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Energy Levels of Light Nuclei
$A = 15$

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Abstract: An evaluation of $A = 13$–15 was published in *Nuclear Physics A*360 (1981), p. 1. This version of $A = 15$ 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. Also, Reference key numbers have been changed to the NNDC/TUNL format.

(References closed August 1, 1980)

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^{15}Li

(Not illustrated)

^{15}Li has not been observed: its atomic mass excess is calculated to be 81.60 MeV. It is then unstable with respect to decay into ^{14}Li + n and ^{13}Li + 2n by 1.24 and 3.90 MeV, respectively (1974TH01). See also ^{13}Li.

^{15}Be

(Not illustrated)

^{15}Be has not been observed. It is calculated to be particle unstable with respect to decay into ^{14}Be + n by 2.42 MeV. The binding energy of ^{13}Be + 2n is $+0.31$ MeV. The calculated mass excess is 51.18 MeV (1974TH01).

^{15}B

(Fig. 13)

The Q-value of the ^{48}Ca(^{18}O, ^{51}V)^{15}B reaction is -21.76 ± 0.05 MeV which leads to an atomic mass excess of 28.96 ± 0.05 MeV for ^{15}B. At $E(^{18}\text{O}) = 102$ MeV, this 3 proton transfer reaction has a $0°$ differential cross section of 1.2 μb/sr. No excited states were observed (1978BH02). ^{15}B is then stable with respect to ^{14}B + n by 2.77 MeV. ^{15}B has neither been observed in the ^{11}B(^{18}O, ^{14}O)^{15}B reaction [$E(^{18}\text{O}) = 96$ and 103 MeV; < 2 nb/sr at $\theta = 10 - 12°$] (1977HI03) nor in the ^{14}C(^{9}Be, ^{8}B)^{15}B reaction [$E(^{9}\text{Be}) = 121$ MeV; < 50 nb/sr at $\theta = 14°$] (1975WI26). See also (1976AJ04) and (1975VO09, 1975WI26).

^{15}C

(Figs. 10 and 13)

GENERAL: (See also (1976AJ04).):

Model calculations: (1976LI16).

Special levels: (1976LI16).

Astrophysical questions: (1977LI1H, 1978SN1A).

Special reactions involing ^{15}C: (1975FE1A, 1975KO1J, 1977AR06, 1978GE1C, 1978HE1C, 1978KO01, 1979AL22).

Muon and neutrino capture and reactions: (1977BA1P).

Pion capture and reactions: (1977BA24).

Other topics: (1976LI16, 1978DA1A, 1979BE1H).

Table 15.1: Energy levels of ^{15}C

E_x (MeV ± keV)	$J^\pi; T$	τ or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
g.s.	$\frac{1}{2}^+; \frac{3}{2}$	$\tau_{1/2} = 2.449 \pm 0.005$ sec	β^-	1, 2, 3, 6
0.7400 ± 1.5	$\frac{5}{2}^+; \frac{3}{2}$	$\tau_m = 3.76 \pm 0.10$ nsec	γ	2, 4, 6
		$g = -0.703 \pm 0.012$		
3.105 ± 5	$\frac{1}{2}^-; \frac{3}{2}$	$\Gamma_{c.m.} \leq 40$		2, 6
4.221 ± 3	$(\frac{7}{2}^+, \frac{5}{2}^-)$	< 14		2, 6
(4.55 ± 30)				2
5.833 ± 20	$\leq \frac{3}{2}$			2
5.858 ± 20	$\leq \frac{1}{2}$			2
6.370 ± 15	$(\frac{5}{2}, \frac{7}{2}^+, \frac{9}{2}^+)$	< 20		2, 6
6.429 ± 7	$(\frac{3}{2} \rightarrow \frac{7}{2})$	≈ 50		2, 6
6.461 ± 20	$(\frac{9}{2}^-, \frac{11}{2})$	< 14		2, 6
6.540 ± 5	[a]	< 14		2, 6
6.639 ± 15	$(\frac{3}{2})$	20 ± 10		2
6.845 ± 5	$(\frac{13}{2}, \frac{11}{2})^+$	< 14		2, 6
6.884 ± 5	$(\frac{9}{2})$ [a]	< 20		2, 6
7.098 ± 6	$(\frac{3}{2})$	< 15		2, 6
7.352 ± 6	$(\frac{9}{2}, \frac{11}{2})$	20 ± 10		2, 4, 6
7.414 ± 20				2
7.75 ± 30 [b]				2, 6
8.01 ± 30				2
8.11 ± 10 [b]				2, 6
8.47 ± 15	$(\frac{9}{2} \rightarrow \frac{13}{2})$	40 ± 15		2, 6
8.559 ± 15	$(\frac{7}{2} \rightarrow \frac{13}{2})$	40 ± 15		2
9.00 ± 30				2
(9.73 ± 30)				2
9.789 ± 20	$(\frac{9}{2} \rightarrow \frac{15}{2})$	20 ± 15		2
10.248 ± 20	$(\frac{5}{2} \rightarrow \frac{9}{2})$	20 ± 15		2
11.015 ± 25				2
11.123 ± 20	$(\frac{11}{2} \rightarrow \frac{19}{2})$	30 ± 20		2
(11.68 ± 30)				2
11.825 ± 20	$\geq \frac{13}{2}$	70 ± 30		2

[a] See Table 15.2.

[b] Broad or unresolved states.

1. $^{15}C(\beta^-)^{15}N$ $Q_m = 9.7717$

The half-life of ^{15}C is 2.449 ± 0.005 sec (1979AL23). Transitions have been observed to $^{15}N_{g.s.}$ and to the upper of the 5.3 MeV states in ^{15}N which has $J^\pi = \frac{1}{2}^+$. Therefore $J^\pi(^{15}C_{g.s.}) = \frac{1}{2}^+$ or $\frac{3}{2}^+$. Weak transitions are observed to $^{15}N^*$(7.30, 8.31, 8.57, 9.05) (1979AL23): see Table 15.16. See also (1976AJ04) and (1977RI08, 1979AL23; theor.).

2. $^9Be(^7Li, p)^{15}C$ $Q_m = 9.094$

Observed proton groups are displayed in Table 15.2. Angular distributions have been reported for $E(^7Li) = 1.7$ to 20 MeV: see (1976AJ04).

3. $^{13}C(t, p)^{15}C$ $Q_m = 0.9127$

$|g| = 0.703 \pm 0.012$ for $^{15}C^*$(0.74) (1980AS01). See also (1976AL16, 1979AL23).

4. $^{13}C(\alpha, 2p)^{15}C$ $Q_m = -18.9013$

At $E_\alpha = 65$ MeV $^{15}C^*$(0.74, 6.74, 7.35) are strongly populated. The angular distribution to $^{15}C^*(6.74 + 7.35)$ is consistent with $L = 4$ leading to $J^\pi = \frac{7}{2}^-$ and $\frac{9}{2}^-$ for these two states on the basis of the $(2J + 1)$ "rule" (1978JA10). See also (1976CE1E, 1976JA13). [However see Table 15.1 for the density of states, and compare with the resolution of (1978JA10).]

5. (a) $^{14}C(n, \gamma)^{15}C$ $Q_m = 1.2182$
(b) $^{14}C(n, n)^{14}C$ $E_b = 1.2182$

$\sigma_\gamma < 1$ μb (1973MU14). See also (1976AJ04).

6. $^{14}C(d, p)^{15}C$ $Q_m = -1.0065$

Observed proton groups are displayed in Table 15.2. See also (1976AJ04).

7. $^{15}N(n, p)^{15}C$ $Q_m = 8.9893$

See ^{16}N in (1977AJ02).

Table 15.2: Proton groups from ^{9}Be(^{7}Li, p)^{15}C and ^{14}C(d, p)^{15}C

(1974GA33) [a]			(1973GO28, 1975GO31) [b]		
E_x (keV)	$\Gamma_{c.m.}$ (keV)	J^π [d]	E_x (keV)	$\Gamma_{c.m.}$ (keV)	J^π [h]
g.s.	bound		g.s.	bound	$\frac{1}{2}^+$ [j]
$\equiv 740$ [c]	bound		744.1 ± 2 [n]	bound	$\frac{5}{2}^+$ [k]
3100 ± 30	< 40	$(\frac{1}{2}^-)$ [e]	3105.3 ± 5	≈ 42	$(\frac{1}{2}^-)$
4223 ± 15	< 15	$(\frac{5}{2}^-)$	4221.1 ± 3	< 14	$(\frac{7}{2}^+, \frac{5}{2}^-)$
(4550 ± 30)			[f]		
5833 ± 20		[l]	[f]		
5858 ± 20		[l]	[f]		
6370 ± 15	< 20	$(\frac{5}{2})$	[g]	< 14 [g]	$(\frac{7}{2}, \frac{9}{2})^+$
6436 ± 20			6428.1 ± 7	≈ 50	$(\frac{3}{2}, \frac{5}{2}, \frac{7}{2})$
6461 ± 20			[g]	< 14 [g]	$(\frac{9}{2}^-, \frac{11}{2})$
6542 ± 15	< 20	$(\frac{3}{2})$	6539.8 ± 5	< 14	$(\frac{9}{2}^-, \frac{11}{2})$
6639 ± 15	20 ± 10	$(\frac{3}{2})$			
6847 ± 15	< 20	$(\frac{11}{2}, \frac{13}{2})$	6844.9 ± 5	< 14	$(\frac{13}{2}, \frac{11}{2})^+$
6894 ± 15	< 20	$(\frac{7}{2}, \frac{9}{2})$	6882.4 ± 5		$((\frac{9}{2}^-, \frac{11}{2}^+, \frac{13}{2}^+))$
7100 ± 15	< 15	$(\frac{3}{2})$	7097.2 ± 6		
7354 ± 15	20 ± 10	$(\frac{9}{2}, \frac{11}{2})$	7351.3 ± 6		
7414 ± 20					
7750 ± 30 [i]			7.81 ± 10 [m]		
8010 ± 30					
8130 ± 30 [i]			8.10 ± 10 [m]		
8491 ± 15	40 ± 15	$(\frac{9}{2}, \frac{11}{2}, \frac{13}{2})$	8.46 ± 10 [m]		
8559 ± 15	40 ± 15	$(\frac{7}{2} \rightarrow \frac{13}{2})$			
9000 ± 30					
(9730 ± 30)					
9789 ± 20	20 ± 15	$(\frac{9}{2} \rightarrow \frac{15}{2})$			
10248 ± 20	20 ± 15	$(\frac{5}{2}, \frac{7}{2}, \frac{9}{2})$			
11015 ± 25					
11123 ± 20	30 ± 20	$(\frac{11}{2} \rightarrow \frac{19}{2})$			
(11680 ± 30)					
11825 ± 20	70 ± 30	$(\frac{13}{2} \rightarrow \frac{31}{2})$			

[a] ^{9}Be(^{7}Li, p): $E(^7\mathrm{Li}) = 20$ MeV. E_x based on 740 keV for first excited state.
[b] ^{14}C(d, p): $E_\mathrm{d} = 12 - 14$ MeV.
[c] $E_\mathrm{x} = 739 \pm 1$ keV (1975HA42): from E_γ; $\tau_\mathrm{m} = 3.77 \pm 0.11$ nsec (1968ME08).
[d] Suggested J^π assignments based on angular distributions (and $2J_\mathrm{f} + 1$ dependence) and l_max from Γ_n: see (1974GA33).
[e] $\theta_\mathrm{n}^2 = 0.0075 \pm 0.0015$ (1974GA33).
[f] Not observed.
[g] Observed in the later work of (1975GO31) but E_x not redetermined.
[h] Analysis of the two bound states is done using DWUCK. For the unbound states DOXY was used. For values of $\Gamma_\mathrm{n}/\Gamma_\mathrm{s.p.}$ under various assumptions see (1975GO31).
[i] Broad or unresolved states.
[j] $S = 0.88$ (1975GO31).
[k] $S = 0.69$ or 0.55 (1975GO31). See also (1976AJ04). g $= -0.77 \pm 0.06$ (1975HA42).
[l] Sum of the J for these two states is 2 [based on $(2J_\mathrm{f} + 1)$ dependence of cross section] (1974GA33).
[m] Observed by (1975CE04): $E_\mathrm{d} = 27$ MeV who also report proton groups to ^{15}C*(0, 0.74, 4.22, 6.43, 6.88, 7.35).
[n] $\tau_\mathrm{m} = 3.73 \pm 0.23$ nsec (1962LO02).

8. ^{18}O(n, α)^{15}C $\qquad Q_\mathrm{m} = -5.0097$

See (1976AJ04).

^{15}N

(Figs. 11 and 13)

GENERAL: (See also (1976AJ04).):

Shell model: (1976LI16, 1977EM01, 1977PO16, 1978BO31).

Cluster and α-particle models: (1977FO1E, 1977SA19, 1978PI1E).

Special states: (1976LI16, 1977RI08, 1978BO31, 1978PI1E).

Electromagnetic transitions: (1976LI16, 1976SH04, 1977BR03, 1977HO04, 1978KR19, 1979SU1G).

Astrophysical questions: (1976BO1M, 1976EP1A, 1976FI1E, 1976ME1H, 1976NO1C, 1976SP1B, 1977AU1E, 1977AU1F, 1977CA1K, 1977CL1C, 1977CO1U, 1977CO1W, 1977HA1L, 1977JO1D, 1977PR1E, 1977ST1H, 1977TR1D, 1977WA1P, 1978BU1H, 1978BU1B, 1978CL1F, 1978DW1B, 1978EN1C, 1978PO1B, 1978SN1A, 1978ST1C, 1978ST1D, 1978YA1B, 1979GU1D, 1979JA1M, 1979LA1H, 1979OL1B, 1980CA1C, 1980PE1F).

Special reactions involving ^{15}N: (1976AB04, 1976BU16, 1976FU1J, 1976HE1H, 1976HI05, 1976LE1F, 1977AR06, 1977KO38, 1978AB08, 1978VO10, 1978CR1B, 1978GE1C, 1978HE1C, 1978KO01, 1978LE15, 1978TU06, 1978VO1A, 1979AL22, 1979GE1A, 1979HE1D, 1979SA27, 1979WU01, 1980MI01, 1980YO02).

Muon and neutrino capture and reactions: (1979ER07).

Pion capture and pion reactions: (1976EN02, 1978BA55, 1978ER04, 1978MO01, 1979BA2M, 1979ER07, 1979LI11, 1979OS1F, 1980LE02, 1980SA04, 1980WU01).

Applied work: (1977KE1B, 1978LA1N, 1978SH1L, 1979EN1D, 1979MA2M, 1980SA1C).

Other topics: (1976BI1A, 1976SA1H, 1977BA3P, 1977EM01, 1978DA1A, 1978PO1A, 1978SH1B, 1979BE1H, 1979HE1F, 1979KA13).

Ground state properties of ^{15}N: (1976FU06, 1976SA1H, 1977AN21, 1977BR03, 1977KO28, 1977PO16, 1977YO1D, 1978AN07, 1978AR1R, 1978HE1D, 1978SH1B, 1978SL1B, 1978ZA1D, 1979NO05, 1979SA27, 1979SU1G).

$$\mu = -0.2831892\ (3)\ \text{nm (1978LEZA)}.$$

^{15}N(6.33):* see (1979WU01, 1979WU08).

1. (a) ^{9}Be(^{6}Li, p)^{14}C	$Q_m = 15.126$	$E_b = 25.334$
(b) ^{9}Be(^{6}Li, t)^{12}C	$Q_m = 10.485$	
(c) ^{9}Be(^{6}Li, α)^{11}B	$Q_m = 14.342$	
(d) ^{9}Be(^{6}Li, 2n)^{13}N	$Q_m = 3.947$	

Table 15.3: Energy levels of ^{15}N [a]

E_x (MeV $\pm$ keV)	$J^\pi; T$	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
0	$\frac{1}{2}^-; \frac{1}{2}$	—	stable	2, 3, 4, 5, 6, 15, 16, 17, 19, 20, 21, 22, 23, 24, 30, 31, 32, 33, 34, 35, 36, 40, 41, 42, 43, 44, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84
5.27012 ± 0.04	$\frac{5}{2}^+$	$\tau_m = 2.6 \pm 0.2$ psec $g = +(0.9 \pm 0.3)$	γ	4, 5, 14, 20, 22, 31, 35, 40, 41, 44, 52, 61, 65, 66, 71, 74, 75, 82, 83
5.29880 ± 0.04	$\frac{1}{2}^+$	25 ± 7 fsec	γ	4, 5, 12, 13, 14, 17, 18, 19, 20, 22, 30, 32, 35, 40, 41, 44, 52, 58, 61, 71, 74, 75, 82, 83
6.32391 ± 0.06	$\frac{3}{2}^-$	0.23 ± 0.02 fsec	γ	3, 4, 5, 12, 13, 15, 17, 18, 19, 20, 30, 31, 32, 35, 40, 41, 44, 52, 60, 61, 65, 66, 71, 73, 74, 75, 76, 78, 83
7.15506 ± 0.06	$\frac{5}{2}^+$	18 ± 8 fsec	γ	4, 5, 19, 20, 30, 31, 32, 40, 44, 52, 61, 65, 66, 74
7.30109 ± 0.17	$\frac{3}{2}^+$	0.25 ± 0.10 fsec	γ	4, 5, 18, 19, 20, 30, 32, 40, 44, 52, 58, 61, 65, 66, 74
7.5671 ± 1.0	$\frac{7}{2}^+$	12^{+11}_{-6} fsec	γ	3, 4, 5, 12, 13, 17, 18, 19, 20, 30, 31, 32, 33, 40, 52, 55, 61, 65, 66, 74
8.31279 ± 0.14	$\frac{1}{2}^+$	< 16 fsec	γ	3, 4, 5, 19, 30, 32, 40, 44, 52, 58, 65, 66, 71

Table 15.3: Energy levels of ^{15}N [a] (continued)

E_x (MeV $\pm$ keV)	$J^\pi; T$	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
8.5714 ± 1.0	$\frac{3}{2}^+$	11 ± 7 fsec	γ	3, 4, 5, 12, 13, 17, 18, 19, 30, 31, 32, 40, 52, 58, 65, 66
9.0500 ± 0.7	$\frac{1}{2}^+$	< 2 fsec	γ	4, 5, 30, 40, 44, 52, 58, 71
9.15161 ± 0.23	$\frac{3}{2}^-$	< 40 fsec	γ	4, 5, 12, 13, 17, 18, 19, 30, 32, 40, 44, 52, 61, 65, 66
9.15492 ± 0.07	$\frac{5}{2}^+$	7^{+6}_{-3} fsec	γ	4, 5, 17, 18, 19, 30, 32, 40, 44, 52, 65, 66
9.225 ± 3	$\frac{1}{2}^-$	< 130 fsec	γ	30, 32, 40, 52, 71
9.760 ± 5	$\frac{5}{2}^-$	12 fsec	γ	14, 30, 44, 52, 61
9.829 ± 3	$\frac{7}{2}^-$	17 ± 7 fsec	γ	4, 5, 12, 13, 18, 19, 20, 30, 31, 32, 33, 40, 52, 65, 66
9.928 ± 4	$\frac{3}{2}^-$	< 10 fsec	γ	19, 30, 40, 44, 52, 74
10.070 ± 3	$\frac{3}{2}^+$	0.16 ± 0.05 fsec	γ	19, 30, 32, 52, 60, 65, 66
10.4497 ± 0.3	$\frac{5}{2}^-$	$\Gamma < 0.5$ keV	γ, p	5, 12, 13, 20, 30, 31, 36, 40, 52
10.5333 ± 0.5	$\frac{5}{2}^+$		γ, p	5, 13, 17, 18, 19, 31, 32, 36, 37
10.6932 ± 0.3	$\frac{9}{2}^+$	$\tau_m = 18 \pm 9$ fsec	γ, p	5, 13, 17, 18, 19, 31, 32, 36, 37
10.7019 ± 0.3	$\frac{3}{2}^-$	$\Gamma = 0.2$ keV	γ, p	12, 13, 30, 31, 32, 36, 37, 52, 65, 74
10.804 ± 2	$\frac{3}{2}^+$	$< 1 \times 10^{-3}$	γ, p	4, 5, 12, 13, 19, 20, 30, 36, 52, 61
11.235 ± 5	$\geq \frac{3}{2}$	3.3	n	40, 45
11.2929 ± 0.8	$\frac{1}{2}^-$	8 ± 3	γ, n, p	36, 37, 38, 40, 45, 65
11.4376 ± 0.7	$\frac{1}{2}^+$	41.4 ± 1.1	γ, n, p, α	7, 12, 13, 19, 36, 37, 38, 40, 45, 46
11.615 ± 4	$\frac{1}{2}^+; T = \frac{3}{2}$	405 ± 6	γ, n, p	36, 37, 38
11.778 ± 5	$\frac{3}{2}^+$	40	n, p, α	7, 37, 38, 45, 46

Table 15.3: Energy levels of ^{15}N [a] (continued)

E_x (MeV ± keV)	$J^\pi; T$	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
11.876 ± 3	$\frac{3}{2}^-$	25	γ, n, p, α	7, 30, 37, 38, 45, 46, 61
11.942 ± 6	$\frac{9}{2}^-$	≤ 3.0	n, α	5, 7, 18, 19, 30, 31, 32, 33, 45, 65
11.965 ± 3	$\frac{1}{2}^-$	17	n, p	5, 12, 13, 37, 38, 45, 46
12.095 ± 3	$\frac{5}{2}^+$	14 ± 5	n, p, α	7, 8, 37, 38, 39, 40, 45, 46, 50
12.145 ± 3	$\frac{3}{2}^-$	41 ± 5	n, p, α	7, 8, 12, 13, 37, 38, 39, 45, 46, 50
12.327 ± 4	$\frac{5}{2}^{(+)}$	22	n, p	18, 19, 31, 37, 38, 45, 46
12.493 ± 4	$\frac{5}{2}^+; \frac{1}{2}$	40 ± 5	n, p, α	7, 8, 37, 38, 39, 45, 46, 50, 65
12.522 ± 8	$\frac{5}{2}^+; \frac{3}{2}$	58 ± 4	γ, p	36, 61
12.559 ± 10	$(\frac{9}{2})$			5, 13, 18, 19
12.920 ± 4	$\frac{3}{2}^-$	56 ± 11	n, p, α	7, 8, 11, 19, 20, 37, 38, 39, 45, 46, 50
12.940 ± 10	$\frac{5}{2}^+$	81	p, α	8, 11, 37, 39
13.004 ± 10	$\frac{11}{2}^-$			5, 12, 13, 14, 17, 19, 31, 32, 33
13.149 ± 10		7 ± 3	n, p, α	7, 8, 20, 50
13.174 ± 7	$(\frac{9}{2})$	7 ± 3	n, p, α	5, 7, 8, 13, 17, 18, 19, 38, 45, 50
13.362 ± 8	$\frac{3}{2}^-$	16 ± 8	n, p, α	7, 8, 11, 37, 38, 39, 50
13.390 ± 10	$\frac{3}{2}^+$	56	γ, n, p, α	8, 11, 36, 37, 38, 39, 46
13.537 ± 10	$\frac{3}{2}^-$	85 ± 30	n, p, α	7, 11, 37, 38, 39
13.608 ± 7	$\frac{5}{2}^{(+)}$	18 ± 4	n, p, α	7, 8, 19, 37, 38, 39, 45, 46, 50
(13.612 ± 10)	$(\frac{1}{2}^+)$	90	α	11
13.713 ± 10		26 ± 8	n, p, α	7, 46, 50
13.84 ± 30	$\frac{3}{2}^+$	75	n, p, α	5, 7, 11, 13, 45, 46, 50

