Energy Levels of Light Nuclei
$A = 15$

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Abstract: An evaluation of $A = 13$–15 was published in *Nuclear Physics A*449 (1986), p. 1. This version of $A = 15$ differs from the published version in that we have corrected some errors discovered after the article went to press. Figures and introductory tables have been omitted from this manuscript. Reference key numbers have been changed to the NNDC/TUNL format.

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^{15}He
(Not illustrated)

^{15}He has not been observed. See also (1983ANZQ; theor.).

^{15}Li
(Not illustrated)

^{15}Li has not been observed. Its atomic mass excess is calculated to be 81.60 MeV: see (1981AJ01). It is then unstable with respect to decay into ^{14}Li + n and ^{13}Li + 2n by 1.24 and 3.90 MeV, repsectively.

^{15}Be
(Not illustrated)

^{15}Be has not been observed. The calculated mass excess is 51.18 MeV: see (1981AJ01). 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. See also (1981SE06, 1983ANZQ; theor.).

^{15}B
(Figs. 10 and 13)

The Q-value of the ^{48}Ca(^{18}O, ^{51}V)^{15}B reaction is -21.768 ± 0.025 MeV, leading to an atomic mass excess of 28969.5 ± 25 keV for ^{15}B (1983HO08) based on the masses of ^{18}O, ^{48}Ca and ^{51}V in (1985WA02). Wapstra adopts 28970 ± 22 keV and we shall also. ^{15}B is then stable with respect to ^{14}B + n by 2.765 MeV. At $E(^{18}\text{O}) = 108$ MeV, $\mathrm{d}\sigma/\mathrm{d}\Omega = 2.0$ μb/sr at $5°$ (1983HO08). The β^- decay of ^{15}B has been reported: $\tau_{1/2} = 11 \pm 1$ msec. Upper limits have been set on the $P_{0\mathrm{n}}$ and $P_{2\mathrm{n}}$: 5% and 1.5%, respectively (1984DU15). See also (1981AJ01) for the earlier work, (1984HI1A, 1984MU27), (1980AL1F) and (1981SE06, 1983ANZQ; theor.).

^{15}C
(Figs. 10 and 13)

GENERAL: (See also (1981AJ01).)

Model calculations: (1983ANZQ, 1984VA06).

Electromagnetic transitions: (1980RI06).

Complex reactions involving ^{15}*C:* (1981GR08, 1983BE02, 1983EN04, 1983FR1A, 1983HO08, 1983MA06, 1983OL1A, 1983WI1A, 1984HI1A, 1984HO23).

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.	$\frac{1}{2}^+; \frac{3}{2}$	$\tau_{1/2} = 2.449 \pm 0.005$ nsec	β^-	1, 2, 3, 4, 6, 7
0.7400 ± 1.5	$\frac{5}{2}^+$	$\tau_m = 3.76 \pm 0.10$ nsec	γ	2, 3, 4, 8
		$g = -0.703 \pm 0.012$		
3.103 ± 4	$\frac{1}{2}^-$	$\Gamma_{c.m.} \le 40$		2, 3
4.220 ± 3	$\frac{5}{2}^-$	< 14		2, 3
4.657 ± 9	$\frac{3}{2}^-$			2, 3
5.833 ± 20	$\le \frac{3}{2}$			2
5.866 ± 8	$\frac{1}{2}^-$			2, 3
6.358 ± 6	$(\frac{5}{2}, \frac{7}{2}^+, \frac{9}{2}^+)$	< 20		2, 3
6.417 ± 6	$(\frac{3}{2} \to \frac{7}{2})$	≈ 50		2, 3
6.449 ± 7	$(\frac{9}{2}^-, \frac{11}{2})$	< 14		2, 3
6.536 ± 4	[a]	< 14		2, 3
6.626 ± 8	$(\frac{3}{2})$	20 ± 10		2, 3
6.841 ± 4	[a]	< 14		2, 3
6.881 ± 4	$(\frac{9}{2})$ [a]	< 20		2, 3
7.095 ± 4	$(\frac{3}{2})$	< 15		2, 3
7.352 ± 6	$(\frac{9}{2}, \frac{11}{2})$	20 ± 10		2, 4
7.414 ± 20				2
7.75 ± 30 [b]				2
8.01 ± 30				2
8.11 ± 10 [b]				2
8.47 ± 15	$(\frac{9}{2} \to \frac{13}{2})$	40 ± 15		2
8.559 ± 15	$(\frac{7}{2} \to \frac{13}{2})$	40 ± 15		2
9.00 ± 30				2
(9.73 ± 30)				2
9.789 ± 20	$(\frac{9}{2} \to \frac{15}{2})$	20 ± 15		2
10.248 ± 20	$(\frac{5}{2} \to \frac{9}{2})$	20 ± 15		2
11.015 ± 25				2
11.123 ± 20	$(\frac{11}{2} \to \frac{19}{2})$	30 ± 20		2
(11.68 ± 30)				2
11.825 ± 20	$\ge \frac{13}{2}$	70 ± 30		2

[a] See also Tables 15.2 and 15.3 and reaction 8.

[b] Broad or unresolved states.

Pion capture and reactions: (1981OS04).

Hypernuclei: (1981WA1J, 1982KA1D, 1983DO1B, 1983FE07, 1983KO1V, 1984AS1D).

Other topics: (1984PO11).

Ground state of ^{15}*C:* (1984FR13).

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

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^π ($^{15}C_{g.s.}$) $= \frac{1}{2}^+$ or $\frac{3}{2}^+$. Weak transitions are observed to ^{15}N*(7.30, 8.31, 8.57, 9.05) (1979AL23): see Table 15.15. The shape of the $^{15}C_{g.s.} \rightarrow {}^{15}N_{g.s.}$ transition differs appreciably from an allowed shape (1984WA07). See also (1981FR23), (1983SN03) and (1980RI06; theor.).

2. ^{9}Be(^{7}Li, p)^{15}C $\quad Q_m = 9.092$

Observed proton groups are displayed in Table 15.2.

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

Observed proton groups are displayed in Table 15.3 (1983TR12). $|g| = 0.703 \pm 0.012$ for ^{15}C*(0.74) (1980AS01).

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

At $E_\alpha = 65$ MeV ^{15}C*(0.74, 6.74, 7.35) are strongly populated: see (1981AJ01).

5. (a) ^{14}C(n, γ)^{15}C $\quad Q_m = 1.2181$

(b) ^{14}C(n, n)^{14}C $\quad E_b = 1.2181$

$\sigma_\gamma < 1$ μb (1981MUZQ). See also (1976AJ04).

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

Obserevd proton groups are displayed in Table 15.2.

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

^{9}Be(^{7}Li, p)^{15}C [b]			^{14}C(d, p)^{15}C [c]		
E_x (keV)	$\Gamma_{c.m.}$ (keV)	J^{π} [d]	E_x (keV)	$\Gamma_{c.m.}$ (keV)	J^{π} [e]
g.s.	bound		g.s.	bound	$\frac{1}{2}^{+}$ [n]
$\equiv 740$ [f]	bound		744.1 ± 2 [j]	bound	$\frac{5}{2}^{+}$ [o]
3100 ± 30	< 40	$(\frac{1}{2}^{-})$ [h]	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)			[k]		
5833 ± 20		[i]	[k]		
5858 ± 20		[i]	[k]		
6370 ± 15	< 20	$(\frac{5}{2})$	[l]	< 14	$(\frac{7}{2}, \frac{9}{2})^{+}$
6436 ± 20			6428.1 ± 7	≈ 50	$(\frac{3}{2}, \frac{5}{2}, \frac{7}{2})$
6461 ± 20			[l]	< 14	$(\frac{9}{2}^{-}, \frac{11}{2})$
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	$(\frac{7}{2}, \frac{9}{2})$	6822.4 ± 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 [g]			7.81 ± 10 [m]		
8010 ± 30					
8130 ± 30 [g]			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] For references see Table 15.2 in (1981AJ01).
[b] $E(^7\text{Li}) = 20$ MeV. E_x based on 740 keV for first excited state.
[c] $E_d = 12 - 14$ MeV.
[d] Suggested J^π assignments based on angular distributions (and $2J_f + 1$ dependence) and l_{max} from Γ_n.
[e] Analysis of the two bound states is done using DWUCK. For the unbound states DOXY was used.
[f] $E_x = 739 \pm 1$ keV [from E_γ]; $\tau_m = 3.77 \pm 0.11$ nsec.
[g] Broad or unresolved states.
[h] $\theta_n^2 = 0.0075 \pm 0.0015$.
[i] Sum of the J for these two states is 2 [based on $(2J + 1)$ dependence of cross section].
[j] $\tau_m = 3.73 \pm 0.23$ nsec.
[k] Not observed.
[l] Observed but E_x not determined.
[m] Observed at $E_d = 27$ MeV.
[n] $S = 0.88$.
[o] $S = 0.69$ or 0.55. g $= -0.77 \pm 0.06$.

7. ^{14}C(^{14}C, ^{13}C)^{15}C $Q_m = -6.9584$

See (1981FR23, 1985KO04).

Table 15.3: Proton groups from ^{13}C(t, p) [a]

E_x (MeV ± keV)	J^π	E_x (MeV ± keV)	J^π
0	$\frac{1}{2}^+$	6.440 ± 6	
0.743 ± 9 [b]	$\frac{5}{2}^+$	6.529 ± 6	
3.100 ± 6 [b]	$\frac{1}{2}^-$	6.622 ± 9	
4.215 ± 9 [b]	$\frac{5}{2}^-$	6.835 ± 6 [b]	$(\frac{7}{2}, \frac{9}{2})^-$
4.657 ± 9 [b]	$\frac{3}{2}^-$	6.876 ± 7	
5.867 ± 8	$\frac{1}{2}^-$	7.093 ± 6	
6.356 ± 6		7.387 ± 7 [b]	$(\frac{9}{2}, \frac{7}{2})^-$
6.404 ± 7			

[a] (1983TR12); $E_t = 18$ MeV; DWBA.
[b] Strong group.

8. ^{15}N(π^-, γ)^{15}C $Q_{\rm m} = 129.796$

Radiative pion capture shows evidence for $J^\pi = \frac{5}{2}^+, T = \frac{3}{2}$ giant magnetic quadrupole states: transitions are reported to ^{15}C*(0.74) as well as to ^{15}C*(6.7, 8.6, 12.0) (1983ST04).

^{15}N

(Figs. 11 and 13)

GENERAL: (See also (1981AJ01).)

Nuclear models: (1983PI03, 1983SH38, 1983VA31, 1984VA06, 1984ZW1A).

Special states: (1979ZA07, 1980FU1G, 1980RI06, 1981IS11, 1981LI19, 1982ZA1D, 1983GO1R, 1983PI03, 1983VA31, 1984GO1M, 1984VA06, 1984ZW1A, 1985HA1J).

Electromagnetic transitions: (1980RI06, 1981LI19, 1983TO08, 1984KU07).

Astrophysical questions: (1980AU1D, 1980WA1M, 1981AD1F, 1981GU1D, 1981WA1N, 1981WA1Q, 1982KE1B, 1983AL23, 1983SI1B, 1985DR1A, 1985GU1A).

Complex reactions involving ^{15}N: (1978WU07, 1980RI06, 1980VO1D, 1981DE1W, 1981HU01, 1981ME13, 1981VA1D, 1981VO06, 1982HO10, 1982LE1N, 1982LO13, 1982LU02, 1982LY1A, 1983CH23, 1983DE26, 1983EN04, 1983FR1A, 1983JA05, 1983MA06, 1983OL1A, 1983PL1A, 1983SA06, 1983SI1A, 1983VO04, 1983WI1A, 1984GR08, 1984HI1A, 1984HO23, 1985GU1A, 1985MO08).

Applied work: (1980SE1E, 1981WA1K, 1982MA1R, 1983AM1A, 1983AM1D, 1983MA1Q, 1983MA83, 1983SC43, 1983SK1B, 1984HA1Q, 1984MA2H, 1985AL1N, 1985WA1R).

Muon and neutrino capture and reactions (See also reaction 59.): (1983GM1A, 1984WA07).

Pion capture and reactions (See also reactions 48 and 61.): (1981BA1P, 1981LE06, 1981OS04, 1981OS05, 1981RE04, 1982DO10, 1982OS01, 1983KA19, 1983KI01, 1983TO17, 1983TR1J, 1984GR27, 1984HAZV, 1984LEZX, 1985GU1A, 1985RE1D).

Reactions involving other mesons and hyperons: (1982DO1L, 1983FE07).

Antiproton reactions: (1983BA2R).

Hypernuclei: (1980IW1A, 1981WA1J, 1982ER1E, 1982GR1P, 1982KA1D, 1982RA1L, 1983CH1T, 1983DO1B, 1983FE07, 1983GA17, 1983KO1D, 1983SH38, 1983SH1E, 1984AS1D, 1984CH1G, 1984SH1J, 1985AH1A).

Other topics: (1981SH17, 1982NG01, 1982ZA1D, 1983GO1R, 1983KH1D, 1983MA38, 1983MA35, 1983SH1T, 1983TO08).

Ground-state properties of ^{15}N: (1981AV02, 1981DE1W, 1982LO13, 1982LU02, 1982NG01, 1982ZA1D, 1983ANZQ, 1983BA33, 1983BU07, 1983DE1X, 1983MA38, 1983TO08, 1983VA31, 1984AR1D, 1984BO11, 1984HUZZ, 1984KA25, 1984KU07, 1984WE04, 1985AR11, 1985GA06, 1985HA18, 1985FA01).

