i}$	$E_{\rm f}$ (MeV)	$J^{\pi}_{\rm f}$	Branch (%)	Refs.
9.23	$\leq \frac{5}{2}$	0	$\frac{1}{2}^{-}$	< 30	(1965WA16)
				41.5 ± 2.2	(1967PH03)
		5.27	$\frac{5}{2}^{+}$	< 25	(1965WA16)
		5.30	$\frac{1}{2}^{+}$	100	(1965WA16)
		$5.27 + 5.30$		31.2 ± 1.7	(1967PH03)
		6.32	$\frac{3}{2}^{-}$	≤ 25	(1965WA16)
				24.7 ± 1.5	(1967PH03)
		7.16	$\frac{5}{2}^{+}$	< 30	(1965WA16)
				< 1	(1967PH03)
		7.30	$\frac{3}{2}^{+}$	< 30	(1965WA16)
				2.6 ± 0.7	(1967PH03)
		7.57	$\frac{7}{2}^{+}$	< 20	(1965WA16)
		8.31	$\frac{1}{2}^{+}$	< 5	(1965WA16)
		$7.57 + 8.31$		< 1	(1967PH03)
9.76	$\frac{5}{2}^{-}$	0	$\frac{1}{2}^{-}$	100	(1965WA16)
				81.5 ± 2.8	(1967PH03)
		$5.27 + 5.30$		< 10	(1965WA16)
				7.5 ± 1.5	(1967PH03)
		6.32	$\frac{3}{2}^{-}$	< 5	(1965WA16)
				3.7 ± 0.8	(1967PH03)
		7.16	$\frac{5}{2}^{+}$	< 10	(1965WA16)
				2.3 ± 0.5	(1967PH03)
		7.30	$\frac{3}{2}^{+}$	< 3	(1965WA16)
				< 2	(1967PH03)
		7.57	$\frac{7}{2}^{+}$	< 10	(1965WA16)
				5.0 ± 0.6	(1967PH03)
		8.31	$\frac{1}{2}^{+}$	< 2	(1965WA16)
				< 1	(1967PH03)
		8.58	$\frac{3}{2}^{+}$	< 2	(1965WA16)
				< 2	(1967PH03)
9.83	$\frac{7}{2}$	0	$\frac{1}{2}^{-}$	< 30	(1965WA16)
				< 4	(1967PH03)
		5.27	$\frac{5}{2}^{+}$	100	(1965WA16)

Table 15.10: Radiative decays in ^{15}N (continued)

$E_{\rm i}$ (MeV)	$J^{\pi}_{\rm i}$	$E_{\rm f}$ (MeV)	$J^{\pi}_{\rm f}$	Branch (%)	Refs.
		5.30	$\frac{1}{2}^+$	< 15	(1965WA16)
		$5.27 + 5.30$		84.4 ± 1.8	(1967PH03)
		6.32	$\frac{3}{2}^-$	< 15	(1965WA16)
				2.2 ± 0.9	(1967PH03)
		7.16	$\frac{5}{2}^+$	< 10	(1965WA16)
				2.4 ± 1.1	(1967PH03)
		7.30	$\frac{3}{2}^+$	< 10	(1965WA16)
				3.7 ± 0.9	(1967PH03)
		7.57	$\frac{7}{2}^+$	< 10	(1965WA16)
				7.3 ± 1.0	(1967PH03)
		$8.31 + 8.58$		< 1	(1967PH03)
9.93	$(\frac{1}{2}, \frac{3}{2})^+$	0	$\frac{1}{2}^-$	80 ± 10	(1965WA16)
				77.6 ± 1.9	(1967PH03)
		$5.27 + 5.30$		10 ± 10	(1965WA16)
				15.4 ± 1.5	(1967PH03)
		6.32	$\frac{3}{2}^-$	10 ± 10	(1965WA16)
				4.9 ± 1.2	(1967PH03)
		7.16	$\frac{5}{2}^+$	< 10	(1965WA16)
				< 1	(1967PH03)
		7.30	$\frac{3}{2}^+$	< 3	(1965WA16)
				2.1 ± 0.8	(1967PH03)
		7.57	$\frac{7}{2}^+$	< 10	(1965WA16)
		8.31	$\frac{1}{2}^+$	< 2	(1965WA16)
		8.58	$\frac{3}{2}^+$	< 2	(1965WA16)
		7.57, 8.31, 8.58		< 1	(1967PH03)
10.07	$\frac{3}{2}^+$	0	$\frac{1}{2}^-$	100	(1965WA16)
				96.0 ± 0.7	(1967PH03)
				94 ± 4	(1966WA08)
		$5.27 + 5.30$		< 10	(1965WA16)
				4.0 ± 0.7	(1967PH03)
				6 ± 2	(1966WA08)
		6.32	$\frac{3}{2}^-$	< 5	(1965WA16)
				< 2	(1966WA08)

Table 15.10: Radiative decays in ^{15}N (continued)

E_i (MeV)	J^π_i	E_f (MeV)	J^π_f	Branch (%)	Refs.
		7.16	$\frac{5}{2}^+$	< 7	(1965WA16)
				< 2	(1966WA08)
		7.30	$\frac{3}{2}^+$	< 3	(1965WA16)
				< 2	(1966WA08)
		7.57	$\frac{7}{2}^+$	< 7	(1965WA16)
				< 2	(1966WA08)
		8.31	$\frac{1}{2}^+$	< 2	(1965WA16)
		8.58	$\frac{3}{2}^+$	< 3	(1965WA16)
10.45	$\frac{3}{2} \to \frac{7}{2}$	0	$\frac{1}{2}^-$	12 ± 12	(1965WA16)
				< 4	(1966WA08, 1967PH03)
		$5.27 + 5.30$		72 ± 8	(1965WA16)
				66 ± 5	(1966WA08)
				62.4 ± 2.4	(1967PH03)
		6.32	$\frac{3}{2}^-$	12 ± 8	(1965WA16)
				28 ± 5	(1966WA08)
				14.7 ± 1.6	(1967PH03)
		7.16	$\frac{5}{2}^+$	< 10	(1965WA16)
				< 6	(1966WA08)
		7.30	$\frac{3}{2}^+$	4 ± 4	(1965WA16)
				< 6	(1966WA08)
		7.57	$\frac{7}{2}^+$	< 10	(1965WA16)
				< 6	(1966WA08)
		8.31	$\frac{1}{2}^+$	1.5 ± 0.5	(1967PH03)
		9.05	$\frac{1}{2}^+$	< 1	(1967PH03)
		$9.15 + 9.23$		5.0 ± 0.5	(1967PH03)
		9.76	$\frac{5}{2}^-$	1.6 ± 0.7	(1967PH03)
		9.83	$\frac{7}{2}$	2.2 ± 1.5	(1967PH03)
		9.93	$(\frac{1}{2}, \frac{3}{2})^+$	3.7 ± 1.1	(1967PH03)
		10.07	$\frac{3}{2}^+$	< 4	(1967PH03)
10.54 [b]	$\frac{5}{2}^+$	0	$\frac{1}{2}^-$	1 ± 0.3	(1969SI04)
		5.27	$\frac{5}{2}^+$	30 ± 2	(1969SI04)
		6.32	$\frac{3}{2}^-$	7 ± 0.5	(1969SI04)
		7.16	$\frac{5}{2}^+$	23 ± 1.5	(1969SI04)

Table 15.10: Radiative decays in ^{15}N (continued)

E_i (MeV)	J^π_i	E_f (MeV)	J^π_f	Branch (%)	Refs.
		7.30	$\frac{3}{2}^+$	37 ± 2.5	(1969SI04)
		8.58	$\frac{3}{2}^+$	1.8 ± 0.4	(1969SI04)
		(9.22)	$\leq \frac{5}{2}^-$	< 1	(1969SI04)
10.70	$\frac{3}{2}^+$	0	$\frac{1}{2}^-$	52 ± 1	(1969SI04)
		5.27	$\frac{5}{2}^+$	38 ± 1	(1969SI04)
		6.32	$\frac{3}{2}^-$	6 ± 0.4	(1969SI04)
		7.16	$\frac{5}{2}^+$	< 1	(1969SI04)
		7.30	$\frac{3}{2}^+$	3 ± 0.3	(1969SI04)
		8.31	$\frac{1}{2}^+$	< 1	(1969SI04)
		9.05	$\frac{1}{2}^+$	< 1	(1969SI04)
		(9.22)	$\leq \frac{5}{2}^-$	< 1	(1969SI04)
10.80	$\frac{3}{2}$	0	$\frac{1}{2}^-$	55 ± 5	(1965WA16)
				53 ± 15	(1966WA08)
				47 ± 1	(1969SI04)
		5.27	$\frac{5}{2}^+$	5 ± 0.5	(1969SI04)
		5.30	$\frac{1}{2}^+$	13 ± 0.6	(1969SI04)
		$5.27 + 5.30$		45 ± 5	(1965WA16)
				47 ± 5	(1966WA08)
		6.32	$\frac{3}{2}^-$	< 5	(1965WA16)
				< 10	(1966WA08)
				7 ± 0.5	(1969SI04)
		7.16	$\frac{5}{2}^+$	< 5	(1965WA16)
				9 ± 0.5	(1969SI04)
		7.30	$\frac{3}{2}^+$	< 5	(1965WA16)
				< 4	(1966WA08)
				8 ± 0.5	(1969SI04)
		7.57	$\frac{7}{2}^+$	< 7	(1965WA16)
		8.31	$\frac{1}{2}^+$	5 ± 0.5	(1969SI04)
		9.05	$\frac{1}{2}^+$	1 ± 0.3	(1969SI04)
		9.152	$\frac{3}{2}^-$	2 ± 0.3	(1969SI04)
		9.155	$(\frac{5}{2})$	4 ± 0.3	(1969SI04)

[a] See also (1965WA16, 1967PH03). [b] See also (1960HE13). [c] See also (1969SI04).

23. ^{13}C(^{6}Li, α)^{15}N $Q_m = 14.688$

Angular distributions have been measured for $E(^6\text{Li}) = 3.2$ to 3.8 MeV for the α_0 and α_{1+2} groups (1964BL1B).

24. ^{13}C(^{7}Li, ^{5}He)^{15}N $Q_m = 6.478$

See (1969TH01).

25. ^{13}C(^{11}B, ^{9}Be)^{15}N $Q_m = 0.341$

See (1966PO1E, 1967PO1E, 1967VO1A).

26. ^{14}C(p, γ)^{15}N $Q_m = 10.208$

Resonances for capture γ-radiation are listed in Table 15.11 (1959FE1C, 1959HE1D, 1968HE12, 1968SI1F, 1969SI04). A combination of ^{15}N*(10.80) and (9.83) permits a good account of the low energy (n, n) and (n, γ) cross sections (1959HE1D). The thermal (n, p) cross section can be ascribed to the $E_p = 1.5$ MeV resonance (^{15}N*(11.62)) (1955BA44: see also ^{14}N(n, γ)^{15}N). See also (1959AJ76) and (1969TI05).

Table 15.10 displays branching ratios obtained in this and in other reactions. The angular distributions of γ-rays at the $E_p = 0.35$ MeV resonance (^{15}N*(10.54)) leads to assignments of $J = \frac{5}{2}$, $(\frac{5}{2})$, $\frac{3}{2}$ and $\frac{5}{2}$, respectively, for ^{15}N*(5.27, 7.16, 7.30, 10.54) (1960HE13). The angular distribution of the $(10.81 \rightarrow 8.31)$ γ-ray fixes $J = \frac{1}{2}$ for ^{15}N*(8.31) (1968SI1E). A triple correlation study by (1968SI1E) of the decay of ^{15}N*(10.80) to the $E_x = 9.15$ MeV states suggests $J = \frac{3}{2}$ for the upper and $J = \frac{5}{2}$ for the lower of these two states. Lifetimes for various ^{15}N states have been measured by (1968COZV): see Table 15.7.

See also (1960FR09, 1961FR1D, 1969ZH1A).

27. ^{14}C(p, p)^{14}C $E_b = 10.208$

Table 15.11: Resonances in ^{14}C + p [a]

E_p (MeV ± keV)	Γ (keV)	Γ_n (keV)	Γ_p (keV)	Γ_γ (eV)	J^π [d]	E_x (MeV)	Refs.
0.261 ± 1 [a]						10.451	(1959HE1D, 1968SI1F, 1969SI04)
0.352 ± 1 [a]				$(3.4 \pm 0.4) \times 10^{-2}$ [c]	$\frac{5}{2}$	10.536	(1959HE1D, 1960HE13, 1968SI1F, 1969SI04)
0.527 ± 1 [a]			0.2	1.78 ± 0.3 [c]	$\frac{3}{2}^+$	10.700	(1959HE1D, 1968SI1F, 1969SI04)
0.634 ± 1 [a]				0.23 ± 0.04 [c]	$\frac{3}{2}$	10.800	(1959HE1D, 1968SI1F, 1969SI04)
1.162 ± 2	7.9 ± 3	2.3	5.6	0.29	$\frac{1}{2}^-$	11.292	(1951RO16, 1955BA44, 1956SA06, 1968HA27)
1.294 ± 4	34 ± 4	22.6	11.1			[e]	(1968HA27)
1.3188 ± 0.5	41.4 ± 1.1	34.6 ± 0.9	6.8 ± 0.5	4.2 ± 0.7	$\frac{1}{2}^+$	11.438	(1951RO16, 1955BA44, 1956SA06, 1968HA27)
1.472 ± 8	418 ± 16	3.7	414.6			[e]	(1968HA27)
1.509 ± 4	404.9 ± 6.3	4.0 ± 0.2	400.9 ± 6.3	19.2 ± 0.4	$\frac{1}{2}^+; T = \frac{3}{2}$	11.615	(1959FE1C, 1968HE12)
1.688 ± 3	37	36.5	0.5		$\frac{3}{2}^+$	11.764	(1951RO16, 1955BA44, 1956SA06)
1.788 ± 3	24.5	24.5	0.03		$\frac{3}{2}^-, (\frac{5}{2}^-)$	11.876	(1951RO16, 1955BA44, 1956SA06)
1.884 ± 3	21.5	21.2	0.3		$\frac{1}{2}^-$	11.965	(1951RO16, 1955BA44, 1956SA06)
2.025 ± 4 [b]	14 ± 5	12.0	1.7		$\frac{5}{2}^+$	12.097	(1951RO16, 1955BA44, 1956SA06, 1960BA34, 1968HA27)
2.077 ± 3 [b]	47 ± 7	30.2	16.6		$\frac{3}{2}^-$	12.145	(1951RO16, 1955BA44, 1956SA06, 1960BA34, 1968HA27, 1968HE12)
2.272 ± 4	22	21.7	0.3		$\frac{5}{2}^{(+)}$	12.327	(1951RO16, 1955BA44, 1956SA06, 1960BA34, 1968HA27)
2.450 ± 4 [b]	40	28	0.3		$\frac{5}{2}^+; T = \frac{1}{2}$	12.493	(1951RO16, 1956SA06, 1960BA34)
2.48 ± 10	80	0	80		$\frac{5}{2}^+; T = \frac{3}{2}$	12.52	(1968HA27, 1968HE12)
2.908 ± 4	75				$\frac{3}{2}^-$	12.921	(1956SA06, 1960BA34, 1961HA12, 1962HA20)
3.19	5.5					13.19	(1960BA34, 1961HA12, 1962HA20)
3.38	22					13.36	(1960BA34, 1961HA12, 1962HA20)