Table 15.3: Energy levels of ^{15}N [a] (continued)

E_x (MeV ± keV)	$J^\pi; T$	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
13.9	$\frac{1}{2}^+$	930	γ, p	36, 37
13.99 ± 30	$\frac{5}{2}^+$	98 ± 10	n, p, α	7, 13, 37, 39
14.090 ± 7		22 ± 6	n, p, α	5, 7, 12, 13, 19, 45, 46, 50
14.10 ± 30	$\frac{3}{2}^+$	≈ 100	n, α	5, 7, 11, 65
14.162 ± 10	$\frac{3}{2}^{(+)}$	27 ± 6	n, α	5, 7, 45, 46, 50
14.24 ± 40	$\frac{5}{2}^+$	150	α	11, 12
14.38 ± 40	$\frac{7}{2}^+$	100	α	11
14.4		≈ 1900	n, p, α	45, 46, 50
14.55 ± 20		200 ± 50	n, (p), α	7, 37
14.647 ± 10		33 ± 6	n, p, α	7, 45, 46, 50
14.71		750	γ, p	36
14.720 ± 10	$\frac{5}{2}^-$	110 ± 50	γ, n, (p), α	7, 12, 13, 19, 37, 39, 61
14.86 ± 20		48 ± 11	n, α	7, 11
14.920 ± 10		12 ± 3	n, α	7, 12, 50
15.025 ± 10		13 ± 3	n, α	7, 19
15.09 ± 20		80 ± 25	n, α	7, 11, 45, 50, 65
15.288 ± 10		26 ± 6	n, α	7, 11
15.373 ± 10	$\frac{13}{2}^+$			5, 12, 13, 17, 18, 19, 20
15.38 ± 20		75 ± 25	n, t, α	7, 11, 16
15.43 ± 20		≈ 100	n, (α)	7, 11
15.45		750	γ, p	36
15.53 ± 20		≈ 35	n, α	7, 12, 13, 50
15.60 ± 20		95 ± 25	n, α	7
15.782 ± 10			p, t, α	16, 19, 20
15.93 ± 20		35 ± 5	n, t, α	7, 16, 18
15.944 ± 15		21 ± 6	n, t, α	7, 16
16.026 ± 10		62 ± 12	n, p, t, α	7, 16, 19, 50
16.190 ± 10	$\frac{3}{2}^+$	450 ± 100	γ, n, p, t, α	12, 16, 18, 19, 37, 39
16.26 ± 20		130 ± 14	n, t, α	7, 11, 16, 20

Table 15.3: Energy levels of ^{15}N [a] (continued)

E_x (MeV ± keV)	$J^\pi; T$	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
16.32 ± 20		≈ 30	n, p, t, α	7, 11, 16
16.35 ± 20	$\frac{3}{2}^+$	270 ± 30	γ, α	6
16.39 ± 20		44 ± 11	n, p, t, α	7, 16, 18, 50
16.46		560	γ, p, d	26, 36
16.576 ± 15		27 ± 15	n, α	7, 50
16.59 ± 25	$\frac{3}{2}^-$	490	γ, n, p, t, α	16
16.677 ± 15	$(\frac{3}{2}^+; \frac{1}{2})$	75 ± 5	γ, n, p, d, t, α	7, 16, 18, 25, 26, 28, 36, 39, 45, 50
16.73 ± 20	$(\frac{1}{2}^+, \frac{3}{2}^+)$	270 ± 30	γ, n, t, α	6, 14, 16
16.85 ± 30	$\frac{5}{2}$	110 ± 50	t, α	16, 39
16.91		≈ 350	n, p, d, t, α	16, 25, 26, 45, 50
(17.05)			p, t	16
17.11		broad	d, α	29
17.15 ± 50	$(\frac{1}{2}^+, \frac{3}{2}^+)$	250 ± 60	γ, t, α	6, 16
17.23 ± 40		≈ 175	d, t, (α)	28, 29
17.37 ± 40		≈ 250	p, d, t, α	16, 26, 28, 29, 45, 50
17.58 ± 40	$\frac{3}{2}^+$	450 ± 120	γ, d, t, α	16, 28, 50
17.67 ± 40	$\frac{3}{2}^+; T = \frac{1}{2}$	600 ± 80	γ, n, d, α	6, 24, 25, 29
17.72 ± 10		48 ± 10	n, (p), d, t, α	26, 28, 29, 50
17.81		167	n, α	20, 45, 50
18.06 ± 10		19 ± 4	(n), d, α	18, 25, 29
18.09 ± 20		≈ 40	(n), p, d, t	22, 26, 28
18.22		158	n, α	45, 50
18.28 ± 30		235 ± 60	n, p, d, α	25, 26, 29, 50
(18.76 ± 10)				18, 30
19.05 ± 50		≈ 700	γ, α	6
19.16	$(\frac{1}{2}^+; \frac{1}{2})$	≈ 130	n, d	25
19.5	$\frac{3}{2}^+; (\frac{3}{2})$	≈ 400	γ, p	36, 37
19.77 ± 60				14, 18
20.5	$\frac{3}{2}^+$	≈ 400	γ, n, p, d	25, 26, 36
21.26 ± 200		≈ 1700	γ, α	6

Table 15.3: Energy levels of ^{15}N [a] (continued)

E_x (MeV ± keV)	$J^\pi; T$	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
21.82		≈ 600	γ, p, d	24, 36, 59, 61
22.92			γ, p	36
23.8		broad	γ, d	24
25.5	$\frac{3}{2}^-; (T = \frac{3}{2})$		γ, p	36, 61
(26.8)			t	16
≈ 37			γ, p	36

[a] See also Tables 15.4 and 15.5.

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 $E_x = 28$ MeV in ^{15}N (1967SE08). The excitation functions for t_0 (reaction (b)) α_0, α_1 and α_2 (reaction (c)) show broad structures for $E(^6\text{Li}) = 4$ to 14 MeV (1971WY01). See also ^{11}B and ^{12}C in (1980AJ01) and ^{14}C. See also (1976AJ04).

2. ^{9}Be(^{7}Li, n)^{15}N $\qquad Q_m = 18.083$

See (1978KA1T).

3. ^{9}Be(^{9}Be, t)^{15}N $\qquad Q_m = 7.645$

At $E(^9\text{Be}) = 12$ MeV partial angular distributions are reported for the tritons to ^{15}N*(0, 6.32, 7.57, 8.31, 8.57) [also $E(^9\text{Be}) = 5$ MeV for t_0, t_3] (1977YO02). See also (1975VE10).

4. ^{10}B(^{6}Li, p)^{15}N $\qquad Q_m = 18.748$

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, 8.57, 9.05 + 9.15) (1966MC05).

5. ^{10}B(^{7}Li, d)^{15}N $\qquad Q_m = 13.723$

At $E(^7\text{Li}) = 24$ MeV angular distributions have been studied to many of the ^{15}N states with $E_x < 15.5$ MeV: see reaction 13 (1976KO11). See also (1976AJ04).

Table 15.4: Radiative decays in ^{15}N [a]

E_i (MeV)	J_i^π	E_f (MeV)	J_f^π	Branch (%)	Mult. mixing ratio δ	Refs.
5.27	$\frac{5}{2}^+$	0	$\frac{1}{2}^-$	100	-0.131 ± 0.013	(1975BE23, 1976BE1B)
5.30	$\frac{1}{2}^+$	0	$\frac{1}{2}^-$	100		
6.32	$\frac{3}{2}^-$	0	$\frac{1}{2}^-$	100	$+\,0.122 \pm 0.006$ [k]	(1975MO28, 1976BE1B)
		5.27	$\frac{5}{2}^+$	< 1		(1965WA16, 1975MO28)
		5.30	$\frac{1}{2}^+$	< 0.5		(1975MO28)
7.16	$\frac{5}{2}^+$	0	$\frac{1}{2}^-$	< 0.1		(1976BE1B)
		5.27	$\frac{5}{2}^+$	100 ± 0.4	$-0.014^{+0.012}_{-0.015}$	(1976BE1B)
		5.30	$\frac{1}{2}^+$	< 4		(1966AL18, 1968GI11)
		6.32	$\frac{3}{2}^-$	< 0.5		(1965WA16)
7.30	$\frac{3}{2}^+$	0	$\frac{1}{2}^-$	99.3 ± 0.7	$-0.017^{+0.005}_{-0.008}$	(1976BE1B)
		5.27	$\frac{5}{2}^+$	0.6 ± 0.1	$+0.18 \pm 0.15$, or $+2.5 \pm 1.0$	(1976BE1B)
		5.30	$\frac{1}{2}^+$	0.2 ± 0.1	-0.31 ± 0.15, or $+4.6 \pm 3.4$	(1976BE1B)
		6.32	$\frac{3}{2}^-$	< 0.25		(1965WA16)
7.57	$\frac{7}{2}^+$	0	$\frac{1}{2}^-$	1.3 ± 0.6		(1975BE23, 1976BE1B)
		5.27	$\frac{5}{2}^+$	98.7 ± 1.0	-0.028 ± 0.012	(1976BE1B)
		5.30	$\frac{1}{2}^+$	< 4		(1966AL18)
		6.32	$\frac{3}{2}^-$	< 0.6		(1965WA16)
8.31	$\frac{1}{2}^+$	0	$\frac{1}{2}^-$	79 ± 2		(1965WA16, 1966WA08, 1967PH03)
		5.27	$\frac{5}{2}^+$	< 3		(1965WA16)
		5.30	$\frac{1}{2}^+$	10 ± 2		(1965WA16)
		6.32	$\frac{3}{2}^-$	7.8 ± 2		(1965WA16)
				4.4 ± 1.0 [A]		(1967PH03)
		7.16	$\frac{5}{2}^+$	1.2 ± 0.6		(1967PH03)
		7.30	$\frac{3}{2}^+$	2.2 ± 0.4		(1965WA16)

Table 15.4: Radiative decays in ^{15}N [a] (continued)

$E_{\rm i}$ (MeV)	$J^\pi_{\rm i}$	$E_{\rm f}$ (MeV)	$J^\pi_{\rm f}$	Branch (%)	Mult. mixing ratio δ	Refs.
				4.4 ± 0.7 [A]		(1967PH03)
8.57 [c]	$\frac{3}{2}^+$	0	$\frac{1}{2}^-$	33 ± 2		(1965WA16, 1966WA08, 1967PH03)
					$-0.085^{+0.005}_{-0.009}$	(1976BE1B)
		5.27	$\frac{5}{2}^+$	65 ± 3		(1966WA08)
					-0.091 ± 0.007	(1976BE1B)
		5.30	$\frac{1}{2}^+$	< 12		(1965WA16)
		6.32	$\frac{3}{2}^-$	3 ± 1		(1965WA16)
				1.4 ± 0.6 [A]		(1967PH03)
		7.16	$\frac{5}{2}^+$	3.6 ± 0.5		(1967PH03)
		7.30	$\frac{3}{2}^+$	< 0.7		(1965WA16)
		7.57	$\frac{7}{2}^+$	< 3		(1965WA16, 1966WA08)
9.05	$\frac{1}{2}^+$	0	$\frac{1}{2}^-$	92 ± 3 [A]		(1965WA16, 1966WA08)
				91.6 ± 00.9		(1967PH03)
		5.27	$\frac{5}{2}^+$	3.5 ± 1 [A]		(1966WA08)
				4.7 ± 0.7		(1967PH03)
		6.32	$\frac{3}{2}^-$	4.5 ± 1 [A]		(1966WA08)
				3.7 ± 0.5		(1967PH03)
		7.16	$\frac{5}{2}^+$	< 10		(1965WA16)
		7.30	$\frac{3}{2}^+$	1.2 ± 0.4 [A]		(1965WA16)
		7.57	$\frac{7}{2}^+$	< 2		(1965WA16)
		8.31	$\frac{1}{2}^+$	< 0.5		(1965WA16)
9.152	$\frac{3}{2}^-$	0	$\frac{1}{2}^-$	100 ± 3		(1969SI04, 1976BE1B)
					$+0.015^{+0.041}_{-0.034}$	(1976BE1B)
9.155 [c,d]	$\frac{5}{2}^+$	0	$\frac{1}{2}^-$	< 2		(1978HA39)

Table 15.4: Radiative decays in ^{15}N [a] (continued)

E_i (MeV)	J^π_i	E_f (MeV)	J^π_f	Branch (%)	Mult. mixing ratio δ	Refs.
		5.27	$\frac{5}{2}^+$	11 ± 1		(1978HA39)
		5.30	$\frac{1}{2}^+$	10 ± 1		(1978HA39)
		6.32	$\frac{3}{2}^-$	22 ± 2		(1978HA39)
		7.16	$\frac{5}{2}^+$	57 ± 3		(1978HA39)
9.23 [e]	$\frac{1}{2}^-$	0	$\frac{1}{2}^-$	22 ± 5		(1979HA38)
		5.30	$\frac{1}{2}^+$	42 ± 8		(1979HA38)
		6.32	$\frac{3}{2}^-$	35 ± 6		(1979HA38)
		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)
9.76 [c]	$\frac{5}{2}^-$	0	$\frac{1}{2}^-$	81.5 ± 2.8		(1967PH03)
		$5.27 + 5.30$		7.5 ± 1.5		(1967PH03)
		6.32	$\frac{3}{2}^-$	3.7 ± 0.8		(1967PH03)
		7.16	$\frac{5}{2}^+$	2.3 ± 0.5		(1967PH03)
		7.57	$\frac{7}{2}^+$	5.0 ± 0.6		(1967PH03)
		8.31	$\frac{1}{2}^+$	< 1		(1967PH03)
		8.57	$\frac{3}{2}^+$	< 2		(1965WA16, 1967PH03)
9.83 [c]	$\frac{7}{2}^-$	0	$\frac{1}{2}^-$	< 4		(1967PH03)
		5.27	$\frac{5}{2}^+$	≈ 85		(1965WA16, 1967PH03)
		5.30	$\frac{1}{2}^+$	< 15		(1965WA16)
		6.32	$\frac{3}{2}^-$	2.2 ± 0.9		(1967PH03)
		7.16	$\frac{5}{2}^+$	2.4 ± 1.1		(1967PH03)

Table 15.4: Radiative decays in ^{15}N [a] (continued)

E_i (MeV)	J_i^π	E_f (MeV)	J_f^π	Branch (%)	Mult. mixing ratio δ	Refs.
		7.30	$\frac{3}{2}^+$	3.7 ± 0.9		(1967PH03)
		7.57	$\frac{7}{2}^+$	7.3 ± 1.0		(1967PH03)
9.93	$\frac{3}{2}^-$	0	$\frac{1}{2}^-$	77.6 ± 1.9		(1967PH03)
		$5.27 + 5.30$		15.4 ± 1.5		(1967PH03)
		6.32	$\frac{3}{2}^-$	4.9 ± 1.2		(1967PH03)
		7.16	$\frac{5}{2}^+$	< 1		(1967PH03)
		7.30	$\frac{3}{2}^+$	2.1 ± 0.8		(1967PH03)
		7.57	$\frac{7}{2}^+$	< 1		(1967PH03)
		8.31	$\frac{1}{2}^+$	< 1		(1967PH03)
		8.57	$\frac{3}{2}^+$	< 1		(1967PH03)
10.07	$\frac{3}{2}^+$	0	$\frac{1}{2}^-$	96.0 ± 0.7		(1967PH03)
		$5.27 + 5.30$		4.0 ± 0.7		(1967PH03)
		6.32, 7.16, 7.30, 7.57		< 2		(1966WA08)
		8.31	$\frac{1}{2}^+$	< 2		(1965WA16)
		8.57	$\frac{3}{2}^+$	< 3		(1965WA16)
10.45	$\frac{5}{2}^-$	0	$\frac{1}{2}^-$	< 12		(1976BE1B)
		5.27	$\frac{5}{2}^+$	55.0 ± 0.8	$+0.021 \pm 0.033$	(1976BE1B)
		5.30	$\frac{1}{2}^+$	< 2		(1976BE1B)
		6.32	$\frac{3}{2}^-$	31.3 ± 1.7	-0.59 ± 0.13	(1976BE1B)
		7.16	$\frac{5}{2}^+$	5.2 ± 0.1	$+0.13^{+0.03}_{-0.04}$	(1976BE1B)
		8.57	$\frac{3}{2}^+$	3.8 ± 0.6	-0.3 ± 0.4	(1976BE1B)
		9.152	$\frac{3}{2}^-$	4.7 ± 0.1	$-0.32^{+0.09}_{-0.10}$	(1976BE1B)
		9.83	$\frac{7}{2}$	< 0.1		(1976BE1B)
10.53	$\frac{5}{2}^+$	0	$\frac{1}{2}^-$	< 0.1		(1976BE1B)
		5.27	$\frac{5}{2}^+$	38.7 ± 0.2	-0.27 ± 0.03	(1976BE1B)

Table 15.4: Radiative decays in ^{15}N [a] (continued)

E_i (MeV)	J_i^π	E_f (MeV)	J_f^π	Branch (%)	Mult. mixing ratio δ	Refs.
		6.32	$\frac{3}{2}^-$	7.7 ± 0.1	-0.028 ± 0.004	(1976BE1B)
		7.16	$\frac{5}{2}^+$	19.4 ± 0.2	$+0.007^{+0.010}_{-0.008}$	(1976BE1B)
		7.30	$\frac{3}{2}^+$	31.4 ± 0.5	$+0.066 \pm 0.005$	(1976BE1B)
		8.57	$\frac{3}{2}^+$	2.4 ± 0.1	$+0.012^{+0.006}_{-0.005}$	(1976BE1B)
		9.152	$\frac{3}{2}^-$	0.3 ± 0.1	$-0.20^{+0.03}_{-0.02}$	(1976BE1B)
10.69 [c]	$\frac{9}{2}^+$	5.27	$\frac{5}{2}^+$	61.6 ± 0.3		(1975BE23, 1976BE1B)
		7.16	$\frac{5}{2}^+$	2.1 ± 0.1	-0.03 ± 0.07	(1975BE23, 1976BE1B)
		7.57	$\frac{7}{2}^+$	36.3 ± 0.6	$+0.118 \pm 0.008$	(1975BE23, 1976BE1B)
10.70 [f]	$\frac{3}{2}^-$	0	$\frac{1}{2}^-$	52.6 ± 0.8	$+0.180^{+0.006}_{-0.002}$	(1976BE1B)
		5.27	$\frac{5}{2}^+$	37.4 ± 0.6	$-0.24^{+0.004}_{-0.008}$	(1976BE1B)
		5.30	$\frac{1}{2}^+$	0.8 ± 0.1	-0.13 ± 0.07	(1976BE1B)
		6.32	$\frac{3}{2}^-$	3.8 ± 0.1	$+0.135 \pm 0.015$	(1976BE1B)
		7.16	$\frac{5}{2}^+$	0.4 ± 0.1	0.3 ± 0.3	(1976BE1B)
		7.30	$\frac{3}{2}^+$	2.3 ± 0.1	-0.027 ± 0.023	(1976BE1B)
		8.31	$\frac{1}{2}^+$	0.8 ± 0.1	$-0.017^{+0.018}_{-0.016}$	(1976BE1B)
		9.05	$\frac{1}{2}^+$	0.2 ± 0.1	-0.007 ± 0.12	(1976BE1B)
		9.152	$\frac{3}{2}^-$	0.2 ± 0.1	-0.11 ± 0.03	(1976BE1B)
		9.23	$\frac{1}{2}^-$	1.5 ± 0.1	$+0.049^{+0.006}_{-0.005}$	(1976BE1B)
10.80	$\frac{3}{2}^+$ [1]	0	$\frac{1}{2}^-$	51.5 ± 0.4	-0.02 ± 0.01 [f]	(1976BE1B)
		5.27	$\frac{5}{2}^+$	4.9 ± 0.1	-0.63 ± 0.04 [f]	(1976BE1B)
		5.30	$\frac{1}{2}^+$	15.5 ± 0.2	-0.55 ± 0.02 [f]	(1976BE1B)
		6.32	$\frac{3}{2}^-$	5.4 ± 0.2	-0.07 ± 0.05 [f]	(1976BE1B)
		7.16	$\frac{5}{2}^+$	7.8 ± 0.1	$+0.14 \pm 0.03$ [f]	(1976BE1B)
		7.30	$\frac{3}{2}^+$	5.8 ± 0.1	-0.12 ± 0.02 [f]	(1976BE1B)
		8.31	$\frac{1}{2}^+$	3.6 ± 0.1	$+0.12 \pm 0.03$ [f]	(1976BE1B)

Table 15.4: Radiative decays in ^{15}N [a] (continued)

$E_{\rm i}$ (MeV)	$J^\pi_{\rm i}$	$E_{\rm f}$ (MeV)	$J^\pi_{\rm f}$	Branch (%)	Mult. mixing ratio δ	Refs.
		9.05	$\frac{1}{2}^+$	0.3 ± 0.1		(1976BE1B)
		9.152	$\frac{3}{2}^-$	0.9 ± 0.1		(1976BE1B)
		9.155	$\frac{5}{2}$	4.2 ± 0.1		(1976BE1B)
11.62 [g]	$\frac{1}{2}^+; T = \frac{3}{2}$	0	$\frac{1}{2}^-$	90.7 ± 3.0		(1971KU01)
		5.27	$\frac{5}{2}^+$	< 1		(1971KU01)
		5.30	$\frac{1}{2}^+$	7.4 ± 1.5		(1971KU01)
		6.32	$\frac{3}{2}^-$	1.9 ± 1.5		(1971KU01)
12.52	$\frac{5}{2}^+; T = \frac{3}{2}$	0	$\frac{1}{2}^-$	< 1		(1971KU01)
		5.27	$\frac{5}{2}^+$	94.2 ± 0.6 [h]		(1971YO03)
		5.30	$\frac{1}{2}^+$	< 1		(1971KU01)
		6.32	$\frac{3}{2}^-$	5.8 ± 0.6 [i]		(1971YO03)
13.39 [j]	$\frac{3}{2}^+$	0	$\frac{1}{2}^-$	100		(1976KU01)

A = adopted.