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

$$\text{Natural abundance} = (0.366 \pm 0.009)\% \text{ (1984DE53)}.$$

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

E_x (MeV ± keV)	$J^\pi; T$	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
0	$\frac{1}{2}^-; \frac{1}{2}$	—	stable	2, 3, 4, 12, 14, 15, 16, 17, 19, 20, 21, 25, 26, 27, 28, 29, 30, 32, 33, 34, 35, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71
5.27015 ± 0.02	$\frac{5}{2}^+$	$\tau_m = 2.58 \pm 0.14$ psec $g = +(0.94 \pm 0.07)$	γ	3, 4, 13, 17, 18, 20, 25, 26, 29, 32, 33, 35, 39, 47, 48, 51, 52, 58, 62, 63, 68, 69, 70
5.29880 ± 0.02	$\frac{1}{2}^+$	25 ± 7 fsec	γ	3, 4, 10, 11, 13, 17, 19, 20, 25, 26, 27, 29, 32, 33, 35, 39, 44, 47, 51, 52, 58, 62, 63, 69, 70
6.32389 ± 0.02	$\frac{3}{2}^-$	0.211 ± 0.012 fsec	γ	2, 3, 4, 10, 11, 14, 17, 19, 20, 25, 27, 29, 32, 33, 35, 39, 46, 47, 48, 51, 52, 58, 59, 61, 62, 63, 64, 66, 70
7.1551 ± 0.02	$\frac{5}{2}^+$	18 ± 8 fsec	γ	3, 4, 17, 18, 19, 20, 25, 26, 27, 32, 33, 35, 39, 42, 47, 51, 52, 62
7.30086 ± 0.02	$\frac{3}{2}^+$	0.61 ± 0.05 fsec	γ	3, 4, 17, 19, 20, 25, 26, 27, 32, 33, 35, 39, 44, 46, 47, 51, 52, 62

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

E_x (MeV $\pm$ keV)	$J^\pi; T$	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
7.5671 ± 1.0	$\frac{7}{2}^+$	12^{+11}_{-6} fsec	γ	2, 3, 4, 10, 11, 17, 18, 19, 20, 25, 26, 27, 28, 32, 39, 42, 47, 48, 51, 52, 62
8.31260 ± 0.02	$\frac{1}{2}^+$	1.7 ± 1.1 fsec	γ	2, 3, 4, 19, 25, 26, 27, 32, 35, 39, 44, 46, 51, 52, 58
8.5714 ± 1.0	$\frac{3}{2}^+$	0.7 ± 0.7 fsec	γ	2, 3, 4, 10, 11, 17, 18, 19, 25, 26, 27, 32, 35, 39, 44, 46, 51, 52
9.0500 ± 0.7	$\frac{1}{2}^+$	0.50 ± 0.08 fsec	γ	3, 4, 25, 26, 32, 35, 39, 44, 46, 47, 58
9.15214 ± 0.06	$\frac{3}{2}^-$	1.40 ± 0.36 fsec	γ	3, 4, 10, 11, 25, 26, 32, 35, 39, 46, 47, 51, 52
9.15500 ± 0.04	$\frac{5}{2}^+$	7^{+6}_{-3} fsec	γ	3, 4, 19, 25, 32, 35, 39, 46
9.225 ± 3	$\frac{1}{2}^-$	< 130 fsec	γ	25, 27, 32, 39, 58
9.7575 ± 3.0	$\frac{5}{2}^-$	2.6 ± 0.9 fsec	γ	25, 35, 39, 46, 47
9.829 ± 3	$\frac{7}{2}^-$	17 ± 7 fsec	γ	3, 4, 10, 11, 18, 19, 20, 25, 27, 28, 32, 39, 51, 52
9.928 ± 4	$\frac{3}{2}^-$	0.31 ± 0.05 fsec	γ	19, 25, 32, 35, 39, 46, 62
10.070 ± 3	$\frac{3}{2}^+$	0.100 ± 0.006 fsec	γ	19, 25, 26, 27, 39, 46, 51, 52
10.4497 ± 0.3	$\frac{5}{2}^-$	$\Gamma < 0.5$ keV	γ, p	4, 10, 11, 20, 25, 30, 39
10.5333 ± 0.5	$\frac{5}{2}^+$		γ, p	4, 10, 11, 19, 25, 26, 30, 32, 39
10.6932 ± 0.3	$\frac{9}{2}^+$	$\tau_m = 18 \pm 9$ fsec	γ, p	4, 11, 17, 30, 48
10.7019 ± 0.3	$\frac{3}{2}^-$	$\Gamma = 0.2$ keV	γ, p	10, 11, 18, 19, 25, 27, 30, 39, 51, 62

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

E_x (MeV $\pm$ keV)	$J^\pi; T$	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
10.804 ± 2	$\frac{3}{2}^+$	$< 1 \times 10^{-3}$	γ, p	3, 4, 10, 19, 20, 25, 30, 31, 47
11.235 ± 5	$\geq \frac{3}{2}$	3.3	n	17, 32, 36
11.2928 ± 0.7	$\frac{1}{2}^-$	8 ± 3	γ, n, p	17, 30, 31, 32, 36, 51
11.4376 ± 0.7	$\frac{1}{2}^+$	41.4 ± 1.1	γ, n, p, α	6, 10, 19, 26, 30, 31, 32, 36, 37
11.615 ± 4	$\frac{1}{2}^+; T = \frac{3}{2}$	405 ± 6	γ, n, p	30, 31
11.778 ± 5	$\frac{3}{2}^+$	40	n, p, α	6, 31, 36, 37
11.876 ± 3	$\frac{3}{2}^-$	25	γ, n, p, α	6, 31, 36, 37, 47
11.942 ± 6	$\frac{9}{2}^-$	≤ 3.0	n, α	4, 6, 17, 18, 19, 26, 27, 28, 36
11.965 ± 3	$\frac{1}{2}^-$	17	n, p	4, 10, 31, 36, 37
12.095 ± 3	$\frac{5}{2}^+$	14 ± 5	n, p, α	6, 7, 26, 31, 32, 36, 37
12.145 ± 3	$\frac{3}{2}^-$	41 ± 5	n, p, α	6, 7, 10, 31, 36, 37
12.327 ± 4	$\frac{5}{2}^{(+)}$	22	n, p	18, 19, 26, 31, 36, 37
12.493 ± 4	$\frac{5}{2}^+; \frac{1}{2}$	40 ± 5	n, p, α	6, 7, 26, 31, 36, 37
12.522 ± 8	$\frac{5}{2}^+; \frac{3}{2}$	58 ± 4	γ, p	30, 47
12.551 ± 10	$\frac{9}{2}^+$			4, 17, 18, 19, 26, 48
12.920 ± 4	$\frac{3}{2}^-$	56 ± 11	n, p, α	6, 7, 9, 19, 20, 31, 36, 37
12.940 ± 10	$\frac{5}{2}^+$	81	p, α	7, 9, 31
13.004 ± 10	$\frac{11}{2}^-$			4, 10, 11, 13, 17, 19, 26, 27, 28
13.149 ± 10		7 ± 3	n, p, α	6, 7, 20, 37
13.174 ± 7	$(\frac{9}{2})$	7 ± 3	n, p, α	4, 6, 7, 11, 17, 18, 19, 31, 36, 37
13.362 ± 8	$\frac{3}{2}^-$	16 ± 8	n, p, α	6, 7, 9, 31, 37
13.390 ± 10	$\frac{3}{2}^+$	56	γ, n, p, α	7, 9, 30, 31, 37
13.537 ± 10	$\frac{3}{2}^-$	85 ± 30	n, p, α	6, 9, 31

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

E_x (MeV $\pm$ keV)	$J^\pi; T$	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
13.608 ± 7	$\frac{5}{2}^{(+)}$	18 ± 4	n, p, α	6, 7, 19, 31, 36, 37
(13.612 ± 10)	$(\frac{1}{2}^+)$	90	α	9
13.713 ± 10		26 ± 8	n, p, α	6, 31, 37
13.84 ± 30	$\frac{3}{2}^+$	75	n, p, α	4, 6, 9, 26, 36, 37
13.9	$\frac{1}{2}^+$	930	γ, p	30, 31
13.99 ± 30	$\frac{5}{2}^+$	98 ± 10	n, p, α	6, 31
14.090 ± 7	$(\frac{9}{2}^+, \frac{7}{2}^+)$	22 ± 6	n, p, α	4, 6, 10, 19, 26, 36, 37, 48
14.10 ± 30	$\frac{3}{2}^+$	≈ 100	n, α	4, 6, 9
14.162 ± 10	$\frac{3}{2}^{(+)}$	27 ± 6	n, α	4, 6, 36, 37
14.24 ± 40	$\frac{5}{2}^+$	150	α	9, 10
14.38 ± 40	$\frac{7}{2}^+$	100	α	9
14.4		≈ 1900	n, p, α	36, 37
14.55 ± 20		200 ± 50	n, (p), α	6
14.647 ± 10		33 ± 6	n, p, α	6, 36, 37
14.71		750	γ, p	30
14.720 ± 10	$\frac{5}{2}^-$	110 ± 50	γ, n, (p), α	6, 10, 19, 47
14.86 ± 20		48 ± 11	n, α	6, 9, 19
14.920 ± 10		12 ± 3	n, α	6, 10, 37
15.025 ± 10		13 ± 3	n, α	6, 19
15.09 ± 20		80 ± 25	n, α	6, 9, 36, 37, 51
15.288 ± 10		26 ± 6	n, α	6, 9
15.373 ± 10	$\frac{13}{2}^+$			4, 10, 11, 17, 18, 19, 20
15.38 ± 20		75 ± 25	n, t, α	6, 9, 15
15.43 ± 20		≈ 100	n, (α)	6, 9
15.45		750	γ, p	30
15.53 ± 20		≈ 35	n, α	6, 10, 11, 37
15.60 ± 20		95 ± 25	n, α	6
15.782 ± 10			p, t, α	15, 19, 20
15.93 ± 20		35 ± 5	n, t, α	6, 15, 18

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

E_x (MeV $\pm$ keV)	$J^\pi; T$	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
15.944 ± 15		21 ± 6	n, t, α	6, 15
16.026 ± 10		62 ± 12	n, p, t, α	6, 9, 15, 19, 37
16.190 ± 10	$\frac{3}{2}^+$	450 ± 100	γ, n, p, t, α	15, 19
16.26 ± 20	$\frac{3}{2}^+$	150 ± 28	γ, n, t, α	5, 6, 9, 15, 18, 19, 20, 31
16.32 ± 20		≈ 30	n, p, t, α	6, 15
16.39 ± 20		44 ± 11	n, p, t, α	6, 15, 18, 37
16.46		560	γ, p, d	22, 30
16.576 ± 15		27 ± 15	n, α	6, 37
16.59 ± 25	$\frac{3}{2}^-$	490	γ, n, p, t, α	15
16.677 ± 15	$\frac{1}{2}^+; \frac{1}{2}$	80 ± 20	γ, n, p, d, t, α	5, 6, 15, 18, 21, 22, 24, 30, 31, 36, 37
16.85 ± 30	$\frac{5}{2}$	110 ± 50	t, α	15
16.91		≈ 350	n, p, d, t, α	15, 22, 36, 37
(17.05)			p, t	15
17.11		broad	d, α	24
17.15 ± 50	$(\frac{1}{2}^+, \frac{3}{2}^+)$	250 ± 60	γ, t, α	5, 15, 48
17.23 ± 40		≈ 175	d, t, (α)	24, 28
17.37 ± 40		≈ 250	p, d, t, α	15, 22, 24, 36, 37
17.58 ± 40	$\frac{3}{2}^+$	450 ± 120	γ, d, t, α	15, 24, 37
17.67 ± 40	$\frac{3}{2}^+; \frac{1}{2}$	600 ± 80	γ, n, d, α	5, 21, 22, 24
17.72 ± 10		48 ± 10	n, (p), d, t, α	19, 22, 24, 37
17.95 ± 20		167	n, α	19, 20, 36, 37
18.06 ± 10		19 ± 4	(n), d, α	18, 22, 24
18.09 ± 20		≈ 40	(n), p, d, t	22, 24
18.22		158	n, α	36, 37
18.27 ± 20		235 ± 60	n, p, d, α	19, 22, 24, 37
18.70 ± 20				19, 25
18.91 ± 150	$\frac{3}{2}^+ + \frac{1}{2}^+$	750 ± 70	γ, α	5
19.20 ± 35	$(\frac{1}{2}^+; \frac{1}{2})$	≈ 130	n, d	19, 22
19.5	$\frac{3}{2}^+; (\frac{3}{2})$	≈ 400	γ, p, t	15, 30, 31

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

E_x (MeV ± keV)	$J^\pi; T$	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
19.72 ± 40		[b]		18, 19
20.12 ± 50	$(T = \frac{3}{2})$			17, 48
20.5	$\frac{3}{2}^+$	≈ 400	γ, n, p, d	30
20.96 ± 65	$\frac{3}{2}^+ + \frac{1}{2}^+$	1740 ± 150	γ, α	5, 19
21.82		≈ 600	γ, p, d	21, 30, 45
23.19 ± 60	$(T = \frac{3}{2})$		γ, p	30, 48
23.8		broad	γ, d	21
24.75 ± 150		[b]		19
25.5	$\frac{3}{2}^-; (T = \frac{3}{2})$		γ, p	30
(26.8)			t	15
≈ 37			γ, p	30

[a] See also Tables 15.5, 15.6 and 15.13.