Table 15.11: Resonances in $^{14}C + p$ [a] (continued)

E_p (MeV ± keV)	Γ (keV)	Γ_n (keV)	Γ_p (keV)	Γ_γ (eV)	J^π [d]	E_x (MeV)	Refs.
3.42	61					13.40	(1960BA34, 1961HA12, 1962HA20)
3.55						(13.52)	(1962HA20)
3.63	12					13.60	(1960BA34, 1961HA12, 1962HA20)
3.71						13.67	(1961HA12, 1962HA20)
3.89	33					13.84	(1960BA34, 1961HA12, 1962HA20)
4.19	105					14.12	(1960BA34, 1961HA12, 1962HA20)
4.24	25					14.17	(1960BA34, 1961HA12, 1962HA20)
4.61	130					14.51	(1960BA34, 1961HA12, 1962HA20)
4.93	99					14.81	(1960BA34, 1961HA12)
5.01						14.88	(1961HA12, 1962HA20)
5.14						15.00	(1961HA12, 1962HA20)
5.26						15.11	(1961HA12, 1962HA20)

[a] See also (1959HE1B) and Table 15.5 in (1959AJ76).

[b] The Γ_α are < 0.3 keV for $E_{res} = 1.16$ to 2.5 MeV, except for the resonances at $E_p = 2.03$, 2.08 and 2.45 MeV for which they are, respectively, 0.6, 2.2 and 5.5 keV (1956SA06).

[c] $\omega\gamma$ (in eV) (1968SI1F, 1969SI04).

[d] See also (1959AJ76).

[e] These states correspond to the levels listed in the line below: a different boundary condition was used to obtain E_{res}.

The elastic scattering has been studied for $E_p = 0.34$ to 2.7 MeV. At the $E_p = 527$ keV resonance (see Table 15.11), the scattering is consistent with d-wave formation of a $J^\pi = \frac{3}{2}^+$ state. No anomalies are observed at $E_p = 0.35$ and 0.63 MeV (1959HE1D). However, anomalies are observed at $E_p = 1.16$, 1.29, 1.47, 2.02, 2.07 and 2.48 MeV: the parameters of these are displayed in Table 15.11 (1968HA27, 1968HE12). The 2.48 MeV anomaly is due to a $J^\pi = \frac{5}{2}^+$; $T = \frac{3}{2}$ state at $E_x = 12.52$ MeV (which is the analog to the first excited state of ^{15}C), and is distinct from the $J^\pi = \frac{5}{2}^+$ resonance in ^{14}C(p, n)^{14}N observed at $E_p = 2.45$ MeV (1968HE12). See also (1968IW1A, 1969IW1E).

28. ^{14}C(p, n)^{14}N $\qquad Q_m = -0.626 \qquad E_b = 10.208$

Resonances reported by (1951RO16, 1955BA44, 1956SA06, 1959FE1C, 1960BA34, 1961HA12, 1962HA20, 1968HE12) are listed in Table 15.11. In addition to these, (1961HA12) report (in an abstract) a broad resonance corresponding to a $T = \frac{3}{2}$ state of ^{15}N at $E_x = 13.6$ MeV. At $E_p = 1.79$ MeV, the distributions favor $\frac{5}{2}^-$, but $\frac{3}{2}^-$ is not excluded (1955BA44: see also (1953KA20)); a computation of the cross section favors $J = \frac{3}{2}$ (1956SA06). At $E_p = 1.88$ MeV, the angular distribution is consistent with the $J^\pi = \frac{1}{2}^-$ assignment from ^{14}N(n, n)^{14}N (1955BA44). The $E_p = 2.27$ MeV state has $J = \frac{3}{2}$ or $\frac{5}{2}$; the σ_{nn} clearly indicates ther latter (1955BA44, 1956SA06). For ^{15}N*(11.62) ($E_p = 1.51$ MeV), the proton reduced width indicates a single-particle level, while the neutron reduced width is only 10^{-3}. This is consistent with the assignment $T = \frac{3}{2}$, corresponding to the ground state of ^{15}C (1955BA44, 1956BA16, 1959FE1C). See also (1967VO1B, 1969BA1N, 1969TI05).

Polarization measurements are reported at $E_p = 7.2$, 8.8 and 10.4 MeV by (1969WO1J; n_0, n_1, n_2).

29. ^{14}C(d, n)^{15}N $\qquad Q_m = 7.984$

Angular distributions have been determined at $E_d = 1.3$, 1.8 and 2.8 MeV (1967CO1R; n_0, n_{1+2}, n_3, n_{4+5+6}), 1.31 to 3.08 MeV (1963IM01; n_0), 2.10 and 2.33 MeV (1963IM01; n_{1+2}, n_3, n_{4+5+6}) and 3.10 MeV (1967LA11; n_0, n_{1+2}, n_3, n_4, n_5, n_6 and ^{15}N*(8.31, 9.06, 9.16, 9.22)). The transitions to ^{15}N*(5.30, 9.06) involve $l_p = 0$: these states therefore have $J^\pi = \frac{1}{2}^+$ (1967LA11). See also (1959AJ76) and (1961CH14, 1964MO1G).

Studies of the γ-decay of ^{15}N states reached in this and in other reactions are summarized in Table 15.10: see (1965WA16). See also (1967CH19).

30. ^{14}C(^{3}He, d)^{15}N $\qquad Q_m = 4.715$

At $E(^3\text{He}) = 14$ MeV, angular distributions of the deuterons corresponding to ^{15}N*(0, 5.28, 5.30, 6.33) have been measured and analyzed by DWBA: the relative spectroscopic factors for the first four states of ^{15}N are 1, 0.50, 0.34, 0.07 in good agreement with the predictions of (1957HA1E). Angular distributions of the d_0 group are also reported at $E(^3\text{He}) = 1 - 9$ MeV by (1963WE15, 1966DU1B, 1968DA1N).

31. ^{14}C(α, t)^{15}N $\quad Q_m = -9.606$

Not reported.

32. ^{14}N(n, γ)^{15}N $\quad Q_m = 10.835$
$Q_0 = 10.8332 \pm 0.0006$ (1968GR14).

The thermal cross section is 80 ± 20 mb (1957BA18), 75 ± 7.5 mb (1964ST25). This large cross section is not understood in terms of the present level structure in ^{15}N: see (1959AJ76).

Observed capture γ rays are displayed in Table 15.12 (1963MO1C, 1967TH05, 1968GR14). The very accurate γ-ray energy determinations of (1968GR14) show that two states at $E_x \approx 9.15$ MeV are involved in this reaction as previously suggested by (1966WA08). The lower of the two, at $E_x = 9.1518$ MeV, decays predominantly to the ground state. The other state at $E_x = 9.1549$ MeV, which is preferentially fed in this reaction, decays primarily by cascades via ^{15}N*(5.27, 5.30, 6.32, 7.16) (1968GR14). See also reactions 21 and 39, (1968GRZY, 1968ST10) and Table 15.10.

Recoil Doppler broadening of cascade γ-rays has been measured by (1969WE07): the derived τ_m are listed in Table 15.7. See also (1968CA1J). Observation of non-isotropic correlations in the C $\rightarrow 6.32$ cascade means that $J \neq \frac{1}{2}$ for ^{15}N*(6.32): the results are consistent with $J = \frac{3}{2}$ (1964BA02).

The importance of measuring the (n, γ) cross section at $E_n = 0.47$ and 0.66 MeV for astrophysical considerations is suggested by (1968FO1A).

See also (1960CA02, 1965JA09, 1969HO1X) and (1958GR01, 1964LI1C).

33. ^{14}N(n, n)^{14}N $\quad E_b = 10.835$

The thermal (bound) scattering cross section is 5.51 b (1961WI1A). The scattering amplitude (bound) is $a = 9.19 \pm 0.11$ fm (1965DO14) [$a = 9.14 \pm 0.10$ fm is recommended by (1964ST25)]. See also (1969BA1P). The coherent scattering cross section is 10.5 ± 0.3 b (1964ST25).

Recent cross section measurements are listed in Table 15.13. Cross section data are summarized in (1964ST25), while angular distribution data are displayed in (1963GO1M).

Observed resonances are listed in Table 15.14 (1951JO23, 1952HI12, 1955FO27, 1959HA13, 1966FO1D, 1966FO1E, 1966MA2K, 1968BO36, 1968JO1F): for a discussion of the evidence

Table 15.12: Gamma radiation from ^{14}N(n, γ)^{15}N

Transition in ^{15}N	E_γ (MeV $\pm$ keV)		E_γ (MeV $\pm$ keV)	I_γ [b]	
	(1967TH05)	(1968GR14)	(1968GR14)	(1967TH05)	(1963MO1C)
C$\rightarrow$ 0	10.830 ± 2	10.8290	10.8832 ± 0.6	13.3 ± 2.0	14
C $\rightarrow$ 5.27	5.562 ± 1	5.5622 ± 0.35		10.3 ± 0.5	11
C $\rightarrow$ 5.30	5.534 ± 1	5.5332 ± 0.35		18.8 ± 0.9	21
C $\rightarrow$ 6.32	4.509 ± 1	4.5088 ± 0.3		16.6 ± 0.8	16
C $\rightarrow$ 7.16	3.678 ± 1	3.6777 ± 0.25		15.9 ± 0.8	< 23
C $\rightarrow$ 7.30	3.532 ± 1	3.5322 ± 0.25		9.9 ± 0.5	9
C $\rightarrow$ 8.31	2.521 ± 2	2.52055 ± 0.10		6.1 ± 0.3	6
C $\rightarrow$ 9.155		1.67819 ± 0.06			
	1.679 ± 2			9.2 ± 0.5	12
C $\rightarrow$ 9.152		1.68141 ± 0.18		1.4 ± 0.3 [d]	
5.27 $\rightarrow$ 0	5.270 ± 1	5.2692 ± 0.35	5.2701 ± 0.3	30.6 ± 1.5	32
5.30 $\rightarrow$ 0	5.298 ± 1	5.2978 ± 0.35	5.2989 ± 0.3	21.4 ± 1.1	21
6.32 $\rightarrow$ 0	6.323 ± 1	6.3220 ± 0.4	6.3235 ± 0.4	18.8 ± 0.9	18
7.16 $\rightarrow$ 0			7.1550 ± 0.4		
7.17 $\rightarrow$ 5.27	1.885 ± 1	1.88481 ± 0.06		19.7 ± 1.0	21
7.16 $\rightarrow$ 5.30	1.857 ± 2			0.8 ± 0.2	
7.30 $\rightarrow$ 0	7.299 ± 1	7.2990 ± 0.5	7.3009 ± 0.5	10.0 ± 0.5	9
8.31 $\rightarrow$ 0	8.311 ± 2	8.3102 ± 0.7	8.3124 ± 0.7	4.4 ± 0.4	4
8.31 $\rightarrow$ 6.32	1.989 ± 2			1.5 ± 0.3	
8.57 $\rightarrow$ 0	8.570 ± 4		8.573 ± 4 [c]	0.2 ± 0.03	
9.05 $\rightarrow$ 0	9.047 ± 4		9.050 ± 4 [c]	0.2 ± 0.03	0.5
9.155 $\rightarrow$ 0			9.1549 ± 0.5		
9.152 $\rightarrow$ 0	9.151 ± 2	9.1498 ± 0.9	9.1518 ± 0.5	1.7 ± 0.2	1.4
9.155 $\rightarrow$ 5.27	3.883 ± 2	3.8837 ± 0.4		0.8 ± 0.1	
9.155 $\rightarrow$ 5.30	3.855 ± 2	3.8552 ± 0.3		1.0 ± 0.1	0.5
9.155 $\rightarrow$ 6.32	2.830 ± 2	2.8311 ± 0.2		2.0 ± 0.2	1.5
9.155 $\rightarrow$ 7.16	1.997 ± 2	1.99965 ± 0.10		4.6 ± 0.2	4

[a] C = capturing state.
[b] In units of photons/100 captures.
[c] (1967TH05).
[d] (1968GR14).

leading to J^π assignments, see (1959AJ76). See also (1960BA34) and (1966AG1A, 1967BE1F, 1968IW1A, 1969IW1E).

A polarization measurement has been made at $E_n = 3.5$ MeV by (1962OT01). See also (1965TA07).