[a] See also Tables 15.5 and 15.17.

[b] Please note that (1976BE1B) is an unpublished Ph.D. thesis.

[c] See also (1979HA38).

[d] See also Table 15.5 in (1976AJ04).

[e] See also (1967PH03).

[f] See (1969SI04).

[g] $\Gamma_\gamma = 49 \pm 20$, 4 ± 2, 1.0 ± 0.8 eV for transitions to ^{15}N*(0, 5.30, 6.32) (1971KU01): see however Table 15.12.

[h] $\Gamma_\gamma = 4.3 \pm 0.7$ eV (1971YO03); $\delta = -0.02 \pm 0.04$ (E2/M1) (1971KU01).

[i] $\Gamma_\gamma = 0.27 \pm 0.05$ eV (1971YO03); $\delta = -0.02 \pm 0.04$ (E2/M1) (1971KU01).

[j] $\Gamma_{\gamma_0} = 3.0 \pm 0.9$ eV, $\Gamma_{\rm p}\Gamma_{\gamma_0}/\Gamma = 1.70 \pm 0.5$ eV; $\delta = 0.00 \pm 0.04$ (M2/E1); B(E1) $= (1.2 \pm 0.4) \times 10^{-3}\ e^2 \cdot$ fm^2. Transitions to ^{15}N*(5.27, 5.30) $< 8\%$ and to ^{15}N*(6.32, 7.16, 7.30) $< 5\%$ (1976KU01).

[k] See also Table 15.17.

[l] π is + because if π were - the Γ_γ and δ of the $10.80 \rightarrow 5.30$ MeV transition would lead to an unacceptably high M2 value (33 W.u.) (P.M. Endt, private communication).

6. ^{11}B(α, γ)^{15}N $Q_m = 10.9913$

The 90° differential cross section for γ_0 production has been measured for $E_\alpha = 5.74$ to 17.80 MeV (1977DE04) and 6 to 11.5 MeV (1978DE23; also angular distributions). Observed resonances are displayed in Table 15.6.

7. ^{11}B(α, n)^{14}N $Q_m = 0.1580$ $E_b = 10.9913$

Reported resonances are displayed in Table 15.7. For angular distributions see ^{14}N. For polarization measurements see (1977NI03: $E_\alpha = 2.049$ MeV) and (1976AJ04). See also (1977LI19).

8. ^{11}B(α, p)^{14}C $Q_m = 0.7839$ $E_b = 10.9913$

Reported resonances are listed in Table 15.7. The yield curve for ^{14}C is dominated by two strong resonances at $E_\alpha = 1.57$ and 2.64 MeV (1976DA06; CTR implications). At higher energies (to 25 MeV) the p_0 excitation functions show broad features: see (1978HO08: $E_\alpha = 4.4$ to 6.7 MeV) and (1976AJ04).

9. ^{11}B(α, d)^{13}C $Q_m = -5.1680$ $E_b = 10.9913$

The yield of d_0 has been measured for $E_\alpha = 13.5$ to 25 MeV (1975VA19). See also (1976AJ04, 1976LE1K).

10. ^{11}B(α, t)^{12}C $Q_m = -3.8571$ $E_b = 10.9913$

Excitation functions for t_0 and t_1 (to 25 MeV) show strong uncorrelated structures: see (1976AJ04). See also (1976LE1K).

11. ^{11}B(α, α)^{11}B $E_b = 10.9913$

Observed resonances for $E_\alpha = 2.1$ to 7.9 MeV are shown in Table 15.7. See also (1976AJ04).

12. ^{11}B(^{6}Li, d)^{15}N $Q_m = 9.5178$

Table 15.5: Lifetimes of some ^{15}N states [a]

E_x (MeV)	τ_m	Reaction	Refs.
5.27	2.6 ± 0.2 psec	mean	Table 15.6 in (1976AJ04)
5.30	25 ± 7 fsec	mean	Table 15.6 in (1976AJ04)
6.32	0.35 ± 0.07 fsec	^{15}N(e, e)	(1975KI08)
	0.23 ± 0.002 fsec [A]	^{15}N(γ, γ)	(1976MO14)
7.16	28 ± 8 fsec	^{13}C(^{14}N, ^{12}C)	(1975SE04)
	9 ± 7 fsec	^{12}C(^{7}Li, α)	(1979HA38)
	18 ± 8 fsec	mean	
7.30	< 10 fsec	^{12}C(^{7}Li, α)	(1979HA38)
	0.25 ± 0.10 fsec [A]	^{15}N(e, e)	(1975KI09)
7.57	12^{+11}_{-6} fsec	^{12}C(^{7}Li, α)	(1979HA38)
	60 ± 20 fsec	^{14}N(d, p)	(1968GI11)
8.31	< 16 fsec	^{12}C(^{7}Li, α)	(1979HA38)
8.57	11 ± 7 fsec	^{12}C(^{7}Li, α)	(1979HA38)
9.05	< 2 fsec	^{12}C(^{7}Li, α)	(1979HA38)
9.152	< 40 fsec	^{13}C(^{3}He, p)	(1972ST22)
9.155	7^{+6}_{-3} fsec	^{12}C(^{7}Li, α)	(1978HA39)
9.23	< 130 fsec	^{13}C(^{3}He, p)	(1972ST22)
9.76	< 12 fsec	^{12}C(^{7}Li, α)	(1979HA38)
9.83	17 ± 7 fsec	^{12}C(^{7}Li, α)	(1979HA38)
9.93	< 10 fsec	^{12}C(^{7}Li, α)	(1979HA38)
10.07	0.16 ± 0.05 fsec	^{15}N(γ, γ)	(1976PA22)
10.69	18 ± 9 fsec	^{12}C(^{7}Li, α)	(1979HA38)

A = adopted.

[a] See also Tables 15.12 and 15.17 for other states.

Table 15.6: Resonances in ^{11}B(α, γ_0)^{15}N [a]

E_α (MeV)	E_x (MeV)	$\Gamma_{c.m.}$ (keV)	Multipol.	Γ_γ (eV)	J^π
7.31	16.35 ± 0.02	270 ± 30	E1	≥ 11	$\frac{3}{2}^+$
7.83	16.73 ± 0.02	270 ± 30	(E1)	≥ 11	$(\frac{1}{2}^+, \frac{3}{2}^+)$
8.40	17.15 ± 0.05	250 ± 60	(E1)	≥ 2	$(\frac{1}{2}^+, \frac{3}{2}^+)$
9.11	17.67 ± 0.05	600 ± 80	E1	≥ 7	$\frac{3}{2}^+$
11.00	19.05 ± 0.05	≈ 700 [b]			
14.0	21.26 ± 0.20 [b]	≈ 1700 [b]			

[a] (1978DE23).
[b] (1977DE04).

At $E(^6\text{Li}) = 34$ MeV angular distributions are reported to the states with $5.3 < E_x < 16.3$ MeV: this reaction appears to be less than reaction 13. The most strongly populated states are ^{15}N*(9.2, 10.5, 10.7, 13.1, 14.8, 15.5) (1976NO01). See also (1976AJ04).

13. ^{11}B(^{7}Li, t)^{15}N $\qquad Q_m = 8.525$

At $E(^7\text{Li}) = 24$ and 34 MeV, angular distributions to states with $5.3 < E_x < 15.6$ MeV have been measured (1976KO11, 1976NO01): ^{15}N*(9.8, 10.5, 10.7, 15.4, 15.5) are particularly strongly populated at 34 MeV. $J^\pi = \frac{9}{2}^+, \frac{9}{2}, \frac{11}{2}, \frac{9}{2}, \frac{11}{2}, \frac{13}{2}, \frac{15}{2}$ are suggested for ^{15}N*(10.69, 12.56, 13.03, 13.19, 13.84, 14.11, 15.37) (1976KO11). (1976NO01) find that only ^{15}N*(15.52) has a large cluster component corresponding to $^{11}\text{B} + \alpha$. The γ-decay of ^{15}N states populated in this reaction has been studied by (1979HA38): see Tables 15.4 and 15.5. For earlier work see (1976AJ04).

14. ^{11}B(^{11}B, ^{7}Li)^{15}N $\qquad Q_m = 2.326$

At $E(^{11}\text{B}) = 114$ MeV broad peaks are observed at ^{15}N*(5.3, 9.7, 13, 16.8, 20) (1974AN36).

15. ^{11}B(^{16}O, ^{12}C)^{15}N $\qquad Q_m = 3.8294$

Angular distributions have been measured at $E(^{16}\text{O}) = 27$, 30, 32.5, 35 and 60 MeV involving $^{15}\text{N}_{g.s.} + {}^{12}\text{C}_{g.s.}$, $^{15}\text{N}_{g.s.} + {}^{12}\text{C}^*_{4.4}$, $^{15}\text{N}^*_{6.32} + {}^{12}\text{C}_{g.s.}$ and $^{15}\text{N}_{g.s.} + {}^{12}\text{C}^*_{9.6}$ (1972SC03, 1972SC17, 1975SC35): the reaction selectively populates the two proton-hole states of ^{15}N: ^{15}N*(0, 6.32) [$J^\pi = \frac{1}{2}^-, \frac{3}{2}^-$]. See also (1976AJ04) and (1976DE08, 1977WE1H; theor.).

Table 15.7: Resonances in $^{11}B + \alpha$

E_α (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Particle out	J^π	E_x (MeV)	Refs.
0.60		n		11.43	(1954BE08) [a]
1.03		n		11.75	(1954BE08)
1.18		n		11.86	(1954BE08)
1.30		n		11.94	(1954BE08)
1.51		n, p	$(\frac{5}{2}^+)$	12.10	(1955SH46, 1976DA06)
1.58	41 ± 5	n, p	$(\frac{3}{2}^-)$	12.15	(1955SH46, 1976DA06)
2.056 ± 10	34 ± 5	n_0, p_0	$\frac{5}{2}^+$	12.499	A, (1975VA06, 1976DA06)
2.610 ± 13	56 ± 11	n_0, p_0, α	$\frac{3}{2}^-$	12.905	A, (1972RA03, 1975VA06, 1976DA06)
2.66 ± 30	81	p_0, α	$\frac{5}{2}^+$	12.94	A, (1972RA03, 1976DA06)
2.942 ± 10	7 ± 3	n_0, p_0		13.149	A, (1975VA06)
2.984 ± 10	7 ± 3	n_0, p_0		13.180	A, (1975VA06)
3.239 ± 15	16 ± 8	n_0, p, α	$\frac{3}{2}^-$	13.366	A, (1972RA03, 1975VA06)
3.31 ± 30	61	p, α	$\frac{3}{2}^+$	13.42	A, (1972RA03)
3.46 ± 30	85 ± 30	n_0, α	$\frac{3}{2}^-$	13.53	(1972RA03, 1975VA06)
3.560 ± 10	18 ± 4	n_0, p	$(\frac{5}{2}, \frac{7}{2})^-$	13.602	A, (1975VA06)
3.57 ± 30	94	α	$\frac{1}{2}^+$	13.61	(1972RA03)
3.712 ± 10	26 ± 8	n_0		13.713	A, (1975VA06)
(3.78 ± 30)	70	α	$(\frac{1}{2}^+)$	(13.76)	(1972RA03)
3.89 ± 30	≈ 70	n_1, α	$(\frac{3}{2}^+)$	13.84	(1972RA03, 1975VA06)
4.09 ± 30	≈ 100	n_1		13.99	(1975VA06)
4.232 ± 10	22 ± 6	n_0		14.094	(1975VA06)
4.24 ± 30	≈ 100	n_1, α	$\frac{3}{2}^+$	14.10	(1972OT04, 1975VA06)
4.324 ± 10	27 ± 6	n_0		14.162	A, (1975VA06)
4.43 ± 40	150	α	$\frac{5}{2}^+$	14.24	(1972OT04)
4.62 ± 40	100	α	$\frac{7}{2}^+$	14.38	(1972OT04)
4.85 ± 20	200 ± 50	n_0		14.55	(1975VA06)
4.986 ± 10	33 ± 6	n_0		14.647	(1975VA06)
5.11 ± 30	110 ± 50	n_0		14.74	(1975VA06)
5.28 ± 20	48 ± 11	n_0, α		14.86	(1972OT04, 1975VA06)
5.538 ± 10	12 ± 3	n_0		14.920	(1975VA06)
5.501 ± 10	13 ± 3	n_0		15.025	(1975VA06)
5.59 ± 20	80 ± 25	n_0, α		15.09	(1972OT04, 1975VA06)
5.860 ± 10	22 ± 6	n_0, α		15.288	(1972OT04, 1975VA06)

Table 15.7: Resonances in ^{11}B + α (continued)

E_α (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Particle out	J^π	E_x (MeV)	Refs.
5.98 ± 20	75 ± 25	n_2, (α)		15.38	(1972OT04, 1975VA06)
6.06 ± 20	≈ 100	n_0, (α)		15.43	(1972OT04, 1975VA06)
6.19 ± 20	≈ 35	n_0		15.53	(1975VA06)
6.29 ± 20	95 ± 25	n_2		15.60	(1975VA06)
(6.65 ± 40)		(α)		(15.87)	(1972OT04)
6.73 ± 20	35 ± 10	n_0, n_2		15.93	(1975VA06)
6.755 ± 15	21 ± 6	n_1		15.944	(1975VA06)
6.83 ± 20	60 ± 20	n_2		16.00	(1975VA06)
6.884 ± 15	62 ± 12	n_0, α		16.039	(1972OT04, 1975VA06)
(6.98 ± 40)		(α)		(16.11)	(1972OT04)
7.18 ± 20	≈ 100	n_0, α		16.26	(1975VA06)
7.27 ± 20	≈ 30	n_0		16.32	(1975VA06)
7.37 ± 20	44 ± 11	n_2		16.39	(1975VA06)
7.616 ± 15	27 ± 15	n_0, (n_2)		16.576	(1975VA06)
7.754 ± 15	60 ± 10	n_0, (n_2)		16.677	(1975VA06)

A: see references listed for this state in Table 15.5 (1970AJ04).

[a] And private communication.

16. (a) ^{12}C(t, γ)^{15}N $\quad Q_m = 14.8484$

(b) ^{12}C(t, n)^{14}N $\quad Q_m = 4.01507 \quad E_b = 14.8484$

(c) ^{12}C(t, p)^{14}C $\quad Q_m = 4.6410$

(d) ^{12}C(t, t)^{12}C

(e) ^{12}C(t, α)^{11}B $\quad Q_m = 3.8571$

The 90° excitation function for γ_0 (reaction (a)) in the range 1.0 to 3.4 MeV shows one very strong resonance (at peak, 4.4 ± 0.5 μb/sr) corresponding to ^{15}N*(16.7). The excitation function and the measured angular distributions were analyzed [S-matrix] (1977SC01): Table 15.8 shows the derived parameters. Table 15.8 also displays the structures observed in reactions (b) → (e). Polarization studies of the elastic scattering are reported at $E_{\vec{t}} = 15.0$ and 17.0 MeV by (1978SC02). See also ^{11}B and ^{12}C in (1980AJ01), ^{14}C and ^{14}N here, and (1976AJ04).

17. ^{12}C(α, p)^{15}N $\quad Q_m = -4.9656$

Table 15.8: Resonances in $^{12}C + t$

E_t (MeV ± keV)	E_x (MeV)	Particles out	J^π	Γ (keV)	Refs. [a]
0.66	15.38	α_0			
1.11	15.74	p_0, t_0, α_1			
1.21	15.82	t_0			
1.30 ± 20	15.89	n, α_0			
1.39 ± 20	15.96	n, t_0, α_0			
1.46	16.02	p_0			
1.54	16.08	n, α_0, α_1			
1.64 ± 40	16.16	γ_0, n, α_0	$\frac{3}{2}^+$	450 ± 100	(1977SC01) [b]
1.78	16.27	α_0			
1.85 ± 20	16.33	n, p_0, α_0, α_1			
1.98 ± 20	16.43	n, p_0			
2.05 ± 30	16.49	p_0, t_0, α_0			
2.18 ± 25	16.59	γ_0, n, p_0, t_0, α_0, α_1	$\frac{3}{2}^-$	490	(1977SC01) [b]
2.30	16.69 ± 0.01	γ_0, n, p_0, α_0, α_1	$\frac{3}{2}^+$	130 ± 15	(1977SC01) [b]
2.39 ± 30	16.76	n, t_0, α_0, α_1			
2.50 ± 30	16.85	α_0, α_1			
2.60	16.93	α_0			
2.75	17.05	p_0			
2.82	17.10	γ_0, t_0, α_0, α_1	$\frac{3}{2}^-$		(1977SC01) [b]
2.89 ± 50	17.16	α_0			
3.14	17.36	α_1			
3.30	17.49 ± 0.09	γ_0	$\frac{3}{2}^+$	450 ± 120	(1977SC01) [b]
15.0	26.8	t_0			

[a] See also references listed for each state in Table 15.8 of (1976AJ04).

[b] S-matrix analysis.

Angular distributions have been measured for $E_\alpha = 13.4$ to 42 MeV [see (1976AJ04)] and at $E_\alpha = 17.52$ to 18.64 MeV (1979MO03; p_0), 24 to 33 MeV (1978BU27; p_3), 40 MeV (1979VA08; p_{1+2} and p to ^{15}N*(10.7, 15.4)) and at 96.8 MeV (1975FA07: see Table 15.9; reduced widths are calculated). At 97 MeV the spectrum at $10.5°$ is dominated by ^{15}N*(15.37) [$J^\pi = \frac{13}{2}^+$]: DWBA calculations have been carried out using a semi-microscopic three-nucleon form factor and several different sets of wave functions (1975FA07). See also (1976BU21, 1979AMZU), (1977FO1E, 1978FA1H), (1980ZE05; theor.) and ^{16}O in (1982AJ01).

18. ^{C}(^{6}Li, ^{3}He)^{15}N $\qquad\qquad Q_m = -0.9455$

Observed ^{3}He groups are displayed in Table 15.9. Comparisons of the angular distributions obtained in this reaction at $E(^6\text{Li}) = 60.1$ MeV and in the (^{6}Li, t) reaction shows analog correspondence for the following pairs of levels: 5.27–5.24, 7.16–6.86, 7.57–7.28, 8.58–8.28, 10.80–10.48, 13.15(u)–12.84, 15.49(u)–15.05 [first listed is E_x in ^{15}N; second in ^{15}O] (1975BI06) [E_x are nominal; u = unresolved.]. For γ-decay measurements see Table 15.4 (1978HA39, 1979HA38). See also (1977MA2G), (1977FO1E) and the earlier work reported in (1976AJ04).

19. ^{12}C(^{7}Li, α)^{15}N $\qquad\qquad Q_m = 12.3817$

Observed α groups are shown in Table 15.9 (1973TS02). Angular distributions have been measured to $E(^7\text{Li}) = 35$ MeV: see (1976AJ04). Comparison of spectra from this reaction ($E(^7\text{Li}) = 34.9$ MeV) with those from ^{13}C(^{6}Li, α) (reaction 32) lead to configurations of (d)^3 for ^{15}N*(10.7, 12.57, 13.20, 15.42) and suggest that ^{15}N*(12.57, 13.20) have lower J than ^{15}N*(10.7, 15.5), probably $J \leq \frac{7}{2}$. ^{15}N*(13.02) is shown to be p(d)^2 in agreement with $J^\pi = \frac{11}{2}^-$ (1976HA31).

^{15}N*(9.155) [$J = \frac{5}{2}$] decays to ^{15}N*(5.30) [$J^\pi = \frac{1}{2}^+$] by an E2 transition; therefore its parity is positive. It has a large triton cluster parentage. This is not true of ^{15}N*(9.152) (1978HA39). For γ-decay measurements see Table 15.4 (1978HA39, 1979HA38). For τ_m measurements see Table 15.5.

20. (a) ^{12}C(^{10}B, ^{7}Be)^{15}N $\qquad\qquad Q_m = -3.820$

(b) ^{12}C(^{11}B, ^{8}Be)^{15}N $\qquad\qquad Q_m = 3.6246$

At $E(^{10}\text{B}) = 100$ MeV angular distributions have been measured for ^{15}N*(5.27, 7.57, 9.87, 10.87, 13.15, 15.72, 16.26, 17.83) and comparisons have been attempted with those to states in ^{15}O, in the mirror reaction (1973NA09) [see however reaction 7 in ^{15}O (1976AJ04)]. (1974AN36; $E(^{10}\text{B}) = 100$ MeV), on the other hand, report population of ^{15}N*(0, 5.24, 7.28, 9.64, 10.47, 12.89, 15.36, 15.88). ^{15}N*(12.89, 15.36) are the most intense groups (1974AN36). For reaction (b) see (1978FR20, 1979FR05). See also (1977FO1E).

Table 15.9: States of ^{15}N from ^{12}C(α, p)^{15}N, ^{12}C(^{6}Li, ^{3}He)^{15}N and ^{12}C(^{7}Li, α)^{15}N

E_x (MeV ± keV)			L [a]	J^π [a]
(1975FA07) [a]	(1975BI06) [b]	(1973TS02) [c]		
0		0	1	$\frac{1}{2}^-$
$5.27 + 5.30$	5.27 ± 60	5.295 ± 10 [c]	$2 + 0$	
		6.332 ± 10		
		7.163 ± 10		
	7.24 ± 60			
		7.310 ± 10		
7.57	7.61 ± 60	7.566 ± 10	4	$\frac{7}{2}^+$
		8.320 ± 10		
8.58	8.59 ± 60	8.580 ± 10 [c]	2	$\frac{3}{2}^+$
$9.15 + 9.15$	9.17 ± 60	9.163 ± 10 [c]	$1 + 2$	[f]
	9.84 ± 60	9.828 ± 10 [c]		
		9.932 ± 10		
		10.072 ± 10		
		10.524 ± 10		
10.70	10.73 ± 60 [e]	10.700 ± 10 [c]	4	$\frac{9}{2}^+$ [f]
		10.808 ± 10		
		11.430 ± 10		
	12.05 ± 60	11.951 ± 10		
	12.36 ± 60	12.320 ± 10 [c]		
	12.64 ± 60	12.559 ± 10 [c,d]		
		12.923 ± 10		
13.01		13.004 ± 10 [c]	5	$(\frac{11}{2}^-)$
13.19	13.15 ± 60 [e]	13.173 ± 10 [c]	2	
		13.614 ± 10		
		14.087 ± 10		
		14.720 ± 10		
		15.021 ± 10		
15.40	15.49 ± 60 [e]	15.373 ± 10	6	$\frac{13}{2}^+$ [f]
		15.782 ± 10		

Table 15.9: States of ^{15}N from ^{12}C(α, p)^{15}N, ^{12}C(^{6}Li, ^{3}He)^{15}N and ^{12}C(^{7}Li, α)^{15}N (continued)

E_x (MeV ± keV)			L [a]	J^π [a]
(1975FA07) [a]	(1975BI06) [b]	(1973TS02) [c]		
	15.88 ± 60			
		16.026 ± 10		
	16.18 ± 60	16.190 ± 10		
	16.41 ± 60			
	16.74 ± 60			
	18.02 ± 60			
	18.82 [g]			
	19.77 ± 60			

[a] $E_\alpha = 96.8$ MeV. E_x are nominal.
[b] $E(^{6}\text{Li}) = 60.1$ MeV: angular distributions measured for states with $E_x < 16.2$ MeV.
[c] $E(^{7}\text{Li}) = 35$ MeV: angular distributions have been measured for the states labeled by this footnote.
[d] (1973TS02) suggest that this state is not the $T = \frac{3}{2}$ state at 12.52 MeV.
[e] $\Gamma_\gamma/\Gamma = 0.9 \pm 0.2, < 0.25, < 0.25$ for ^{15}N*(10.69, 13.15, 15.5) (1977KR1A).
[f] See also (1979VA08).
[g] (1977ZE1E); preliminary work.