[b] Wide or unresolved.

1. (a) ^{9}Be(^{6}Li, p)^{14}C $\quad Q_m = 15.1244 \quad E_b = 25.3318$

   (b) ^{9}Be(^{6}Li, t)^{12}C $\quad Q_m = 10.4834$

   (c) ^{9}Be(^{6}Li, α)^{11}B $\quad Q_m = 14.3404$

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. 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. See (1976AJ04) for the references.

2. ^{9}Be(^{9}Be, t)^{15}N $\quad Q_m = 7.6440$

See (1981AJ01).

3. ^{10}B(^{6}Li, p)^{15}N $\quad Q_m = 18.7459$

At $E(^6\text{Li}) = 4.9$ MeV, thirty proton groups are observed corrresponding 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): see (1976AJ04).

Table 15.5: Radiative decays in ^{15}N [a]

E_i (MeV)	J_i^π	E_f (MeV)	J_f^π	Branch (%)	Mult. mixing ratio δ
5.27	$\frac{5}{2}^+$	0	$\frac{1}{2}^-$	100	-0.131 ± 0.013
5.30	$\frac{1}{2}^+$	0	$\frac{1}{2}^-$	100	
6.32 [b]	$\frac{3}{2}^-$	0	$\frac{1}{2}^-$	100	$+\,0.132 \pm 0.004$ [p]
7.16 [c]	$\frac{5}{2}^+$	5.27	$\frac{5}{2}^+$	100 ± 0.4	$-0.014^{+0.012}_{-0.015}$
7.30	$\frac{3}{2}^+$	0	$\frac{1}{2}^-$	99.3 ± 0.7	$-0.017^{+0.005}_{-0.008}$
		5.27	$\frac{5}{2}^+$	0.6 ± 0.1	$+0.18 \pm 0.15$, or $+2.5 \pm 1.0$
		5.30	$\frac{1}{2}^+$	0.2 ± 0.1	-0.31 ± 0.15, or $+4.6 \pm 3.4$
		6.32	$\frac{3}{2}^-$	< 0.25	
7.57 [d]	$\frac{7}{2}^+$	0	$\frac{1}{2}^-$	1.3 ± 0.6	
		5.27	$\frac{5}{2}^+$	98.7 ± 1.0	-0.028 ± 0.012
8.31	$\frac{1}{2}^+$	0	$\frac{1}{2}^-$	79 ± 2	
		5.27	$\frac{5}{2}^+$	< 3	
		5.30	$\frac{1}{2}^+$	10 ± 2	
		6.32	$\frac{3}{2}^-$	4.4 ± 1.0	
		7.16	$\frac{5}{2}^+$	1.2 ± 0.6	
		7.30	$\frac{3}{2}^+$	4.4 ± 0.7	
8.57 [e]	$\frac{3}{2}^+$	0	$\frac{1}{2}^-$	33 ± 2	$-0.085^{+0.005}_{-0.009}$
		5.27	$\frac{5}{2}^+$	65 ± 3	-0.091 ± 0.007
		6.32	$\frac{3}{2}^-$	1.4 ± 0.6	
		7.16	$\frac{5}{2}^+$	3.6 ± 0.5	
9.05 [f]	$\frac{1}{2}^+$	0	$\frac{1}{2}^-$	92 ± 3	
		5.27	$\frac{5}{2}^+$	3.5 ± 1	
		6.32	$\frac{3}{2}^-$	4.5 ± 1	
		7.30	$\frac{3}{2}^+$	1.2 ± 0.4	
9.152	$\frac{3}{2}^-$	0	$\frac{1}{2}^-$	100 ± 3	$+0.015^{+0.041}_{-0.034}$
9.155	$\frac{5}{2}^+$	0	$\frac{1}{2}^-$	< 2	
		5.27	$\frac{5}{2}^+$	11 ± 1	
		5.30	$\frac{1}{2}^+$	10 ± 1	
		6.32	$\frac{3}{2}^-$	22 ± 2	
		7.16	$\frac{5}{2}^+$	57 ± 3	
9.23 [g]	$\frac{1}{2}^-$	0	$\frac{1}{2}^-$	22 ± 5	

Table 15.5: 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
		5.30	$\frac{1}{2}^+$	42 ± 8	
		6.32	$\frac{3}{2}^-$	35 ± 6	
		7.30	$\frac{3}{2}^+$	2.6 ± 0.7	
9.76 [h]	$\frac{5}{2}^-$	0	$\frac{1}{2}^-$	81.5 ± 2.8	
		$5.27 + 5.30$		7.5 ± 1.5	
		6.32	$\frac{3}{2}^-$	3.7 ± 0.8	
		7.16	$\frac{5}{2}^+$	2.3 ± 0.5	
		7.57	$\frac{7}{2}^+$	5.0 ± 0.6	
9.83 [i]	$\frac{7}{2}^-$	5.27	$\frac{5}{2}^+$	≈ 85	
		6.32	$\frac{3}{2}^-$	2.2 ± 0.9	
		7.16	$\frac{5}{2}^+$	2.4 ± 1.1	
		7.30	$\frac{3}{2}^+$	3.7 ± 0.9	
		7.57	$\frac{7}{2}^+$	7.3 ± 1.0	
9.93 [j]	$\frac{3}{2}^-$	0	$\frac{1}{2}^-$	77.6 ± 1.9	
		$5.27 + 5.30$		15.4 ± 1.5	
		6.32	$\frac{3}{2}^-$	4.9 ± 1.2	
		7.30	$\frac{3}{2}^+$	2.1 ± 0.8	
10.07 [k]	$\frac{3}{2}^+$	0	$\frac{1}{2}^-$	96.0 ± 0.7	
		$5.27 + 5.30$		4.0 ± 0.7	
10.45 [l]	$\frac{5}{2}^-$	5.27	$\frac{5}{2}^+$	55.0 ± 0.8	$+0.021 \pm 0.033$
		6.32	$\frac{3}{2}^-$	31.3 ± 1.7	-0.59 ± 0.13
		7.16	$\frac{5}{2}^+$	5.2 ± 0.1	$+0.13^{+0.03}_{-0.04}$
		8.57	$\frac{3}{2}^+$	3.8 ± 0.6	-0.3 ± 0.4
		9.152	$\frac{3}{2}^-$	4.7 ± 0.1	$-0.32^{+0.09}_{-0.10}$
10.53	$\frac{5}{2}^+$	0	$\frac{1}{2}^-$	< 0.1	
		5.27	$\frac{5}{2}^+$	38.7 ± 0.2	-0.27 ± 0.03
		6.32	$\frac{3}{2}^-$	7.7 ± 0.1	-0.028 ± 0.004
		7.16	$\frac{5}{2}^+$	19.4 ± 0.2	$+0.007^{+0.010}_{-0.008}$
		7.30	$\frac{3}{2}^+$	31.4 ± 0.5	$+0.066 \pm 0.005$
		8.57	$\frac{3}{2}^+$	2.4 ± 0.1	$+0.012^{+0.006}_{-0.005}$
		9.152	$\frac{3}{2}^-$	0.3 ± 0.1	$-0.20^{+0.03}_{-0.02}$

Table 15.5: Radiative decays in ^{15}N [a] (continued)

E_i (MeV)	J^π_i	E_f (MeV)	J^π_f	Branch (%)	Mult. mixing ratio δ
10.69	$\frac{9}{2}^+$	5.27	$\frac{5}{2}^+$	61.6 ± 0.3	
		7.16	$\frac{5}{2}^+$	2.1 ± 0.1	-0.03 ± 0.07
		7.57	$\frac{7}{2}^+$	36.3 ± 0.6	$+0.118 \pm 0.008$
10.70	$\frac{3}{2}^-$	0	$\frac{1}{2}^-$	52.6 ± 0.8	$+0.180^{+0.006}_{-0.002}$
		5.27	$\frac{5}{2}^+$	37.4 ± 0.6	$-0.24^{+0.004}_{-0.008}$
		5.30	$\frac{1}{2}^+$	0.8 ± 0.1	-0.13 ± 0.07
		6.32	$\frac{3}{2}^-$	3.8 ± 0.1	$+0.135 \pm 0.015$
		7.16	$\frac{5}{2}^+$	0.4 ± 0.1	0.3 ± 0.3
		7.30	$\frac{3}{2}^+$	2.3 ± 0.1	-0.027 ± 0.023
		8.31	$\frac{1}{2}^+$	0.8 ± 0.1	$-0.017^{+0.018}_{-0.016}$
		9.05	$\frac{1}{2}^+$	0.2 ± 0.1	-0.007 ± 0.12
		9.152	$\frac{3}{2}^-$	0.2 ± 0.1	-0.11 ± 0.03
		9.23	$\frac{1}{2}^-$	1.5 ± 0.1	$+0.049^{+0.006}_{-0.005}$
10.80 [m]	$\frac{3}{2}^+$	0	$\frac{1}{2}^-$	51.5 ± 0.4	-0.02 ± 0.01
		5.27	$\frac{5}{2}^+$	4.9 ± 0.1	-0.63 ± 0.04
		5.30	$\frac{1}{2}^+$	15.5 ± 0.2	-0.55 ± 0.02
		6.32	$\frac{3}{2}^-$	5.4 ± 0.2	-0.07 ± 0.05
		7.16	$\frac{5}{2}^+$	7.8 ± 0.1	$+0.14 \pm 0.03$
		7.30	$\frac{3}{2}^+$	5.8 ± 0.1	-0.12 ± 0.02
		8.31	$\frac{1}{2}^+$	3.6 ± 0.1	$+0.12 \pm 0.03$
		9.05	$\frac{1}{2}^+$	0.3 ± 0.1	
		9.152	$\frac{3}{2}^-$	0.9 ± 0.1	
		9.155	$\frac{5}{2}$	4.2 ± 0.1	
11.62 [n]	$\frac{1}{2}^+; T = \frac{3}{2}$	0	$\frac{1}{2}^-$	90.7 ± 3.0	
		5.27	$\frac{5}{2}^+$	< 1	
		5.30	$\frac{1}{2}^+$	7.4 ± 1.5	
		6.32	$\frac{3}{2}^-$	1.9 ± 1.5	
12.52	$\frac{5}{2}^+; T = \frac{3}{2}$	0	$\frac{1}{2}^-$	< 1	
		5.27	$\frac{5}{2}^+$	94.2 ± 0.6	-0.02 ± 0.04
		5.30	$\frac{1}{2}^+$	< 1	
		6.32	$\frac{3}{2}^-$	5.8 ± 0.6	-0.02 ± 0.04

Table 15.5: Radiative decays in ^{15}N [a] (continued)

E_i (MeV)	J_i^π	E_f (MeV)	J_f^π	Branch (%)	Mult. mixing ratio δ
13.39 [o]	$\frac{3}{2}^+$	0	$\frac{1}{2}^-$	100	

[a] See also Tables 15.6, 15.13 and 15.16. For references see Table 15.4 in (1981AJ01). Please note that (1976BE1B) is an unpublished Ph.D. thesis.
[b] Transitions to ^{15}N*(5.27, 5.30) are $< 0.1\%$ and $< 0.05\%$, respectively (1975MO28).
[c] Transitions to ^{15}N*(0, 5.30, 6.32) are $< 0.1\%$, $< 4\%$ and $< 0.5\%$.
[d] Transitions to ^{15}N*(5.30, 6.32) are $< 4\%$ and $< 0.6\%$.
[e] Transitions to ^{15}N*(5.30, 7.30, 7.57) are $< 12\%$, $< 0.7\%$ and $< 3\%$.
[f] Transitions to ^{15}N*(7.16, 7.57, 8.31) are $< 10\%$, $< 2\%$ and $< 0.5\%$.
[g] Transitions to ^{15}N*(7.16, 7.57, 8.31) are $< 1\%$, $< 20\%$ and $< 5\%$.
[h] Transitions to ^{15}N*(7.30, 8.31, 8.57) are $< 2\%$, $< 1\%$ and $< 2\%$.
[i] Transitions to ^{15}N*(0, 5.30) are $< 4\%$ and $< 15\%$.
[j] Transitions to ^{15}N*(7.16, 7.57, 8.31, 8.57) are each $< 1\%$.
[k] For upper limits for transitions to other states see Table 15.4 (1981AJ01).
[l] Transitions to ^{15}N*(0, 5.30, 9.83) are $< 12\%$, $< 2\%$ and $< 0.1\%$.
[m] 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).
[n] See footnote [g] in Table 15.4 (1981AJ01).
[o] $\Gamma_{\gamma_0} = 3.0\pm0.9$ eV, $\Gamma_p\Gamma_{\gamma_0}/\Gamma = 1.70\pm0.5$ eV; $\delta = 0.00\pm0.04$ (M2/E1); B(E1) $= (1.2\pm0.4)\times10^{-3}\, e^2\cdot$fm^2. Transitions to ^{15}N*(5.27, 5.30) $< 8\%$ and to ^{15}N*(6.32, 7.16, 7.30) $< 5\%$.
[p] Weighted mean of all measurements (E.K. Warburton, private communication).

4. ^{10}B(^{7}Li, d)^{15}N $\qquad Q_m = 13.7203$

At $E(^7$Li$) = 24$ MeV angular distributions have been studied to many of the ^{15}N states with $E_x < 15.5$ MeV: see (1981AJ01).

5. ^{11}B(α, γ)^{15}N $\qquad Q_m = 10.9914$

The 90° differential cross section for γ_0 production has been measured for $E_\alpha = 5.74$ to 18.0 MeV [see (1981AJ01)] and for 6.89 to 8.0 and 12.8 to 15 MeV (1984DE09). For the observed resonances see Table 15.7. See also (1982DU1A; theor.).