34. $^{14}N(n, 2n)^{13}N$ $Q_m = -10.553$ $E_b = 10.835$

Table 15.13: Recent cross section measurements for $^{14}N + n$ [a]

E_n (MeV)	Measurements of	Refs.
0.01 – 0.2	σ_t	(1959BI19)
1.7 – 4.0	σ_t	(1960BA34)
2.0 – 4.2	σ_t	(1966MA2K, 1968JO1F)
4.2 – 6.3	σ_{ne}	(1968BO36)
4.2 – 8.7	σ_e	(1968BO36)
4.5, 6, 7	$\sigma_{nn'\gamma}$	(1968CO1W)
5.80 – 8.55	$\sigma_{nn'\gamma}$	(1969DI1B)
6.8 – 14.0	σ_t, σ_e, σ_{ne}	(1967BA03)
13.3 – 19.5	σ_e	(1968BO36)
14	σ_e	(1963BA46)
15	σ_{ne}	(1969NY1A)
15.2, 19.8	σ_{ne}	(1965DE1G)
15.3	σ_t, σ_{ne}	(1968HA1V)
17.7 – 29.1	σ_t	(1960PE25)
88 – 152	σ_t	(1966ME14)
10 – 37	$\sigma_{n,2n}$	(1961BR1A)
12.5 – 18	$\sigma_{n,2n}$	(1960FE12)
13.2 – 18.8	$\sigma_{n,2n}$	(1965BO42)
13.3 – 15.2	$\sigma_{n,2n}$	(1960MC05)
14.1	$\sigma_{n,2n}$	(1962CE1B)
14.4	$\sigma_{n,2n}$	(1961RA06)
14.7	$\sigma_{n,2n}$	(1967PA27)
14.8	$\sigma_{n,2n}$	(1965GR41)
1.3 – 4.2	$\sigma_{n,p}$	(1959GA14)

Table 15.13: Recent cross section measurements for ^{14}N + n [a] (continued)

E_n (MeV)	Measurements of	Refs.
$7.4 - 8.6$	$\sigma_{n,p}$	(1969DI1B)
14.7	$\sigma_{n,p}$, $\sigma_{n,np}$	(1966CS1B, 1967CS03)
15	$\sigma_{n,p}$, $\sigma_{n,d}$	(1969NY1A)
$5.6 - 6.4$	$\sigma_{n,t}$	(1966SC21)
$5.7 - 8.2$	$\sigma_{n,t}$	(1959GA14)
14.1	$\sigma_{n,2\alpha}$	(1967MO21)
15	$\sigma_{n,t}$	(1969NY1A)
15.7	$\sigma_{n,t}$	(1967MO21)
$1.3 - 8.2$	$\sigma_{n,\alpha}$	(1959GA14)
$3.9 - 6.4$	$\sigma_{n,\alpha}$	(1966SC21)
$4.5 - 7.0$	$\sigma_{n,\alpha}$	(1968CO1W)
$5.7 - 8.2$	$\sigma_{n,\alpha}$	(1959HA13)
$5.8 - 8.6$	$\sigma_{n,\alpha}$	(1969DI1B)
14.7	$\sigma_{n,\alpha}$	(1966CS1B)
15	$\sigma_{n,\alpha}$	(1969NY1A)

[a] See also (1959AJ76).

Recent measurements of cross sections for this reaction are listed in Table 15.13 (1960FE12, 1960MC05, 1961BR1A, 1961RA06, 1962CE1B, 1965BO42, 1965GR41, 1967PA27): see the summaries in (1964ST25, 1966JE1B). See also (1964HE18, 1966CS1C, 1967CS02) and (1959AJ76).

35. ^{14}N(n, p)^{14}C $Q_m = 0.626$ $E_b = 10.835$

The thermal cross-section is 1.81 ± 0.05 b (1964ST25), 1.83 ± 0.03 b (1961HA43). A number of resonances are reported by (1950JO57), (1959GA14) and (1963EN01): see Table 15.14. The results are summarized in (1964ST25, 1966JE1B). See also (1960BU1C, 1968DA1F).

Recent cross-section measurements are listed in Table 15.13 (1959GA14, 1966CS1B, 1967CS03, 1969DI1B). See also (1964FO1A, 1969BA1N) and (1959AJ76).

36. (a) ^{14}N(n, d)^{13}C $Q_m = -5.325$ $E_b = 10.835$
(b) ^{14}N(n, np)^{13}C $Q_m = -7.550$

For reaction (a) see (1967LI06) and (1959AJ76). For reaction (b) see (1966CS1B, 1967CS03).

Table 15.14: Resonances in ^{14}N + n [a]

E_{res} (MeV ± keV)	Γ_{lab} (keV)	Γ_n (keV)	Γ_p (keV)	Γ_α (keV)	J^π	^{15}N* (MeV)	Refs.
0.430 ± 5	3.5	< 3	< 0.01		$\geq \frac{3}{2}$	11.236	(1951JO23, 1952HI12)
0.4926 ± 0.65	7.5	< 3	< 10		$\frac{1}{2}^-$	11.2943	(1950JO57, 1952HI12, 1963EN01)
0.639 ± 5	43	34	9		$\frac{1}{2}^+$	11.431	(1950JO57, 1951JO23, 1952HI12)
0.998 ± 5	46	45	0.8		$\frac{3}{2}^+$	11.766	(1950JO57, 1951JO23, 1952HI12)
1.120 ± 6	19	19	0.20		$\frac{3}{2}^-$	11.880	(1951JO23, 1952HI12, 1955FO27)
1.188 ± 6	≤ 3.2	< 2	< 0.1		$\geq \frac{3}{2}$	11.943	(1952HI12)
1.211 ± 7	13	12	0.4		$\frac{1}{2}^-$	11.965	(1952HI12)
1.350 ± 7	21	20	0.9	0.4	$\frac{5}{2}^{(+)}$	12.094	(1951JO23, 1952HI12, 1955FO27, 1959GA14)
1.401 ± 8	54	41	11	1.8	$\frac{3}{2}^{(-)}$	12.142	(1950JO57, 1951JO23, 1952HI12, 1955FO27, 1959GA14)
1.595 ± 8	22	21	0.2	< 0.1	$\frac{5}{2}^{(-)}$	12.323	(1952HI12, 1955FO27, 1959GA14, 1966FO1D, 1966FO1E)
1.779 ± 10	47	37	0.5	9.0	$(\frac{5}{2}^+)$	12.494	(1950JO57, 1952HI12, 1955FO27, 1959GA14, 1966FO1E)
2.23	65	39	7.8	18	$\frac{3}{2}^-$	12.92	(1959GA14, 1966FO1D, 1966FO1E, 1966MA2K, 1968JO1F)
2.47	< 3			r		13.14	(1959GA14)
2.52	≈ 7			r		13.19	(1959GA14)
2.71	40			r	$\frac{3}{2}^-$	13.36	(1959GA14)
2.74	95		r		$\frac{5}{2}^+$	13.39	(1959GA14)
2.95	20	16	1.1	3.2	$\frac{5}{2}^+$	13.59	(1959GA14, 1966FO1E, 1966MA2K, 1968JO1F)
3.09	60		r	r		13.72	(1959GA14)
3.21	85		r	r	$\frac{3}{2}^+$	13.83	(1959GA14, 1966FO1E, 1966MA2K, 1968JO1F)
3.51	≈ 20		r	r		14.11	(1959GA14)
3.57	30		r	r	$\frac{3}{2}^{(+)}$	14.17	(1959GA14, 1966MA2K, 1968JO1F)
≈ 3.8	≈ 2000	≈ 1000	200	≈ 1000		14.4	(1959GA14)
4.09	50		r	r		14.65	(1959GA14, 1966SC21)
≈ 4.1	≈ 300		r	r		14.7	(1959GA14)
4.38	40			r		14.92	(1959GA14, 1966SC21)
4.60				r		15.13	(1959GA14, 1966SC21)
5.03				r		15.52	(1959GA14, 1966SC21, 1968BO36)
5.60	100			r		16.06	(1959GA14, 1966SC21, 1968BO36)

Table 15.14: Resonances in ^{14}N + n [a] (continued)

E_{res} (MeV ± keV)	Γ_{lab} (keV)	Γ_n (keV)	Γ_p (keV)	Γ_α (keV)	J^π	^{15}N* (MeV)	Refs.
5.94				r		16.38	(1959GA14, 1966SC21)
6.16	75			r		16.58	(1959GA14, 1966SC21)
6.26	110	r		r		16.67	(1959GA14, 1959HA13, 1966SC21)
6.55	170	r		r		16.95	(1959GA14, 1959HA13)
6.94				r		17.31	(1959GA14)
	200	r					(1959HA13)
7.16				r		17.51	(1959GA14)
7.34	120			r		17.68	(1959GA14)
7.48	180	r		r		17.81	(1959GA14, 1959HA13)
7.92	170			r		18.22	(1959HA13)
8.00	120			r		18.30	(1959GA14, 1959HA13)

r = resonant channel.

[a] See also (1959AJ76).

37. (a) ^{14}N(n, t)^{12}C $\quad Q_{\rm m} = -4.015 \quad E_{\rm b} = 10.835$

(b) ^{14}N(n, t)^{4}He^{4}He^{4}He $\quad Q_{\rm m} = -11.289$

(c) ^{14}N(n, 2α)^{7}Li $\quad Q_{\rm m} = -8.822$

For reaction (a) see (1959GA14, 1966SC21, 1967LI06, 1967RE01) and (1968AJ02). For reaction (b) see (1967MO21). For reaction (c) see (1967MO21). See also (1960FA10, 1964SA1E), Table 15.13, the summaries in (1964ST25, 1966JE1B) and (1959AJ76).

38. (a) ^{14}N(n, α)^{11}B $\quad Q_{\rm m} = -0.157 \quad E_{\rm b} = 10.835$

(b) ^{14}N(n, nα)^{10}B $\quad Q_{\rm m} = -11.613$

Recent cross-section measurements for reaction (a) are displayed in Table 15.13: these include measurements of cross sections for several different α-groups (1959GA14, 1966SC21) and γ-rays (1959HA13, 1968CO1W, 1969DI1B). For summaries of the experimental evidence, see (1964ST25, 1966JE1B).

Observed resonances are listed in Table 15.14 (1950JO57, 1959GA14, 1966SC21). See also (1960FA10), (1960BU1C, 1963CH1C) and (1964GA1A, 1968GA1M; theor.). For reaction (b), see (1960FA10).

39. ^{14}N(d, p)^{15}N $\quad Q_{\rm m} = 8.610$

$Q_0 = 8.614 \pm 0.006$ (1964MA57).

Proton groups corresponding to levels of ^{15}N are listed in Table 15.15 (1950MA65, 1954SP01, 1956DO41, 1965AL19, 1966GA08, 1966GO1J, 1969PH02). The J^π assignments are based on PWBA and DWBA analyses: see (1959AJ76), (1969PH02) and Table 15.16 for a listing of recent angular distribution studies in the range $E_{\rm d} = 0.5$ to 27 MeV. See also (1966RO1V). The angular distributions of protons corresponding to ^{15}N*(6.32) and the p-γ angular correlation fixes $J^\pi = \frac{3}{2}^-$ for that state (1961GO03). (1960HO1B) has looked for additional states of ^{15}N with $E_{\rm x} \approx 7$ MeV: he finds the upper limits to proton groups corresponding to $7.10 < E_{\rm x} < 7.31$ to be 1%, and to be 5% of the intensities of groups to known nearby states for $7.31 < E_{\rm x} < 7.57$ MeV.

Recent very accurate γ-ray energy measurements have been reported by (1967CH19) [$E_\gamma = 5299.03 \pm 0.43$ and 5270.60 ± 0.46 keV] by (1966AL18) and by (1965WA16): the derived $E_{\rm x}$ values are displayed in Table 15.15. Branching ratios have been determined by (1965WA16, 1968GI11, 1968ST10) and are shown in Table 15.10 together with the multipolarities determined by (1965WA16). Lifetime measurements are listed in Table 15.7 (1965AL19, 1967BI11, 1968GI11).

The two states of ^{15}N at $E_{\rm x} = 9.15$ MeV [see Table 15.10 for branching ratios] are separated by 2.5 ± 0.5 keV (1968ST10, 1969YO1C): see also reaction 32.

Table 15.15: ^{15}N levels from ^{14}N(d, p)^{15}N

E_x (MeV ± keV)					l_n	J^π
(1950MA65, 1966GO1J)	(1954SP01)	(1956DO41, 1967CH19)	A	(1966GA08)		
0					1 [b]	$\frac{1}{2}^-, \frac{3}{2}^-, \frac{5}{2}^-$
5.276 ± 6	5.280 ± 10	5.27159 ± 0.46 [a]	5.272 ± 10		2 [c]	$\leq \frac{7}{2}^+$
5.305 ± 6		5.30003 ± 0.43 [a]	5.300 ± 11		[c,d]	
6.328 ± 6	6.330 ± 10				1 [e,i]	$\frac{3}{2}^-$ [j]
7.164 ± 6	7.165 ± 10		7.1555 ± 1.7		2 [f,i]	$\leq \frac{7}{2}^+$
7.309 ± 6	7.314 ± 10	7.307 ± 8			0 [f,i]	$\frac{1}{2}^+, \frac{3}{2}^+$
	7.575 ± 10	7.570 ± 8	7.5671 ± 1.0		2 [g,i]	$\leq \frac{7}{2}^+$
8.315 ± 6	8.316 ± 10	8.319 ± 8	8.309 ± 4.1		0 [e,i]	$\frac{1}{2}^+, \frac{3}{2}^+$
	8.571 ± 10	8.577 ± 8	8.573 ± 3.2	8.582 ± 5	$0 + 2$ [h,i]	$\leq \frac{7}{2}^+$
	9.062 ± 10			9.056 ± 5		
	9.165 ± 10			9.159 ± 6	[i]	
9.225 ± 6				9.226 ± 6	1 or 2 [i]	$(\frac{3}{2}^-)$
9.762 ± 6				9.764 ± 6		
	9.834 ± 10			9.831 ± 6		
9.929 ± 7				9.929 ± 6		
	10.069 ± 10			10.071 ± 6	2, 0 [i]	$\frac{3}{2}^+$
	10.458 ± 10			10.456 ± 7		
	10.544 ± 10			10.541 ± 7		
	10.705 ± 10			10.702 ± 7	2, 0 [i]	$\frac{3}{2}^+$
	10.811 ± 10			10.809 ± 9	1 [i]	$\frac{1}{2}^-, \frac{3}{2}^-, \frac{5}{2}^-$
	11.2				1 [j]	$\frac{1}{2}^-, \frac{3}{2}^-, \frac{5}{2}^-$

A: (1965AL19, 1965WA16, 1966AL18).