21. (a) ^{12}C(^{16}O, ^{13}N)^{15}N $Q_m = -10.184$
(b) ^{12}C(^{18}O, ^{15}N)^{15}N $Q_m = -0.9861$

For reaction (a) see (1979PR07). Angular distributions for reaction (b) are reported at $E(^{18}\text{O}) =$ 32.3 and 35 MeV (1978CH16).

22. ^{12}C(^{19}F, ^{16}O)^{15}N $Q_m = 3.1481$

At $E(^{19}\text{F}) = 40$, 60 and 68.8 MeV angular distributions have been measured for the transitions involving ^{15}N*(0, 5.3) and various ^{16}O states: ^{15}N*(5.3) is very strongly excited (1972SC17). See also (1975PU02, 1977KO38).

Table 15.10: Resonances in ^{13}C + d

E_d (MeV)	Particles out	Γ_{lab} (keV)	^{15}N* (MeV)	Refs. [a]
0.37	p		16.48	
0.64	n, p_0, t_0	≈ 100	16.71	
0.85	n, p_0	≈ 400	16.90	
1.10	α_0	broad	17.11	
1.24 ± 0.04	t_0, (α_0)	≈ 200	17.23	
1.40 ± 0.04	p_0, t_0, α_0	≈ 400	17.37	
1.64 ± 0.04	t_0	≈ 200	17.58	
1.74 ± 0.04	γ_0, n, α_0	≈ 600	17.67 [b]	(1978DE05)
1.80 ± 0.01	(p_0), t_0, α_1	55 ± 10	17.72	
2.20 ± 0.01	(n), α_0, α_1	22 ± 4	18.06	
2.23 ± 0.02	(n), p_0, t	≈ 50	18.09	
2.45 ± 0.03	n, p_0, α_0	270 ± 70	18.28	
3.46 ± 0.03	n	≈ 150	19.16	
5.1	n_1, p_0	≈ 50	20.6	
6.65	γ_0	≈ 700	21.92	(1976DE32, 1979SK04)
8.8	γ_0	broad	23.8	(1976DE32)

[a] See references listed in Table 15.10 (1976AJ04).
[b] $J^\pi = \frac{1}{2}^-$ or $\frac{3}{2}^+$; $T = \frac{1}{2}$ (1973WE12).

23. ^{12}C(^{20}Ne, ^{17}F)^{15}N $\qquad Q_m = -9.0962$

See (1979OR01).

24. ^{13}C(d, γ)^{15}N $\qquad Q_m = 16.1594$

The $90^\circ - 95^\circ$ yields of γ_0 have been measured for $E_d = 1$ to 10 MeV: observed resonances are displayed in Table 15.10. The γ-ray angular distributions are consistent with the emission of predominantly E1 radiation except for evidence of M1/E2 transitions in the region $E_x = 20$–21.5 MeV (1976DE32).

25. ^{13}C(d, n)^{14}N $\qquad Q_m = 5.3260 \qquad E_b = 16.1594$

Table 15.11: Energy levels in ^{15}N from ^{13}C(^{3}He, p)^{15}N

E_x (MeV ± keV)		
(1959YO25, 1966GA08) [a]	(1966WA08) [c]	(1967PH03)
5.283 ± 12		
6.333 ± 12		
7.169 ± 12		
7.310 ± 12		
7.577 ± 13		
8.323 ± 6	8.312	
8.581 ± 5	8.570	
9.056 ± 5	9.052	9.054 ± 4
9.159 ± 5		
9.225 ± 6		9.225 ± 3
9.760 ± 5		
9.827 ± 6		9.829 ± 4
9.929 ± 8		
10.064 ± 7	10.074	10.072 ± 4
10.454 ± 6	10.452	
10.536 ± 7		
10.704 ± 6		
10.805 ± 7	10.800	
	(10.94 ± 30)	[b]

[a] First five values are from (1959YO25).

[b] (1979HAYZ) report states at 11.88, 11.98, 18.76 ± 0.01 and 19.91 ± 0.01 MeV.

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

Observed resonances are shown in Table 15.10. See also (1976AJ04).

26. ^{13}C(d, p)^{14}C $\quad Q_m = 5.9519 \quad E_b = 16.1594$

Observed resonances are displayed in Table 15.10. At $E_{\vec{d}} = 13$ MeV, the vector analyzing power (VAP) has been measured for the transitions to ^{14}C*(0, 6.09, 7.34) (1978DA17).

27. ^{13}C(d, d)^{13}C $\quad E_b = 16.1594$

Excitation functions for elastically scattered deuterons have been measured in the range $E_d = 0.4$ to 5.7 MeV: see (1976AJ04). Polarization studies are reported at $E_d = 12.5$ MeV (1975ZA08; d_0) and 15 MeV (1974BU06; d_0) and at $E_{\vec{d}} = 13$ MeV (1978DA17: VAP; ^{13}C*(0, 3.09, 3.68, 3.85)).

28. (a) ^{13}C(d, t)^{12}C $\quad Q_m = 1.3109 \quad E_b = 16.1594$

(b) ^{13}C(d, ^{3}He)^{12}B $\quad Q_m = -12.040$

Observed resonances are listed in Table 15.10. Polarization measurements have been reported at $E_d = 12.1$ and 15 MeV [see reaction (a), (1976AJ04)] and at $E_{\vec{d}} = 13$ MeV (1978DA17: VAP; ^{12}C*(0, 4.4, 7.7)) and 29 MeV (1979CO08: VAP; ^{12}C*(0, 4.4, 12.7, 15.1, 16.1), ^{12}B$_{g.s.}$). See also ^{12}B and ^{12}C in (1980AJ01).

29. ^{13}C(d, α)^{11}B $\quad Q_m = 5.1680 \quad E_b = 16.1594$

Observed resonances are listed in Table 15.10. See also (1976AJ04).

30. ^{13}C(^{3}He, p)^{15}N $\quad Q_m = 10.6658$

Observed proton groups and γ-rays are listed in Table 15.11. Gamma ray branching ratios are displayed in Table 15.4 and τ_m in Table 15.5. Angular distributions have been measured at $E(^3\text{He}) = 4.37$ to 5.57 MeV (1978CH19; p_0) and at 20 MeV (1977PE23: to ^{15}N*(0, $5.27 + 5.30$, 6.32, 8.31, 8.57, 9.05, 9.15, 9.23, 9.76, 9.83, 9.93 [parity probably −], 10.07)). The earlier work at $E(^3\text{He}) = 5$ MeV led to an assignment of $J^\pi = \frac{1}{2}^-$ for ^{15}N*(9.22) and is consistent with $J = \frac{5}{2}$ for ^{15}N*(9.152) (1972ST22). The g-factor for ^{15}N*(5.27) [$J^\pi = \frac{5}{2}^+$] is $+(0.9 \pm 0.3)$ (1975FO06). See also ^{16}O in (1982AJ01), (1976EP1A; astrophys.) and (1976AJ04).

Table 15.12: Resonances in $^{14}C + p$ [a]

E_p (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Γ_n (keV)	Γ_p (keV)	Γ_α (keV)	Γ_γ (eV)	J^π	E_x (MeV ± keV)	Refs.
0.261 ± 0.6	< 0.5		$(0.08 \pm 0.01) \times 10^{-6}$		> 21 meV	$\frac{5}{2}^-$	10.4497 ± 0.3 [f]	A, (1975BE23, 1976BE1B)
0.352 ± 1					$(3.4 \pm 0.4) \times 10^{-2}$ [b]	$\frac{5}{2}^+$	10.5333 ± 0.5 [f]	A, (1975BE23, 1976BE1B)
0.519 ± 1			$(0.49 \pm 0.10) \times 10^{-6}$		> 40 meV	$\frac{9}{2}^+$	10.6932 ± 0.3 [f]	(1975BE23, 1976BE1B)
0.527 ± 1			0.2		0.37 ± 0.07	$\frac{3}{2}^-$	10.7019 ± 0.3 [f]	A, (1976BE1B)
0.634 ± 1			$(0.22 \pm 0.10) \times 10^{-3}$		0.27 ± 0.14	$\frac{3}{2}^{(+)}$	10.804 ± 2 [f]	A, (1975BE23, 1976BE1B)
1.162 ± 2	7.9 ± 3	2.3	5.6	< 0.3	0.29 [g]	$\frac{1}{2}^-$	11.291	A, (1977NI03)
1.3188 ± 0.5	41.4 ± 1.1	34.6 ± 0.9	6.8 ± 0.5	< 0.3	4.2 ± 0.7 [g]	$\frac{1}{2}^+$	11.4376	A, (1977NI03)
1.509 ± 4	404.9 ± 6.3	4.0 ± 0.2	400.9 ± 6.3	< 0.3	19.2 ± 0.4 [g,h]	$\frac{1}{2}^+; T = \frac{3}{2}$	11.615	A, (1975HA39, 1977NI03)
1.688 ± 3	37	36.5	0.5	< 0.3		$\frac{3}{2}^+$	11.782	A, (1977NI03)
1.788 ± 3	24.5	24.5	0.03	< 0.3		$\frac{3}{2}^-, (\frac{5}{2}^-)$	11.875	A, (1977NI03)
1.884 ± 3	21.5	21.2	0.3	< 0.3		$\frac{1}{2}^-$	11.965	A, (1977NI03)
2.025 ± 4	14 ± 5	12.0	1.7	0.6		$\frac{5}{2}^+$	12.096	A, (1977NI03)
2.077 ± 3	47 ± 7	30.2	16.6	2.2		$\frac{3}{2}^-$	12.145	A, (1977NI03)
2.272 ± 4	22	21.7	0.3	< 0.3		$\frac{5}{2}^{(+)}$	12.327	A
2.450 ± 4	44 ± 3	28	0.3	5.5		$\frac{5}{2}^+; T = \frac{1}{2}$	12.493	A, (1977NI03)
2.482 ± 8	58 ± 4				4.6 ± 0.7	$\frac{5}{2}^+; T = \frac{3}{2}$	12.523	A, (1975HA39, 1977NI03)
2.908 ± 4	70	25	9.0	15		$\frac{3}{2}^-$	12.920	A, (1974WE06, 1977NI03)
2.93 ± 10	81	n.r.	0.5	80		$\frac{5}{2}^+$	12.940	A
3.19	5.5	r					13.18	A
3.38 ± 10	24	6	6.0	12		$\frac{3}{2}^-$	13.360	A, (1974WE06)
3.421 ± 10	57	20.6	35	5.5	3.0 ± 0.9	$\frac{3}{2}^+$ [d]	13.390	A, (1974WE06, 1975HA39, 1976KU01)
3.57 ± 10	124	≈ 75	8.0	≈ 40		$\frac{3}{2}^-$	13.537	A, (1974WE06)
3.65 ± 10	88	≈ 16	12.0	≈ 60		$\frac{1}{2}^+$	13.612	A, (1974WE06)
3.71		r					13.67	A
4.0	930		500		r	$\frac{1}{2}^+$	13.9	(1974WE06, 1975HA39)
4.1 ± 100	98 ± 10		25	r		$\frac{5}{2}^+$	14.0	(1974WE06, 1975WE09)
4.2 ± 100				r		$(\frac{3}{2})$	14.1	(1975WE09)
4.6 ± 150	74 ± 7		20	r	(r)	$\frac{3}{2}^-$	14.5	(1974WE06, 1975WE09)
4.8	149 ± 18		39	r	(r)	$\frac{3}{2}^+$	14.7	(1972WE07, 1974WE06, 1975WE09)
4.83	750				r		14.71	(1975HA39)
5.08	158 ± 19		20		r	$\frac{3}{2}^+$	14.95	(1974WE06, 1975WE09, 1976WE07)
5.16 ± 130	28 ± 3		9.0	r		$\frac{3}{2}^+$	15.0	(1974WE06, 1975WE09)
5.54 ± 130	39 ± 5		12	r	(r)	$\frac{3}{2}^-$	15.4	(1972WE07, 1974WE06, 1975WE09)
5.62	750				r		15.45	(1975HA39)
6.4 ± 150	130 ± 14		19	r		$\frac{3}{2}^+$	16.2	(1974WE06, 1975WE09)

Table 15.12: Resonances in ^{14}C + p [a] (continued)

E_p (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Γ_n (keV)	Γ_p (keV)	Γ_α (keV)	Γ_γ (eV)	J^π	E_x (MeV ± keV)	Refs.
6.70	560				r		16.46	(1975HA39)
6.925	90 ± 10			r	r	$(\frac{3}{2}^+; \frac{1}{2})$ [c]	16.67	(1975HA39, 1975WE09, 1976WE07)
7.18 ± 180	110 ± 50			r		$\frac{5}{2}$	16.9	(1975WE09)
≈ 9					r	$\frac{1}{2}^+; \frac{1}{2}$	19	(1973WE04, 1974WE01)
10.0	sharp		(1000)		r	$\frac{3}{2}^+; (T = \frac{3}{2})$	19.5 [e]	(1973WE04, 1974WE01, 1974WE07, 1975HA39, 1976SN01, 1976WE07)
11.0	sharp				r	$\frac{3}{2}^+$	20.5	(1973WE04, 1974WE01, 1975HA39, 1976SN01, 1976WE07)
12.35					r		21.72	(1975HA39, 1976WE07)
13.65					r		22.94	(1975HA39, 1976SN01)
16.4					r	$(T = \frac{3}{2})$	25.5 [e]	(1975HA39, 1976SN01)
≈ 29					r		≈ 37	(1975HA39)

A: see references listed for this state in Table 15.11 of (1970AJ04) and Table 15.12 of (1976AJ04).

r = resonant.

n.r. = non-resonant.

[a] See also Tables 15.5 in (1959AJ76) and 15.11 in (1970AJ04).

[b] $\omega\gamma$ (in eV) (1969SI04).

[c] See, however, (1976WE11).

[d] (1970RA22, 1972RA03) suggest that this state has $T = \frac{3}{2}$: however, no analog state has been observed in ^{15}C (see, e.g., Fig. 13).

[e] Not observed in ^{14}N(p, γ)^{15}O (1975HA39).

[f] E_x measured directly ((1976BE1B) and R.P. Beukens, private communication).

[g] Γ_{γ_0}. I am indebted to P.M. Endt for this correction.

[h] See also (1971KU01).

31. ^{13}C(α, d)^{15}N $Q_{\mathrm{m}} = -7.6874$

This reaction has been studied at $E_\alpha = 40.1$ MeV: see Table 15.11 of (1976AJ04). See also (1976BU21, 1976LE1K) and (1978ZE03, 1979ZE1B; theor.).

32. ^{13}C(^{6}Li, α)^{15}N $Q_{\mathrm{m}} = 14.6859$

Angular distributions have been measured at $E(^6\mathrm{Li}) = 32$ MeV to ^{15}N*(0, 5.30, 6.32, 7.16, 7.30, 7.57, 8.31, 8.57, 9.15, 9.23, 9.83, 10.07, 10.70, 11.94, 13.00): the results are consistent with the previously known J^π, with (odd) parity for ^{15}N*(9.83) and with $J^\pi = \frac{9}{2}^-$ for ^{15}N*(11.94) (1977HA30). See also (1976HA31) in reaction 19.

33. ^{13}C(^{11}B, ^{9}Be)^{15}N $Q_{\mathrm{m}} = 0.3434$

At $E(^{11}\mathrm{B}) = 114$ MeV, strong population of ^{15}N*(7.57, 9.83, 11.94, 13.00, 15.1, 16.1, 18.7, 19.2) is reported by (1974AN36, 1975PO10): the dominant group is ^{15}N*(13.00).

34. ^{13}C(^{14}N, ^{12}C)^{15}N $Q_{\mathrm{m}} = 5.8870$

See (1976AJ04).

35. ^{13}C(^{17}O, ^{15}N)^{15}N $Q_{\mathrm{m}} = 2.1121$

Angular distributions are reported at $E(^{17}\mathrm{O}) = 29.8$ and 32.3 MeV involving ^{15}N*(0, 5.27 + 5.30, 6.32) (1977CH22, 1978CH16).

36. ^{14}C(p, γ)^{15}N $Q_{\mathrm{m}} = 10.2074$

Observed resonances are displayed in Table 15.12; the branching ratios are shown in Table 15.4. In the γ_0 yield for $E_{\mathrm{p}} = 2.8$ to 30 MeV (1975HA39) find that the $T = \frac{1}{2}$ and $\frac{3}{2}$ components of the GDR are located near $E_{\mathrm{x}} = 20$ and 26 MeV. Narrow anomalies are reported at $E_{\mathrm{p}} = 10.0$ and 11.0 MeV (relative strength is not in agreement with (1973WE04)), 12.35, 13.6 and 16.4 MeV. Above the giant dipole resonance region the 90° γ_0 cross section decreases smoothly with energy except for a small peak which would correspond to ^{15}N*(37.) (1975HA39). (1976SN01; $E_{\overline{\mathrm{p}}} = 7.5$

to 19 MeV) find that a good fit to the total cross section is obtained with the GDR split into peaks at $E_{\rm x} = 21.0$ and 25.5 MeV with $\Gamma = 6$ and 2 MeV respectively. The integrated E2 cross section for $E_{\rm x} = 19.5$ to 27.0 MeV is $(6.8 \pm 1.4)\%$ of the isoscalar sum rule. The reaction thus shows no sign of a collective E2 resonance in that $E_{\rm x}$ region. This is confirmed by (1976WE07; $E_{\overline{\rm p}} = 4.0$ to 16.2 MeV) who find no appreciable E2 strength concentration for $E_{\rm x} = 14.3$ to 23.3 MeV. See also (1978WE07, 1979SN1A).

37. ^{14}C(p, p)^{14}C $E_{\rm b} = 10.2074$

Observed anomalies are displayed in Table 15.12. Polarization measurements are reported for $E_{\rm p} = 3.2$ to 5.7 MeV (1974WE06). See also (1976AJ04).

38. ^{14}C(p, n)^{14}N $Q_{\rm m} = -0.6259$ $E_{\rm b} = 10.2074$

Observed resonances are listed in Table 15.12. Polarization measurements are reported at several energies in the range $E_{\rm p} = 1.79$ to 2.45 MeV (1977NI03) and 7.2 to 13.3 MeV (1971WO03). See (1977NI03) for a discussion of an R-matrix analysis of resonance parameters for $11.2 < E_{\rm x} < 14.4$ MeV.

39. ^{14}C(p, α)^{11}B $Q_{\rm m} = -0.7839$ $E_{\rm b} = 10.2074$

Observed resonances are displayed in Table 15.12. See also (1976AJ04).

40. ^{14}C(d, n)^{15}N $Q_{\rm m} = 7.9828$

Angular distributions have been measured for $E_{\rm d} = 1.3$ to 6.5 MeV: see (1970AJ04) and (1975BO34, 1975BO35; 6.5 MeV; to $E_{\rm x} < 12.1$ MeV; spectroscopic factors). See also (1976AJ04) and (1976SH13, 1977RI08; theor.).

41. ^{14}C(^{3}He, d)^{15}N $Q_{\rm m} = 4.7139$

Angular distributions have been studied at $E(^{3}{\rm He}) = 23$ MeV to ^{15}N*(0, 5.27+5.30, 6.32, 7.16, 7.30) (1979SE07; see for S values). For the earlier work to $E(^{3}{\rm He}) = 14$ MeV see (1976AJ04).

Table 15.13: Gamma radiation from ^{14}N(n, γ)^{15}N

Transition in ^{15}N	E_γ [a] (keV)	E_x (keV)	I_γ [c]	
	(1974GR37, 1980GR1E)	(1974GR37, 1979GR1M)	(1967TH05)	(1971BE34)
C → 0	10829.10 ± 0.04	10833.24 ± 0.04	13.3 ± 2.0	13.8 ± 0.2
C → 5.27	5562.07 ± 0.04		10.3 ± 0.5	10.3 ± 0.4
C → 5.30	5533.40 ± 0.04		18.8 ± 0.9	18.9 ± 0.4
C → 6.32	4508.67 ± 0.05		16.6 ± 0.8	15.3 ± 0.4
C → 7.16	3677.75 ± 0.06		15.9 ± 0.8	16.2 ± 0.3
C → 7.30	3532.10 ± 0.15		9.9 ± 0.5	10.2 ± 0.1
C → 8.31	2520.62 ± 0.11		6.1 ± 0.3	5.8 ± 0.3
C → 9.05				0.7 ± 0.4
C → 9.152	1681.59 ± 0.23		1.4 ± 0.3 [d]	
			9.2 ± 0.5	
C → 9.155	1678.26 ± 0.06			9.5 ± 0.3
C → 9.76		9757.5 ± 3 [e]		0.2 ± 0.05
C → 9.93				0.1 ± 0.04
5.27 → 0	5269.12 ± 0.04	5270.12 ± 0.04 [f]	30.6 ± 1.5	31.2 ± 0.7
5.30 → 0	5297.79 ± 0.04	5298.80 ± 0.04 [f]	21.4 ± 1.1	22.2 ± 0.4
6.32 → 0	6322.47 ± 0.06	6323.91 ± 0.06 [f]	18.8 ± 0.9	18.1 ± 1.3
7.16 → 0		7155.06 ± 0.06 [f]		
7.16 → 5.27	1884.82 ± 0.05		19.7 ± 1.0	20.5 ± 0.2
7.16 → 5.30	1857 ± 2 [b]		0.8 ± 0.2	
7.30 → 0	7299.18 ± 0.17	7301.09 ± 0.17	10.0 ± 0.5	9.2 ± 0.2
7.30 → 5.30				1.2 ± 0.4
8.31 → 0	8310.32 ± 0.14	8312.79 ± 0.14	4.4 ± 0.4	3.6 ± 0.1
				1.1 ± 0.4
8.31 → 6.32	1989 ± 2 [b]		1.5 ± 0.3	1.5 ± 0.2
8.57 → 0	8570 ± 4 [b]	8573 ± 4 [b]	0.2 ± 0.03	0.2 ± 0.04
9.05 → 0	9047 ± 4 [b]	9050 ± 4 [b]	0.2 ± 0.03	0.3 ± 0.05
9.152 → 0	9148.61 ± 0.23	9151.61 ± 0.23 [f]	1.7 ± 0.2	
9.155 → 0		9154.92 ± 0.07 [f]		1.6 ± 0.07
9.155 → 5.27	3884.38 ± 0.10		0.8 ± 0.1	0.8 ± 0.2
9.155 → 5.30	3855 ± 2 [b]		1.0 ± 0.1	0.4 ± 0.04

Table 15.13: Gamma radiation from ^{14}N(n, γ)^{15}N (continued)

Transition in ^{15}N	E_γ [a] (keV)	E_x (keV)	I_γ [c]	
	(1974GR37, 1980GR1E)	(1974GR37, 1979GR1M)	(1967TH05)	(1971BE34)
$9.155 \to 6.32$	2831.13 ± 0.11		2.0 ± 0.2	2.4 ± 0.4
$9.155 \to 7.16$	1999.73 ± 0.08		4.6 ± 0.2	3.9 ± 0.4
$9.155 \to 7.30$				0.9 ± 0.2

C = capturing state.