6. ^{11}B(α, n)^{14}N $\qquad Q_m = 0.1581 \qquad E_b = 10.9914$

Table 15.6: Lifetimes of some ^{15}N states [a]

E_x (MeV)	τ_m	Reaction
5.27	2.47 ± 0.24 psec	^{1}H(^{18}O, α) [b]
	2.58 ± 0.14 psec	mean
5.30	25 ± 7 fsec	mean
6.32	0.211 ± 0.012 fsec	^{15}N(γ, γ) [c]
7.16	18 ± 8 fsec	mean
7.30	0.61 ± 0.05 fsec	^{15}N(γ, γ) [c]
7.57	12^{+11}_{-6} fsec	^{12}C(^{7}Li, α)
	60 ± 20 fsec	^{14}N(d, p)
8.31	1.7 ± 1.1 fsec	^{15}N(γ, γ) [c]
8.57	11 ± 7 fsec	^{12}C(^{7}Li, α)
	0.7 ± 0.7 fsec	^{15}N(γ, γ) [c]
9.05	0.50 ± 0.08 fsec	^{15}N(γ, γ) [c]
9.152	1.40 ± 0.36 fsec	^{15}N(γ, γ) [c]
9.155	7^{+6}_{-3} fsec	^{12}C(^{7}Li, α)
9.23	< 130 fsec	^{13}C(^{3}He, p)
9.76	2.6 ± 0.9 fsec	^{15}N(γ, γ) [c]
9.83	17 ± 7 fsec	^{12}C(^{7}Li, α)
9.93	0.31 ± 0.05 fsec	^{15}N(γ, γ) [c]
10.07	0.100 ± 0.006 fsec	^{15}N(γ, γ) [c]
10.69	18 ± 9 fsec	^{12}C(^{7}Li, α)

[a] See also Tables 15.12 and 15.16 for other states. See Table 15.5 in (1981AJ01) for references.

[b] (1983BI10).

[c] (1981MO09). See also Table 15.5 in (1981AJ01).

Table 15.7: Resonances in ^{11}B(α, γ_0)^{15}N [a]

E_α (MeV)	E_x (MeV)	$\Gamma_{c.m.}$ (keV)	Γ_γ [b] (eV)	J^π
7.20	16.27 ± 0.04	240 ± 30	≥ 11	$\frac{3}{2}^+$
7.70	16.64 ± 0.04	250 ± 30	≥ 11	$\frac{1}{2}^+$
8.40 [b,c]	17.15 ± 0.05	250 ± 60	≥ 2	$(\frac{1}{2}^+, \frac{3}{2}^+)$
9.11 [b,c]	17.67 ± 0.05	600 ± 80	≥ 7	$\frac{3}{2}^+$
10.80 [d]	18.91 ± 0.15	750 ± 70		$\frac{3}{2}^+ + \frac{1}{2}^+$
14.00 [d]	21.25 ± 0.15	1740 ± 150		$\frac{3}{2}^+ + \frac{1}{2}^+$

[a] (1984DE09) [also angular distributions]. See also Table 15.6 in (1981AJ01).

[b] (1978DE23).

[c] These E_α may be 100 keV too high: see (1984DE09).

[d] There is indication of M1/E2 transitions interfering with the predominant E1 transitions.

Reported resonances are displayed in Table 15.8. For thick-target yields (E_α = 3.5 to 7.5 MeV) see (1979BA48).

7. ^{11}B(α, p)^{14}C $\qquad Q_m = 0.7840 \qquad E_b = 10.9914$

Reported resonances are listed in Table 15.8. The yield curve for ^{14}C is dominated by two strong resonances at $E_\alpha = 1.57$ and 2.64 MeV. At higher energies (to 25 MeV) the p_0 excitation functions show broad features. See (1981AJ01).

8. (a) ^{11}B(α, d)^{13}C $\qquad Q_m = -5.1679 \qquad E_b = 10.9914$

(b) ^{11}B(α, t)^{12}C $\qquad Q_m = -3.8570$

Table 15.8: Resonances in ^{11}B + α [a]

E_α (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Particle out	J^π	E_x (MeV)
0.60		n		11.43
1.03		n		11.75
1.18		n		11.86
1.30		n		11.94

Table 15.8: Resonances in ^{11}B + α [a] (continued)

E_α (MeV $\pm$ keV)	$\Gamma_{\text{c.m.}}$ (keV)	Particle out	J^π	E_x (MeV)
1.51		n, p	$(\frac{5}{2}^+)$	12.10
1.58	41 ± 5	n, p	$(\frac{3}{2}^-)$	12.15
2.056 ± 10	34 ± 5	n_0, p_0	$\frac{5}{2}^+$	12.499
2.610 ± 13	56 ± 11	n_0, p_0, α	$\frac{3}{2}^-$	12.905
2.66 ± 30	81	p_0, α	$\frac{5}{2}^+$	12.94
2.942 ± 10	7 ± 3	n_0, p_0		13.149
2.984 ± 10	7 ± 3	n_0, p_0		13.180
3.239 ± 15	16 ± 8	n_0, p, α	$\frac{3}{2}^-$	13.366
3.31 ± 30	61	p, α	$\frac{3}{2}^+$	13.42
3.46 ± 30	85 ± 30	n_0, α	$\frac{3}{2}^-$	13.53
3.560 ± 10	18 ± 4	n_0, p	$(\frac{5}{2}, \frac{7}{2})^-$	13.602
3.57 ± 30	94	α	$\frac{1}{2}^+$	13.61
3.712 ± 10	26 ± 8	n_0		13.713
(3.78 ± 30)	70	α	$(\frac{1}{2}^+)$	(13.76)
3.89 ± 30	≈ 70	n_1, α	$(\frac{3}{2}^+)$	13.84
4.09 ± 30	≈ 100	n_1		13.99
4.232 ± 10	22 ± 6	n_0		14.094
4.24 ± 30	≈ 100	n_1, α	$\frac{3}{2}^+$	14.10
4.324 ± 10	27 ± 6	n_0		14.162
4.43 ± 40	150	α	$\frac{5}{2}^+$	14.24
4.62 ± 40	100	α	$\frac{7}{2}^+$	14.38
4.85 ± 20	200 ± 50	n_0		14.55
4.986 ± 10	33 ± 6	n_0		14.647
5.11 ± 30	110 ± 50	n_0		14.74
5.28 ± 20	48 ± 11	n_0, α		14.86
5.538 ± 10	12 ± 3	n_0		14.920
5.501 ± 10	13 ± 3	n_0		15.025
5.59 ± 20	80 ± 25	n_0, α		15.09
5.860 ± 10	22 ± 6	n_0, α		15.288
5.98 ± 20	75 ± 25	n_2, (α)		15.38
6.06 ± 20	≈ 100	n_0, (α)		15.43

Table 15.8: Resonances in $^{11}B + \alpha$ [a] (continued)

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

[a] For references see Table 15.7 in (1981AJ01).

The yield of d_0 has been measured for $E_\alpha = 13.5$ to 25 MeV. The exciation functions for t_0 and t_1 (to 25 MeV) show strong uncorrelated structures. See (1976AJ04, 1981AJ01).

9. $^{11}B(\alpha, \alpha)^{11}B$ $\qquad E_b = 10.9914$

Observed resonances for $E_\alpha = 2.1$ to 7.9 MeV are shown in Table 15.8.

10. $^{11}B(^6Li, d)^{15}N$ $\qquad Q_m = 9.5163$

At $E(^6Li) = 34$ MeV angular distributions are reported to the states with $5.3 < E_x < 16.3$ MeV: this reaction appears to be less selective than reaction 11. The most strongly populated states are $^{15}N^*$(9.2, 10.5, 10.7, 13.1, 14.8, 15.5). See (1981AJ01).

11. $^{11}B(^7Li, t)^{15}N$ $\qquad Q_m = 8.5234$

At $E(^7\text{Li}) = 24$ and 34 MeV, angular distributions to states with $5.3 < E_x < 15.6$ MeV have been measured: ^{15}N*(9.8, 10.5, 10.7, 15.4, 15.5) are patricularly 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). Only ^{15}N*(15.52) appears to have a large cluster component corresponding to $^{11}\text{B} + \alpha$. See (1981AJ01). The γ-decay of ^{15}N states populated in this reaction has been studied by (1979HA38): see Tables 15.5 and 15.6.

12. ^{11}B(^{9}Be, ^{5}He)^{15}N $\qquad Q_m = 8.524$

See (1984DA17) for cross sections and S-factors.

13. ^{11}B(^{11}B, ^{7}Li)^{15}N $\qquad Q_m = 2.3277$

See (1976AJ04).

14. ^{11}B(^{16}O, ^{12}C)^{15}N $\qquad Q_m = 3.8295$

Angular distributions have been measured at $E(^{16}\text{O}) = 27$ to 60 MeV involving the two proton-hole states of ^{15}N[^{15}N*(0, 6.32); $J^\pi = \frac{1}{2}^-, \frac{3}{2}^-$] and ^{12}C*(0, 4.4, 9.6): see (1976AJ04). See also (1983EL01; theor.).

15. (a) ^{12}C(t, γ)^{15}N $\qquad Q_m = 14.8484$
(b) ^{12}C(t, n)^{14}N $\qquad Q_m = 4.01511 \qquad E_b = 14.8484$
(c) ^{12}C(t, p)^{14}C $\qquad Q_m = 4.6410$
(d) ^{12}C(t, t)^{12}C
(e) ^{12}C(t, α)^{11}B $\qquad Q_m = 3.8570$

The $90°$ excitation function for γ_0 in the range 1.0 to 6.5 MeV [see (1981AJ01) and (1983DR13; polarized tritons and γ-rays; $E_{\vec{t}} = 2.3$ to 6.5 MeV)] shows one very strong resonance (at peak, 4.4 ± 0.5 μb/sr) corresponding to ^{15}N*(16.7) as well as two other strong (unresolved and/or broad resonances) at $E_t \approx 3.3$ and 6 MeV: Table 15.9 shows the derived parameters. Table 15.9 also displays the structures observed in reactions (b) $\rightarrow$ (e). At $E_{\vec{t}} = 17$ MeV the polarization and analyzing power for the transition to $^{14}\text{C}_{\text{g.s.}}$ (reaction (c)) are shown to be the same as required by the conservation of parity (1982HA06). The VAP for the elastic scattering (reaction (d)) has been measured at $E_{\vec{t}} = 9$ and 11 MeV (1984FI01). See (1981AJ01) for the earlier work. See also (1984SAZP, 1984SL04; theor.).

Table 15.9: Resonances in $^{12}C + t$ [a]

E_t (MeV $\pm$ keV)	E_x (MeV)	Particles out	J^π	Γ (keV)
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
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
2.30	16.69 ± 0.01	γ_0, n, p_0, α_0, α_1	$\frac{3}{2}^+$	130 ± 15
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	$\frac{3}{2}^-$	
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
≈ 6 [b]	19.6	γ_0		
15.0	26.8	t_0		

[a] For references see Tables 15.8 in (1976AJ04, 1981AJ01).

[b] (1983DR13); broad and/or unresolved state(s); E_t estimated by reviewer.

16. ^{12}C(^{3}He, π^{+})^{15}N $\qquad Q_{\rm m} - 124.7375$

See (1984BI08; $E(^{3}\text{He}) = 235$ MeV).

17. ^{12}C(α, p)^{15}N $\qquad Q_{\rm m} = -4.9656$

Angular distributions have been measured at many energies for $E_{\alpha} = 13.4$ to 96.8 MeV [see (1976AJ04, 1981AJ01)] and at $E_{\alpha} = 18.5$, 21.7 and 25.4 MeV (1981BE19; p_0) and 34.9 MeV (1983HA32). See also (1982AM02) in ^{16}O (1982AJ01, 1986AJ04). At $E_{\alpha} = 34.9$ MeV angular distributions are reported to ^{15}N*(0, 5.3, 6.3, 7.1, 7.3, 7.6, 8.6, 9.2, 9.8, 10.7, 11.2, 11.9, 12.6, 13.0, 13.2, 14.1, 15.3, 15.4, 20.15 ± 0.10). Those to the states with high spin ^{15}N*(10.7, 11.9, 12.6, 13.0, 13.2, 15.3, 15.4) have been analyzed with DWBA, the predictions depending strongly on the choice of the α-particle optical potential (1983HA32). See also Table 15.9 in (1981AJ01), (1984GA11) and (1981KA04, 1983PI03; theor.).

18. ^{12}C(^{6}Li, ^{3}He)^{15}N $\qquad Q_{\rm m} = -0.9472$

Observed ^{3}He groups are displayed in Table 15.9 of (1981AJ01). 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: $5.27 - 5.24$, $7.16 - 6.86$, $7.57 - 7.28$, $8.57 - 8.28$, $10.80 - 10.48$, 13.15(u)–12.84, 15.49(u)–15.05 [first listed is $E_{\rm x}$ in ^{15}N, second in ^{15}O]. [$E_{\rm x}$ are nominal; u = unresolved.] For γ-decay measurements see Table 15.5. See also (1976AJ04) and (1983PI03; theor.).

19. ^{12}C(^{7}Li, α)^{15}N $\qquad Q_{\rm m} = 12.3804$

Observed α-groups are shown in Table 15.10. Angular distributions have been measured to $E(^{7}\text{Li}) = 48$ MeV. Comparison of spectra from this reaction ($E(^{7}\text{Li}) = 34.9$ MeV) with those from ^{13}C(^{6}Li, α) (reaction 27) lead to configurations of $(\text{d})^3$ 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 $J^{\pi} = \frac{11}{2}^{-}$: see (1981AJ01).