[a] See also (1965AL19, 1965WA03).

[b] (1952GI01, 1957WA01).

[c] (1955SH28: see (1958WA1C)).

[d] Isotropic: no clear stripping pattern.

[e] (1952GI01, 1955SH28, 1956GR37, 1958WA1C).

[f] (1955SH28, 1956GR37).

[g] (1956GR37): (1957WA01) find a possible $l = 0$ component.

[h] (1955SH28, 1957WA01).

[i] (1969PH02): absolute spectroscopic factors are also given.

[j] (1956GR37).

[k] (1961GO03). (This footnote is not labeled in the table content.)

Table 15.16: ^{14}N(d, p)^{15}N angular distribution studies [a]

E_d (MeV)	Distribution of proton groups	Refs.
$0.5 - 0.8$	p_0, p_1, p_2	(1957SJ68, 1961SJ1B)
$1 - 2.2$	p_0, $p_3 \rightarrow p_7$	(1967BE09)
$1 - 3.2$	$p_4 \rightarrow p_7$	(1969BE08)
$1.1 - 3.1$	p_{1+2}, p_3, p_4, p_5, p_6	(1969GO14)
1.3, 4.5	p_{1+2}, p_3	(1961GO03, 1965FI05, 1966GA09)
$1.3 - 5.5$	p_0	(1962GO21, 1965FI05, 1966GA09)
$1.4 - 3$	p_0, p_3	(1969BE08)
$1.4 - 3.2$	p_0, $p_1 + p_2$	(1961KA05)
2	$p_1 \rightarrow p_5$, p_7	(1962RO13)
7, 8, 9	$p_{3\rightarrow 8}$, p_{10+11}, p_{12}, p_{16}, p_{19}, p_{20}	(1969PH02)
12	p_0	(1967SC29)
13.8, 15.2	p_0	(1961MO13)
16	p_0	(1960MO03)
27	p_0	(1962ER03)

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

See also (1961JA23, 1961TE02, 1962ST17, 1963GO1L, 1965HE1B), (1959BO1C, 1960BE1B, 1961KO1E, 1963TA1A, 1964BA1V, 1964ST1J, 1966HO1D; theor.), (1959AJ76) and ^{16}O in (1971AJ02).

40. ^{14}N(t, d)^{15}N $\qquad Q_m = 4.577$

The angular distribution of the deuterons corresponding to the ground state of ^{15}N has been measured at $E_t = 1.50$, 1.83 and 1.98 MeV. The cross section at $E_t = 2$ MeV is 48 mb: this large value and the energy and angular behavior of the differential cross section suggest that this reaction may proceed by a cluster exchange process (1964SC09).

41. ^{14}N(α, ^{3}He)^{15}N $\qquad Q_m = -9.743$

At $E_\alpha = 56$ MeV, the angular distribution of the ground state ^{3}He particles has been measured by (1969GA11) and analyzed by DWBA: the ratio of the (α, ^{3}He) and (α, t) cross sections at this energy is 1.50 ± 0.15. See also (1968GA1C).

42. ^{14}N(^{9}Be, ^{8}Be)^{15}N $\quad Q_{\rm m} = 9.170$

The lifetime of ^{15}N*(5.27) is ≈ 1 psec (1969NI09): see Table 15.7 and (1967BI11). See also (1963HO1E).

43. ^{14}N(^{11}B, ^{10}B)^{15}N $\quad Q_{\rm m} = -0.621$

See (1967PO13). See also (1969BR1D).

44. ^{14}N(^{14}N, ^{13}N)^{15}N $\quad Q_{\rm m} = 0.282$

Angular distributions of the transition to the ground state of ^{15}N have been measured for E(^{14}N)(cm) $= 5.5$ to 16 MeV (1961TO07, 1964JO1A, 1965BE1B, 1965HI1A). See also (1961TO01). Below $\approx$ 6.5 MeV, the tunneling theory of neutron transfer gives a good account of the data. At higher energies, nuclear absorption of the incident ^{14}N ions occur (1965HI1A, 1966GA04). See also (1968GA03). For reviews of the work on this reaction, see (1964FL1D, 1967DA1E, 1967VO1A, 1969BR1D). For discussions of relevant theories, see (1962BR1G, 1963BR1G, 1964BR1M, 1964GR1G, 1965BR1F, 1966BU1B, 1967BR1M, 1967BR1Q, 1967PE1D, 1968MA2G, 1968NA1F, 1969KA1G).

45. ^{14}N(^{19}F, ^{18}F)^{15}N $\quad Q_{\rm m} = 0.405$

See (1968GA03).

46. ^{15}C(β^-)^{15}N $\quad Q_{\rm m} = 9.773$

The β^- decay takes place to ^{15}N*(0, 5.30, 7.30, 8.31, 9.05): see Table 15.2.

Measurements of γ-ray energies give $E_\gamma = 5299.03 \pm 0.43$ keV (1967CH19), 8315 ± 6 and 9048 ± 4 keV (1966AL12). See also ^{15}C.

47. ^{15}N(γ, n)^{14}N $\quad Q_{\rm m} = -10.835$

See (1967ZH1A, 1968YA1E, 1969ZH1A).

48. ^{15}N(γ, p)^{14}C $\qquad Q_{\rm m} = -10.208$

The integrated cross section for transitions to ^{14}C(0) for E_γ up to 30.5 MeV $= 22\pm3$ MeV·mb, assuming an isotropic angular distribution. Pronounced maxima are observed at $E_\gamma = 19.5$, 20.4, 22.7 and 24.5 MeV. In addition a "pigmy" resonance at $E_\gamma = 15.2$ MeV and less pronounced structures at $E_\gamma = 13.6$ and 17.0 MeV are also observed (1964KO10). See also (1963FI04) and (1967ZH1A, 1968YA1E, 1969UB1C, 1969ZH1A).

49. ^{15}N(e, e)^{15}N

Using the harmonic oscillator function, analysis of the scattering of 250 and 400 MeV electrons gives, respectively, $r_{\rm rms} = 2.68\pm0.05$ fm and 2.63 ± 0.05 fm for ^{15}N (1968DA1Q). At $E_{\rm e} = 50-57$ MeV, excitation of ^{15}N*(6.32) gives Γ^0_γ(M1) $= 3.4 \pm 0.7$ eV and Γ^0_γ(E2) $= 0.06 \pm 0.02$ eV: $|\delta$(E2/M1)$| = 0.13 \pm 0.03$ (1968BE14).

50. ^{15}N(n, n)^{15}N

See ^{16}N.

51. ^{14}N(p, p)^{15}N

The angular distribution of elastically scattered protons has been measured at $E_{\rm p} = 39.8$ MeV (1969SN04). See also (1963NA1C).

52. ^{15}N(^{3}He, ^{3}He)^{15}N

At E(^{3}He) $= 39.8$ MeV, a number of inelastically scattered ^{3}He groups are observed corresponding to states in ^{15}N: see Table 15.17. Angular distributions were obtained for a number of these, and were analyzed using a local two-body interaction with an arbitrary spin-isospin exchange mixture (1969BA06). See also (1968BA1E). (1969BO13) measured the angular distribution of elastically scattered ^{3}He particles at E(^{3}He) $= 11$ MeV.

53. ^{15}N(α, α)^{15}N

Table 15.17: ^{15}N levels from ^{15}N(^{3}He, ^{3}He′) and ^{15}N(α, α')

^{15}N* [a] (MeV ± keV)	L [a]	^{15}N* [b] (MeV)	L [b]
0		0	
5.28 ± 30	3	$5.27 + 5.30$	3
6.32	2	6.32	2
7.15	3	7.16	[c]
7.30	1	7.30	1
7.56	3	7.57	3
8.31	1	8.31	[c]
8.57	1	8.58	[c]
9.17 ± 30		9.16	
9.79 ± 40		9.83	
10.03 ± 40		10.07	
10.71 ± 40			
11.34 ± 40			
11.92 ± 40			
12.52 ± 40			
14.12 ± 40			
15.11 ± 40			

[a] (^{3}He, ^{3}He′): (1969BA06).

[b] (α, α') (1966HA19). The E_x were determined.

[c] Weakly excited. See also (1965BU05, 1969BA06).

The surface thickness $a = 0.36$ fm, as determined from analysis of the scattering of 44 MeV α-particles from ^{15}N (1968FA1A). At $E_\alpha = 40.5$ MeV, a number of particle groups have been observed, and angular distributions have been measured: see Table 15.17 (1966HA19). See also (1965BU05), B(E2)↓ $/e^2 = 4.9$ fm^4 for ^{15}N*(6.32): B(E2)↓ $/e^2 = 60$ fm^6 for both ^{15}N*(5.27, 7.57) (1966HA19). See also (1969BA06).

54. ^{15}O(β^+)^{15}N $\qquad Q_m = 2.760$

See ^{15}O.

55. (a) ^{16}O(γ, p)^{15}N $\qquad Q_m = -12.126$

(b) ^{16}O(e, ep)^{15}N $\qquad Q_m = -12.126$

Over the giant resonance region in ^{16}O, the decay takes place to the odd parity states of ^{15}N at $E_x = 0$ and 6.32 MeV as well as to both of the even parity states at $E_x = 5.27$ and 5.30 MeV. The branching ratios are functions of the excitation energy in ^{16}O and of the authors: see (1965DE24, 1965MA45, 1965MO13, 1966KO1G, 1966OW01, 1967CA1C, 1967CA1P, 1968BA2L, 1969MU07, 1969SH02). The results are in fair agreement with the predictions of the single-particle, single-hole theory of photoexcitation of ^{16}O, although some non-single-particle excitation appears to be necessary in some portions of the ^{16}O giant resonance: see, e.g. (1968BA2L). High-energy γ-rays have also reported from the decay of ^{15}N*(7.30, 8.31, 9.05, 9.23) (1968BA2L, 1969HO1T, 1969MU07). See also the review in (1968SC1B), (1957JO20, 1959BR69, 1963SC32, 1968TU02, 1969FR20, 1969UL01) and (1968ZH1B; theor.). The τ_m of ^{15}N*(5.27) $>> 0.1$ psec; τ_m for ^{15}N*(6.33, 9.23) < 0.1 psec (1969MU07): see also Table 15.7.

For reaction (b), see (1962DO1A).

56. ^{16}O(n, d)^{15}N $\qquad Q_m = -9.901$

Angular distribution of the deuterons corresponding to the ground state of ^{15}N have been determined at $E_n = 14.4$ MeV (1964PA11, 1965VA05) and at 14 MeV (1963GA10). See also (1965DI1E; theor.).

57. ^{16}O(p, 2p)^{15}N $\qquad Q_m = -12.126$

At $E_p = 460$ MeV, the summed proton spectrum shows two peaks corresponding to the knowckout of $p_{1/2}$ and $p_{3/2}$ protons with binding energies of 12.4 and 19.0 MeV, respectively [^{15}N*(0, 6.32)] (1966TY01). See also the discussions in (1963CL1B, 1963RI1B), (1962FO03, 1967FU1A), (1963BE1A, 1963BE42; theor.) and (1959AJ76).

58. ^{16}O(d, ^{3}He)^{15}N $\qquad Q_{\rm m} = -6.632$

Angular distributions of the ^{3}He groups have been measured at $E_{\rm d} = 20$ MeV (1969PU04: to ^{15}N*(0, 5.27, 5.30)), 28 MeV (1968GA13: to ^{15}N(0)), 34.4 MeV (1967HI06: to ^{15}N*(0, $5.27 + 5.30$, 6.32)), 52 MeV (1969KA1A, 1969KA1W: to ^{15}N(0)), and 82 MeV (1969DO04: to ^{15}N*(0, $5.27 + 5.30$, 6.32)) and analyzed by DWBA. The ^{3}He group to ^{15}N*(5.2) does not show a stripping pattern (1969PU04). See also (1968BA2J; theor.).

59. ^{16}O(t, α)^{15}N $\qquad Q_{\rm m} = 7.688$

Angular distributions have been measured at $E_{\rm t} = 0.9$ to 1.7 MeV (1967KO1G; α_0), 1.15 to 1.95 MeV (1959JO32; α_0), 1.5 to 3.0 MeV (1966SE1D; α_0), and 13 MeV (1965AJ01; α_0, α_{1+2}, α_3). A γ-ray with $E_\gamma = 5.272 \pm 0.010$ MeV has been observed in this reaction: see Table 15.7 (1965AL19). See also (1959AJ76).

60. ^{16}O(^{14}N, ^{15}O)^{15}N $\qquad Q_{\rm m} = -4.833$

See (1963TO1D, 1969BR1D).

61. ^{17}O(d, α)^{15}N $\qquad Q_{\rm m} = 9.803$

See (1954PA39).

62. ^{18}O(p, α)^{15}N $\qquad Q_{\rm m} = 3.981$

Angular distributions of ground state α-particles are reported at $E_{\rm p} = 0.84$ to 2.00 MeV (1961CA02) and at 7.9, 10.6 and 13.3 MeV (1964EC03). Angular correlation measurements lead to $J = \frac{5}{2}$, $\frac{3}{2}$, $(\frac{1}{2})$, $(\frac{3}{2})$ for ^{15}N*(5.28, 6.32, 8.31, 8.58) (1965WA06), $J = \frac{5}{2}$, $\frac{5}{2}$, $\frac{3}{2}$, $\frac{7}{2}$ for ^{15}N*(5.28, 7.16, 7.30, 7.57) (1966HA30), $J = \frac{3}{2}$ for ^{15}N*(6.32) (1966LO02). The M2/E1 mixing ratio of the $7.30 \rightarrow$ g.s. transition indicates an unusually large retardation of an E1 transition in a non-self-conjugate nucleus (1966HA30). $J = \frac{5}{2}$ for ^{15}N*(5.27) and the mixing parameter fix $J = \frac{5}{2}$ for ^{15}N*(10.54) which fed the first excited state of ^{15}N (1959HE1D) in the ^{14}C(p, γ)^{15}N reaction (1965WA06).

See also (1960CL02, 1961LO10, 1964AM1A, 1964MA25, 1964MA57, 1964SC01), (1959AJ76) and ^{19}F in (1959AJ76, 1972AJ02).