[a] See also Table 15.13 in (1976AJ04) and (1979GR1M).

[b] (1967TH05).

[c] In units of photons/100 captures.

[d] (1968GR14).

[e] (1971BE34).

[f] E.K. Warburton, private communication.

42. (a) ^{14}C(^{14}C, ^{13}B)^{15}N $\quad Q_m = -10.624$

(b) ^{14}C(^{14}N, ^{13}C)^{15}N $\quad Q_m = 2.6568$

For reaction (a) see (1980NA14); for (b) see (1975VO1B).

43. (a) ^{14}C(^{16}O, ^{15}N)^{15}N $\quad Q_m = -1.9201$

(b) ^{14}C(^{18}O, ^{17}N)^{15}N $\quad Q_m = -5.735$

The angular distributions leading to the ground state (reaction (a)) have been studied at $E(^{16}\text{O}) =$ 20, 25 and 30 MeV (1975SC42). For reaction (b) see (1972EY01).

44. ^{14}N(n, γ)^{15}N $\quad Q_m = 10.8334$

$Q_0 = 10833.395 \pm 0.030$ keV (1975SM02);

$Q_0 = 10833.297 \pm 0.039$ keV (1979GR1J; see also (1974SP04).

The thermal cross section is 75 ± 7.5 mb (see (1973MU14)). This large cross section is not understood in terms of the level structure in ^{15}N: see (1959AJ76).

Observed γ-rays are displayed in Table 15.13. See also Tables 15.4 and 15.5. The 90° γ_0 yield has been measured for $E_n = 6.0$ to 13.0 MeV. The angular distributions of γ_0 are consistent with essentially pure E1 radiation in the region $E_x = 16.5$ to 23.0 MeV (1979WEZX; prelim.). See also (1978DU1E; applied).

Table 15.14: Resonances in $^{14}N + n$

E_{res} (MeV $\pm$ keV)	Γ_{lab} (keV)	Γ_n (keV)	Γ_p (keV)	Γ_α (keV)	J^π	^{15}N* (MeV)
0.430 ± 5	3.5	< 3	< 0.01		$\geq \frac{3}{2}$	11.235
0.4926 ± 0.65	7.5	< 3	< 10		$\frac{1}{2}^-$	11.2929
0.639 ± 5	43	34	9		$\frac{1}{2}^+$	11.429
0.998 ± 5	46	45	0.8		$\frac{3}{2}^+$	11.764
1.120 ± 6	19	19	0.20		$\frac{3}{2}^-$	11.878
1.188 ± 6	≤ 3.2	< 2	< 0.1		$\geq \frac{3}{2}$	11.942
1.211 ± 7	13	12	0.4		$\frac{1}{2}^-$	11.963
1.350 ± 7	21	20	0.9	0.4	$\frac{5}{2}^{(+)}$	12.093
1.401 ± 8	54	41	11	1.8	$\frac{5}{2}^{(+)}$	12.140
1.595 ± 8	22	21	0.2	< 0.1	$\frac{5}{2}^{(-)}$	12.321
1.779 ± 10	47	37	0.5	9.0	$(\frac{5}{2}^+)$	12.493
2.23	65	39	7.8	18	$\frac{3}{2}^-$	12.91
2.47	< 3			r		13.14
2.52	≈ 7	r		r		13.18
2.71	40			r	$\frac{3}{2}^-$	13.36
2.74	95		r		$\frac{5}{2}^+$	13.39
2.95	20	16	1.1	3.2	$\frac{5}{2}^+$	13.59
3.09	60		r	r		13.72
3.21	85	r	r	r	$\frac{3}{2}^+$	13.83
3.51	≈ 20	r	r	r		14.11
3.57	30	r	r	r	$\frac{3}{2}^{(+)}$	14.16
≈ 3.8	≈ 2000	≈ 1000	200	≈ 1000		14.4
4.09	50	r	r	r		14.65
≈ 4.2	≈ 300	r	r	r		14.8
4.38	40			r		14.92
4.60		r		r		15.12
5.03				r		15.52
5.60	100			r		16.06
5.94				r		16.37
6.16	75			r		16.58
6.26	100	r		r		16.67

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

E_{res} (MeV ± keV)	Γ_{lab} (keV)	Γ_n (keV)	Γ_p (keV)	Γ_α (keV)	J^π	^{15}N* (MeV)
6.55	170	r		r		16.94
6.94	200	r		r		17.31
7.16				r		17.51
7.34	120			r		17.68
7.48	180	r		r		17.81
7.92	170	r		r		18.22
8.00	120			r		18.29

r = resonant.

[a] See references for this state in Tables 15.14 in (1970AJ04, 1976AJ04).

45. ^{14}N(n, n)^{14}N $\qquad E_b = 10.8334$

The scattering amplitude (bound) $a = 9.37 \pm 0.03$ fm, $\sigma_{free} = 10.05 \pm 0.12$ b, $\sigma_{inc.}^{spin}$ (bound nucleus) $= 0.49 \pm 0.11$ b (1979KO26). See also (1976KO38).

Cross-section measurements are displayed in (1976GAYV). Recent measurements of σ_t are reported for $E_n = 1.0$ to 5.2 MeV by (1976BO17). See also (1976AJ04). Observed resonances are shown in Table 15.14: for a discussion of the evidence leading to J^π assignments see (1959AJ76).

Cross sections for production of γ-rays due to the decay of excited states of ^{14}N have been measured in the range $E_n = 4$ to 20 MeV [see (1976AJ04)]. See also (1975RO30; to $E_n = 19$ MeV) and (1977DI11; 2.0 to 20.0 MeV). See also (1973DI1A, 1978SU1E) and (1975YO1A).

46. ^{14}N(n, 2n)^{13}N $\qquad Q_m = -10.554 \qquad E_b = 10.8334$

For older cross-section measurements [$E_n = 10$ to 37 MeV] see Table 15.13 of (1970AJ04) and (1976GAYV). The cross section has recently been reported for $E_n = 14.7$ to 19.0 MeV by (1978RY02). See also (1974BO1E).

47. ^{14}N(n, p)^{14}C $\qquad Q_m = 0.6259 \qquad E_b = 10.8334$

The thermal cross section is 1.81 ± 0.05 b (1973MU14). Reported resonances are displayed in Table 15.14. For cross section measurements see (1976GAYV), and (1979MO09; p_0; to 7.0 MeV), (1976FE02; 14.7 MeV), (1975RO30; $\gamma_{6.09}$, $\gamma_{6.73}$; to 19 MeV). See also (1973DI1A, 1974SH1E, 1979ROZV) and (1974BO1E, 1976SL2A).

48. (a) ^{14}N(n, d)^{13}C $\quad Q_m = -5.3260 \quad E_b = 10.8334$

(b) ^{14}N(n, np)^{13}C $\quad Q_m = -7.55063$

Differential cross sections for production of γ-rays from ^{13}C*(3.09, 3.68) have been measured for $E_n = 10$ to 11 MeV by (1970DI1A). See also (1975RO30) and (1976AJ04, 1976SL2A).

49. (a) ^{14}N(n, t)^{12}C $\quad Q_m = -4.0151 \quad E_b = 10.8334$

(b) ^{14}N(n, t)^{4}He^{4}He^{4}He $\quad Q_m = -11.2899$

(c) ^{14}N(n, 2α)^{7}Li $\quad Q_m = -8.823$

See (1975RO30, 1978QA01) and (1976AL02, 1976SL2A).

50. (a) ^{14}N(n, α)^{11}B $\quad Q_m = -0.1580 \quad E_b = 10.8334$

(b) ^{14}N(n, nα)^{10}B $\quad Q_m = -11.6133$

Observed resonances are listed in Table 15.14. For cross-section measurements see (1976GAYV), and (1979MO09; α_0, α_1; $1 \rightarrow 15$ MeV and 4 to 15 MeV, respectively), (1978MO09; α_0; 13.9 MeV) and (1977DI11; $\gamma_{4.4}$; to 19 MeV). See also (1973DI1A, 1975RO30, 1978SU1D) and (1976AJ04, 1976SL2A).

51. ^{14}N(p, π^+)^{15}N $\quad Q_m = -129.516$

See (1979MA38, 1979MA39).

52. ^{14}N(d, p)^{15}N $\quad Q_m = 8.6087$

Proton groups corresponding to levels of ^{15}N are listed in Table 15.15. Angular distributions have been measured in the range $E_d = 0.5$ to 27 MeV [see (1959AJ76, 1970AJ04, 1976AJ04)] and at $E_{\vec{d}} = 0.324$ to 0.626 MeV (1976VA20; p_0, p_{1+2}, $p_3 \rightarrow p_5$), $E_{\vec{d}} = 2.0$ and 2.2 MeV (1979US01;

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

E_x (MeV ± keV) A	E_x (MeV ± keV) B	l_n [b]	J^π [c]	S [d]
0		1	$\frac{1}{2}^-$	1.45 ± 0.15 [g]
5.276 ± 6	5.27159 ± 0.46	2	$\frac{5}{2}^+$	$< 0.15 \pm 0.07$
5.305 ± 6	5.30003 ± 0.43	[e]		$< 0.02 \pm 0.01$
6.328 ± 6		1	$\frac{3}{2}^-$	0.07 ± 0.02 ($j_n = \frac{1}{2}$); 0.04 ± 0.01 ($j_n = \frac{3}{2}$)
7.164 ± 6	7.1555 ± 1.7	2	$\frac{5}{2}^+$	0.92 ± 0.07
7.309 ± 6 [a]		$0 + 2$	$\frac{3}{2}^+$	0.87 ± 0.07 ($j_n = \frac{1}{2}$); 0.07 ± 0.04 ($j_n = \frac{5}{2}$)
7.570 ± 8	7.5671 ± 1.0	2	$\frac{7}{2}^+$	0.89 ± 0.05
8.315 ± 6 [a]	8.309 ± 4.1	$0 + 2$	$\frac{1}{2}^+$	0.77 ± 0.08 ($j_n = \frac{1}{2}$); 0.11 ± 0.05 ($j_n = \frac{3}{2}$)
8.582 ± 5 [a]	8.573 ± 3.2	$0 + 2$	$\frac{3}{2}$	0.05 ± 0.03 ($j_n = \frac{1}{2}$); 0.12 ± 0.05 ($j_n = \frac{5}{2}(\frac{3}{2})$)
9.056 ± 5		0	$(\frac{1}{2}, \frac{3}{2})^+$	
9.159 ± 6		[f]		
9.226 ± 6		1	$(\frac{1}{2}^-)$	
9.764 ± 6		1	$(\frac{1}{2}^-)$	
9.831 ± 6				
9.929 ± 6		[e]		
10.071 ± 6		2, 0	$\frac{3}{2}^+$	
10.456 ± 7		(1)		
10.541 ± 7				
10.702 ± 7		2, 0	$\frac{3}{2}^+$	
10.809 ± 9		1	$\leq \frac{5}{2}^-$	
11.2		1	$\leq \frac{5}{2}^-$	

A: (1950MA65, 1954SP01, 1956DO41, 1966GA08).
B: (1965AL19, 1965WA16, 1966AL18, 1967CH19).
[a] 7307, 8319 and 8577 keV (±8 keV) (1956DO41).
[b] See also Tables 15.15 in (1970AJ04, 1976AJ04).
[c] (1980KR01) and Tables 15.15 in (1970AJ04, 1976AJ04).
[d] (1980KR01). See also (1969PH02) and (1972AM06). values shown are close to those given by the extreme weak coupling model (1980KR01).
[e] No clear stripping pattern.
[f] Doublet.
[g] $S_{\rm DWBA} = 0.89 \pm 0.2$, $S_{\rm IA} = 0.82 \pm 0.08$ (1977HE01; $E_d = 52$ MeV).

p_5), $E_{\overline{d}} = 10$ MeV (1980KR01; see Table 15.15), $E_d = 10.03$ and 11.65 MeV (1979AO01; p_0) and $E_{\overline{d}} = 52$ MeV (1977HE01; p_0).

Branching ratios and multipolarities are shown in Table 15.4; τ_m in Table 15.5. The two states of ^{15}N at $E_x = 9.15$ MeV are separated by 2.8 ± 0.5 keV: see (1976AJ04). See also (1977KO33), (1977RI08), (1976EP1A; astrophys.), (1978GO1R; applications) and ^{16}O in (1982AJ01).

53. ^{14}N(t, d)^{15}N $\quad Q_m = 4.5760$

The d_0 angular distributions have been measured at $E_t = 1.5$ to 2.0 MeV (1964SC09).

54. ^{14}N(α, ^{3}He)^{15}N $\quad Q_m = -9.7444$

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.

55. (a) ^{14}N(^{9}Be, ^{8}Be)^{15}N $\quad Q_m = 9.1682$
(b) ^{14}N(^{11}B, ^{10}B)^{15}N $\quad Q_m = -0.6219$
(c) ^{14}N(^{12}C, ^{11}C)^{15}N $\quad Q_m = -7.888$

For reaction (a) see (1970AJ04). For reaction (b) see (1976AJ04). At $E(^{12}\text{C}) = 114$ MeV, the strongly populated states are ^{15}N*(0, 7.5) (1974AN36).

56. ^{14}N(^{14}N, ^{13}N)^{15}N $\quad Q_m = 0.280$

Angular distributions to the ground state of ^{15}N have been measured for $E(^{14}\text{N})(\text{c.m.}) = 5.5$ to 16 MeV: see (1976AJ04). Below ≈ 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 (1976SW02) for a comparison of the nuclear reaction S-factors for this reaction and for $^{14}\text{N} + {}^{14}\text{N}$ fusion.

57. (a) ^{14}N(^{18}O, ^{17}O)^{15}N $\quad Q_m = 2.789$
(b) ^{14}N(^{19}F, ^{18}F)^{15}N $\quad Q_m = 0.4021$

Table 15.16: Beta decay of ^{15}C [a]

Decay to ^{15}N* (keV)	J^π	Branch (%)	$\log ft$
g.s.	$\frac{1}{2}^-$	32 ± 2	5.99 ± 0.03
5298.87 ± 0.15 [b]	$\frac{1}{2}^+$	68 ± 2	4.08 ± 0.01
6323.3 ± 0.6	$\frac{3}{2}^-$	$\leq 0.4 \times 10^{-2}$	≥ 7.8
7301.1 ± 0.5	$\frac{3}{2}^+$	$(0.74 \pm 0.08) \times 10^{-2}$	6.89 ± 0.05
8312.9 ± 0.5	$\frac{1}{2}^+$	$(4.1 \pm 0.5) \times 10^{-2}$	5.18 ± 0.05
8571.4 ± 1.0	$\frac{3}{2}^+$	$(1.3 \pm 0.2) \times 10^{-2}$	5.34 ± 0.07
9050.0 ± 0.7	$\frac{1}{2}^+$	$(3.4 \pm 0.3) \times 10^{-2}$	4.05 ± 0.04

[a] (1979AL23).
[b] (1976AL16).

See (1976AJ04).

58. ^{15}C(β^-)^{15}N $\qquad Q_m = 9.7717$

The β^- decay takes place to ^{15}N*(0, 5.30, 7.30, 8.31, 8.57, 9.05): see Table 15.16.

59. (a) ^{15}N(γ, n)^{14}N $\qquad Q_m = -10.8334$
(b) ^{15}N(γ, p)^{14}C $\qquad Q_m = -10.2074$
(c) ^{15}N(e, p$_0$e$'$)^{14}C $\qquad Q_m = -10.2074$
(d) ^{15}N(γ, d)^{13}C $\qquad Q_m = -16.1594$
(e) ^{15}N(γ, t)^{12}C $\qquad Q_m = -14.8484$

Below $E_\gamma = 15$ MeV, the giant resonance of ^{15}N decays entirely by ground state transitions. The total integrated cross section up to 35 MeV for transitions to excited states [^{14}N*(2.31, 3.95, $5.11 + 5.83$, 7.03), ^{14}C*($6.09 + 6.59 + 6.90$, 7.01), ^{12}C*(4.4)] is 44 MeV · mb. The nature of the transitions is such as to indicate a very strong $(1p_{3/2})^0(1p_{1/2})^3$ component in ^{15}N$_{\rm g.s.}$. The presence of $T = \frac{1}{2}$ in the main giant resonance region is indicated by the strong population of ^{14}N*(7.03) (1976PA22).

A study at $E_e = 18.8$, 20.8, 25.7 and 29.7 MeV (reaction (c)) shows a "pigmy" resonance at $E_x = 14.8$ MeV, a shoulder at 15.6 MeV, a peak at 16.7 MeV [probably $\frac{1}{2}^+$ but $\frac{3}{2}^+$ is not ruled out], and the giant dipole resonance, which exhibits a great deal of structure, centered at 22 MeV. The data on the pigmy resonance are consistent with an admixture of $\approx 1\%$ $\frac{3}{2}^-$ (E2) or $\frac{1}{2}^-$ (M1) to a predominantly $\frac{1}{2}^+$ (E1) state. The experiment shows that for $14 < E_x < 28$ MeV the reaction goes predominantly via $\frac{1}{2}^+$ or $\frac{3}{2}^+$ (E1) states in ^{15}N; the $T = \frac{3}{2}$ strength is concentrated above 18 MeV (1975MU07) [see also (1975HA39)].

The cross section for d_0 [reaction (d)] is reported at $90°$ for $E_\gamma \approx 20.5$ to 28.5 MeV: a resonance is observed at $E_x \approx 21.9$ MeV (1979SK04: see Table 15.10).

The (γ, t_0) cross section (reaction (e)) at $90°$ decreases from a value of 30 μb/sr at 20 MeV to 5 μb/sr at 22 MeV and remains flat out to 25 MeV. Comparison of this cross section, and those of other photonuclear reactions, suggests an isospin splitting of ≈ 6 MeV with the $T = \frac{1}{2}$ strength concentrated between 16 and 21 MeV and the $T = \frac{3}{2}$ strength between 21 and 28 MeV. ^{15}N*(21.9) is not observed (1979UE01). See also (1977SP06, 1978JU1A) and (1977AL32; theor.).

60. ^{15}N(γ, γ)^{15}N

$\Gamma_{\gamma 0} = 2.9 \pm 0.3$ eV for ^{15}N*(6.32) (1976MO14) and 4.2 ± 1.5 eV for ^{15}N*(10.07) (1976PA22). See also (1980SH05).

61. ^{15}N(e, e)^{15}N

The r.m.s. radius of ^{15}N is 2.580 ± 0.026 fm (1973FE13, 1975SC18). Inelastic groups are displayed in Table 15.17. The giant resonance is split into two main peaks at $E_x = 22$ and 25.5 MeV with some structure around 20 MeV. $\Gamma_{\gamma 0}(\mathrm{C1}) = (1.1 \pm 0.3) \times 10^3$ eV (14–18.5 MeV), $\Gamma_{\gamma 0}(\mathrm{C2}) = (12.5 \pm 2.0)$ eV assuming the states responsible are $\frac{3}{2}^+$ and $\frac{3}{2}^-$, respectively. For $E_x = 18.5$ to 30 MeV, $\Gamma_{\gamma 0}(\mathrm{C1}) = (1.96 \pm 0.04) \times 10^4$ eV while $\Gamma_{\gamma 0} < 0.1$ eV for any C2 strength (1978AN12). See also (1976MA30, 1979SH1T), (1979MO19) and (1976SU07, 1977HO04, 1977SU1H; theor.).

62. ^{15}N(n, n)^{15}N

See (1976AJ04).

63. ^{15}N(p, p)^{15}N

Angular distributions of elastically scattered protons have been measured at E_p to 39.8 MeV [see (1976AJ04)] and at $E_p = 5.85$ MeV (1977SA1B) and 18.0 to 44.2 MeV (1980FA06, 1980FA07). See also (1976NO02, 1979MA2M), (1977BL07, 1979RO1B; theor.) and ^{16}O in (1982AJ01).

Table 15.17: Ground state radiative widths [a] from ^{15}N(e, e′)

E_x (MeV ± keV)	J^π	Trans.	Γ_{γ_0} (eV)	$B(\lambda)\uparrow$ ($e^2 \cdot \mathrm{fm}^{2L}$)
5.27	$\frac{5}{2}^+$	E3	$(4.2 \pm 0.3) \times 10^{-6}$	4.40 ± 40
		M2	$(1.2 \pm 0.7) \times 10^{-4}$	0.30 ± 0.07
5.30	$\frac{1}{2}^+$	E1	2.2 ± 2.3	
6.32	$\frac{3}{2}^-$	E2	0.060 ± 0.004 [b]	14.8 ± 1.0
		M1	1.9 ± 0.4	
7.16	$\frac{5}{2}^+$	E3	$(0.86 \pm 0.10) \times 10^{-5}$	
7.30	$\frac{3}{2}^+$	E1	2.6 ± 1.0	
		M2	$(0.3 \pm 0.2) \times 10^{-5}$	
7.57	$\frac{7}{2}^+$	E3	$(1.84 \pm 0.16) \times 10^{-5}$	
9.152	$\frac{3}{2}^-$	E2	0.095 ± 0.005 [c]	3.85 ± 0.2
		M1	0.2 ± 0.8	
9.76	$\frac{5}{2}^-$	E2	0.20 ± 0.05	8.4 ± 2.1
10.8	$\frac{3}{2}^+$	M2	$(1.8 \pm 0.8) \times 10^{-2}$	
11.88	$\frac{3}{2}^-$	E2	0.44 ± 0.10	4.6 ± 1
		M1	4.4 ± 3.8	
12.5	$\frac{5}{2}^+$	M2	$(5.2 \pm 2.0) \times 10^{-2}$	
(13.98) [d]				
14.7	$\frac{5}{2}^-$	E2	1.8 ± 0.2	
20.10 [d]				
23.25 [d]				

[a] (1975KI08, 1975KI09, 1977AN25, 1977MA42, 1978AN12). See also Tables 15.4 and 15.5.