^{15}N*(9.155) [$J^{\pi} = \frac{5}{2}$] 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): see (1981AJ01). For γ-decay measurements see Table 15.5. For $\tau_{\rm m}$ measurements see Table 15.6. See also (1983PI03; theor.).

Table 15.10: States of ^{15}N from ^{12}C(^{7}Li, α)

E_x (MeV $\pm$ keV)		E_x (MeV $\pm$ keV)	
(1973TS02) [a]	(1980ZE02) [b]	(1973TS02) [a]	(1980ZE02) [b]
0		12.923	
5.295	5.284	13.004 [a]	13.001
6.332	6.323	13.173 [a]	13.178
7.163	7.157	13.614	
7.310	7.299	14.087	14.097
7.566	7.574	14.720	14.693
8.320			14.874
8.580 [a]	8.574	15.021	15.024
9.163 [a]	9.159	15.373	15.379
9.828 [a]	9.809	15.782	15.778
9.932	9.921	16.026	16.032
10.072	10.075	16.190	16.210
10.524	10.518		17.735
10.700 [a]	10.714		17.949 [b]
10.808			18.272
	11.274		18.698 [b]
11.430	11.456		19.27 $\pm$ 40
11.951	11.936		19.68 $\pm$ 50 [b,d]
12.320 [a]	12.328		20.93 $\pm$ 50 [b,d]
12.559 [a,c]	12.551		24.75 $\pm$ 150 [b,d]

[a] $E(^{7}\text{Li}) = 35$ MeV; angular distributions have been measured for the states labelled by this footnote; $E_x \pm 10$ keV.

[b] $E(^{7}\text{Li}) = 48$ MeV; angular distributions have been measured for the states labelled by this footnote; $E_x \pm 20$ keV unless otherwise shown.

[c] (1973TS02) suggests that this state is not the $T = \frac{3}{2}$ state at 12.52 MeV.

[d] Wide or unresolved.

20. (a) ^{12}C(^{10}B, ^{7}Be)^{15}N $\quad Q_{\rm m} = -3.8194$
(b) ^{12}C(^{11}B, ^{8}Be)^{15}N $\quad Q_{\rm m} = 3.6248$

See (1981AJ01). See also (1983DEZW).

21. ^{13}C(d, γ)^{15}N $\quad Q_{\rm m} = 16.1593$

The $90° - 95°$ yields of γ_0 have been measured for $E_{\rm d} = 1$ to 10 MeV: observed resonances are displayed in Table 15.11. The γ-ray angular distributions are consistent with the emission of predominantly E1 radiation except for evidence of M1/E2 transitions in the region $E_{\rm x} = 20 - 21.5$ MeV: see (1981AJ01).

22. (a) ^{13}C(d, n)^{14}N $\quad Q_{\rm m} = 5.3260 \quad E_{\rm b} = 16.1593$
(b) ^{13}C(d, p)^{14}C $\quad Q_{\rm m} = 5.9519$

Observed resonances are displayed in Table 15.11. Polarization measurements have been carried out at $E_{\vec{\rm d}} = 12.3$ MeV (1983LIZW) for reaction (a) and at $E_{\vec{\rm d}} = 13$ MeV [see (1981AJ01)] and 56 MeV (1984HA26; $\rm p_0$) for reaction (b).

23. ^{13}C(d, d)^{13}C $\quad E_{\rm b} = 16.1593$

Excitation functions for elastically scattered deuterons have been measured in the range $E_{\rm d} = 0.4$ to 5.7 MeV: see (1976AJ04). Polarization studies are reported for $E_{\rm d} = 12.5$ to 15 MeV [see (1981AJ01)] and at $E_{\vec{\rm d}} = 56$ MeV (1984HA26; $\rm d_0$). See also (1980BO31; 3.1 GeV).

24. (a) ^{13}C(d, t)^{12}C $\quad Q_{\rm m} = 1.3109 \quad E_{\rm b} = 16.1593$
(b) ^{13}C(d, ^{3}He)^{12}B $\quad Q_{\rm m} = -12.040$
(c) ^{13}C(d, α)^{11}B $\quad Q_{\rm m} = 5.1679$

Observed resonances are listed in Table 15.11. For polarization measurements to $E_{\vec{\rm d}} = 29$ MeV [reactions (a, b)] see (1981AJ01).

25. ^{13}C(^{3}He, p)^{15}N $\quad Q_{\rm m} = 10.6658$

Table 15.11: Resonances in ^{13}C + d [a]

E_d (MeV)	Particles out	Γ_{lab} (keV)	^{15}N* (MeV)
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]
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
8.8	γ_0	broad	23.8

[a] See references listed in Tables 15.10 (1976AJ04, 1981AJ01).
[b] $J^\pi = \frac{1}{2}^-$ or $\frac{3}{2}^+$; $T = \frac{1}{2}$.

Observed proton groups and γ-rays are listed in Table 15.11 of (1981AJ01). Gamma-ray branching ratios are displayed in Table 15.5 and τ_m in Table 15.6. Angular distributions have been reported for $E(^3\text{He}) = 4.37$ to 20 MeV: see (1981AJ01). The g-factor for ^{15}N*(5.27)[$J^\pi = \frac{5}{2}^+$] is $+(0.9 \pm 0.3)$. See also ^{16}O in (1982AJ01) and (1976AJ04).

26. ^{13}C(α, d)^{15}N $\qquad Q_m = -7.6874$

At $E_\alpha = 34.9$ MeV a ZRDWBA analysis has been made of the angular distributions to ^{15}N*(5.27, 5.30, 7.16, 7.30, 7.56, 8.31, 8.57, 9.05, 9.15, 10.07, 10.53, 10.69, 11.43, 11.94, 12.10, 12.33, 12.49, 12.56, 13.00, 13.83, 14.08). $L = 0$ for the group(s) to ^{15}N*(9.15, 10.69); $L = 2$ for ^{15}N*(12.56); $L = 3$ for ^{15}N*(5.27, 7.16, 7.56); $L = 4$ for ^{15}N*(11.94, 13.00); $L = 1$ fopr the remaining transitions (1984YA03). See also Table 15.11 of (1976AJ04).

27. ^{13}C(^{6}Li, α)^{15}N $\qquad Q_{\mathrm{m}} = 14.6842$

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): see (1981AJ01).

28. (a) ^{13}C(^{10}B, ^{8}Be)^{15}N $\qquad Q_{\mathrm{m}} = 10.1326$

(b) ^{13}C(^{11}B, ^{9}Be)^{15}N $\qquad Q_{\mathrm{m}} = 0.3438$

For reaction (a) see (1983DEZW). At $E(^{11}\mathrm{B}) = 114$ MeV the dominant group is ^{15}N*(13.00): see (1981AJ01).

29. ^{13}C(^{17}O, ^{15}N)^{15}N $\qquad Q_{\mathrm{m}} = 2.1127$

See (1981AJ01).

30. ^{14}C(p, γ)^{15}N $\qquad Q_{\mathrm{m}} = 10.2074$

Observed resonances are displayed in Table 15.12; the branching ratios are shown in Table 15.5. Narrow anomalies (in the γ_0 yield for $E_{\mathrm{p}} = 2.8$ to 30 MeV) are reported at $E_{\mathrm{p}} = 10.0$, 11.0, 12.35, 13.6, 16.4 MeV. A good fit to the total cross section ($E_{\vec{\mathrm{p}}} = 7.5$ to 19 MeV) is obtained with the GDR split into peaks at $E_{\mathrm{x}} = 21.0$ and 25.5 MeV with $\Gamma = 6$ and 2 MeV, respectively. The integrated E2 cross section for $E_{\mathrm{x}} = 19.5$ 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_{x} region. [Another study shows no appreciable E2 strength concentration for $E_{\mathrm{x}} = 14.3$ to 23.3 MeV.] Above the GDR region the 90° γ_0 cross section decreases smoothly with energy except for a small peak which would correspond to ^{15}N*(37.). See (1981AJ01) for the references. See also (1984WA07) and (1980WE1D, 1982WE01).

31. (a) ^{14}C(p, n)^{14}N $\qquad Q_{\mathrm{m}} = -0.6259 \qquad E_{\mathrm{b}} = 10.2074$

(b) ^{14}C(p, p)^{14}C

(c) ^{14}C(p, α)^{11}B $\qquad Q_{\mathrm{m}} = -0.7840$

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)
0.261 ± 0.6	< 0.5		$(0.08 \pm 0.01) \times 10^{-6}$		> 21 meV	$\frac{5}{2}^-$	10.4497 ± 0.3 [d]
0.352 ± 1					$(3.4 \pm 0.4) \times 10^{-2}$ [b]	$\frac{5}{2}^+$	10.5333 ± 0.5 [d]
0.519 ± 1			$(0.49 \pm 0.10) \times 10^{-6}$		> 40 meV	$\frac{9}{2}^+$	10.6932 ± 0.3 [d]
0.527 ± 1			0.2		0.37 ± 0.07	$\frac{3}{2}^-$	10.7019 ± 0.3 [d]
0.634 ± 1			$(0.22 \pm 0.10) \times 10^{-3}$		0.27 ± 0.14	$\frac{3}{2}^{(+)}$	10.804 ± 2 [d]
1.162 ± 2	7.9 ± 3	2.3	5.6	< 0.3	0.29 [c]	$\frac{1}{2}^-$	11.291
1.3188 ± 0.5	41.4 ± 1.1	34.6 ± 0.9	6.8 ± 0.5	< 0.3	4.2 ± 0.7 [c]	$\frac{1}{2}^+$	11.4376
1.509 ± 4	404.9 ± 6.3	4.0 ± 0.2	400.9 ± 6.3	< 0.3	19.2 ± 0.4 [c]	$\frac{1}{2}^+; T = \frac{3}{2}$	11.615
1.688 ± 3	37	36.5	0.5	< 0.3		$\frac{3}{2}^+$	11.782
1.788 ± 3	24.5	24.5	0.03	< 0.3		$\frac{3}{2}^-, (\frac{5}{2}^-)$	11.875
1.884 ± 3	21.5	21.2	0.3	< 0.3		$\frac{1}{2}^-$	11.965
2.025 ± 4	14 ± 5	12.0	1.7	0.6		$\frac{5}{2}^+$	12.096
2.077 ± 3	47 ± 7	30.2	16.6	2.2		$\frac{3}{2}^-$	12.145
2.272 ± 4	22	21.7	0.3	< 0.3		$\frac{5}{2}^{(+)}$	12.327
2.450 ± 4	44 ± 3	28	0.3	5.5		$\frac{5}{2}^+; T = \frac{1}{2}$	12.493
2.482 ± 8	58 ± 4				4.6 ± 0.7	$\frac{5}{2}^+; T = \frac{3}{2}$	12.523
2.908 ± 4	70	25	9.0	15		$\frac{3}{2}^-$	12.920
2.93 ± 10	81	n.r.	0.5	80		$\frac{5}{2}^+$	12.940
3.19	5.5	r.					13.18
3.38 ± 10	24	6	6.0	12		$\frac{3}{2}^-$	13.360
3.421 ± 10	57	20.6	35	5.5	3.0 ± 0.9	$\frac{3}{2}^+$	13.390
3.57 ± 10	124	≈ 75	8.0	≈ 40		$\frac{3}{2}^-$	13.537

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)
3.65 ± 10	88	≈ 16	12.0	≈ 60		$\frac{1}{2}^+$	13.612
3.71		r.					13.67
4.0	930		500		r.	$\frac{1}{2}^+$	13.9
4.1 ± 100	98 ± 10		25	r.		$\frac{5}{2}^+$	14.0
4.2 ± 100				r.		$(\frac{3}{2})$	14.1
4.6 ± 150	74 ± 7		20	r.	(r.)	$\frac{3}{2}^-$	14.5
4.8	149 ± 18		39	r.	(r.)	$\frac{3}{2}^+$	14.7
4.83	750				r.		14.71
5.08	158 ± 19		20		r.	$\frac{3}{2}^+$	14.95
5.16 ± 130	28 ± 3		9.0	r.		$\frac{3}{2}^+$	15.0
5.54 ± 130	39 ± 5		12	r.	(r.)	$\frac{3}{2}^-$	15.4
5.62	750				r.		15.45
6.4 ± 150	130 ± 14		19	r.		$\frac{3}{2}^+$	16.2
6.70	560				r.		16.46
6.925	90 ± 10			r.	r.	$(\frac{3}{2}^+; \frac{1}{2})$	16.67
7.18 ± 180	110 ± 50			r.		$\frac{5}{2}$	16.9
≈ 9					r.	$\frac{1}{2}^+; \frac{1}{2}$	19
10.0	sharp		(1000)		r.	$\frac{3}{2}^+; (T = \frac{3}{2})$	19.5 [e]
11.0	sharp				r.	$\frac{3}{2}^+$	20.5
12.35					r.		21.72
13.65					r.		22.94
16.4					r.	$(T = \frac{3}{2})$	25.5 [e]

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)
≈ 29					r.		≈ 37

r. = resonant.

n.r. = non-resonant.

[a] See Tables 15.5 in (1959AJ76), 15.11 in (1970AJ04) and 15.12 in (1981AJ01) for references and additional comments.

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

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

[d] E_x measured directly: see (1981AJ01).

[e] Analog not observed in ^{14}N(p, γ)^{15}O.