63. ^{19}F(γ, α)^{15}N $\qquad Q_{\rm m} = -4.011$

See (1965HA1G).

64. (a) ^{19}F(p, pα)^{15}N $\qquad Q_{\rm m} = -4.011$

(b) ^{19}F(α, 2α)^{15}N $\qquad Q_{\rm m} = -4.011$

For reaction (a) see (1962FO03). For reaction (b) see (1963LA02).

65. ^{19}F(d, ^{6}Li)^{15}N $\qquad Q_{\rm m} = -2.539$

Angular distributions of the ^{6}Li ions corresponding to ^{15}N(0) have been measured at $E_{\rm d} = 9.0$ to 12.5 MeV (1967DE14), 14.5 MeV (1964DA1B), 14.9 MeV (1966DE09) and 21 MeV (1965SL1C). Attempts have been made to fit the data with DWBA: see references above and (1963DR1B). See also (1964BL1C).

66. ^{19}F(^{14}N, ^{18}F)^{15}N $\qquad Q_{\rm m} = 0.405$

See (1965WI1A).

^{15}O
(Figs. 11 and 12)

GENERAL:

Model calculations: (1960TA1E, 1960TA1C, 1963CO12, 1963KU1B, 1964AL1L, 1964AM1D, 1964BR1H, 1964RI1A, 1965CO25, 1965GI1B, 1965GR1H, 1965GU1A, 1965HU1D, 1966BO1R, 1966EL08, 1966RI1F, 1966SO05, 1967BO1T, 1967EL03, 1968DE13, 1968EL1A, 1968HO1H, 1968MA2B, 1968SH08, 1968WO1C, 1968ZH1B, 1968ZU02, 1969DE16, 1969EL1B, 1969GU1M, 1969SA1J).

General calculations and reviews: (1964EV1A, 1967FA1A, 1967NE1D, 1968BI1C).

Electromagnetic transitions: (1965RO1N, 1966PO11, 1966RO1P, 1966WA1E, 1967KU1E, 1967PO1J, 1967WA1C, 1968BI1C, 1968SH08, 1968ZH1B, 1968ZH06, 1969KH1C, 1969ZH1A).

Other: (1966WA1K, 1967AU1B, 1969FO1D, 1969HA1G).

Ground state: $J = \frac{1}{2}$ (1963CO17); $\mu = 0.71898$ nm (1963CO17, 1964LI14, 1967CO1D).

See also (1964ST1B, 1965MA1T, 1966MA1V, 1967NE1D, 1967SH14, 1968PE16, 1968RO1E, 1969FU11).

1. ^{15}O(β^+)^{15}N $\qquad Q_{\rm m} = 2.760$

Reported half-lives are listed in Table 15.19 (1954KL36, 1955BA83, 1957KI22, 1957PE12, 1959KI99, 1960JA12): the weighted mean is 122.24 ± 0.16 sec. See also (1963CS02, 1963VA31). Using this value for $\tau_{1/2}$ and $Q_{\rm m}$, $\log ft = 3.643$. See also (1968BA42) and (1965GA1D, 1966MI1F, 1967AM1H, 1968SH08, 1969LE1D, 1969SU15; theor.).

2. ^{7}Li(^{14}N, ^{6}He)^{15}O $\qquad Q_{\rm m} = -2.687$

See (1957AL78).

3. (a) ^{10}B(^{6}Li, n)^{15}O $\qquad Q_{\rm m} = 15.209$
(b) ^{10}B(^{7}Li, 2n)^{15}O $\qquad Q_{\rm m} = 7.957$

See (1957NO17).

Table 15.18: Energy levels of ^{15}O [a]

E_x (MeV $\pm$ keV)	J^π	τ_m (psec) or Γ (keV)	Decay	Reactions
0	$\frac{1}{2}^-$	$\tau_{1/2} = 122.24 \pm 0.16$ sec	β^+	1, 2, 3, 4, 6, 7, 8, 9, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29
5.181 ± 5	$\frac{1}{2}^+$	$\tau_m < 0.1$ psec	γ	8, 9, 16, 17, 22, 24, 25, 26
5.24151 ± 0.52	$\frac{5}{2}^+$	3.2 ± 0.5	γ	8, 9, 16, 17, 20, 21, 22, 24, 25, 26
6.176 ± 3	$\frac{3}{2}^-$	< 0.047	γ	8, 9, 16, 17, 21, 22, 24, 25, 26
6.788 ± 4	$\frac{3}{2}^+$	< 0.028	γ	8, 9, 16, 17, 26
6.859 ± 1	$\frac{5}{2}^+$	0.10 ± 0.06	γ	8, 9, 16, 17, 21, 26
7.2760 ± 0.6	$\frac{7}{2}^+$		γ	8, 16, 17, 21, 24, 26
7.5522 ± 0.5	$\frac{1}{2}^+$	$\Gamma = 1.7 \pm 0.5$ keV	γ, p	9, 16, 17, 21
8.2833 ± 1.5	$\frac{3}{2}^+$	3.6 ± 0.7	γ, p	9, 17, 21
8.739 ± 6	$\frac{1}{2}^+$	32	γ, p	9
8.9180 ± 1.4	$\frac{3}{2}$	3.7 ± 1	γ, p	8, 9, 21
8.9781 ± 1.6	$(\frac{1}{2}, \frac{3}{2})^-$	3.9 ± 0.4	γ, p	8, 9, 21
9.483 ± 3	$\frac{5}{2}^-$	10.1 ± 0.5	γ, p	8, 9, 21
9.50 ± 40	$\frac{3}{2}^+(\frac{1}{2})^+$	280 ± 24	γ, p	9
9.606 ± 1.8	$\frac{3}{2}^-$	8.8 ± 0.5	γ, p	8, 9, 21, 24
9.660 ± 4	$\frac{1}{2}^-$	2 ± 1	p	8, 10, 21
9.72 ± 50	$(\frac{1}{2}, \frac{3}{2})^+$	1190 ± 50	γ, p	9
10.278 ± 8	$+$	16 ± 4	p	10, 21
10.46 ± 10		47	γ, p	9, 10, 21, 24
10.91 ± 15	$\frac{7}{2}^+$	91	p	10, 21
10.939 ± 7	$\frac{1}{2}^+$	84	γ, p	9, 10, 21
11.023 ± 7	$\frac{1}{2}^-$	21	p	10
11.15 ± 15		< 10	p	10
11.20 ± 15	$(\frac{1}{2}, \frac{3}{2})^+$	36	γ, p	9, 10, 21
11.5 ± 100	$T = \frac{3}{2}$			8
11.56 ± 15		< 10	p	10
11.57		140	γ, p	10
11.57 ± 15	$\frac{5}{2}^-$	25	p	9

Table 15.18: Energy levels of ^{15}O [a] (continued)

E_x (MeV ± keV)	J^π	τ_m (psec) or Γ (keV)	Decay	Reactions
11.61 ± 15	$\frac{3}{2}^-(\frac{1}{2}^-)$	25	p	10
11.71 ± 15		< 10	p	10, 21
11.75 ± 15	$\frac{5}{2}^+$	80	p	10
11.846 ± 10	$\frac{5}{2}^-$	50	p	10
11.98 ± 15	$\frac{5}{2}^-$	30	p	10
12.12 ± 15	$\frac{5}{2}^+$	160	p	10
12.47 ± 15	$\frac{5}{2}^-(\frac{3}{2}^-)$	60	p	10
12.8		≈ 230	γ, p	9
12.82	$+$	9	p	10
13.00	$\frac{5}{2}$	28	p, ^{3}He, α	5, 10, 15
13.1			p, d, ^{3}He, α	5
13.4	$\frac{3}{2}^+$	broad	(p, α)	10, 15
13.49	$(\frac{3}{2}^+)$		p	10
13.60	$\frac{5}{2}^+$		p, α	15
13.70	$\frac{3}{2}^-$		p	10
13.79	$\frac{3}{2}^-$		n, p, ^{3}He, α	5, 10, 15, 21
13.87		≈ 140	γ, p	9
14.03 ± 40	$(\frac{1}{2}, \frac{3}{2})^-$	160 ± 20	n, p, ^{3}He	5
14.17	$\frac{5}{2}^-$		p, α	15
14.27 ± 40	$\frac{1}{2}^+$	340 ± 30	n, p, ^{3}He, α	5, 10, 11, 15
14.34	$\frac{5}{2}^+$		p, α	15
14.460 ± 10	$\frac{5}{2}^+$	100 ± 10	n, p, ^{3}He, α	5, 11
14.69 ± 40		170 ± 30	n, p, ^{3}He	5, 11
14.95 ± 40		400 ± 25	n, p, ^{3}He	5, 11
15.43 ± 10		65 ± 15	p, ^{3}He, α	5
15.56 ± 40	$\frac{1}{2}^+$	80 ± 25	p, ^{3}He, α	5
15.84 ± 50	$(\frac{1}{2}, \frac{3}{2})^-$	350	n, p, ^{3}He, α	5, 11
16.04			^{3}He, α	5
16.09			n, ^{3}He, α	5
16.19			^{3}He, α	5
16.43 ± 50	$\frac{1}{2}^+$	170	^{3}He, α	5

Table 15.18: Energy levels of ^{15}O [a] (continued)

E_x (MeV ± keV)	J^π	τ_m (psec) or Γ (keV)	Decay	Reactions
16.48 ± 50		560 ± 90	n, p	11
16.77 ± 50		200	n, ^{3}He, α	5
17.50 ± 50	$(\frac{1}{2}, \frac{3}{2})^-$	600	n, p, ^{3}He, α	5
17.99 ± 50	$(\frac{1}{2}, \frac{3}{2})^-$	200	^{3}He, α	5
18.22 ± 50			n, p, ^{3}He	5
19.02 ± 50			n, ^{3}He	5
19.90 ± 50			n, p, ^{3}He	5
≈ 21		broad	γ, p	9

[a] See also Tables 15.22 and 15.25.

4. ^{11}B(^{6}Li, 2n)^{15}O $\quad Q_m = 3.753$

See (1963HO1E).

5. (a) ^{12}C(^{3}He, n)^{14}O $\quad Q_m = -1.148 \quad E_b = 12.071$
(b) ^{12}C(^{3}He, p)^{14}N $\quad Q_m = 4.779$
(c) ^{12}C(^{3}He, d)^{13}N $\quad Q_m = -3.550$
(d) ^{12}C(^{3}He, ^{3}He)^{12}C
(e) ^{12}C(^{3}He, α)^{11}C $\quad Q_m = 1.858$
(f) ^{12}C(^{3}He, ^{8}Be)^{7}Be $\quad Q_m = -5.782$

Excitation functions for these reactions have been measured over a wide range of energies: see Table 15.20. Observed resonances are displayed in Table 15.21. For discussions of angular distribution measurements which have been measured at many energies over the range displayed in Table 15.20, see the writeups of ^{7}Be in (1966LA04), ^{11}C and ^{12}C in (1968AJ02), and ^{13}N, ^{14}N, and ^{14}O. See also (1964DE1E).

Consideration of the relative yields at $E(^3\text{He}) = 1.21$ and 2.15 MeV lead to the tentative J^π assignments given in Table 15.21 for ^{15}O*(13.00, 13.79) (1957BR18). The assignments for ^{15}O*(14.03, 14.27, 14.46) are derived from analyses of the ^{3}He elastic scattering, particle and $\gamma_{6.44}$ angular distributions, and the total cross sections of the n_0 and p_1 groups (1964KU05). Above $E(^3\text{He}) \approx 5$ MeV, the excitation functions show broad maxima (see Table 15.21) but it is not

Table 15.19: The half-life of ^{15}O

$\tau_{1/2}$ (sec)	Refs.
123.4 ± 1.3	(1954KL36)
121 ± 3	(1955BA83)
120 ± 2	(1957KI22)
123.95 ± 0.5	(1957PE12)
124.1 ± 0.5	(1959KI99)
122.1 ± 0.1	(1960JA12)
122.24 ± 0.16	weighted average

clear that they correspond to excited states in ^{15}O: for instance the maxima in the yields of n_0 (1964DE1C), p_6, d_0, α_0 and α_1 (1960HI07) are not correlated. See, however, (1969WE08). The structures observed in the excitation functions for $p_0 \rightarrow p_9$ at $E(^3\text{He}) = 4.6$ to 11 MeV are attributed to quasi-giant resonances involving single proton orbitals coupled to excited ^{14}N core configurations (1969HA49). Above $E(^3\text{He}) \approx 12$ MeV, the excitation functions do not show clear resonant behavior: see, e.g. (1967GR1L, 1968FO06, 1969FO02).

Broad resonance-like structures in the yield of protons are reported at $E(^3\text{He}) = 7.0$, 7.8, 9.6, 10.6, 13.4 and 14.6 MeV [$\Gamma \approx 1$ MeV] (1970SP1E).

Over the range $E(^3\text{He}) = 6.5 \rightarrow 11$ MeV, the ratio $d\sigma_n/d\sigma_{p_1}$ [to $^{14}O_{g.s.}$ and the first $T = 1$ state of ^{14}N), determined at $10°$, is approximately constant and ≈ 2, as would be expected if isospin were conserved and if Coulomb scattering and Q-value differences can be neglected (1965FU16). (1968LA19) find that the compound nucleus level overlap parameter Γ/D_0 and the spin cut-off parameter σ as obtained from elastic scattering and from the statistical model analysis of three proton groups [$E(^3\text{He}) = 5.29 - 5.50$ MeV] are constant. See also (1970CA1G).

For a survey of the energies at which polarization measurements have been made, see Table 15.20. (1968HU1A) find that at $E(^3\text{He}) = 36$ and 42 MeV, the ^{3}He polarization results are such that optical model calculations require an optical spin-orbit potential depth ≤ 3.5 MeV. See also (1959AJ76).

6. ^{12}C(α, n)^{15}O $\qquad Q_m = -8.507$

$$E_{\text{thresh.}} = 11.341 \pm 0.015 \text{ (1963NE05).}$$

Angular distributions of neutrons corresponding to the ground state of ^{15}O have been measured at $E_\alpha = 14$ MeV (1965AL1J) and at 20.0 to 21.8 MeV (1963KO03). See also ^{16}O in (1971AJ02).