[b] δ(E2/M1) $= 0.16 \pm 0.03$.

[c] δ(E2/M1) > 0.3.

[d] See also (1980SI1F) and the text.

64. ^{15}N(d, d)^{15}N

Angular distributions of elastic scattered deuterons have been measured at $E_d = 5 - 6$ MeV: see (1972FO17, 1976AJ04).

65. ^{15}N(^{3}He, ^{3}He)^{15}N

Angular distributions have been studied at $E(^{3}\text{He}) = 11$ to 39.8 MeV: see reaction 68 and Table 15.17 in (1976AJ04).

66. ^{15}N(α, α)^{15}N

At $E_\alpha = 40.5$ MeV, a number of particle groups have been observed, and angular distributions have been measured: see Table 15.17 of (1976AJ04) (1966HA19). B(E2)↓ $/e^2 = 4.7$ fm^4 for ^{15}N*(6.32): B(E3)↓ $/e^2 = 60$ fm^6 for both ^{15}N*(5.27, 7.57) (1966HA19). At $E_\alpha = 22$, 24 and 28 MeV, the intensity of the back scattering is greatly enhanced over pure Coulomb scattering (1972OE01, 1973OE01). Angular distributions are also reported at $E_\alpha = 20.1$ MeV (α_0; back angles) and at 23.7 MeV (α_0, α_{1+2}, α_3, groups to unresolved states and to ^{15}N*(10.07)) (1977FE08). (1976WO11) find $S_\alpha = 0.42$ for ^{15}N$_{\text{g.s.}}$. See also (1977KN1E), (1975GR41, 1977MA2E, 1979KN1F) and (1976CO27, 1977OH01, 1977SA19, 1979LE18; theor.).

67. ^{15}N(^{12}C, ^{12}C)^{15}N

Angular distrbutions of elastic scattering have been measured at $E(^{15}\text{N}) = 31.5$, 36, 39.5 and 47 MeV (1978CO20). For fusion cross sections see (1978CO20, 1979KO20). See also (1977PH1C) and (1977BA3E; theor.).

68. (a) ^{15}N(^{15}N, ^{15}N)^{15}N
(b) ^{15}N(^{16}O, ^{16}O)^{15}N
(c) ^{15}N(^{19}F, ^{19}F)^{15}N

For reaction (a) see (1980KR06; theor.). For reaction (b) see (1976AJ04). Elastic angular distributions (reaction (c)) have been studied at $E(^{15}\text{N}) = 23$, 26 and 29 MeV (1973GA14).

69. (a) ^{15}N(^{27}Al, ^{27}Al)^{15}N
(b) ^{15}N(^{28}Si, ^{28}Si)^{15}N
(c) ^{15}N(^{40}Ca, ^{40}Ca)^{15}N

Elastic distrbutions (reaction (a)) have been measured at $E(^{15}\text{N}) = 32.8$, 47.9, 62.1 and 69.8 MeV (1980PR06; see also for fusion cross sections). An elastic distribution (reaction (b)) is reported at $E(^{15}\text{N}) = 44$ MeV (1978PE13). See also (1979KA27; theor.). For reaction (c) see (1979SA27; theor.).

70. ^{15}O(β^+)^{15}N $\qquad Q_\text{m} = 2.7539$

See ^{15}O.

71. (a) ^{16}O(γ, p)^{15}N $\qquad Q_\text{m} = -12.1276$

(b) ^{16}O(e, ep)^{15}N $\qquad Q_\text{m} = -12.1276$

Over the giant resonance region in ^{16}O, the decay takes place to the odd parity states ^{15}N*(0, 6.32) and less strongly to the even parity states ^{15}N*(5.27, 5.30, 8.31, 9.05) and to ^{15}N*(9.23): see (1970HO21) and the earlier references in (1970AJ04). At $E_\text{e} = 500$ MeV most of the 1p hole-hole strength is concentrated in the groups to ^{15}N*(0, 6.32). The 1s state shows up as a very wide asymmetric structure centered at $E_\text{x} \approx 41$ MeV (1977MO1F, 1977BE1Q, 1979MO1G). See also (1977MA01) and ^{16}O in (1982AJ01). See also (1979GO1V, 1979KI1H), (1976HA1Q) and (1977WA1R, 1978SC11, 1979LO03, 1979WA1G; theor.).

72. ^{16}O(n, d)^{15}N $\qquad Q_\text{m} = -9.9029$

Angular distributions of the d_0 group have been reported at $E_\text{n} = 14$ and 14.4 MeV: see (1976AJ04). See also (1976KI1D, 1978NE1B).

73. ^{16}O(p, 2p)^{15}N $\qquad Q_\text{m} = -12.1276$

At $E_\text{p} = 460$ MeV, the summed proton spectrum shows two peaks corresponding to the knock-out 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). The ground state angular correlation has been studied at $E_\text{p} = 45$ MeV (1971EI06). See also (1976SI1A) and (1978HA36, 1979KU07, 1979MA20; theor.).

74. ^{16}O(d, ^{3}He)^{15}N $\qquad Q_\text{m} = -6.6340$

Angular distributions of ^{3}He groups have been measured for $E_d = 20$ to 82 MeV (see (1976AJ04)). Recent measurements are reported at $E_d = 29$ MeV (1976FI01: to ^{15}N states with $E_x < 10.1$ MeV; see for spectroscopic factors), at $E_{\vec{d}} = 29$ MeV (1978CO13: to ^{15}N*(0, 6.32)) and 52 MeV (1977BE70: to ^{15}N*(0, 6.32, 9.94 ± 0.02, 10.705 ± 0.01)). The spectra are dominated by transitions to ^{15}N*(0, 6.32). A ZRDWBA analysis of the 29 MeV data leads to $C^2S = 2.25$ and 3.25 for these two states [and to 2.37 and 3.31 for the analog states in ^{15}O studied with the (d, t) reaction] (C^2S are average of values obtained from two parameter sets) (1978CO13). The $E_{\vec{d}} = 52$ MeV work leads to $J^\pi = \frac{3}{2}^-$ for both ^{15}N*(9.94, 10.71) (1977BE70). See also (1975FA06, 1976CH21; theor.).

75. ^{16}O(t, α)^{15}N $\quad Q_m = 7.6865$

Angular distributions have been measured at $E_t = 13$ MeV (1965AJ01; α_0, α_{1+2}, α_3).

76. (a) ^{16}O(^{7}Li, ^{8}Be)^{15}N $\quad Q_m = 5.1279$
(b) ^{16}O(^{10}B, ^{11}C)^{15}N $\quad Q_m = -3.437$
(c) ^{16}O(^{11}B, ^{12}C)^{15}N $\quad Q_m = 3.8294$

For reaction (a) see (1979MAZL). The ground state angular distribution has been studied at $E(^{10}\mathrm{B}) = 100$ MeV (1975NA15). At $E(^{11}\mathrm{B}) = 115$ MeV ^{15}N*(0, 6.32) are populated (1979RA10).

77. (a) ^{16}O(^{14}N, ^{15}O)^{15}N $\quad Q_m = -4.8305$
(b) ^{16}O(^{16}O, ^{17}F)^{15}N $\quad Q_m = -11.5272$
(c) ^{16}O(^{19}F, ^{20}Ne)^{15}N $\quad Q_m = 0.7171$

Angular distributions are reported at $E(^{14}\mathrm{N}) = 76.2$ MeV and $E(^{16}\mathrm{O}) = 95.2$ MeV (1979MO14, 1977MO1A), and $E(^{14}\mathrm{N}) = 155$ MeV (1975NA15, 1975VO05). Angular distributions are also reported at $E(^{19}\mathrm{F}) = 36$ MeV involving $^{15}\mathrm{N}_{\mathrm{g.s.}}$ and ^{20}Ne*(0, 1.63) (1973GA14).

78. ^{17}O(p, ^{3}He)^{15}N $\quad Q_m = -8.5537$

At $E_p = 39.8$ MeV angular distributions of the groups to ^{15}N*(0, 6.32) have been compared with those to the analog states in ^{15}O (1970OL1B, 1971OL04).

79. ^{17}O(d, α)^{15}N $\qquad Q_{\rm m} = 9.7995$

See (1976AJ04).

80. (a) ^{18}O(p, α)^{15}N $\qquad Q_{\rm m} = 3.9796$

(b) ^{18}O(p, tp)^{15}N $\qquad Q_{\rm m} = -15.8345$

Angular distributions of α_0 have been measured for $E_{\rm p} = 0.84$ to 2.00 MeV and at several energies in the range 20.6 to 42.2 MeV [see (1976AJ04)] as well as at $E_{\rm p} = 125$ to 850 keV (1979LO01), 296 to 549 keV (1978MA30) and 6.6 to 10.4 MeV (1979WI09). For astrophysical considerations see ^{19}F in (1983AJ01) and (1978MA30, 1979LO01). See also (1977CO1W). For angular correlation measurements see (1976AJ04). For reaction (b) see reaction 82 in ^{16}O (1977AJ02).

81. ^{18}O(^{18}O, ^{20}F)^{15}N $\qquad Q_{\rm m} = -1.6505$

See (1976AJ04).

82. (a) ^{19}F(γ, α)^{15}N $\qquad Q_{\rm m} = -4.0138$

(b) ^{19}F(p, pα)^{15}N $\qquad Q_{\rm m} = -4.0138$

(c) ^{19}F(α, 2α)^{15}N $\qquad Q_{\rm m} = -4.0138$

The cross section for reaction (a) to ^{15}N*(5.27, 5.30) has been measured for $E_{\rm bs} = 14$ to 30 MeV (1979TH05, 1976TH1E). See also (1972SH07). For reaction (c) see ^{19}F. See also (1970AJ04) and (1977SP06).

83. ^{19}F(d, ^{6}Li)^{15}N $\qquad Q_{\rm m} = -2.5404$

Angular distributions involving ^{15}N$_{\rm g.s.}$ have been measured at $E_{\rm d} = 9.0$ to 2.8 MeV [see (1976AJ04); also at $E_{\rm d} = 19.5$ MeV to ^{15}N*(5.3, 6.3)] and at $E_{\rm d} = 13.6$ MeV (1975GO21).

84. ^{19}F(^{3}He, ^{7}Be)^{15}N $\qquad Q_{\rm m} = -2.428$

Angular distributions have been measured at $E(^{3}{\rm He}) = 30$ MeV (1970DE12) and 40.7 MeV (1971DE04, 1971DE37) involving ^{15}N$_{\rm g.s.}$ and ^{7}Be*(0, 0.43).

^{15}O

(Figs. 12 and 13)

GENERAL: (See also (1976AJ04).):

Shell model: (1976LI16, 1976SA37, 1977EM01, 1977PO16).

Special states: (1976LI16, 1977RI08).

Electromagnetic transitions: (1976LI16, 1976SH04, 1977HO04, 1978KR19).

Astrophysical questions: (1977BA1V, 1977SI1D, 1978BU1B, 1979PE1E, 1979WO07).

Special reactions involving ^{15}O: (1976AB04, 1976BU16, 1976HE1H, 1976HI05, 1976LE1F, 1977AR06, 1977SC1G, 1978AB08, 1978BO1W, 1979AL22).

Pion capture and pion reactions: (1975KA1G, 1977BA24, 1977BA2G, 1978MO01, 1979LI11, 1979OS1F).

Applied work: (1976BE1X, 1977ST1M, 1977SU1G, 1977TH1H, 1978BI1M, 1978HI1D, 1978TI1A, 1978WI1F, 1978WO1C, 1979AL1Q, 1979DE1H, 1979WI1G).

Other topics: (1976SA1H, 1977BA3P, 1977EM01, 1978SH1B, 1979BE1H, 1979KA13).

Ground state properties of ^{15}O: (1976FU06, 1976SA1H, 1977KO28, 1977PO16, 1977YO1D, 1978AR1R, 1978SL1B, 1979NO05).

$$\mu = 0.7189\ (8)\ \text{nm (1978LEZA)}.$$

1. ^{15}O(β^+)^{15}N $\qquad Q_{\rm m} = 2.7539$

The half-life of ^{15}O is 122.24 ± 0.14 sec based on the values listed in Table 15.19 of (1970AJ04) and on $\tau_{1/2} = 122.23 \pm 0.23$ sec (1977AZ01). $\log f_0 t = 3.637$ [calculated from tables of (1971GO40)]. The K/β^+ ratio is $(10.7 \pm 0.6) \times 10^{-4}$ (1972LE33). See also (1977BA48, 1978RA2A), (1978TA1U, 1979DA1D; astrophys.) and (1977AZ02, 1977RI08, 1977YO1E, 1979BA08, 1979OS1E, 1979TO1B; theor.).

2. ^{10}B(^{6}Li, n)^{15}O $\qquad Q_{\rm m} = 15.212$

See (1976AJ04).

3. ^{10}B(^{14}N, ^{9}Be)^{15}O $\qquad Q_{\rm m} = 0.712$

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

E_x in ^{15}O (MeV ± keV)	$J^\pi; T$	τ or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
0	$\frac{1}{2}^-; \frac{1}{2}$	$\tau_{1/2} = 122.24 \pm 0.16$ sec	β^+	1, 2, 3, 4, 5, 6, 7, 10, 11, 12, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34
5.183 ± 1	$\frac{1}{2}^+$	$\tau_m = 8.2 \pm 1.0$ fsec	γ	3, 7, 10, 12, 21, 25, 26, 28, 29, 34
5.2409 ± 0.3	$\frac{5}{2}^+$	3.25 ± 0.30 psec	γ	3, 7, 8, 10, 12, 13, 21, 22, 24, 25, 26, 28, 29
6.1763 ± 1.7	$\frac{3}{2}^-$	< 2.5 fsec	γ	7, 12, 21, 22, 25, 26, 27, 28, 29, 33, 34
6.7931 ± 1.7	$\frac{3}{2}^+$	< 28 fsec	γ	3, 7, 12, 21, 22, 25, 29
6.8594 ± 0.9	$\frac{5}{2}^+$	16.0 ± 2.5 fsec	γ	3, 7, 12, 21, 22, 25, 26, 29
7.2759 ± 0.6	$\frac{7}{2}^+$	0.70 ± 0.15 psec	γ	7, 8, 10, 12, 13, 21, 22, 25, 29
7.5565 ± 0.8	$\frac{1}{2}^+$	$\Gamma = 1.6 \pm 0.5$ keV	γ, p	12, 14, 21, 22, 25, 29
8.2840 ± 0.9	$\frac{3}{2}^+$	3.6 ± 0.7	γ, p	7, 12, 14, 21, 22, 29
8.743 ± 6	$\frac{1}{2}^+$	32	γ, p	12, 14, 29
8.922 ± 2	$\frac{5}{2}^+$	3.3 ± 0.3	γ, p	7, 12, 14, 16, 29
8.922 ± 2	$\frac{1}{2}^+$	7.5	γ, p	7, 12, 14, 16, 29
8.9821 ± 1.7	$(\frac{1}{2})^-$	3.9 ± 0.4	γ, p	7, 12, 14, 29
9.488 ± 3	$\frac{5}{2}^-$	10.1 ± 0.5	γ, p	7, 12, 14, 29
9.527 ± 17	$(\frac{3}{2})^+$	280 ± 25	γ, p	12, 14, 16, 29
9.609 ± 2	$\frac{3}{2}^-$	8.8 ± 0.5	γ, p	7, 8, 12, 14, 28, 29
9.662 ± 3	$(\frac{7}{2}, \frac{9}{2})^-$	2 ± 1	p	7, 8, 12, 16, 29
10.29 [b]	$(\frac{5}{2}^-)$	3 ± 1	p	7, 12, 16, 29
10.30 [b]	$\frac{5}{2}^+$	11 ± 2	p	7, 12, 16
10.461 ± 5	$(\frac{9}{2}^+)$	< 2	γ, p	7, 8, 14, 29
10.48	$(\frac{3}{2}^-)$	25 ± 5	γ, p	(8), 12, 14, 16, 28, 29
(10.506)	$(\frac{3}{2})^+$	140 ± 40	γ, p	14, 16, 26
10.917 ± 12	$\frac{7}{2}^+$	90	p	16, 29
10.938 ± 3	$\frac{1}{2}^+$	99 ± 5	γ, p	14, 16, 29

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

E_x in ^{15}O (MeV $\pm$ keV)	$J^\pi; T$	τ or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
11.025 ± 3	$\frac{1}{2}^-$	25 ± 2	γ, p	14, 16, 29
11.151 ± 7		< 10	p	7, 16, 29
11.218 ± 3	$\frac{3}{2}^+$	40 ± 4	γ, p	14, 16, 29
11.565 ± 15		< 10	p	7, 16, 29
11.569 ± 15	$\frac{5}{2}^-$	20 ± 15	γ, p	7, 14, 16, 29
11.616 ± 15	$(\frac{3}{2}, \frac{1}{2})^-$	80 ± 50	γ, p	14, 16
11.719 ± 8		< 10	p	7, 16
11.748 ± 3	$\frac{5}{2}^+$	99 ± 5	γ, p	14, 16
11.846 ± 3	$\frac{5}{2}^-$	65 ± 3	γ, p	14, 16
11.980 ± 10	$\frac{5}{2}^-$	20 ± 5	p	7, 16, 29
12.129 ± 15	$\frac{5}{2}^+$	200 ± 50	p	16, 29
12.222 ± 20		100 ± 50	p	16
12.255 ± 13	$\frac{5}{2}^+; \frac{3}{2}$	135 ± 15	p	33
12.295 ± 10				7
12.471 ± 3	$\frac{5}{2}^-(\frac{3}{2}^-)$	77 ± 4	p	16
12.60 ± 10				7
12.80		≈ 250	γ, p	14
12.835 ± 3	$(\frac{1}{2}^-)$	16 ± 1	p	7, 8, 9, 10, 16
13.008 ± 3		215 ± 3	p	16
13.025 ± 3		40 ± 30	p, (^{3}He)	5, 16
13.45	$(\frac{1}{2}, \frac{3}{2})^+$	≈ 1000	γ, p, (α)	14, 16, 20
(13.49)	$(\frac{3}{2}^+)$		(p)	16
13.60	$\frac{5}{2}^+$		p, α	20
13.70	$\frac{3}{2}^-$		p	16
13.79	$\frac{3}{2}^-$		n, p, ^{3}He, α	5, 7, 16, 20
13.87		≈ 150	γ, p	14
14.03 ± 40	$(\frac{1}{2}^-, \frac{3}{2}^-)$	160 ± 20	n, p, ^{3}He	5
14.17	$\frac{5}{2}^-$		p, α	20
14.27 ± 10	$\frac{1}{2}^+$	340 ± 30	n, p, ^{3}He, α	5, 7, 15, 16, 19, 20
14.34	$\frac{5}{2}^+$	(240)	p, (^{3}He), α	5, 20

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

E_x in ^{15}O (MeV ± keV)	$J^\pi; T$	τ or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
14.465 ± 10	$\frac{3}{2}^+, \frac{5}{2}^+$	100 ± 10	n, p, ^{3}He, α	5, 15, 16, 20
14.70 ± 40		170 ± 35	n, p, ^{3}He	5, 15
14.95 ± 40		400 ± 25	n, p, ^{3}He, α	5, 15, 16, 19, 20
15.05 ± 10	$((\frac{13}{2}^+))$			7, 9, 10
15.1	$(\frac{1}{2}, \frac{3}{2})^+$	≈ 1000	γ, p	14
15.45 ± 30		70 ± 20	p, ^{3}He, α	5, 7, 8
15.54 ± 10			(p, ^{3}He, α)	5, 7
15.60 ± 10			(p, ^{3}He, α)	5, 7
15.65 ± 10				7
15.80 ± 10			n, ^{3}He	5, 7
15.90 ± 15	$\frac{1}{2}^-, \frac{3}{2}^-$	350	^{3}He, α	5, 8
16.05 ± 20		≈ 185	n, p, ^{3}He, α	5, 15, 16, 20
16.10 ± 20			(n) ^{3}He, α	5
16.21 ± 20		≈ 140	(n), p, ^{3}He, α	5, 16, 19, 20
16.43 ± 50	$\frac{1}{2}^+$	560 ± 100	^{3}He, α	5
16.75 ± 50			n, ^{3}He	5, 29
17.04 ± 60	$(\frac{1}{2}, \frac{3}{2})^+$	700 ± 70	γ, p, ^{3}He	5, 8, 14
17.46 ± 20				7
17.51 ± 20	$\frac{1}{2}^-, \frac{3}{2}^-$	600	n, ^{3}He, α	5, 7
17.99 ± 50	$\frac{1}{2}^-, \frac{3}{2}^-$	200	^{3}He	5
18.23 ± 50			n, p, ^{3}He	5
18.65 ± 60	$(\frac{1}{2}^+, \frac{3}{2}^+); \frac{1}{2}$	520 ± 110	γ, ^{3}He	5
19.03 ± 50			n, ^{3}He	5
19.55 ± 80	$(\frac{1}{2}^+, \frac{3}{2}^+); \frac{1}{2}$	780 ± 270	γ, ^{3}He	5
19.91 ± 50			n, ^{3}He	5
20.40 ± 70	$(\frac{1}{2}^+, \frac{3}{2}^+); \frac{1}{2}$	970 ± 240	γ, p, ^{3}He	5, 14
21.61 ± 70	$(\frac{1}{2}^+, \frac{3}{2}^+); \frac{1}{2}$	730 ± 120	γ, p, ^{3}He	5, 14
(26.0)	$(\frac{13}{2}^-)$	≈ 600	^{3}He	5
(28.0)	$(\frac{9}{2}^-, \frac{11}{2}^-)$	≈ 2500	^{3}He	5
(29.0)		≈ 2500	^{3}He	5

[a] See also Table 15.19.

[b] It is possible that these two are in fact a single state: see (1976AJ04).

Angular distributions have been measured at $E(^{14}\text{N}) = 73.9$ MeV (1977MO1A; to g.s.) and 100 MeV (1975NA15; to ^{15}O*(0, $5.18 + 5.24$, $6.79 + 6.86$)).