Observed resonances and anomalies are displayed in Table 15.12. Polarization measurements for reaction (a) have been reported for $E_p = 1.79$ to 13.3 MeV [see (1981AJ01)] and at $E_{\vec{p}} = 120$ and 160 MeV (1981GOZX, 1982MAZZ) and for reaction (b) at $E_p = 3.2$ to 5.7 MeV [see (1981AJ01)] and at $E_{\vec{p}} = 25$ and 35 MeV (1984BAZZ, 1985BAZZ). See also (1984TA02) and ^{14}C, ^{14}N.

32. ^{14}C(d, n)^{15}N $\qquad Q_m = 7.9829$

Angular distributions have been measured for $E_d = 1.3$ to 6.5 MeV: see (1976AJ04). See also (1983CR1A).

33. ^{14}C(^{3}He, d)^{15}N $\qquad Q_m = 4.7139$

Angular distributions have been studied at $E(^3\text{He}) = 23$ MeV to ^{15}N*(0, $5.27 + 5.30$, 6.32, 7.16, 7.30): see (1981AJ01). See also (1976AJ04).

34. ^{14}C(^{16}O, ^{15}N)^{15}N $\qquad Q_m = -1.9201$

Angular distributions to $^{15}\text{N}_{\text{g.s.}}$ have been studied at $E(^{16}\text{O}) = 20$, 25 and 30 MeV: see (1976AJ04). See also (1981KO07; yields).

35. ^{14}N(n, γ)^{15}N $\qquad Q_m = 10.8333$

$Q_0 = 10833.343 \pm 0.009$ keV (1983KE11). [However values of E_γ obtained by (1983KE11) [see Table 15.13] are based on $Q_0 = 10833.302$ keV: see (1983CO09).]

The thermal cross section is 77.2 ± 2.1 mb (1981IS07). See also (1981MUZQ). 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 15.5 and 15.6. The 90° γ_0 yield and angular distributions have been measured for $E_n = 5.6$ to 15.3 MeV. The cross section shows two prominent dips at $E_x = 16.7$ and 18.1 MeV [compare with ^{14}N(p, γ); reaction 11 in ^{15}O] and broad structures at $E_x \approx 17$ and 19 MeV. The angular distribution data are consistent with essentially pure E1 radiation in the region $E_x = 17$ to 24 MeV (1982WE01). See also (1980WE1D).

36. ^{14}N(n, n)^{14}N $\qquad E_b = 10.8333$

The scattering amplitude (bound) $a = 9.37 \pm 0.03$ fm, $\sigma_{\text{free}} = 10.05 \pm 0.12$ b, $\sigma^{\text{spin}}_{\text{inc}}$(bound nucleus) $= 0.49 \pm 0.11$ b (1979KO26). See also (1981MUZQ).

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

Transition in ^{15}N	E_γ [b] (keV)	E_x [b] (keV)	I_γ [c]
C $\rightarrow$ 0	10829.10 (2)	10833.30 (1.4)	13.8 (7)
C $\rightarrow$ 5.27	5562.04 (2)		10.7 (1.4)
C $\rightarrow$ 5.30	5533.40 (2)		20.0 (2.6)
C $\rightarrow$ 6.32	4508.71 (3)		16.6 (2.6)
C $\rightarrow$ 7.16	3677.73 (2)		14.9 (2.7)
C $\rightarrow$ 7.30	3532.00 (3)		9.72 (19)
C $\rightarrow$ 8.31	2520.47 (2)		6.16 (24)
C $\rightarrow$ 9.05			[a]
C $\rightarrow$ 9.152	1681.12 (6)		[a]
C $\rightarrow$ 9.155	1678.24 (3)		[a]
C $\rightarrow$ 9.76		9757.5 (30) [a]	[a]
C $\rightarrow$ 9.93			[a]
5.27 $\rightarrow$ 0	5269.14 (2)	5270.15 (2)	30.1 (4.1)
5.30 $\rightarrow$ 0	5297.79 (2)	5298.80 (2)	21.1 (3)
6.32 $\rightarrow$ 0	6322.47 (3)	6323.89 (2)	18.8 (3)
7.16 $\rightarrow$ 0		7155.11 (2)	
7.16 $\rightarrow$ 5.27	1884.85 (2)		19.7 (10) [e]
7.16 $\rightarrow$ 5.30			0.8 (2) [e]
7.30 $\rightarrow$ 0	7298.98 (4)	7300.86 (2)	9.59 (19)
7.30 $\rightarrow$ 5.30			[a]
8.31 $\rightarrow$ 0	8310.14 (4)	8312.60 (2)	4.20 (12)
8.31 $\rightarrow$ 6.32	1989 (2) [e]		1.5 (3) [e]
8.57 $\rightarrow$ 0	8570 (4) [e]		0.2 (0.3) [e]
9.05 $\rightarrow$ 0	9047 (4) [e]		0.2 (0.3) [e]
9.152 $\rightarrow$ 0		9152.14 (6)	
	9149.18 (3)		1.67 (7)
9.155 $\rightarrow$ 0		9155.00 (4)	
9.155 $\rightarrow$ 5.27	3884.28 (7) [d]		0.8 (1) [e]
9.155 $\rightarrow$ 5.30	3855.60 (7) [d]		1.0 (1) [e]
9.155 $\rightarrow$ 6.32	2830.75 (9) [d]		2.03 (9)
9.155 $\rightarrow$ 7.16	1999.73 (10) [d]		4.6 (2) [e]

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

Transition in ^{15}N	E_γ [b] (keV)	E_x [b] (keV)	I_γ [c]
$9.155 \rightarrow 7.30$			[a]

C = capturing state.

[a] See also Table 15.13 in (1981AJ01).

[b] Weighted mean of values from (1980GR12, 1983KE11); uncertainties are rounded off. 12 eV has been added in quadrature to the uncertainties of (1983KE11). I am very grateful to T.J. Kennett for his comments. See also (1981KE02).

[c] In units of photons/100 captures. based on earlier values of (1967TH05) but recalculated by (1980KE1K).

[d] (1980GR12).

[e] (1967TH05).

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 die to the decay of excited states of ^{14}N have been measured in the range $E_n = 2$ to 20 MeV: see (1976AJ04, 1981AJ01). Analyzing powers for the n_0 group have been measured for $E_{\vec{n}} = 5 \rightarrow 17$ MeV (1985ANZX). See also (1984TEZZ), (1982HA1A) and (1982DI1E; applied).

37. ^{14}N(n, 2n)^{13}N $\quad Q_m = -10.5535 \quad E_b = 10.8333$

Cross sections have been measured for $E_n = 10$ to 37 MeV: see (1970AJ04, 1981AJ01). See also (1983CSZX).

38. (a) ^{14}N(n, p)^{14}C $\quad Q_m = 0.6259 \quad E_b = 10.8333$
(b) ^{14}N(n, d)^{13}C $\quad Q_m = -5.3260$
(c) ^{14}N(n, t)^{12}C $\quad Q_m = -4.0151$
(d) ^{14}N(n, α)^{11}B $\quad Q_m = -0.1581$

The thermal cross section for reaction (a) is 1.83 ± 0.03 b (1981MUZQ). Reported resonances for reactions (a) and (d) are displayed in Table 15.14. For a listing of cross-section measurements see (1981AJ01). See also (1981HAZJ, 1985BO1D).

39. ^{14}N(d, p)^{15}N $\quad Q_m = 8.6087$

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

$E_{\rm res}$ (MeV $\pm$ keV)	$\Gamma_{\rm lab}$ (keV)	$\Gamma_{\rm n}$ (keV)	$\Gamma_{\rm p}$ (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		$\frac{1}{2}^-$	11.2928
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	$\frac{5}{2}^+$	13.39
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 [a] (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 in Tables 15.14 in (1970AJ04, 1976AJ04).

Proton groups (and γ-rays) from this reaction are displayed in Table 15.15 of (1981AJ01). The results include $E_x = 7567.1 \pm 1.0$ keV for ^{15}N*(7.57). Angular distributions have been measured for $E_d = 0.32$ to 52 MeV and lead to l_n, J^π and spectroscopic factors: see Table 15.15 in (1981AJ01). Branching ratios and multipolarities are shown in Table 15.5; τ_m in Table 15.6. See also (1982BE64; applied), (1978GR16; theor.) and ^{16}O in (1982AJ01).

40. (a) ^{14}N(t, d)^{15}N $\qquad Q_m = 4.5760$
    (b) ^{14}N(^{3}He, 2p)^{15}N $\qquad Q_m = 3.1152$

See (1981AJ01) for reaction (a). For reaction (b) see (1985HA01) and ^{16}O in (1986AJ04).

41. ^{14}N(α, ^{3}He)^{15}N $\qquad Q_m = -9.7445$

See (1981AJ01).

42. (a) ^{14}N(^{11}B, ^{10}B)^{15}N $\qquad Q_m = -0.6208$
    (b) ^{14}N(^{13}C, ^{12}C)^{15}N $\qquad Q_m = 5.8870$

At $E(^{11}\mathrm{B}) = 115$ MeV and at $E(^{13}\mathrm{C}) = 105$ MeV (1980PR09) have studied the transitions to ^{15}N*(0, 7.16, 7.57). See also (1981AJ01).

Table 15.15: Beta decay of ^{15}C [a]

Decay to ^{15}N* (keV)	J^π	Branch (%)	log ft
g.s.	$\frac{1}{2}^-$	36.8 ± 0.8 [c]	5.99 ± 0.03 [c]
5298.87 ± 0.15 [b]	$\frac{1}{2}^+$	63.2 ± 0.8 [c]	4.11 ± 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). 5297.794 ± 0.035 keV: see (1981WA06).

[c] (1984WA07).

43. ^{14}N(^{14}N, ^{13}N)^{15}N $\qquad Q_{\mathrm{m}} = 0.2799$

See (1981AJ01).

44. ^{15}C(β^-)^{15}N $\qquad Q_{\mathrm{m}} = 9.7717$

See reaction 1 in ^{15}C and Table 15.15.

45. (a) ^{15}N(γ, n)^{14}N $\qquad Q_{\mathrm{m}} = -10.8333$
(b) ^{15}N(γ, p)^{14}C $\qquad Q_{\mathrm{m}} = -10.2074$
(c) ^{15}N(e, ep$_0$)^{14}C $\qquad Q_{\mathrm{m}} = -10.2074$
(d) ^{15}N(γ, d)^{13}C $\qquad Q_{\mathrm{m}} = -16.1593$
(e) ^{15}N(γ, t)^{12}C $\qquad Q_{\mathrm{m}} = -14.8484$

The total photoneutron cross section from threshold to 38 MeV shows a very broad GDR which extends from $\approx$ 16 to 30 MeV with a maximum $\sigma \approx 11$ mb at 23.5 MeV. Most of the strength in the GDR goes via transitions to excited states of ^{14}N (1982JU03: monoenergetic photons). The (γ, n$_0$) cross section for $E_{\mathrm{x}} = 13$ to 24 MeV shows a broad structure centered at $E_{\mathrm{x}} \approx 14.5$ MeV and a resonance at $E_{\mathrm{x}} = 17.3 \pm 0.1$ MeV. A large fraction of the photoabsorption strength leading to ^{14}N$_{\mathrm{g.s.}}$ is due to the formation of $\frac{3}{2}^+$, $T = \frac{1}{2}$ states in ^{15}N which decay by d-wave emission.

The absorption is essentially pure E1 (1983WA03). 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$_{g.s.}$. The presence of $T = \frac{1}{2}$ in the main giant resonance region is indiacted by strong population of ^{14}N*(7.03): see (1981AJ01).

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.

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. 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 the 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. See (1981AJ01) for references.

46. ^{15}N(γ, γ)^{15}N

See Table 15.16 (1981MO09) and (1981AJ01).

47. ^{15}N(e, e)^{15}N

The rms radius of ^{15}N is 2.580 ± 0.026 fm. Inelastic groups are displayed in Table 15.16. The transverse form factors for the transitions to ^{15}N*(0, 6.32) have been measured at $E_e = 70.4$ to 326.7 MeV (1983SI11).

The giant resonance is split into two main peaks at $E_x = 22$ and 25.5 MeV with some structure around 20 MeV. Γ_{γ_0}(C1) $= (1.1 \pm 0.3) \times 10^3$ eV (14–18.5 MeV), Γ_{γ_0}(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, Γ_{γ_0}(C1) $= (1.96 \pm 0.04) \times 10^4$ eV while $\Gamma_{\gamma_0} < 0.1$ eV for any C2 strength. See (1981AJ01) for references. See also (1984DO20) and (1981SU03, 1981SU08, 1982LIZW; theor.).

48. ^{15}N($\pi^\pm$, $\pi^\pm$)^{15}N

At $E_{\pi^\pm} = 164$ MeV angular distributions have been studied to states at $E_x = 10.68 \pm 0.03$, 12.52 ± 0.02, 14.04 ± 0.03 and 17.19 ± 0.03 MeV: $J^\pi = \frac{9}{2}^+$, $\frac{9}{2}^+$, $(\frac{9}{2}^+, \frac{7}{2}^+)$ and $(\frac{9}{2}^+, \frac{7}{2}^+)$, respectively, as well as to the ^{15}N$_{g.s.}$. Additional π^+ cross sections were measured at 120 and 260

MeV: peaks were observed at $E_x = 20.11 \pm 0.06$ and 23.19 ± 0.06 MeV [both are probably $T = \frac{3}{2}$ states]. ^{15}N*(5.27, 6.32, 7.57) were also populated (1985SE06). See also (1984SAZU), (1982OS01; theor.) and the "GENERAL" section here.