Table 15.20: Recent yield and polarization measurements in $^{12}C + {}^3He$ [a]

(a) *Excitation functions* [b]

$E(^3He)$	Yield of	Refs.
1.0 – 1.8	p_0, p_1, p_2, d_0, α_0	(1965GR1R)
1.4 – 3.5	n	(1964KU06)
1.4 – 6.0	n, α	(1966CI01)
1.4 – 11.45	n_0	(1964OS01)
1.75 – 5.2	α_0	(1963LU05)
2 – 5.5	^{11}C	(1966GO1E)
1.8 – 5.4	$p_0 \rightarrow p_9$, ^3He, α_0	(1964KU05)
1.8 – 5.5	n	(1964DI02)
2 – 4	$p_0 \rightarrow p_8$	(1967CL1C)
2.0 – 5.7	n_0	(1961TO03)
2 – 6.2	^3He, α_0, α_1	(1966BL01, 1966SC12)
2.4 – 3.3	^3He, α_0	(1970JA1E)
≈ 2.5	p_2	(1963LU01, 1963LU1F)
2.7 – 5.4	$\gamma_{6.44}$	(1964KU05)
3.50 – 3.91	^3He	(1967SC27)
4.0 – 5.4	α_1	(1964KU05)
4.0 – 6.0	$p_2 \rightarrow p_6$	(1966BL01)
4.4 – 8.2	^3He, α_0	(1968WE15, 1969WE03)
4.5 – 6.0	α_0	(1969WE03)
4.6 – 11.0	$p_0 \rightarrow p_9$	(1969HA49)
5 – 30	^{11}C, ^{13}N	(1965BR42)
5.2 – 7.8	α_1	(1968WE15, 1969WE03)
5.5 – 11	n_0	(1964DE1C)
5.7 – 10.23	p_6, d_0, α_0, α_1	(1960HI07)
6 – 17	p	(1970SO1G)
6 – 24	^7Be, ^{11}C, ^{13}N	(1962CO31)
8 – 10	^3He, α_0	(1966SC22)
9 – 29	^7Be	(1965EN01)
12.0 – 18.6	$\alpha_0 \rightarrow \alpha_7$	(1967GR1L)
12 – 18.6	d_0, d_1, d_{2+3}, $^3He(0)$, $^3He(1)$	(1968FO06, 1969FO02)

Table 15.20: Recent yield and polarization measurements in $^{12}C + {}^{3}He$ [a] (continued)

$E(^3He)$	Yield of	Refs.
21 – 31.2	^{11}C, ^{13}N	(1959MA1D)
21 – 31	^{7}Be	(1965MA1V)
(b) *Polarization measurements* [b]		
2.24 – 3.70	n_0	(1967SC27)
2.48 – 3.15	p_0	(1967KR1F)
4.1 – 5.9	n	(1967SO1B)
4.5 – 5.5	p_0, p_1	(1967MA1M)
18	^{3}He	(1969LU1C)
29	^{3}He	(1961AG1A, 1964BU1D, 1965FR1E)
31.6	^{3}He	(1969EN03)
36, 42	^{3}He	(1968HU1A)

[a] See also (1959AJ76, 1961FO02).
[b] See also (1964BR1G, 1964DI1C, 1965SC1D, 1966HA21, 1966MA1R, 1968PA1F, 1969PA1C).
[c] See also (1965PE1H, 1966CA1H).

7. (a) $^{12}C(^{6}Li, t)^{15}O$ $\qquad Q_m = -3.721$
(b) $^{12}C(^{14}N, {}^{11}B)^{15}O$ $\qquad Q_m = -8.664$

For reaction (a) see (1969GI1B); for reaction (b) see (1969BR1G).

8. $^{13}C(^{3}He, n)^{15}O$ $\qquad Q_m = 7.125$

Angular distributions of neutrons corresponding to the ground state of ^{15}O have been measured at $E(^3He) = 1.70$ to 5.35 MeV (1965DI07), 2.6, 2.8 and 3.1 MeV (1961JO07, 1961JO24), 2.66 MeV (1961DU1B, 1963DU12: also n_3), 5.0 and 6.2 MeV (1969HO1F: also to $^{15}O^*$(6.18, 6.86, 8.92, 8.98, 9.50, 9.60, 9.66) and 7.8, 8.6 amd 10.1 MeV (1964DE1C). DWBA analyses have been made: (1969HO1F) find $L = 0$ for $^{15}O^*$(0, 8.92, 8.98, 9.66) and $L = 2$ for $^{15}O^*$(6.18, 9.49, 9.60). At $E(^3He) = 11.6$ MeV, a neutron group assigned to a $T = \frac{3}{2}$ state at 11.5 ± 0.10 is reported by (1969BR30).

Table 15.21: Resonances in ^{12}C + ^{3}He

$E(^3\mathrm{He})$ (MeV ± keV)	Resonant for	E_x [a] (MeV)	J^π	$\Gamma_{\mathrm{c.m.}}$ (keV)	Refs.
1.21	p_0, p_2	13.04	$(\frac{5}{2})^-$		(1957BR18)
1.3	p_0, p_1, p_2, p_3, d_0, α_0	12.1			(1957BR18, 1965GR1R)
2.15	n, p_0	13.79	$(> \frac{5}{2})$		(1957BR18)
2.45 ± 40	n_0, p_0, p_1, p_2, p_3	14.03	$(\frac{1}{2}^-, \frac{3}{2}^-)$	160 ± 20	(1957BR18, 1961TO03, 1964KU05, 1964KU06, 1964OS01)
2.75 ± 40	n_0, p_1, p_2, ^{3}He, α	14.27	$\frac{1}{2}^+$	340 ± 30	(1957BR18, 1964KU05, 1964KU06, 1964OS01, 1966CI01, 1970JA1E)
2.990 ± 10	n_0, p_0, p_1, p_2, p_4, p_5, p_8, ^{3}He, α_0	14.460	$\frac{5}{2}^+$	100 ± 10	(1958JO20, 1961TO03, 1964KU05, 1964KU06, 1964OS01, 1970JA1E)
3.28 ± 40	p_0	14.69		180 ± 40	(1964KU05)
3.60 ± 40	p_0, p_1, p_2	14.95		400 ± 25	(1958JO20, 1964KU05)
4.20 ± 10	p_5, p_6, α_0	15.43		65 ± 15	(1964KU05)
4.37 ± 40	p_0, p_1, p_2, p_4, p_7, p_8, α_0	15.56	$\frac{1}{2}^+$	80 ± 25	(1958JO20, 1961TO03, 1964KU05, 1966CI01)
4.65 ± 50	n_0	15.79			(1961TO03, 1964DI02, 1964KU05, 1964OS01)
4.77	α_0	15.89	$\frac{1}{2}^-, \frac{3}{2}^-$	350	(1969WE03)
4.97 ± 20	α_0	16.04			(1969WE08)
5.03 ± 20	α_0 } n_0, ^{3}He	16.09			{ (1961TO03, 1964DI02, 1964KU05, 1964OS01, 1966SC12, 1969WE08)
5.15 ± 20	α_0 }	16.19			
5.45	α_0	16.43	$\frac{1}{2}^+$	170	(1969WE03)
5.88 ± 50	n_0, ^{3}He, α_0	16.77	$\frac{1}{2}^-, \frac{3}{2}^-$	200	(1964OS01, 1966SC12, 1969WE03)
6.80 ± 50	n_0, p	17.50	$\frac{1}{2}^-, \frac{3}{2}^-$	600	(1964OS01, 1969WE03, 1970SO1G)
7.4	α_0	17.99	$\frac{1}{2}^-, \frac{3}{2}^-$	200	(1969WE03)
7.70 ± 50	n_0, p	18.22			(1964OS01, 1970SO1G)
8.70 ± 50	n_0	19.02			(1964OS01)
9.80 ± 50	n_0, p	19.90			(1964OS01, 1970SO1G)

[a] See also text.

Table 15.22: Radiative decays in ^{15}O

E_i (MeV)	J_i^π	E_f (MeV)	J_f^π	Branch (%)	Γ_γ [a] (eV)	Refs.
6.18	$\frac{3}{2}^-$	0	$\frac{1}{2}^-$	100		(1965WA16)
		5.18	$\frac{1}{2}^+$	< 2.5		(1965WA16)
		5.24	$\frac{5}{2}^+$	< 2.5		(1965WA16)
6.79	$\frac{3}{2}^+$	0	$\frac{1}{2}^-$	100		(1965WA16, 1968GI11)
		5.18	$\frac{1}{2}^+$	< 6		(1965WA16)
				< 3		(1968GI11)
		5.24	$\frac{5}{2}^+$	< 6		(1965WA16)
				< 3		(1968GI11)
		6.18	$\frac{3}{2}^-$	< 7		(1965WA16)
6.86	$\frac{5}{2}^+$	0	$\frac{1}{2}^-$	< 10		(1965WA16)
				< 12		(1968GI11)
		5.18	$\frac{1}{2}^+$	< 15		(1965WA16)
				< 4		(1968GI11)
		5.24	$\frac{5}{2}^+$	100		(1965WA16, 1968GI11)
		6.18	$\frac{3}{2}^-$	< 0.4		(1965WA16)
7.28	$\frac{7}{2}^+$	0	$\frac{1}{2}^-$	< 30		(1965WA16)
				< 12		(1968GI11)
				3.8 ± 1.2		(1969KU01)
		5.18	$\frac{1}{2}^+$	< 10		(1965WA16)
				< 4		(1968GI11)
		5.24	$\frac{5}{2}^+$	100		(1965WA16, 1968GI11)
				96.2 ± 1.2		(1969KU01)
		6.18	$\frac{3}{2}^-$	< 2		(1965WA16)
7.55	$\frac{1}{2}^+$	0	$\frac{1}{2}^-$	≈ 3		(1960TA17)
				3.5 ± 0.5		(1963HE11)
		5.18	$\frac{1}{2}^+$	16.2 ± 2		(1960TA17)
				15.8 ± 0.6		(1963HE11)
		6.18	$\frac{3}{2}^-$	57.9 ± 0.6		(1960TA17)
				57.4 ± 0.6		(1963HE11)
		6.79	$\frac{3}{2}^+$	22.9 ± 2		(1960TA17)
				23.3 ± 0.6		(1963HE11)

Table 15.22: Radiative decays in ^{15}O (continued)

E_i (MeV)	J_i^π	E_f (MeV)	J_f^π	Branch (%)	Γ_γ [a] (eV)	Refs.
		6.86	$\frac{5}{2}^+$	[b]		
8.28	$\frac{3}{2}^+$	0	$\frac{1}{2}^-$	53.8 ± 0.25	0.531	(1966EV01)
		5.24	$\frac{5}{2}^+$	42.7 ± 0.5	0.405	(1966EV01)
		6.18	$\frac{3}{2}^-$	2.2 ± 0.6	0.021	(1966EV01)
		6.86	$\frac{5}{2}^+$	1.2 ± 0.3	0.011	(1966EV01)
8.74 [c]	$\frac{1}{2}^+$	5.18	$\frac{1}{2}^+$	67	0.32	(1966EV01)
		6.18	$\frac{3}{2}^-$	33	0.16	(1966EV01)
8.92	$\frac{1}{2}^-$	0	$\frac{1}{2}^-$	21 ± 2	0.056	(1966EV01)
		5.18	$\frac{1}{2}^+$	23 ± 6	0.094	(1966EV01)
		6.18	$\frac{3}{2}^-$	30 ± 3	0.094	(1966EV01)
		6.86	$\frac{5}{2}^+$	26 ± 3	0.069	(1966EV01)
8.98	$\frac{1}{2}^-$	0	$\frac{1}{2}^-$	93.4	0.74	(1966EV01)
		5.18	$\frac{1}{2}^+$	5.9	0.046	(1966EV01)
9.49	$\frac{5}{2}^-$	0	$\frac{1}{2}^-$	86	2.1	(1967EV02)
		5.24	$\frac{5}{2}^+$	6.5	0.15	(1967EV02)
		6.18	$\frac{3}{2}^-$	0.7	0.22	(1967EV02)
		6.86	$\frac{5}{2}^+$	3.4	0.08	(1967EV02)
		7.28	$\frac{7}{2}^+$	5.1	0.11	(1967EV02)
9.50	$\frac{3}{2}^+(\frac{1}{2}^+)$	0	$\frac{1}{2}^-$	≈ 100		(1967EV02)
9.60	$\frac{3}{2}^-$	0	$\frac{1}{2}^-$	79	4.0	(1967EV02)
		5.24	$\frac{5}{2}^+$	19	1.0	(1967EV02)
		6.18	$\frac{3}{2}^-$	2	0.1	(1967EV02)

[a] (1951DU08, 1966EV01). See also (1959HE47).
[b] Intensity $< 25\%$ of transition to ^{15}O*(6.79) (1959PO79).
[c] See also (1959HE47).

Branching ratios measured by (1965WA16) are listed in Table 15.22. The measured E_γ lead to $E_x = 6.180 \pm 0.004$, 6.857 ± 0.0032 and 7.284 ± 0.007 MeV (1965WA16).

See also (1964BR13, 1968HI1J, 1968ST19), (1965SH1E, 1966SH1F; theor.) and ^{16}O in (1971AJ02).