4. ^{11}B(^{14}N, ^{10}Be)^{15}O $\qquad Q_{\rm m} = -3.932$

Elastic angular distributions have been studied at $E(^{14}\text{N}) = 41$, 77 and 113 MeV (1971LI11). See also (1978MA1F).

5. (a) ^{12}C(^{3}He, γ)^{15}O $\qquad Q_{\rm m} = 12.0759$
   (b) ^{12}C(^{3}He, n)^{14}O $\qquad Q_{\rm m} = -1.1484$ $\qquad E_{\rm b} = 12.0759$
   (c) ^{12}C(^{3}He, p)^{14}N $\qquad Q_{\rm m} = 4.7788$
   (d) ^{12}C(^{3}He, d)^{13}N $\qquad Q_{\rm m} = -3.5501$
   (e) ^{12}C(^{3}He, t)^{12}N $\qquad Q_{\rm m} = -17.357$
   (f) ^{12}C(^{3}He, ^{3}He)^{12}C
   (g) ^{12}C(^{3}He, α)^{11}C $\qquad Q_{\rm m} = 1.856$
   (h) ^{12}C(^{3}He, ^{7}Li)^{8}B $\qquad Q_{\rm m} = -22.899$
   (i) ^{12}C(^{3}He, ^{8}Be)^{7}Be $\qquad Q_{\rm m} = -5.781$

Excitation functions and polarization measurements for these reactions have been measured over a wide range of energies: see Tables 15.20 in (1970AJ04, 1976AJ04) and the text below. Observed resonances are displayed in Table 15.20. For angular distributions see the write-ups of the residual nuclei in (1979AJ01, 1980AJ01) and in ^{13}N, ^{14}N and ^{14}O. The $90°$ yield of γ_0, measured for $E(^3\text{He}) = 5.24$ to 13.95 MeV shows five resonances attributed to E1 transitions from $J^\pi = \frac{1}{2}^+$ or $\frac{3}{2}^+$, $T = \frac{1}{2}$ states in the GDR characterized by a considerable 3p-4h admixture: see Table 15.20 (1978DE33; see also for ω_γ). The yield of n_0 (reaction (b)) shows resonances for $E(^3\text{He}) < 10$ MeV and little structure above, to 30.6 MeV: see (1976AJ04) and (1978FE03; n_0, 11.5 to 23.5 MeV; also n_1 and n_{2+3+4}, 14.5 to 26 MeV). The yield of protons (reaction (c)) shows some clear resonances below $E(^3\text{He}) = 4.5$ MeV and some uncorrelated structures [see Fig. 3 in (1973SO04)] at higher energies (to $E(^3\text{He}) = 12$ MeV), with the possible exception of states at $E_{\rm res} = 7.8$, 9.2–9.6 and (10.5) MeV (1973SO04). For $E(^3\text{He}) = 16$ to 30.6 MeV no appreciable structure is observed in the p_0, p_1 and p_2 yields (1970SI15).

For reaction (d) see (1976AJ04) and (1976KA23; $E(^3\vec{\text{He}}) = 33.3$ MeV; polarization measurements; d_0, d_{2+3}). For reaction (e) see (1976AJ04). The elastic scattering (reaction (f)) shows some resonant structure near 3, 5 and 6 MeV and some largely uncorrelated structures in the range

$E(^3\text{He}) = 16.5$ to 24 MeV. There is some suggestion, however, of two resonances at $E(^3\text{He}) = 17$ and 20 MeV (1972MC01). Polarization measurements have been carried out for $E(^3\vec{\text{He}}) = 20.5$ to 32.6 MeV for the groups to ^{12}C*(0, 4.4). The elastic 66.8° data show a resonance-like behavior at $E(^3\vec{\text{He}}) = 29$ MeV (1977KA25). See also (1976AJ04). The yield of α-particles displays resonance structure below 8 MeV, and broad fluctuations for $E(^3\text{He}) = 12$ to 18.6 MeV: see (1976AJ04). Polarization measurements are reported for $E(^3\vec{\text{He}}) = 33.3$ MeV for the α_0 and α_1 groups (1976KA23). For reaction (h) see (1976AJ04). For reaction (i) see (1976PA07; cross section in range 7 to 20 MeV). For π^0 production see (1976WA10). See also (1976KR1C, 1976TOZM) and (1974LO1B, 1976RO1L, 1976WA1B).

6. ^{12}C(α, n)^{15}O $\qquad Q_{\text{m}} = -8.5019$

Angular distributions of the n_0 group have been measured for $E_\alpha = 18.4$ to 23.1 MeV: see (1976AJ04).

7. ^{12}C(^{6}Li, t)^{15}O $\qquad Q_{\text{m}} = -3.7180$

States observed in this reaction are displayed in Table 15.21 (1975BI06: $E(^6\text{Li}) = 59.8$ MeV). Comparisons of angular distributions of the triton groups in this reaction and of the ^{3}He groups to analog states in ^{15}N have been made: analog correspondence is established for (10.48–10.80), (12.84–13.15(u)) and (15.05–15.49(u)) [E_{x} in ^{15}O, E_{x} in ^{15}N; u = unresolved] (1975BI06). See also (1976AJ04) for the earlier work on this reaction, (1977MA2G) and (1977FO1E).

8. ^{12}C(^{10}B, ^{7}Li)^{15}O $\qquad Q_{\text{m}} = -5.712$

At $E(^{10}\text{B}) = 100$ MeV ^{15}O*(12.89, 15.36) are very strongly populated (1973NA09). See also reaction 20 in ^{15}N and (1977FO1E, 1979NA1G).

9. ^{12}C(^{11}B, ^{8}Li)^{15}O $\qquad Q_{\text{m}} = -15.134$

At $E(^{11}\text{B}) = 114$ MeV, $\theta_{\text{lab}} = 7°$ the spectrum is dominated by ^{15}O*(12.84, 15.05). ^{15}O*(7.28, 10.48) are also populated (1974AN36).

10. ^{12}C(^{12}C, ^{9}Be)^{15}O $\qquad Q_{\text{m}} = -14.2034$

At $E(^{12}\text{C}) = 187$ MeV, $\theta_{\text{lab}} = 8°$ the spectrum is dominated by ^{15}O*(12.84, 15.05) [assumed

Table 15.19: Radiative decays in ^{15}O

E_i (MeV)	J_i^π	E_f (MeV)	J_f^π	Branch (%)	δ [b]	Refs.
5.24	$\frac{5}{2}^+$	0	$\frac{1}{2}^-$	100	$+0.10 \pm 0.04$	[b]
					(E3/M2)	
6.18	$\frac{3}{2}^-$	0	$\frac{1}{2}^-$	100	-0.141 ± 0.016	(1965WA16, 1974KE02)
					-0.121 ± 0.008	(1971AV04)
					(E2/M1)	
		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	-0.02 ± 0.02	(1965WA16, 1968GI11, 1971AV04)
					(M2/E1)	
		5.18	$\frac{1}{2}^+$	< 3		(1968GI11)
		5.24	$\frac{5}{2}^+$	< 3		(1968GI11)
		6.18	$\frac{3}{2}^-$	< 7		(1965WA16)
6.86	$\frac{5}{2}^+$	0	$\frac{1}{2}^-$	< 10		(1965WA16)
		5.18	$\frac{1}{2}^+$	< 4		(1968GI11)
		5.24	$\frac{5}{2}^+$	100	$+0.04 \pm 0.03$	(1965WA16, 1968GI11, 1971AV04)
					(E2/M1)	
		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)
7.56	$\frac{1}{2}^+$	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 15.19: Radiative decays in ^{15}O (continued)

E_i (MeV)	J_i^π	E_f (MeV)	J_f^π	Branch (%)	Γ_γ (eV)	Refs.
		6.86	$\frac{5}{2}^+$	[c]	[f]	
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	$\frac{1}{2}^+$	5.18	$\frac{1}{2}^+$	67	0.32	(1966EV01)
		6.18	$\frac{3}{2}^-$	33	0.16	(1966EV01)
8.922 [d]	$\frac{1}{2}^-$	0	$\frac{1}{2}^-$	50 ± 25		(1972KR14)
		5.18	$\frac{1}{2}^+$	20 ± 10		(1972KR14)
		6.18	$\frac{3}{2}^-$	20 ± 10		(1972KR14)
		6.86	$\frac{5}{2}^+$	(10 ± 10)		(1972KR14)
8.982	$(\frac{3}{2})^-$	0	$\frac{1}{2}^-$	94 ± 1		(1972KR14)
		5.18	$\frac{1}{2}^+$	6 ± 1		(1972KR14)
		6.18	$\frac{3}{2}^-$	< 1		(1972KR14)
		6.86	$\frac{5}{2}^+$	< 1		(1972KR14)
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 [e]	$\frac{3}{2}^+(\frac{1}{2}^+)$	0	$\frac{1}{2}^-$	≈ 100		(1967EV02)
9.61	$\frac{3}{2}^-$	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)
10.46	$(\frac{9}{2}^+)$	5.24	$\frac{5}{2}^+$	62 ± 6	18 ± 6 [g]	(1977KU03)
		6.86	$\frac{5}{2}^+$	< 4	< 1.5	(1977KU03)
		7.28	$\frac{7}{2}^+$	38 ± 6	11 ± 4 [g]	(1977KU03)
10.48	$(\frac{3}{2})^-$	0	$\frac{1}{2}^-$	60 ± 8	0.21 ± 0.07 [g]	(1977KU03)
		5.24	$\frac{5}{2}^+$	40 ± 6	0.14 ± 0.01 [g]	(1977KU03)
		6.18	$\frac{3}{2}^-$	< 4	< 0.02	(1977KU03)
		9.79	$\frac{3}{2}^+$	< 4	< 0.02	(1977KU03)
10.94	$\frac{1}{2}^+$	0	$\frac{1}{2}^-$	44 ± 8	14 ± 4	(1972PH02)
		5.18	$\frac{1}{2}^+$	34 ± 3	11 ± 2	(1972PH02)

Table 15.19: Radiative decays in ^{15}O (continued)

E_i (MeV)	J^π_i	E_f (MeV)	J^π_f	Branch (%)	Γ_γ (eV)	Refs.
		6.18	$\frac{3}{2}^-$	22 ± 8	7 ± 2	(1972PH02)
		6.79	$\frac{3}{2}^+$	< 8	< 3	(1972PH02)
11.03	$\frac{1}{2}^-$	0	$\frac{1}{2}^-$	100	1.4 ± 0.4	(1972PH02)
		6.79	$\frac{3}{2}^+$	< 25	< 0.4	(1972PH02)
11.22	$\frac{3}{2}^+$	0	$\frac{1}{2}^-$	74 ± 5	5.5 ± 0.5	(1972PH02)
		5.18	$\frac{1}{2}^+$	14 ± 5	1.0 ± 0.2	(1972PH02)
		5.24	$\frac{5}{2}^+$	12 ± 5	0.9 ± 0.2	(1972PH02)
		6.79	$\frac{3}{2}^+$	< 4	< 0.4	(1972PH02)
11.57	$\frac{5}{2}^-$	0	$\frac{1}{2}^-$	18 ± 9	0.3 ± 0.2	(1972PH02)
		5.24	$\frac{5}{2}^+$	63 ± 9	1.2 ± 0.1	(1972PH02)
		6.18	$\frac{3}{2}^-$	20 ± 9	0.4 ± 0.2	(1972PH02)
		6.79	$\frac{3}{2}^+$	< 3	< 0.1	(1972PH02)
11.75	$\frac{5}{2}^+$	0	$\frac{1}{2}^-$	< 30		(1972PH02)
		5.18	$\frac{1}{2}^+$	< 25		(1972PH02)
		5.24	$\frac{5}{2}^+$	47 ± 7	5 ± 1	(1972PH02)
		6.18	$\frac{3}{2}^-$	53 ± 7	5 ± 1	(1972PH02)
		6.79	$\frac{3}{2}^+$	< 20		(1972PH02)
11.85	$\frac{5}{2}^-$	0	$\frac{1}{2}^-$	< 50		(1972PH02)
		5.24	$\frac{5}{2}^+$	100	1.4 ± 0.6	(1972PH02)
		6.79	$\frac{3}{2}^+$	< 40		(1972PH02)

[a] δ = multipole mixing ratio.

[b] Average of results of (1966GO15, 1968GI01, 1971AV04) (P.M. Endt, private communication).

[c] Intensity $< 25\%$ of transition to ^{15}O*(6.79).

[d] See, however, (1977DR02) and the comments in reaction 14.

[e] Unresolved doublet: see Table 15.23.

[f] Sum is 0.97 eV, but see Table 15.23 [$\Gamma_\gamma = 1.4$ eV].

[g] Γ_γ values assume J values in column 2.

$J^\pi = \frac{1}{2}^-, \frac{13}{2}^+$, respectively]. ^{15}O*(7.28) [$J^\pi = \frac{7}{2}^+$] is populated but ^{15}O*(0, 6.79) are not observed (1974AN36). The situation is similar at $E(^{12}C) = 114$ MeV but at $E(^{12}C) = 72$ MeV ($\theta_{lab} = 11°$) ^{15}O*(0, 5.2, 7.28) are populated with comparable intensities (1974AN36). See also (1977FO1E, 1977PH1D, 1978HO1C, 1978MA1F).

11. (a) $^{12}C(^{14}N, ^{11}B)^{15}O$ $\qquad Q_m = -8.6599$

Table 15.20: Resonances in $^{12}C + ^{3}He$

$E(^3He)$ (MeV ± keV)	Resonant for	$\Gamma_{c.m.}$ (keV)	J^π	E_x (MeV)	Refs.
1.21	p_0, p_2		$(\frac{5}{2})^-$	13.04	A
1.3	$p_0 \to p_3$			13.1	A
2.15	n, p_0		$(> \frac{5}{2})$	13.79	A
2.45 ± 40	$n_0, p_0 \to p_3$	160 ± 20	$(\frac{1}{2}^-, \frac{3}{2}^-)$	14.03	A
2.75 ± 40	n_0, p_1, p_2, ^{3}He, α_0	340 ± 30	$\frac{1}{2}^+$	14.27	A
(2.87)	p_0, p_2	240		(14.37)	A
2.990 ± 10	$n_0, p_0, p_1, p_2, p_4, p_5, p_8$, ^{3}He, α_0	100 ± 10	$\frac{3}{2}^+, \frac{5}{2}^+$	14.465	A
3.28 ± 40	$p_0, (p_1, p_2)$	180 ± 40		14.70	A
3.60 ± 40	p_0, p_1, p_2	400 ± 25		14.95	A
4.20 ± 10	p_5, p_6, α_0	65 ± 15		15.43	A
4.37 ± 40	$p_0, p_1, p_2, p_4, p_7, p_8, \alpha_0$	80 ± 25		15.57	A
4.65 ± 50	n_0			15.79	A
4.78 ± 50	^{3}He, α_0	350	$\frac{1}{2}^-, \frac{3}{2}^-$	15.90	A
4.97 ± 20	α_0			16.05	A
5.03 ± 20	n_0, ^{3}He, α_0			16.10	A
5.15 ± 20	n_0, ^{3}He, α_0			16.19	A
5.45 ± 50	^{3}He, α_0	170	$\frac{1}{2}^+$	16.43	A
5.85 ± 50	n_0, ^{3}He			16.75	A
6.23 ± 70	γ_0	700 ± 70	[a]	17.05 ± 0.06 [b]	(1978DE33)
6.80 ± 50	n_0, ^{3}He, α_0	600	$\frac{1}{2}^-, \frac{3}{2}^-$	17.51	A
7.40 ± 50	^{3}He	200	$\frac{1}{2}^-, \frac{3}{2}^-$	17.99	A
7.70 ± 50	n_0, p_0			18.23	A
8.25 ± 70	γ_0	520 ± 110	$(\frac{1}{2}, \frac{3}{2})^+$ A	18.65 ± 0.06 [b]	(1978DE33)
8.70 ± 50	n_0			19.03	A
9.38 ± 100	γ_0	780 ± 270	[a]	19.55 ± 0.08	(1978DE33)
9.80 ± 50	n_0			19.91	A
10.45 ± 90	$\gamma_0, (p_0)$	970 ± 240	[a]	20.40 ± 0.07	A, (1978DE33)
11.87 ± 80	γ_0	730 ± 120	[a]	21.61 ± 0.07	(1978DE33)
(17.0) [c]	^{3}He	≈ 600	$(\frac{13}{2}^-)$	(26.0)	A
(20.0) [c]	^{3}He	≈ 2500	$(\frac{9}{2}^-, \frac{11}{2}^-)$	(28.0)	A
(21.5)	^{3}He to ^{12}C*(15.1)	≈ 2500		(29.0)	A

A: See references listed for this state in Table 15.21 (1976AJ04).
[a] See text.
[b] $\Gamma_{^3He}/\Gamma_p = 0.17 \pm 0.07$ and 0.09 ± 0.04 for ^{15}O*(17.04, 18.65).
[c] $\Gamma_p = 0.06$ and ≥ 0.1 MeV for ^{15}O*(26, 28) (1972MC01).

Table 15.21: Levels of ^{15}O from ^{12}C(^{6}Li, t)^{15}O [a]

E_x (MeV ± keV)	L	E_x (MeV ± keV)	L
5.180 ± 5		11.72 ± 10	[c]
5.242 ± 5	[b]	11.98 ± 10	
6.179 ± 5		12.295 ± 10	[c]
6.790 ± 5		12.60 ± 10	
6.865 ± 5	[b]	12.835 ± 10 [e]	3
7.275 ± 5	[b]	13.55 ± 10	[c,d]
8.285 ± 5	[b]	13.75 ± 10	[c,d]
8.918 ± 5	[c]	14.27 ± 10	[c]
8.978 ± 5		15.05 ± 10 [e]	3
9.485 ± 5		15.48 ± 10	
9.610 ± 5	[c,d]	15.54 ± 10	
9.658 ± 5	[c,d]	15.60 ± 10	[c,d]
9.76 ± 5		15.65 ± 10	[c,d]
10.27 ± 5		15.80 ± 10	
10.45 ± 5 [e]	3	17.46 ± 20	
11.145 ± 10		17.51 ± 20	
11.56 ± 10			

[a] (1975BI06): $E(^{6}\text{Li}) = 59.8$ MeV.

[b] Angular distributions measured and compared with those of the (^{6}Li, ^{3}He) reaction to analog states in ^{15}N.

[c] Angular distributions measured: analog states in ^{15}N not known.

[d] Unresolved in angular distribution.

[e] $\Gamma_{\gamma}/\Gamma < 0.13$. (1977KR1A)

(b) ^{12}C(^{16}O, ^{13}C)^{15}O $Q_m = -10.7175$

(c) ^{12}C(^{20}Ne, ^{17}O)^{15}O $Q_m = -9.089$

For reaction (a) see (1976AJ04); for (b) see (1979PR07); for (c) see (1979OR01).

12. ^{13}C(^{3}He, n)^{15}O $Q_m = 7.1295$

Observed groups are displayed in Table 15.22.

13. ^{13}C(^{11}B, ^{9}Li)^{15}O $Q_m = -16.018$

At $E(^{11}\text{B}) = 114$ MeV the states which are strongly populated are ^{15}O*(5.24, 7.28, 11.2, 11.7) (1974AN36).

14. ^{14}N(p, γ)^{15}O $Q_m = 7.2971$

Observed resonances in the yield of γ-rays are listed in Table 15.23. Branching ratios are displayed in Table 15.19.

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 $E_p = 0.28$ MeV resonance gives $S(0) = 2.75 \pm 0.50$ keV · b, with zero slope to $E_p = 0.05$ MeV (1963HE11). Measurements of E_γ lead to $E_x = 5183 \pm 1$, 5240.9 ± 0.4, 6175 ± 2, 6794 ± 2, 6858 ± 2, 8284.1 ± 0.8, 8922 ± 2 and 8978 ± 2 keV (1972KR14, 1972NE05, 1977DR02). See also Table 15.24 in (1976AJ04). (1977DR02) find, on the basis of the analysis of (p, p) excitation curves and $\gamma\gamma$ correlation data, that the two states at $E_x = 8922$ keV are separated by $\Delta E = 0.5 \pm 0.5$ keV: for their parameters see Table 15.23. This is in disagreement with the earlier work of (1972KR14) which assumed a larger ΔE, and suggests that the branching ratios for the $\frac{5}{2}^+$ and $\frac{1}{2}^-$ states at $E_x = 8.92$ MeV shown in Table 15.19 should be remeasured (1977DR02).

The 90° γ_0 yield curve has been measured for $E_p = 2.2$ to 19.0 MeV: resonances are observed over most of the range in the γ_0 yield. The $(\gamma_1 + \gamma_2)$ yield is relatively weak (1970KU09). For

Table 15.22: Levels of ^{15}O from ^{13}C(^{3}He, n)^{15}O

E_x [a] (MeV)	J^{π} [a]	L [b]	S [e]
g.s.	$\frac{1}{2}^-$	0	1 [g]
5.18 [c]	$\frac{1}{2}^+$	1	0.15
5.24 [c]	$\frac{5}{2}^+$	3	0.17
6.180 ± 4 [f]	$\frac{3}{2}^-$	2	0.10 [h]
6.79 [c]	$\frac{3}{2}^+$	1	0.12
6.857 ± 3.2 [f]	$\frac{5}{2}^+$	3	0.29
7.284 ± 7 [f]	$\frac{7}{2}^+$	3	(< 0.03)
7.56	$\frac{1}{2}^+$	1	0.02
8.28	$\frac{3}{2}^+$	1	(0.38)
8.74	$\frac{1}{2}^+$	1	
8.92 [l]		1	0.55 [i]
8.98	$(\frac{1}{2})^-$	0	0.44 [j]
9.49	$\frac{5}{2}^-$	2	
9.53	$(\frac{1}{2})^+$	1	
9.61	$\frac{3}{2}^-$	2	1.05 [j]
9.66	$(\frac{7}{2}, \frac{9}{2})^-$	0 [k]	
10.29 [l]		≥ 3 [d]	
10.48 [l]		0 [c], 2 [d]	

[a] Nominal energies and known J^{π}: see Table 15.18, exccept where uncertainties are shown.
[b] (1971ET1A, 1972ET01): $E(^{3}\text{He}) = 5.5$ and 6.2 MeV; used codes DWUCK and MANDY.
[c] These states were unresolved.
[d] (1972GE02): $E(^{3}\text{He}) = 6$ MeV.
[e] (1971HI04); see also (1972GE02).
[f] From γ-ray measurements: see Table 15.19 (1965WA16).
[g] $(p_{1/2})^2$.
[h] $(p_{3/2}, p_{1/2})$.
[i] $(p_{1/2}, d_{3/2})$.
[j] $(d_{5/2})^2$.
[k] (1971HI04) report $L = 4$.
[l] Known to be a doublet: see Table 15.19.