Table 15.16: Radiative widths [a] from ^{15}N(γ, γ') and ^{15}N(e, e')

E_x (MeV ± keV)	J^π	Mult.	Γ_{γ_0} (eV)
5.27	$\frac{5}{2}^+$	C3	$(4.2 \pm 0.3) \times 10^{-6}$
		M2	$(1.2 \pm 0.7) \times 10^{-4}$
5.30	$\frac{1}{2}^+$	C1	2.2 ± 2.3
6.323 ± 1 [b]	$\frac{3}{2}^-$	C2	0.050 ± 0.004
		M1	1.9 ± 0.4 [c]
		M1 + E2	3.12 ± 0.18 [b,d,e]
7.16	$\frac{5}{2}^+$	C3	$(0.86 \pm 0.10) \times 10^{-5}$
7.301 ± 1 [b]	$\frac{3}{2}^+$	C1	2.6 ± 1.0
		M2	$(0.3 \pm 0.2) \times 10^{-5}$
		E1 + M2	1.08 ± 0.08 [b]
7.57	$\frac{7}{2}^+$	C3	$(1.84 \pm 0.16) \times 10^{-5}$
8.310 ± 4 [b]	$\frac{1}{2}^+$	E1	0.3 ± 0.2 [b]
8.575 ± 4 [b]	$\frac{3}{2}^+$	E1 + M2	0.3 ± 0.3 [b]
9.048 ± 1 [b]	$\frac{1}{2}^+$	E1	1.2 ± 0.2 [b]
9.150 ± 1 [b]	$\frac{3}{2}^-$	C2	0.095 ± 0.005 [f]
		M1	0.2 ± 0.8
		M1 + E2	0.47 ± 0.12 [b,g]
9.760 ± 1 [b]	$\frac{5}{2}^-$	C2	0.20 ± 0.05
		E2	0.21 ± 0.07 [b]
9.924 ± 1 [b]	$\frac{3}{2}^-$	M1	1.6 ± 0.2 [b]
10.064 ± 1 [b]	$\frac{3}{2}^+$	E1	6.3 ± 0.4 [b]
10.8	$\frac{3}{2}^+$	M2	$(1.8 \pm 0.8) \times 10^{-2}$
11.88	$\frac{3}{2}^-$	C2	0.44 ± 0.10
		M1	4.4 ± 3.8
12.5	$\frac{5}{2}^+$	M2	$(5.2 \pm 2.0) \times 10^{-2}$
(13.98)			
14.7	$\frac{5}{2}^-$	C2	1.8 ± 0.2
20.10			

Table 15.16: Radiative widths [a] from ^{15}N(γ, γ') and ^{15}N(e, e') (continued)

E_x (MeV $\pm$ keV)	J^π	Mult.	Γ_{γ_0} (eV)
23.25			

[a] For references and $B(\lambda)\uparrow$ see Table 15.17 in (1981AJ01). See also Tables 15.5 and 15.6 here.
[b] (1981MO09): (γ, γ).
[c] See note added in proof in (1975MO28).
[d] δ(E2/M1) $= 0.137 \pm 0.005$. See, however, Table 15.5.
[e] Using δ(E2/M1) $= 0.132 \pm 0.004$ [see Table 15.5] $\Gamma_{\gamma_0} = 3.07 \pm 0.18$ eV (M1) and $(5.34 \pm 0.44) \times 10^{-2}$ eV (E2) (D.J. Millener, private communication).
[f] δ(E2/M1) > 0.3.
[g] Mixing ratio is very small [see Table 15.5] and the transition is almost purely M1 (D.J. Millener, private communication).

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

See ^{16}N in (1982AJ01).

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

Angular distributions of elastically scattered protons have been measured at E_p to 44.2 MeV [see (1981AJ01)] and at $E_{\vec{p}} = 2.8$ to 7.0 MeV (1984DA18). See also ^{16}O in (1982AJ01, 1986AJ04).

51. (a) ^{15}N(d, d)^{15}N
(b) ^{15}N(^{3}He, ^{3}He)^{15}N

Angular distributions of elastically scattered deuterons have been measured at $E_d = 5 - 6$ MeV. Elastic and inelastic ^{3}He distributions have been studied for $E(^3\text{He}) = 11$ to 39.8 MeV: see (1976AJ04).

52. ^{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). See also (1981AJ01) for additional information.

53. ^{15}N(^{7}Li, ^{7}Li)^{15}N

The elastic scattering angular distribution has been measured at $E(^{7}\text{Li}) = 28.8$ MeV (1982WO09).

54. (a) ^{15}N(^{12}C, ^{12}C)^{15}N
(b) ^{15}N(^{13}C, ^{13}C)^{15}N

Angular distributions of elastic scattering have been measured at $E(^{15}\text{N}) = 31.5$ to 47 MeV for reaction (a) [see (1981AJ01)] and at $E(^{13}\text{C}) = 105$ MeV (1980PR09). The SFP (to ^{12}C*(4.4)) has been studied at $E(^{15}\text{N}) = 94$ MeV by (1981TA21). For fusion cross sections see (1981AJ01) and (1982NO12). See also (1983BI13, 1983DU13, 1984FR1A, 1984HA53) and (1982LO13, 1983CI08, 1983GO13; theor.).

55. (a) ^{15}N(^{16}O, ^{16}O)^{15}N
(b) ^{15}N(^{17}O, ^{17}O)^{15}N
(c) ^{15}N(^{18}O, ^{18}O)^{15}N
(d) ^{15}N(^{19}F, ^{19}F)^{15}N

Elastic angular distributions (reaction (a)) have been measured at $E(^{16}\text{O}) = 35.1$ and 42.6 MeV (1983SR01). For fusion cross sections see (1981VO01). See also (1976AJ04). For reaction (d) see (1976AJ04). See also (1983DU13) and (1981AB1A, 1982LO13, 1982OH05, 1982OK02, 1983CI08; theor.).

56. (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 distributions (reaction (a)) have been measured in the range $E(^{15}\text{N}) = 32.8$ to 69.8 MeV (1980PR06; see also for fusion cross sections). An elastic distribution (reaction (b)) is reported at $E(^{15}\text{N}) = 44$ MeV: see (1981AJ01). See also (1983BI13, 1983DU13 [also scattering on ^{22}Ne, ^{26}Mg, ^{30}Si, ^{36}S], 1984FR1A, 1984HA53).

57. ^{15}O(β^+)^{15}N $\qquad Q_m = 2.7540$

See ^{15}O.

58. (a) ^{16}O(γ, p)^{15}N $\qquad Q_m = -12.1276$

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

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 o the even parity states ^{15}N*(5.27, 5.30, 8.31, 9.05) and to ^{15}N*(9.23): see (1970AJ04, 1976AJ04). At $E_e = 500$ MeV most of the 1p 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 $E_x \approx 41$ MeV: see (1981AJ01). In the range $E_\gamma = 101.5$ to 382 MeV differential cross sections are reported for the p_0, (p_{1+2}) and p_3 groups at $\theta = 45°$, 90° and 135° (1985LE07).

Forward differential cross sections have been measured at $E_\gamma = 80$ MeV (1980SC27; p_0) and at $E_\gamma = 200$ MeV angular distributions have been studied by (1984AD1D, 1984TUZZ; p to ^{15}N*(5.3, 6.3); prelim.). ^{15}N*(0, 6.3) are populated at $E_e = 128$ MeV (1983VO1F; prelim.) and 500 MeV (1982BE02; also ^{15}N*(10.8)). See also (1980KH1C), (1980GO13, 1981GA1M, 1981WI1E, 1983TR1J, 1984WA1J) and (1981BO14, 1982BO28, 1983MA2B, 1985CO01; theor.).

59. ^{16}O(μ^-, νn)^{15}N $\qquad Q_m = 92.7495$

Gamma rays from the decay of one of the states at 5.3 MeV and from ^{15}N*(6.3) are reported by (1983VA1E).

60. ^{16}O(n, d)^{15}N $\qquad Q_m = -9.9030$

Angular distributions of the d_0 group have been reported at $E_n = 14$ and 14.4 MeV: see (1976AJ04).

61. (a) ^{16}O($\pi^\pm$, $\pi^\pm$p)^{15}N $\qquad Q_m = -12.1276$

(b) ^{16}O(p, 2p)^{15}N $\qquad Q_m = -12.1276$

At $E_{\pi^\pm} = 240$ MeV, the spectra are dominated by ^{15}N*(0, ≈ 6.5). The π^+/π^- ratio has been measured for the ground state transitions (1984KY01). At $E_{\pi^+} = 2.0$ GeV/c differential cross sections have been determined for the transition to ^{15}N*(6.3) (1983KI01).

At $E_p = 460$ 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)]: see (1976AJ04). See also (1980MA28; theor.).

62. ^{16}O(d, ^{3}He)^{15}N $\quad Q_m = -6.6340$

Angular distributions of ^{3}He groups have been measured for $E_d = 20$ to 82 MeV: see (1976AJ04, 1981AJ01). The spectra are dominated by the transitions to ^{15}N*(0, 6.32). A ZRDWBA analysis 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]. $J^\pi = \frac{3}{2}^-$ for both ^{15}N*(9.94, 10.71): see (1981AJ01). See also (1981MA14).

63. ^{16}O(t, α)^{15}N $\quad Q_m = 7.6865$

See (1970AJ04).

64. (a) ^{16}O(^{7}Li, ^{8}Be)^{15}N $\quad Q_m = 5.1265$
(b) ^{16}O(^{9}Be, ^{10}B)^{15}N $\quad Q_m = -5.5416$
(c) ^{16}O(^{10}B, ^{11}C)^{15}N $\quad Q_m = -3.438$
(d) ^{16}O(^{11}B, ^{12}C)^{15}N $\quad Q_m = 3.8295$

For reaction (a) see (1983DEZW). For reaction (b) see (1985WI18). The ground-state angular distribution has been studied at $E(^{10}\mathrm{B}) = 100$ MeV. At $E(^{11}\mathrm{B}) = 115$ MeV ^{15}N*(0, 6.32) are populated: see (1981AJ01).

65. (a) ^{16}O(^{14}N, ^{15}O)^{15}N $\quad Q_m = -4.8306$
(b) ^{16}O(^{16}O, ^{17}F)^{15}N $\quad Q_m = -11.5271$
(c) ^{16}O(^{19}F, ^{20}Ne)^{15}N $\quad Q_m = 0.7203$

See (1981AJ01). See also (1983OS08, 1984CL09; theor.).

66. ^{17}O(p, ^{3}He)^{15}N $\quad Q_m = -8.5531$

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 reached in the (p, t) reaction: see (1976AJ04).

67. ^{18}O(γ, t)^{15}N $\qquad Q_m = -15.8336$

The cross section to $^{15}N_{g.s.}$ has been determined in the GDR region (1982BA03): see ^{18}O in (1983AJ01).

68. ^{18}O(p, α)^{15}N $\qquad Q_m = 3.9804$

Angular distributions of α_0 have been measured for $E_p = 0.125$ to 42.2 MeV: see (1976AJ04, 1981AJ01) and ^{19}F in (1983AJ01). $\tau_m = 2.49 \pm 0.24$ psec, $|g| = 0.94 \pm 0.07$ for ^{15}N*(5.27) (1983BI10). See also (1983LI1T; applied).

69. (a) ^{19}F(γ, α)^{15}N $\qquad Q_m = -4.0138$
(b) ^{19}F(p, pα)^{15}N $\qquad Q_m = -4.0138$
(c) ^{19}F(α, 2α)^{15}N $\qquad Q_m = -4.0138$

See ^{19}F in (1983AJ01) and (1981AJ01).

70. ^{19}F(d, ^{6}Li)^{15}N $\qquad Q_m = -2.5387$

Angular distributions involving ^{15}N*(0, 5.3, 6.3) have been measured in the range $E_d = 9.0$ to 28 MeV [see (1976AJ04, 1981AJ01)]. See also (1984GO1H; 50 MeV) and (1984NE1A).

71. ^{19}F(^{3}He, ^{7}Be)^{15}N $\qquad Q_m = -2.4263$

See (1976AJ04).

^{15}O

(Figs. 12 and 13)

GENERAL: (See also (1981AJ01).)

Nuclear models: (1982WA1Q, 1982YA1D, 1983SH38).

Special states: (1979GO27, 1980GO1Q, 1980HI1C, 1984ST1E).

Electromagentic transitions: (1980KO1L, 1980MI1G, 1980RI06, 1982AW02, 1983TO08, 1984CA02).

Astrophysical questions: (1980BA1P, 1981WA1Q, 1983LI01, 1985GI1C).

Complex reactions involving ^{15}O: (1981HU1D, 1981SC1P, 1983DE26, 1983FR1A, 1983JA05, 1983OL1A, 1983WI1A, 1984FI1N, 1984GR08, 1984HI1A, 1984HO23, 1985MO08).

Applied work: (1982BO1N, 1982HI1H, 1982PI1H, 1982YA1C, 1983KO1Q, 1984HA1F, 1984HI1D, 1984NI1C).

Pion and other mesons capture and reactions (See also reactions 10, 20 and 24): (1980BAZF, 1980SC1E, 1981OS04, 1981RE04, 1982VI05, 1983KA19, 1983KI01, 1983TR1J, 1984MA63, 1985RE1D).

Hypernuclei: (1981WA1J, 1982KA1D, 1983SH38, 1983SH1E, 1984AS1D).