9. ^{14}N(p, γ)^{15}O $\qquad Q_m = 7.293$

Table 15.23: Resonances in ^{14}N + p

E_p (keV)	Γ_{lab} (keV)	$\omega\Gamma_\gamma$ (eV)	Particles out	J^π	E_x (MeV)	Refs.
278.1 ± 0.4	1.7 ± 0.5	0.014	γ	$\frac{1}{2}^+$	7.5522	(1951DU08, 1955BA83, 1957PIZZ, 1959PO79, 1960TA17, 1963HE11)
1061.6 ± 1.4	3.9 ± 0.7	0.95	γ	$\frac{3}{2}^+$	8.2833	(1951DU08, 1956TA16, 1957HA03, 1959GA05, 1959HE47, 1959VA04, 1959VA08, 1963HE11, 1966EV01)
1550 ± 6	34	0.16	γ	$\frac{1}{2}^+$	8.739	(1951DU08, 1956TA16, 1957BO58, 1957HA03, 1966EV01)
1742.0 ± 1.2 [a]	4 ± 1	0.21	γ	$\frac{3}{2}$	8.918	(1951DU08, 1956TA16, 1957BO58, 1957HA03, 1959BA16, 1959VA08, 1963CO13, 1966EV01)
1806.4 ± 1.5 [a]	4.2 ± 0.4	0.52	γ	$(\frac{1}{2}, \frac{3}{2})^-$	8.9781	(1951DU08, 1956TA16, 1957BO58, 1957HA03, 1959VA08, 1963CO13, 1966EV01)
2348 ± 3	10.8 ± 0.5	2.4	γ	$\frac{5}{2}^-$	9.483	(1951DU08, 1957BO58, 1959VA08, 1967EV02, 1967LA05, 1967LA10, 1969OC1B)
2368 ± 32	300 ± 26		γ	$\frac{3}{2}^+(\frac{1}{2}^+)$	9.50	(1957BO58, 1959VA08, 1967EV02, 1967LA05, 1967LA10)
2479 ± 1.7	9.4 ± 0.5	3.3	γ	$\frac{3}{2}^-$	9.606	(1951DU08, 1959VA08, 1967EV02, 1967LA05, 1967LA10, 1969OC1B)
2537 ± 4	2 ± 1		p	$(\frac{7}{2}, \frac{9}{2})^-$	9.660	(1967LA05, 1967LA10)
2600 ± 50	1270 ± 50	46	γ	$(\frac{1}{2}, \frac{3}{2})^+$	9.72	(1951DU08)
3200 ± 8	17 ± 4		p	$+$	10.278	(1957BO58, 1959VA08, 1967KU1M)
3390 ± 10	50		γ, p		10.46	(1957BO58, 1959VA08, 1969OC1B)
3880 ± 15	97		p_0	$\frac{7}{2}^+$	10.91	(1959BA16, 1967KU1M, 1969WE02)
3908 ± 7	90		γ, p_0, p_1	$\frac{1}{2}^+$	10.939	(1956BA34, 1969OC1B, 1969WE02)
3998 ± 7	22		p_0, p_1	$\frac{1}{2}^-$	11.023	(1956BA34, 1969WE02)
4130 ± 15	< 10		p_0		11.15	(1969WE02)
4190 ± 15	39		γ, p_0	$(\frac{1}{2}, \frac{3}{2})^+$	11.20	(1969OC1B, 1969WE02)
4575 ± 15	< 10		p_0		11.561	(1969WE02)
4580 ± 15	27		p_0	$\frac{5}{2}^-$	11.57	(1969WE02)
4580	150		γ		11.57	(1969OC1B)
4630 ± 15	27		p_0	$\frac{3}{2}^-(\frac{1}{2}^-)$	11.61	(1969WE02)
4740 ± 15	< 10		p_0		11.71	(1969WE02)
4780 ± 15	85		p_0, p_1	$\frac{5}{2}^+$	11.75	(1956BA34, 1969WE02)
4881 ± 10	54		p_0, p_1	$\frac{5}{2}^-$	11.846	(1956BA34, 1969WE02)
5020 ± 15	32		p_0	$\frac{5}{2}^-$	11.98	(1969WE02)
5180 ± 15	172		p_0, p_1	$\frac{5}{2}^+$	12.12	(1969WE02)
5550 ± 15	64		p_0, p_1, p_2	$\frac{5}{2}^-(\frac{3}{2}^-)$	12.47	(1969WE02)
5900	≈ 250		γ		12.8	(1969OC1B)
5920	10		p	$+$	12.82	(1967KU1M)
6100	30		$p_0 \rightarrow p_2$, α_0	$\frac{5}{2}^+$	12.9	(1967KU1M, 1968SH11)
6600	broad		(p_2, α_0)	$\frac{3}{2}^+$	13.45	(1968SH11, 1969OC1B)
6640			(p_0), p_2	$(\frac{3}{2}^+)$	13.49	(1968SH11)
6760			α_0	$\frac{5}{2}^+$	13.60	(1968SH11)
6870			p_2	$\frac{3}{2}^-$	13.70	(1968SH11)

Table 15.23: Resonances in ^{14}N + p (continued)

E_{p} (keV)	Γ_{lab} (keV)	$\omega\Gamma_{\gamma}$ (eV)	Particles out	J^{π}	E_{x} (MeV)	Refs.
6960			p_1, p_2, p_4, α_0	$\frac{3}{2}^-$	13.79	(1968SH11)
7050	≈ 150		γ		13.87	(1969OC1B)
7370			α_0	$\frac{5}{2}^-$	14.17	(1968SH11)
7500	≈ 800		n, p_2, α_0		14.3	(1964KU06, 1968SH11)
7550			α_0	$\frac{5}{2}^+$	14.34	(1968SH11)
7700			n		14.5	(1964KU06)
7950	170 ± 50		n		14.71	(1964KU06)
8200			n		14.94	(1964KU06)
9050			n		15.73	(1964KU06)
9400			n		16.1	(1964KU06)
9850 ± 50	600 ± 100		n		16.48	(1964KU06)

[a] Comparison of analog states in ^{15}N and ^{15}O shows that there should be a (as yet unreported) state in ^{15}O at $E_{\mathrm{x}} \approx 8.95$ MeV. This corresponds to $E_{\mathrm{p}} \approx 1.75$ MeV, and the analysis of the $E_{\mathrm{p}} = 1.74$ and 1.81 MeV resonances is therefore possible in error (E.K. Warburton, private communication).

Observed resonances are listed in Table 15.23 (1951DU08, 1955BA83, 1957PIZZ, 1959GA05, 1959HE47, 1959PO79, 1959VA04, 1959VA08, 1960TA17, 1963HE11, 1966EV01, 1967EV02, 1969OC1B). Branching ratios are displayed in Table 15.22 (1960TA17, 1963HE11, 1966EV01).

The cross section increases from $(8.5 \pm 3.7) \times 10^{-12}$ b at 100 keV to $(140 \pm 30) \times 10^{-12}$ b at 135 keV (1957LA13). Extrapolation from the $E_{\rm p} = 0.28$ MeV resonance gives $S(0) = 2.75 \pm 0.50$ keV · b, with zero slope to $E_{\rm p} = 0.05$ MeV (1963HE11). For astrophysical implications, see (1964FO1A, CA65, 1968DU1F). The J^π assignments shown in Table 15.23 arise from considerations of branching ratios, measurements of angular distributions of γ-rays and the studies discussed in reaction 10. Angular correlation measurements also lead to $J^\pi = \frac{3}{2}^+$ and $\frac{3}{2}^-$ for ^{15}O*(6.79, 6.18). The results are also consistent with $J = \frac{1}{2}$ for ^{15}O*(5.18) (1959PO79). Energies for states involved in the cascade decays are $E_{\rm x} = 5.19 \pm 0.01$, 6.15 ± 0.03 and 6.79 ± 0.01 MeV (1959PO79), 5.168 ± 0.015, 6.154 ± 0.010, 6.788 ± 0.008 MeV (1960TA17). At $E_{\rm p} = 0.8$ MeV, the non-resonant radiation goes primarily [$(81 \pm 3\%)$] via cascades through ^{15}O*(5.2, 6.18, 6.79) (1963BA1P). See also (1959HE47).

The excitation function for γ_0 for $E_{\rm p} = 6.4$ to 19 MeV is characterized by four very pronounced peaks, ≈ 1 MeV, wide, below $E_{\rm x} = 19$ MeV. The $90°$ excitation function then shows a giant resonance peak centered at $E_{\rm x} \approx 21$ MeV (1968KU1F): see, however, (1959CO1C, 1961CO02). See also (1964TA05).

See also (1966ED1A) and (1969ZH1A; theor.).

10. (a) ^{14}N(p, p)^{14}N $\qquad E_{\rm b} = 7.293$

(b) ^{14}N(p, 2p)^{13}C $\qquad Q_{\rm m} = -7.550$

The yields of elastic and inelastic protons, and of γ-rays have been studied at many energies: see (1959AJ76) and Table 15.24. The scattering anomalies are superposed on a background which decreases less rapidly than the Rutherford cross section; for $E_{\rm p} < 2.3$ MeV, the background is largely s-wave with some p-wave contribution above $E_{\rm p} = 1.5$ MeV.

Observed resonances are displayed in Table 15.23: see (1959AJ76) and (1959BA16, 1959VA08, 1963CO13, 1967KU1M, 1967LA05, 1967LA10, 1968SH11, 1969WE02). At $E_{\rm p} = 9$, 10 and 10.7 MeV, broad structures, possibly intermediate-state resonances, are reported by (1968BO36). See also (1961TA06, 1964DO03, 1966MA02) and (1969AL1H; theor.).

Polarization studies have been made at many energies: see Table 15.24 (1961RO05, 1961RO13, 1965RO22, 1966BE1M, 1966BR09, 1966DR02, 1966ST05, 1968GE04). See also the reviews in (1966RO1R, 1966RO1B, 1969WA11) and (1965TA07; theor.).

Spallation measurements are reported by (1967AU1A, 1967GR1K, 1968JA1M, 1968JU1B). For astrophysical considerations see (1967LI1B).

For reaction (b), see (1966MA02).

11. ^{14}N(p, n)^{14}O $\qquad Q_{\rm m} = -5.927 \qquad E_{\rm b} = 7.293$

Table 15.24: Recent ^{14}N(p, p)^{14}N yield curves and polarization studies [a]

(a) *Yield curves*

E_p (MeV)	of protons to ^{14}N*	Refs.
0.9 – 4.0	g.s.	(1959BA16)
1.0 – 2.0	g.s.	(1961CO29, 1963CO13)
1.7 – 3.5	g.s.	(1959VA08)
1.9 – 3.0	g.s.	(1967LA05, 1967LA10)
2.6 – 4.8	g.s.	(1966DR02)
3.6 – 14.5	g.s.	(1967KU1M)
3.7 – 5.7	g.s., 2.31	(1967WE1B, 1969WE02)
5.28 – 5.7	3.94	(1967WE1B, 1969WE02)
6 – 9	g.s., 2.31, 3.94	(1968SH11)
6 – 11.5	g.s., 2.31, 3.94	(1968BO36)
6.8 – 9	5.11	(1968SH11)
6.8 – 11.5	5.11	(1968BO36)
8.4 – 11.5	5.83	(1968BO36)
9 – 11.5	4.91, 5.69	(1968BO36)
10 – 12	6.44, 7.03	(1968BO36)

(b) *Polarization measurements*

3.0 – 4.8	g.s.	(1966DR02)
4.9 – 10.1	g.s.	(1966BR09)
7.1 – 8.5	2.31	(1966BR09)
7.6 – 11.8	g.s.	(1966ST05)
7.8	g.s.	(1961RO13)
8.1 – 8.5	3.94	(1966BR09)
10.4	g.s.	(1961RO05)
14.5	g.s.	(1965RO22)
21.0	g.s.	(1966BE1M)
155	g.s.	(1968GE04)

[a] See also (1959AJ76).

The excitation function has been measured for $E_p = 6.3$ to 12 MeV. Broad resonances are observed for $E_p = 7.5$ to 9.85 MeV: see Table 15.23 (1964KU06). Broad resonance structure continues in the region up to $E_p \approx 16.5$ MeV (1966KU12). See also (1963VA1C, 1965VA23, 1969VE02), (1969AL1H; theor.) and ^{14}O. See also (1966RE1D, 1969BA1N) for astrophysical considerations.

12. ^{14}N(p, d)^{13}N $\qquad Q_m = -8.328 \qquad E_b = 7.293$

See ^{13}N and (1963VA1C).

13. ^{14}N(p, t)^{12}N $\qquad Q_m = -22.139 \qquad E_b = 7.293$

See ^{12}N in (1968AJ02).

14. ^{14}N(p, ^{3}He)^{12}C $\qquad Q_m = -4.779 \qquad E_b = 7.293$

The integrated cross section for this reaction has been studied for $E_p = 8.2$ to 10.5 MeV (1968SH11). See also (1966MA02).

15. ^{14}N(p, α)^{11}C $\qquad Q_m = -2.920 \qquad E_b = 7.293$

In the range $E_p = 6$ to 9 MeV, the cross section for ground state α-particles is large and shows many resonances: see Table 15.23 (1968SH11). Integrated cross sections for α_0 and α_1 are also reported for $E_p = 8.2$ to 10.5 MeV by (1968SH11). See also (1952BL64, 1963VA1C, 1966MA02, 1969WE02) and see (1966RE1D) for astrophysical implications.

16. ^{14}N(d, n)^{15}O $\qquad Q_m = 5.068$

Angular distribution studies have been conducted at many energies: see Table 15.26 (1953EV03, 1960EL04, 1960MO18, 1960RE07, 1962GR18, 1963CH1D, 1963GI16, 1965SI13, 1966LO1N, 1967MU12, 1968RI1T, 1969RI1C). Information derived from DWBA analysis of the angular distributions, and from the very accurate γ-ray measurements of (1965WA16, 1966AL18, 1967CH19) are shown in Table 15.27.