Table 15.23: Resonances in $^{14}N + p$ [a]

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	$\frac{1}{2}^+$	7.5565	A
1058.0 ± 0.5 [b]	3.9 ± 0.7 [b]	0.95	γ	$\frac{3}{2}^+$	8.2840	A
1550 ± 6	34	0.16	γ	$\frac{1}{2}^+$	8.743	A
1742 ± 2	3.5 ± 0.3	0.16	γ, p_0	$\frac{5}{2}^+$	8.922	A, (1977DR02)
1742 ± 2	8	0.06	γ, p_0	$\frac{1}{2}^+$	8.922	A
1806.4 ± 1.5	4.2 ± 0.4	0.52	γ	$(\frac{3}{2})^-$	8.9821	A
2348 ± 3	10.8 ± 0.5	2.4	γ	$\frac{5}{2}^-$	9.488	A
2368 ± 32	300 ± 26		γ	$(\frac{3}{2}^+)$	9.506	A
2479 ± 1.7	9.4 ± 0.5	3.3	γ	$\frac{3}{2}^-$	9.609	A
2537 ± 4	2 ± 1		p_0	$(\frac{7}{2}, \frac{9}{2})^-$	9.664	A
3209	3 ± 1		p_0	$(\frac{5}{2}^-)$	10.291	A
3215	12 ± 2		p_0	$\frac{5}{2}^+$	10.296	A
3392 ± 5	< 2	0.029 ± 0.010	γ_2, γ_6	$(\frac{9}{2}^+)$	10.461	(1977KU03)
3410	27 ± 5		γ_0, γ_2, p_0	$(\frac{3}{2})^-$	10.478	A, (1977KU03)
3440	150 ± 45		γ, p_0	$(\frac{3}{2})^+$	10.506	A
3880 ± 15	97		p_0	$\frac{7}{2}^+$	10.916	A
		Γ_{γ_0} (eV)				A
3903 ± 3	106 ± 5	14 ± 3	γ, p_0, p_1	$\frac{1}{2}^+$	10.938	A
3996 ± 3	27 ± 2	1.4 ± 0.4	γ, p_0, p_1	$\frac{1}{2}^-$	11.025	A
4130 ± 15	< 10		p_0		11.150	A
4203 ± 3	43 ± 4	5.2 ± 0.4	γ, p_0	$\frac{3}{2}^+$	11.218	A
4575 ± 15	< 10		p_0		11.565	A
4580 ± 15	21 ± 15	0.7 ± 0.2	γ, p_0	$\frac{5}{2}^-$	11.569	A
4580	150		γ		11.57	A
4630 ± 15	86 ± 50		γ, p_0	$(\frac{3}{2}, \frac{1}{2})^-$	11.616	A
4740 ± 15	< 10		p_0		11.718	A
4772 ± 3	106 ± 5		γ, p_0, p_1	$\frac{5}{2}^+$	11.748	A
4877 ± 3	70 ± 3		γ, p_0, p_1	$\frac{5}{2}^-$	11.846	A
5025 ± 15	21 ± 5		p_0, p_1	$\frac{5}{2}^-$	11.984	A
5180 ± 15	214 ± 50		p_0, p_1	$\frac{5}{2}^+$	12.129	A
5280 ± 20	106 ± 50		p_1 [c]		12.222	A
5547 ± 3	82 ± 4		p_1, p_2	$\frac{5}{2}^-(\frac{3}{2}^-)$	12.471	A
5900	≈ 250		γ		12.80	A
5937 ± 3	17 ± 1		p_2 [d]		12.835	A
(6100)	30		$p_0 \rightarrow p_2$, α_0	$\frac{5}{2}^+$	(12.99)	A
6123 ± 3	230 ± 30		p_2 [d]		13.008	A
6141 ± 3	43 ± 30		p_2 [d]		13.025	A
6600	≈ 1000		γ, (p_2, α_0)	$(\frac{1}{2}, \frac{3}{2})^+$	13.45	A

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

E_p (keV)	Γ_{lab} (keV)	$\omega\Gamma_\gamma$ (eV)	Particles out	J^π	E_x (MeV)	Refs.
6640			(p_0), (p_2)	$(\frac{3}{2}^+)$	13.49	A
6760			α_0	$\frac{5}{2}^+$	13.60	A
6870			p_2	$\frac{3}{2}^-$	13.70	A
6960			p_1, p_2, p_4, α_0	$\frac{3}{2}^-$	13.79	A
7050	≈ 150		γ		13.87	A
7370			α_0	$\frac{5}{2}^-$	14.17	A
7500	≈ 500		n, $p_0 \to p_2$, ^{3}He, α		14.29	A
7550			α_0	$\frac{5}{2}^+$	14.34	A
7700			n, p_0, α_0		14.48	A
7950	170 ± 50		n		14.71	A
8200			n, $p_2 \to p_6$, ^{3}He, α_0, α_1		14.94	A
8400	≈ 1000		γ	$(\frac{1}{2}, \frac{3}{2})^+$	15.1	A
9050			n		15.74	A
[e]						
9370 ± 20	≈ 200		n, p_2, p_8, α_1		16.04	A
9580 ± 20	≈ 150		p_0, p_1, $p_3 \to p_7$, p_9, ^{3}He, α_1		16.23	A
9850 ± 50	600 ± 100		n, ^{3}He		16.48	A
10300	≈ 1000		γ	$(\frac{1}{2}, \frac{3}{2})^+$	16.9	A
10600			$p_4 \to p_9$, α_0, α_1		17.2	A
11900	≈ 1000		γ	$(\frac{1}{2}, \frac{3}{2})^+$	18.4	A
14200	≈ 2000		γ	$(\frac{1}{2}, \frac{3}{2})^+$	20.5	A
15800	≈ 2000		γ	$(\frac{1}{2}, \frac{3}{2})^+$	22.0	A

A: See earlier references for this resonance in (1970AJ04) and Table 15.25 of (1976AJ04).

[a] See also Table 15.19.

[b] (1978LA1M; prelim.) report $E_p = 1057.7 \pm 0.5$ keV, $\Gamma = 3.5 \pm 0.5$ keV.

[c] Weak.

[d] Strong.

[e] (1974HU02) report three large structures in the α_0 yield [E_p = 9 to 12 MeV] corresponding to excitations of 16.2, 17.2 and 17.8 MeV in ^{15}O: these appear to be composed of substructures. For instance ^{15}O*(16.2) appears to have components at E_x = 15.9, 16.1 and 16.25 MeV; ^{15}O*(17.2) appears to involve E_x = 17.0 and a sharper peak at 17.25 MeV; ^{15}O*(17.8) involves E_x = 17.7 and 17.9 MeV. It appears that this region is better studied via the ^{12}C + ^{3}He reaction: see Table 15.20.

E_p = 18 to 28 MeV the excitation function for γ_0 decreases smoothly with energy: there is no evidence for structures (1975HA39). See also (1976AJ04).

Lifetime measurements are reported by (1977KE15): $\tau_m = 8.2 \pm 1.0$, > 3000, < 2.5, 16.0 ± 2.5 and 750 ± 200 fsec for ^{15}O*(5.18, 5.24, 6.18, 6.86, 7.28), respectively. For questions related to astrophysics see (1974FO1F, 1975ZI1A, 1976AJ04, 1976BR1H, 1977CO1W). See also (1976TRZZ), (1974LO1B) and (1977YO1F, 1979RO12, 1979TR1G; applications).

15. ^{14}N(p, n)^{14}O $\quad$ $Q_m = -5.9273$ $\quad$ $E_b = 7.2971$

The excitation function has been measured for $E_p = 6.3$ to 12 MeV (1964KU06). Observed resonances are displayed in Table 15.23. See also (1978WA1D), (1977YO1G; applications) and ^{14}O.

16. ^{14}N(p, p)^{14}N $\quad$ $E_b = 7.2971$

The yields of elastic and inelastic protons, and of γ-rays, have been studied at many energies: see (1959AJ76, 1970AJ04, 1976AJ04). Observed resonances are displayed in Table 15.23. At higher energies excitation functions have been measured for the p_0, p_1 and p_2 groups for $E_p = 17$ to 26.5 MeV: there is no evidence for resonant behavior but the p_1 yield shows a large increase between $E_p = 20$ and 23 MeV (1972LU10). Total cross sections for the $p_0 \rightarrow p_9$ groups have been measured at $E_p = 8.6$, 10.6, 12.6 and 14.6 MeV by (1973HA54). See also (1980FO05) and ^{14}N.

Polarization measurements have been reported for $E_p = 3.0$ to 155 MeV: see Table 15.25 in (1970AJ04), and (1976AJ04). A recent measurement of VAP for the p_0 and p_1 groups is reported at $E_{\overline{p}} = 21$ MeV (1979AO02). The depolarization parameter, D, has been determined for p_0 at $E_p = 16.15$ MeV (1976CL1B; prelim.). See also (1978GO05) and (1976TH06; theor.).

17. ^{14}N(p, d)^{13}N $\quad$ $Q_m = -8.3290$ $\quad$ $E_b = 7.2971$

See ^{13}N.

18. ^{14}N(p, t)^{12}N $\quad$ $Q_m = -22.135$ $\quad$ $E_b = 7.2971$

See ^{12}N in (1980AJ01).

19. ^{14}N(p, ^{3}He)^{12}C $\quad$ $Q_m = -4.7788$ $\quad$ $E_b = 7.2971$

Excitation functions for the ground state groups have been measured at $E_p = 7$ to 11 MeV: some resonant structure is indicated (see Table 15.23) (1970ME30). Total cross sections for the transitions to ^{12}C*(0, 4.4) have been measured in the range $E_p = 20.5$ to 44.6 MeV (1974PI05). See also ^{12}C in (1980AJ01).

20. (a) ^{14}N(p, α)^{11}C $\qquad Q_m = -2.922 \qquad E_b = 7.2971$
(b) ^{14}N(p, 2α)^{7}Be $\qquad Q_m = -10.468$

Excitation functions and total cross section measurements have been carried out for the α_0 group for $E_p = 3.8$ to 45 MeV: see (1976AJ04). Fairly sharp structures persist until $E_p = 15$ MeV (1974JA11): see Table 15.23 for the parameters of observed resonances and in particular footnote [e]. Reaction (b), whose cross section has been measured to $E_p = 52$ MeV, displays a broad peak at ≈ 20 MeV (1974JA11, 1976IN04). For spallation studies see (1977MO1C, 1979RA20, 1979VD02, 1979WE06). See also (1975ZI1A; astrophys.).

21. ^{14}N(d, n)^{15}O $\qquad Q_m = 5.0725$

Angular distributions have been studied at many energies in the range $E_d = 0.9$ to 11.8 MeV: see Table 15.27 in (1970AJ04), and (1976AJ04). Observed states are displayed in Table 15.19. Lifetimes have been measured for ^{15}O*(5.24, 6.79, 7.28): $\tau_m = 3.2 \pm 0.5$ psec (1967BI11), < 28 fsec, 700 ± 150 fsec (1968GI11), respctively: see also Table 15.26 in (1970AJ04). See also (1974LO1B), (1976LO1B; applied) and ^{16}O in (1982AJ01).

22. ^{14}N(^{3}He, d)^{15}O $\qquad Q_m = 1.8035$

Angular distributions have been obtained at $E(^3\text{He}) = 11$ and 14 MeV: see (1976AJ04) and Table 15.24.

23. ^{14}N(α, t)^{15}O $\qquad Q_m = -12.5170$

Angular distributions of the t_0 group have been studied at $E_\alpha = 56$ MeV: see (1976AJ04).

24. ^{14}N(p, n)^{15}O $\qquad Q_m = -3.5363$

Table 15.24: Levels of ^{15}O from ^{14}N(d, n) and ^{14}N(^{3}He, d)

E_x in ^{15}O [a] (MeV ± keV)	l_p	S [c]	J^π
0	1 [d]	0.87	$\frac{1}{2}^-$
5.18	(0) [e]	0	$\frac{1}{2}^+$
5.2410 ± 0.5 [b]	2 [d]	(0.03)	$\frac{5}{2}^+$
6.180 ± 4 [b]	1 [d]	0.04	$\frac{3}{2}^-$
6.79	0 [d]	≤ 0.3	$\frac{3}{2}^+$
6.8598 ± 1.0 [b]	2 [d]	0.4	$\frac{5}{2}^+$
7.2762 ± 0.6 [b]	2 [d]	0.42	$\frac{7}{2}^+$
7.56	0 [d]	≤ 0.4	$\frac{1}{2}^+$
8.28	0 [e]		$\frac{3}{2}^+$

[a] Nominal energies if uncertainty is not indicated.

[b] From γ-ray measurements: see Table 15.26 in (1976AJ04) for references for these and other measurements displayed in this table.

[c] See (1971BO35: (d, n)) also for a review of spectroscopic factors derived from other work.

[d] From both (d, n) and (^{3}He, d) work: see (1976AJ04).

[e] From (^{3}He, d).

Angular distributions have been measured for the n_0 group at $E_p = 3.95$ to 18.5 MeV [and for the n_2 group at $E_p = 5.5$ MeV]: see (1970AJ04) for a listing of the older references, and (1978CH09: n_0; $E_p = 11.98$, 12.98, 14.58, 15.13, 15.28 MeV). See also (1980BY1A) and ^{16}O in (1982AJ01).

25. ^{15}N(^{3}He, t)^{15}O $\qquad Q_m = -2.7725$

Angular distributions for the t_0, t_{1+2}, t_3, t_{4+5}, t_6 and t_7 groups have been studied for $E(^3\text{He}) = 16.5$ to 44.6 MeV: see (1976AJ04). See also Table 15.27 in (1976AJ04).

26. ^{16}O(γ, n)^{15}O $\qquad Q_m = -15.6639$

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 $E_x = 0$ and 6.18 MeV, consistent with the basic validity of the single-particle, single-hole theory of photoexcitation in ^{16}O. However, the positive parity states at $E_x = 5.18$, 5.24, 6.86 MeV are also populated suggesting some more complicated excitations in ^{16}O: see (1970HO21) and the earlier references in (1970AJ04). See also (1979PH07) and ^{16}O in (1982AJ01). The angular distributions of the ground state neutrons have been measured from threshold to $E_\gamma = 28$ MeV [see (1976AJ04)] and at $E_\gamma = 57.8$ and 80 MeV (1979GO1V). Polarization measurements are reported for $E_\gamma = 21.6$ to 25.7 MeV (1979NA1R). See also (1977CO1Y, 1977MA2H, 1978EL05, 1978SC11; theor.).

27. (a) ^{16}O(p, d)^{15}O $\quad Q_m = -13.4392$
(b) ^{16}O(p, pn)^{15}O $\quad Q_m = -15.6639$

Reaction (a) goes primarily to ^{15}O*(0, 6.18). Angular distributions have been reported at many energies for $E_p = 18.5$ to 155.6 MeV: see Table 15.30 in (1970AJ04) and (1975RO27: $E_p = 65$ MeV; d_0, d_3). See (1975RO27) for a review of spectroscopic factors. See also (1978WH1A, 1979BO1A, 1979CA1A, 1979WH1A), ^{17}F in (1982AJ01), (1976SI1A, 1980WH1A) and (1978HE03; theor.). For reaction (b) see (1976AJ04).

28. ^{16}O(d, t)^{15}O $\quad Q_m = -9.4065$

Angular distributions have been reported at a number of energies in the range $E_d = 20$ to 52 MeV [see (1970AJ04, 1976AJ04)] and at $E_{\vec{d}} = 29$ MeV (1978CO13; t_0, t_3). For determinations of C^2S for ^{15}O*(0, 6.2), and for a comparison of the results in the mirror reaction, see reaction 74 in ^{15}N (1978CO13). See also ^{18}F in (1978AJ03, 1983AJ01) and (1975FA06; theor.).

29. ^{16}O(^{3}He, α)^{15}O $\quad Q_m = 4.9140$

The $p_{1/2}$ and $p_{3/2}$ hole states at $E_x = 0$ and 6.18 MeV are strongly populated. Information on these and other states are displayed in Table 15.25. Angular distributions have been measured at $E(^3\text{He}) = 5.2$ to 36.6 MeV [see (1976AJ04) and Table 15.32 of (1970AJ04)], at $E(^3\vec{\text{He}}) = 33.3$ MeV (1980LU03; α_0, α_3) and at 217 MeV (1974GE09, 1978VA05; α_0, α_3 and groups to higher, unresolved states). Branching ratios and multipole mixing ratios are displayed in Table 15.19. (1978BE73) report τ_m of ^{15}O*(5.24) $= 3.25 \pm 0.30$ psec, $|g| = 0.260 \pm 0.028$.

^{15}O*(7.28) has an excitation energy of 7274.2 ± 1.4 keV (1967HE1A) (which is 23.2 keV below the E_b of ^{14}N + p) and $J^\pi = \frac{7}{2}^+$; thus it plays no significant role in determining the rate of the ^{14}N(p, γ)^{15}O reaction in stars (1967HE1A). See also (1978CH1P) and ^{16}O in (1982AJ01).

30. ^{16}O(^{6}Li, ^{7}Li)^{15}O $\quad Q_m = -8.413$

Table 15.25: States of ^{15}O from ^{16}O(^{3}He, α)

E_x [a] (MeV ± keV)	l_n	S	E_x [a] (MeV ± keV)	l_n	S
0	1	0.9	9.67	1	
5.18	0	≤ 0.10	10.286 ± 10 [b]	(2)	
5.24	2	0.04	10.469 ± 10 [b]		
6.18	1	1	10.900 ± 20		
6.79	2		10.94		
6.86	2		11.03		
7.2742 ± 1.4	(4)		11.15		
7.56	0		11.22		
8.28	2		11.57 [b]		
8.74	0		11.72		
8.92 [b]	2		11.960 ± 20		
8.98	1		11.995 ± 20		
9.49 [b]			16.8 [c]	[c]	
9.535 ± 20			23.0 [c]	[c]	
9.61	1		(32.0) [c]	[c]	

[a] Nominal values except when uncertainties are shown. See Table 15.28 in (1976AJ04) for actual measured values and references.
[b] Unresolved.
[c] (1974GE09, 1978VA05): $E(^{3}\mathrm{He}) = 217$ MeV.

At $E(^{6}\mathrm{Li}) = 36$ MeV angular distributions have been measured for the transitions $^{15}\mathrm{O}_{\mathrm{g.s.}} + {}^{7}\mathrm{Li}_{\mathrm{g.s.},0.48}$ (1973SC26).

31. ^{16}O(^{10}B, ^{11}B)^{15}O $\qquad Q_m = -4.209$

Angular distributions involing $^{15}\mathrm{O}_{\mathrm{g.s.}}$ have been investigated at $E(^{10}\mathrm{B}) = 100$ MeV (1975NA15).

32. ^{16}O(^{14}N, ^{15}N)^{15}O $\qquad Q_m = -4.8305$

See reaction 77 in ^{15}N.

33. ^{17}O(p, t)^{15}O $Q_m = -11.326$

At $E_p = 39.8$ MeV angular distributions of t_0 and t_3 groups have been compared to those of the ^{3}He groups to the analog states in ^{15}N (1971OL04). At $E_p = 45$ MeV a state, assumed to be the $J^\pi = \frac{5}{2}^+$, $T = \frac{3}{2}$ analog of ^{15}C*(0.74), is observed at $E_x = 12.255 \pm 0.013$ MeV, $\Gamma_{c.m.} = 135 \pm 15$ keV. The state decays by proton emission to the $T = 1, 0^+$ state ^{14}N*(2.31) (1978BE26; population of some $T = \frac{1}{2}$ states is also reported).

34. ^{19}F(^{3}He, ^{7}Li)^{15}O $Q_m = -4.320$

Angular distributions are reported at $E(^3\text{He}) = 40.7$ MeV involving ($^{15}\text{O}_{\text{g.s.}} + {}^7\text{Li}^*_{\text{g.s.},0.48}$), ($^{15}\text{O}^*_{5.19+5.24} + {}^7\text{Li}^*_{\text{g.s.},0.48}$) and ($^{15}\text{O}^*_{6.18} + {}^7\text{Li}_{\text{g.s.}}$) (1971DE37, 1971DE04): see also the analog reaction ^{19}F(^{3}He, ^{7}Be)^{15}N [reaction 84 in ^{15}N].

^{15}F

(Fig. 13)

GENERAL: (See also (1976AJ04).):

General reviews and calculations: (1978GU10, 1979BE1H).

Mass of ^{15}F: The atomis mass excess of ^{15}F is 16.77 ± 0.13 MeV, based on the mean of the reported Q-values of the ^{20}Ne(^{3}He, ^{8}Li)^{15}F reaction. ^{15}F is unstable with respect to breakup into ^{14}O + p by 1.47 MeV.

1. ^{20}Ne(^{3}He, ^{8}Li)^{15}F $Q_{\rm m} = -29.83$

$Q_0 = -29.73 \pm 0.18$ MeV (1978KE06);

$Q_0 = -29.96 \pm 0.2$ MeV (1978BE26).

This reaction has been studied at $E(^{3}\text{He}) = 74.5$ MeV (1978BE26) and 75.4 and 87.8 MeV (1978KE06). Two groups are observed: the ground state [$\Gamma_{\rm cm} = 0.8 \pm 0.3$ MeV (1978KE06). Two groups are observed: the ground state [$\Gamma_{\rm cm} = 0.8 \pm 0.3$ MeV (1978KE06), 1.2 ± 0.3 MeV (1978BE26)] and a relatively strongly populated state, presumed to be the mirror of ^{15}C*(0.74) [$J^\pi = \frac{5}{2}^+$], with $E_{\rm x} = 1.3 \pm 0.1$ MeV (1978KE06), 1.2 ± 0.2 MeV (1978BE26) and $\Gamma_{\rm cm} = 0.5 \pm 0.2$ MeV (1978KE06), 0.24 ± 0.03 MeV (1978BE26). The differential cross section for populating ^{15}F*(1.3) is 250 ± 20 nb/sr at $10°$ and $E(^{3}\text{He}) = 74.5$ MeV (1978BE26) and 80 ± 25 nb/sr at $9°$, 87.8 MeV (1978KE06). At $E(^{3}\text{He}) = 75.4$ MeV, $\theta = 9°$, the ground state is populated with 8 ± 4 nb/sr (1978KE06).

Table 15.26: Energy levels of ^{15}F

$E_{\rm x}$ in ^{15}F (MeV)	$J^\pi; T$	$\Gamma_{\rm c.m.}$ (MeV)	Decay	Reaction
g.s.	$(\frac{1}{2}^+); \frac{3}{2}$	1.0 ± 0.2	p	1
1.3 ± 0.1	$(\frac{5}{2}^+); \frac{3}{2}$	0.24 ± 0.03	p	1

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(Closed 01 August 1980)

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

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