Table 15.25: Lifetimes of some ^{15}O states

E_x (MeV)	τ_m (psec)	Reaction	Refs.
5.18	< 0.3	^{16}O(^{3}He, α)	(1965AL19)
	< 0.3	^{14}N(d, n)	(1965WA03)
	< 0.1	^{16}O(γ, n)	(1969MU07)
5.24	> 1	^{14}N(d, n), ^{16}O(^{3}He, α)	(1965AL19)
	> 5	^{14}N(d, n)	(1965WA03)
	3.2 ± 0.5	^{14}N(d, n)	(1967BI11)
6.18	< 0.047	^{14}N(d, n)	(1968GI11)
	< 0.1	^{16}O(γ, n)	(1969MU07)
6.79	< 0.028	^{14}N(d, n)	(1968GI11)
6.86	0.10 ± 0.06	^{14}N(d, n)	(1966AL18)
	< 0.018	^{14}N(d, n)	(1968GI11)
7.28	(1.25 ± 0.3)	^{14}N(d, n)	(1966AL18)
	(0.70 ± 0.15)	^{14}N(d, n)	(1968GI11)

Table 15.26: Recent ^{14}N(d, n)^{15}O angular distribution studies [a]

E_d (MeV)	Distribution of neutron groups	Refs.
$0.91 - 5.27$	n_0	(1960RE07)
$1.35 - 2.80$	n_0	(1960EL04, 1965SI13)
$1.53 - 2.90$	n_0	(1960MO18)
2.2	n_0	(1966LO1N)
2.55, 2.7	n_{4+5}	(1960EL04)
2.83	$n_1 + n_2$, n_3	(1962GR18, 1963GI16)
2.85	n_1, n_2, n_4, n_5	(1963CH1D)
$3.4 - 5.35$	n_0, n_2, n_3, n_4, n_5, n_6, n_7	(1968RI1T, 1969RI1C)
5	n_0, n_3, n_{4+5}, n_6	(1967MU12)
7.7	n_0, n_{1+2}, n_3, n_{4+5}, n_7, n_8	(1953EV03)

[a] See also (1959AJ76).

Table 15.27: Levels of ^{15}O from ^{14}N(d, n)^{15}O and ^{14}N(^{3}He, d)^{15}O

E_x [a] (MeV)	l_p [b]	l_p [c]	l_p [d]	E_x [e] (MeV ± keV)	l_p [f]	l_p [g]	J^π [h]
0	1	1	1		1	1	$\frac{1}{2}^-$
5.18					(0)	(0)	$\frac{1}{2}^+$
5.24	(2)		2	5.24151 ± 0.52	2	2	$\frac{5}{2}^+$
6.18	1	1	1	6.180 ± 4	1	1	$\frac{3}{2}^-$
6.79	0	$0+2$	0		0	0	$\frac{3}{2}^+$
6.86	2	$0+2$	0	6.8598 ± 1.0	2	2	$\frac{5}{2}^+$
7.28	2	2		7.2762 ± 0.6	2	2	$\frac{7}{2}^+$
7.55	0		1			0	$\frac{1}{2}^+$
8.28						0	$\frac{3}{2}^+$

[a] Nominal energies.
[b] (d, n): (1968RI1T, 1969RI1C).
[c] (d, n): (1967MU12).
[d] (d, n): (1953EV03).
[e] (d, n): (1965WA16, 1966AL18, 1967CH19).
[f] (^{3}He, d): (1968BO14).
[g] (^{3}He, d): (1969AL04).
[h] (1968RI1T, 1969AL04, 1969RI1C).

Neutron thresholds have been observed at $E_d = 0.143 \pm 0.004$ and 0.206 ± 0.005 MeV (1963CS02), 1.24 ± 0.02, 1.967 ± 0.004 and 2.044 ± 0.004 (1955MA85), corresponding to ^{15}O*(5.19, 5.25, 6.15, 6.79, 6.86). See also (1965MA1K).

Gamma ray branding ratios are shown in Table 15.22 (1965WA16, 1968GI11). Lifetime measurements are listed in Table 15.25 (1965AL19, 1965WA03, 1966AL18, 1967BI11, 1968GI11). See also (1959MO10, 1966AV1A).

17. (a) ^{14}N(^{3}He, d)^{15}O $\quad Q_m = 1.799$

(b) ^{14}N(^{3}He, np)^{15}O $\quad Q_m = -0.425$

$Q_0 = 1.803 \pm 0.010$ (1959YO25);

$Q_0 = 1.802 \pm 0.015$ (1960FO01).

Angular distributions obtained at $E(^3\text{He}) = 11$ MeV (1968BO14) and 14 MeV (1969AL04) have been analyzed by DWBA: see Table 15.27. The angular distribution of deuterons has also been measured at $E(^3\text{He}) = 5.1$ MeV (1960FO01). For reaction (b) see (1967AD1F) and ^{16}F in (1971AJ02).

18. ^{14}N(α, t)^{15}O $\qquad Q_\text{m} = -12.521$

Angular distributions of tritons corresponding to the ground state of ^{15}O have been determined at $E_\alpha = 43$ MeV (1967DE1K) and at 56 MeV (1968GA1C, 1969GA11). At the higher energy, a detailed comparison is made with the results from the mirror reaction ^{14}N(α, ^{3}He)^{15}N (1969GA11).

19. ^{14}N(^{11}B, ^{10}Be)^{15}O $\qquad Q_\text{m} = -3.936$

See (1967PO13, 1969BR1D).

20. ^{15}N(p, n)^{15}O $\qquad Q_\text{m} = -3.542$

$$E_\text{thresh.} = 3.7808 \pm 0.0011 \; [Q_0 = -3.5425 \pm 0.0011] \text{ (1958JO28, 1958WE1C).}$$

Angular distributions of ground state neutrons have been measured at $E_\text{p} = 3.95$ to 5.99 MeV (1958JO28), 3.95 to 8.99 MeV, 11.4 and 13.6 MeV (1963HA46; also n_2 at $E_\text{p} = 5.5$ MeV), 5.5 to 13.6 MeV (1961WO03) and 18.5 MeV (1964AN1B). See also (1961SA01), (1968WO1D), (1964SA1D, 1968HA15; theor.), and ^{16}O in (1971AJ02).

21. ^{15}N(^{3}He, t)^{15}O $\qquad Q_\text{m} = -2.778$

A number of triton groups have been seen in this reaction. Angular distributions of these at $E(^3\text{He}) = 39.8$ and 44.6 MeV, analyzed using a local two-body interaction with an arbitrary spin-isospin exchange mixture, lead to the L-values shown in Table 15.28 (1967BA13, 1968BA1E, 1969BA06). See also (1966EC1B, 1969BO13).

22. ^{16}O(γ, n)^{15}O $\qquad Q_\text{m} = -15.668$

Table 15.28: Levels of ^{15}O from ^{15}N(^{3}He, t)^{15}O [a]

E_x (MeV ± keV)	L	E_x (MeV ± keV)
0	0	9.63 ± 40
5.24 ± 30	1, 3	10.30 ± 40
6.18	0	10.49 ± 40
6.84 ± 40	1, 3	10.97 ± 50
7.28	3	11.21 ± 60
7.55	3	11.69 ± 40
8.28	1	12.34 ± 40
8.94 ± 40		13.78 ± 40
9.47 ± 50		

[a] (1967BA13, 1968BA1E, 1969BA06); $E(^{3}\text{He}) = 39.8$, 44.6 MeV.

The spectrum of photoneutrons has been investigated at many energies. Measurements over the giant dipole resonance region show the predominant strength is to the $J^\pi = \frac{1}{2}^-$ and $\frac{3}{2}^-$ states at $E_x = 0$ and 6.18 MeV, consistent with the basic validity of the single-particle, single-hole theory of photoexcitation in ^{16}O. However, the two positive parity states at $E_x = 5.18$ and 5.24 MeV MeV are also strongly populated, auggesting some non-single-particle excitation in that region in ^{16}O (1965CA14, 1965MA45, 1966OW01, 1967CA1C, 1967CA1P, 1968BA2L, 1969UL01). See also (1963FU05, 1964TA1C, 1965WI03, 1967FI1E, 1968JO1H, 1969CO15, 1969HO1T, 1969JO1N, 1969MU07). See also (1968ZH1B; theor.). For lifetime measurements of ^{15}O*, see Table 15.25 (1969MU07). See also ^{16}O in (1971AJ02).

23. ^{16}O(n, 2n)^{15}O $\qquad Q_m = -15.668$

See (1955AJ61).

24. (a) ^{16}O(p, d)^{15}O $\qquad Q_m = -13.443$

(b) ^{16}O(p, pn)^{15}O $\qquad Q_m = -15.668$

Reaction (a) goes primarily to the ground state and 6.18 MeV state ($J^\pi = \frac{1}{2}^-$ and $\frac{3}{2}^-$, respectively). Angular distributions have been reported at many energies: see Table 15.29 (1961LE1A, 1963KA26, 1963LE03, 1966GR1A, 1967CH15, 1968LE01, 1969BA05, 1969SN03). See also

Table 15.29: ^{16}O(p, d)^{15}O angular distribution studies

E_p (MeV)	Distribution of deuteron groups to ^{15}O*	Refs.
$18.5 - 20$	g.s.	(1961LE1A, 1963LE03)
$21.3 - 45.3$	g.s.	(1969SN03)
$25.5 - 45.3$	$5.18 + 5.24$, 6.18	(1969SN03)
30.3	g.s., 6.18	(1967CH15)
35, 40	g.s., 5.18, 6.18	(1966GR1A)
39.8	g.s., 6.18	(1963KA26)
45.3	7.28, 9.60, 10.46 [a]	(1969SN03)
100	g.s., 6.18	(1968LE01, 1968LI1A)
155.6	g.s., 6.18, 7, 10 [b]	(1965DE1A, 1969BA05, 1969TO1A)

[a] Partial angular distributions to many excited states.
[b] See, however, (1968LE01).

(1968SH08; theor.). The energy of ^{15}O*(7.28) is 7.285 ± 0.010 MeV (1966MA1A). See also (1964BA04, 1966SH1A).

For reaction (b), see (1962BA1A, 1962FO03, 1963BE1A, 1967FU1A, 1968PU1A).

25. ^{16}O(d, t)^{15}O $\qquad Q_m = -9.411$

Angular distributions have been measured at $E_d = 15$ MeV (1961KE01; t_0), 20 MeV (1961VL02; t_0), 20 MeV (1969PU04; t_0, t_1, t_2, t_3; $l_n = 1, 0, 2, 1$) and 28 MeV (1968GA13; t_0). At $E_d = 28$ MeV, detailed comparison is made with the results from the mirror reaction ^{16}O(d, ^{3}He)^{15}N (1968GA13).

26. ^{16}O(^{3}He, α)^{15}O $\qquad Q_m = 4.910$

$Q_0 = 4.916 \pm 0.010$ (1959HI68);

$Q_0 = 4.917 \pm 0.015$ (1962SH21).

The $p_{1/2}$ and $p_{3/2}$ hole states at $E_x = 0$ and 6.18 MeV are strongly populated in this reaction, see e.g. (1965WA17). Information on these and other states of ^{15}O observed in this reaction is shown in Table 15.30 (1959HI68, 1959YO25, 1967HE1A, 1968BO14). The J-values are derived from angular correlation measurements (1967HE1A, 1966GA19, 1966GO15, 1967GO07,

Table 15.30: Excited states of ^{15}O from ^{16}O(^{3}He, α)^{15}O

E_x (MeV ± keV)	Refs.	l [b]	J	Refs.
0		1		
5.174 ± 10	(1959HI68)	0		
5.167 ± 15	(1959YO25)			
5.193 ± 11	(1965AL19)			
5.233 ± 10	(1959HI68)	2	$\frac{5}{2}$	(1966GO15, 1967GO07)
5.243 ± 10	(1965AL19)			
6.18	[a]	1	$\frac{3}{2}$	(1966GO15)
6.79	[a]	2	$\frac{3}{2}$	(1966GA19, 1968GI01)
6.86	[a]	2	$\frac{5}{2}$	(1966GA19, 1968GI01)
7.2742 ± 1.4	(1967HE1A)		$\frac{7}{2}$	(1967HE1A)

[a] Nominal energy.
[b] (1968BO14).

1968GI01): see also (1968BO14). Angular distributions have been measured for $E(^3\text{He}) = 5.2$ to 36.6 MeV: see Table 15.31 (1959HI73, 1960TA12, 1962SE13, 1965AL05, 1965AR07, 1968BO14, 1969BR07). Branching ratios are displayed in Table 15.22 (1965WA16, 1969KU01). See also (1965WA03). The lifetimes of ^{15}O*(5.18, 5.24) are < 0.3 and > 1 psec, respectively (1965AL19): see also Table 15.25. A comparison of the 5 MeV transitions E3/M2 mixing ratios in ^{15}O and ^{15}N strongly suggest a collective character for the E3 component of these transitions (1968GI01).

The ratio of mixing ratios of the mirror decays ^{15}O*($6.18 \rightarrow 0$) and ^{15}N*($6.32 \rightarrow 0$) are in disagreement with the IPM suggesting a collective contribution to the mirror $\frac{3}{2}^-$ levels (1966RO1U).

The M2/E1 mixing ratio for the ^{15}O*(6.79) transition indicates an exceptionally high retardation of an E1 transition in a non-self-conjugate nucleus, as is also true of the analog transition in ^{15}N (1968GI01).

The $E_x = 7.28$ MeV state, $J = \frac{7}{2}$, has a negligable effect on the (astrophysical) CNO cycle (1967HE1A).

See also (1961DU02, 1961SI09, 1966AG1B) and ^{19}Ne in (1972AJ02).

27. ^{16}O(^{14}N, ^{15}N)^{15}O $\qquad Q_m = -4.833$

See (1965GA1B, 1969BR1D).

28. ^{17}O(p, t)^{15}O $\qquad Q_m = -11.329$

Table 15.31: $^{16}O(^3He, \alpha)$ angular distribution studies

$E(^3He)$ (MeV)	Distribution of α groups to $^{15}O^*$	Refs.
5.2	g.s.	(1960TA12)
5.7, 5.9	g.s.	(1959HI73)
$8 - 10$	g.s.	(1965AL05)
9.2	g.s., 5.18, 5.24	(1959HI73)
$9.8 - 11.7$	g.s.	(1966BR13, 1969BR07)
11	g.s., 5.18, 5.24, 6.18, 6.79, 6.86	(1968BO14)
16.6, 25.8, 36.6	g.s., $5.18 + 5.24$, 6.18	(1965AR07)
29	$5.18 + 5.24$, 6.18	(1962SE13)

See (1969ME1M).

29. $^{19}F(p, n\alpha)^{15}O$ $\qquad Q_m = -7.553$

See (1962FO03).

^{15}F

Mass of ^{15}F: A calculation using an isobaric mass formula predicts that ^{15}F is unstable with respect to proton emission by 2.32 MeV: the mass excess of ^{15}F is then 17.62 MeV (1966KE16). See also (1957MU99, 1961BA1C).

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(Closed 31 December 1969)

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