Other topics: (1980GO1Q, 1980HI1C, 1981SH17, 1982AW02, 1982CA12, 1982NG01, 1983KH1D, 1983MA38, 1983SH1T, 1983TO08).

Ground-state properties of ^{15}O: (1979GO27, 1980HI1C, 1981NO1F, 1982CA12, 1982NG01, 1983BU07, 1983DE1X, 1983MA38, 1983TO08, 1984KA25, 1984ST1E, 1985AR11, 1985HA18, 1985FA01).

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

1. ^{15}O(β^+)^{15}N $\qquad Q_{\rm m} = 2.7540$

The half-life of ^{15}O is 122.24 ± 0.16 sec: see (1981AJ01); $\log f_0 t = 3.637$. The K/β^+ ratio is $(10.7 \pm 0.6) \times 10^{-4}$: see (1976AJ04). See also (1982OS1C, 1983GO2C), (1981BA2G, 1982CO1D, 1983LI01, 1984BO1C, 1984DA1H, 1984HA1M, 1985KL1A; astrophys.), (1982KA1C; applied) and (1980AF1A, 1981ME1H, 1982OS1C; theor.).

2. ^{10}B(^{14}N, ^{9}Be)^{15}O $\qquad Q_{\rm m} = 0.7110$

Table 15.17: Energy levels of ^{15}O [a]

E_x in ^{15}O (MeV $\pm$ 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, 8, 9, 10, 11, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30
5.183 ± 1	$\frac{1}{2}^+$	$\tau_m = 8.2 \pm 1.0$ fsec	γ	2, 6, 9, 11, 16, 17, 22, 23, 25, 26, 27
5.2409 ± 0.3	$\frac{5}{2}^+$	3.25 ± 0.30 psec g $= +0.248 \pm 0.026$	γ	2, 5, 6, 9, 11, 16, 17, 21, 22, 23, 25, 26, 27
6.1763 ± 1.7	$\frac{3}{2}^-$	< 2.5 fsec	γ	6, 9, 11, 16, 17, 21, 22, 23, 24, 25, 26, 27, 29
6.7931 ± 1.7	$\frac{3}{2}^+$	< 28 fsec	γ	2, 6, 9, 11, 16, 17, 22, 27
6.8594 ± 0.9	$\frac{5}{2}^+$	16.0 ± 2.5 fsec	γ	2, 5, 6, 9, 11, 16, 17, 19, 22, 23, 27
7.2759 ± 0.6	$\frac{7}{2}^+$	0.70 ± 0.15 psec	γ	5, 6, 7, 8, 9, 10, 16, 17, 19, 22, 25, 27
7.5564 ± 0.5	$\frac{1}{2}^+$	$\Gamma = 1.2 \pm 0.2$ keV	γ, p	9, 11, 16, 17, 22, 25, 27
8.2839 ± 0.6	$\frac{3}{2}^+$	3.6 ± 0.7	γ, p	6, 9, 11, 16, 17, 27
8.743 ± 6	$\frac{1}{2}^+$	32	γ, p	9, 11, 27
8.922 ± 2	$\frac{5}{2}^+$	3.3 ± 0.3	γ, p	5, 6, 11, 13, 25, 27
8.922 ± 2	$\frac{1}{2}^+$	7.5	γ, p	6, 11, 13, 25, 27
8.9821 ± 1.7	$(\frac{1}{2})^-$	3.9 ± 0.4	γ, p	6, 9, 11, 27
9.488 ± 3	$\frac{5}{2}^-$	10.1 ± 0.5	γ, p	6, 9, 11, 27
9.527 ± 17	$(\frac{3}{2})^+$	280 ± 25	γ, p	9, 11, 13, 27
9.609 ± 2	$\frac{3}{2}^-$	8.8 ± 0.5	γ, p	6, 9, 11, 21, 27
9.662 ± 3	$(\frac{7}{2}, \frac{9}{2})^-$	2 ± 1	p	6, 9, 13, 27
10.29 [b]	$(\frac{5}{2}^-)$	3 ± 1	p	6, 9, 13, 27
10.30 [b]	$\frac{5}{2}^+$	11 ± 2	p	6, 9, 13, 27
10.461 ± 5	$(\frac{9}{2}^+)$	< 2	γ, p	6, 11, 27
10.48	$(\frac{3}{2}^-)$	25 ± 5	γ, p	7, 9, 11, 13, 26
(10.506)	$(\frac{3}{2})^+$	140 ± 40	γ, p	11, 13

Table 15.17: 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
10.917 ± 12	$\frac{7}{2}^+$	90	p	13, 27
10.938 ± 3	$\frac{1}{2}^+$	99 ± 5	γ, p	11, 13, 27
11.025 ± 3	$\frac{1}{2}^-$	25 ± 2	γ, p	11, 13, 27
11.151 ± 7		< 10	p	6, 13, 27
11.218 ± 3	$\frac{3}{2}^+$	40 ± 4	γ, p	11, 13, 27
11.565 ± 15		< 10	p	6, 13, 27
11.569 ± 15	$\frac{5}{2}^-$	20 ± 15	γ, p	6, 11, 13
11.616 ± 15	$(\frac{3}{2}, \frac{1}{2})^-$	80 ± 50	γ, p	11, 13
11.719 ± 8		< 10	p	5, 6, 13, 27
11.748 ± 3	$\frac{5}{2}^+$	99 ± 5	γ, p	11, 13
11.846 ± 3	$\frac{5}{2}^-$	65 ± 3	γ, p	11, 13
11.980 ± 10	$\frac{5}{2}^-$	20 ± 5	p	6, 13, 27
12.129 ± 15	$\frac{5}{2}^+$	200 ± 50	p	13
12.222 ± 20		100 ± 50	p	13
12.255 ± 13	$\frac{5}{2}^+; \frac{3}{2}$	135 ± 15	p	29
12.295 ± 10				6
12.471 ± 3	$\frac{5}{2}^-, (\frac{3}{2}^-)$	77 ± 4	p	13
12.60 ± 10				6
12.80		≈ 250	γ, p	11
12.835 ± 3	$(\frac{1}{2}^-)$	16 ± 1	p	5, 6, 7, 8, 13
13.008 ± 3		215 ± 3	p	13
13.025 ± 3		40 ± 30	p, (^{3}He)	4, 13
13.45	$(\frac{1}{2}, \frac{3}{2})^+$	≈ 1000	γ, p, (α)	5, 11, 13, 15
(13.49)	$(\frac{3}{2}^+)$		(p)	13
13.60	$\frac{5}{2}^+$		p, α	15
13.70	$\frac{3}{2}^-$		p	5, 13
13.79	$\frac{3}{2}^-$		n, p, ^{3}He, α	4, 13, 15
13.87		≈ 150	γ, p	11
14.03 ± 40	$(\frac{1}{2}^-, \frac{3}{2}^-)$	160 ± 20	n, p, ^{3}He	4
14.17	$\frac{5}{2}^-$		p, α	15

Table 15.17: 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
14.27 ± 10	$\frac{1}{2}^+$	340 ± 30	n, p, ^{3}He, α	4, 5, 6, 12, 13, 14, 15
14.34	$\frac{5}{2}^+$	(240)	p, (^{3}He), α	4, 15
14.465 ± 10	$\frac{3}{2}^+, \frac{5}{2}^+$	100 ± 10	n, p, ^{3}He, α	4
14.70 ± 40		170 ± 35	n, p, ^{3}He	4
14.95 ± 40		400 ± 25	n, p, ^{3}He, α	4
15.05 ± 10	$((\frac{13}{2}^+))$			6, 7, 8
15.1	$(\frac{1}{2}, \frac{3}{2})^+$	≈ 1000	γ, p	11
15.45 ± 30		70 ± 20	p, ^{3}He, α	4, 6
15.54 ± 10			(p, ^{3}He, α)	4, 6
15.60 ± 10			(p, ^{3}He, α)	6
15.65 ± 10				6
15.80 ± 10			n, ^{3}He	4, 6
15.90 ± 15	$\frac{1}{2}^-, \frac{3}{2}^-$	350	^{3}He, α	4
16.05 ± 20		≈ 185	n, p, ^{3}He, α	4
16.10 ± 20			(n) ^{3}He, α	4
16.21 ± 20		≈ 140	(n), p, ^{3}He, α	4
16.43 ± 75	$\frac{1}{2}^+$	560 ± 100	^{3}He, α	4
16.75 ± 50			n, ^{3}He	4, 27
17.05 ± 60	$(\frac{1}{2}, \frac{3}{2})^+; \frac{1}{2}$	700 ± 70	γ, p, ^{3}He	4
17.46 ± 20				6
17.51 ± 20	$\frac{1}{2}^-, \frac{3}{2}^-$	600	n, ^{3}He, α	4, 6
17.99 ± 50	$\frac{1}{2}^-, \frac{3}{2}^-$	200	^{3}He	4
18.23 ± 50			n, p, ^{3}He	4
18.67 ± 60	$(\frac{1}{2}, \frac{3}{2})^+; \frac{1}{2}$	520 ± 110	γ, ^{3}He	4
19.03 ± 50			n, ^{3}He	4
19.57 ± 80	$(\frac{1}{2}, \frac{3}{2})^+; \frac{1}{2}$	780 ± 270	γ, ^{3}He	4
19.91 ± 50			n, ^{3}He	4
20.42 ± 70	$(\frac{3}{2}, \frac{1}{2})^+; \frac{1}{2}$	970 ± 240	γ, p, ^{3}He	4
21.56 ± 70	$(\frac{3}{2}, \frac{1}{2})^+; \frac{1}{2}$	730 ± 120	γ, p, ^{3}He	4
(26.0)	$(\frac{13}{2}^-)$	≈ 600	^{3}He	4

Table 15.17: 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
(28.0)	$(\frac{9}{2}^-, \frac{11}{2}^-)$	≈ 2500	^{3}He	4
(29.0)		≈ 2500	^{3}He	4

[a] See also Table 15.18.

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

Angular distributions have been measured at $E(^{14}\text{N}) = 73.9$ and 100 MeV: see (1981AJ01).

3. ^{11}B(^{14}N, ^{10}Be)^{15}O $\qquad Q_m = -3.9311$

Elastic angular distributions have been studied at $E(^{14}\text{N}) = 41, 77$ and 113 MeV: see (1976AJ04). See also (1984CL09; theor.).

Table 15.18: Radiative decays in ^{15}O [a]

E_i (MeV)	J_i^π	E_f (MeV)	J_f^π	Branch (%)	δ [b]
5.24	$\frac{5}{2}^+$	0	$\frac{1}{2}^-$	100	$+0.10 \pm 0.04$ (E3/M2)
6.18 [c]	$\frac{3}{2}^-$	0	$\frac{1}{2}^-$	100	-0.125 ± 0.007 (E2/M1) [k]
6.79 [d]	$\frac{3}{2}^+$	0	$\frac{1}{2}^-$	100	-0.02 ± 0.02 (M2/E1)
6.86 [e]	$\frac{5}{2}^+$	5.24	$\frac{5}{2}^+$	100	$+0.04 \pm 0.03$ (E2/M1)
7.28 [f]	$\frac{7}{2}^+$	0	$\frac{1}{2}^-$	3.8 ± 1.2	
		5.24	$\frac{5}{2}^+$	96.2 ± 1.2	
7.56 [g]	$\frac{1}{2}^+$	0	$\frac{1}{2}^-$	3.5 ± 0.5	
		5.18	$\frac{1}{2}^+$	15.8 ± 0.6	
		6.18	$\frac{3}{2}^-$	57.5 ± 0.4	
		6.79	$\frac{3}{2}^+$	23.2 ± 0.6	
		6.86	$\frac{5}{2}^+$	[l]	
					Γ (eV)
8.28	$\frac{3}{2}^+$	0	$\frac{1}{2}^-$	53.8 ± 0.25	0.531 [m]
		5.24	$\frac{5}{2}^+$	42.7 ± 0.5	0.405
		6.18	$\frac{3}{2}^-$	2.2 ± 0.6	0.021
		6.86	$\frac{5}{2}^+$	1.2 ± 0.3	0.011

Table 15.18: Radiative decays in ^{15}O [a] (continued)

E_i (MeV)	J_i^π	E_f (MeV)	J_f^π	Branch (%)	δ [b]
8.74	$\frac{1}{2}^+$	5.18	$\frac{1}{2}^+$	67	0.32
		6.18	$\frac{3}{2}^-$	33	0.16
8.922 [h]	$\frac{5}{2}^+$	0	$\frac{1}{2}^-$	9 ± 4	
		5.18	$\frac{1}{2}^+$	39 ± 3	
		6.18	$\frac{3}{2}^-$	24 ± 3	
		6.86	$\frac{5}{2}^+$	28 ± 3	
8.922 [h]	$\frac{1}{2}^-$	0	$\frac{1}{2}^-$	50 ± 25	
		5.18	$\frac{1}{2}^+$	20 ± 10	
		6.18	$\frac{3}{2}^-$	20 ± 10	
		6.86	$\frac{5}{2}^+$	(10 ± 10)	
8.982 [i]	$(\frac{3}{2})^-$	0	$\frac{1}{2}^-$	94 ± 1	
		5.18	$\frac{1}{2}^+$	6 ± 1	
9.49	$\frac{5}{2}^-$	0	$\frac{1}{2}^-$	86	2.1
		5.24	$\frac{5}{2}^+$	6.5	0.15
		6.18	$\frac{3}{2}^-$	0.7	0.22
		6.86	$\frac{5}{2}^+$	3.4	0.08
		7.28	$\frac{7}{2}^+$	5.1	0.11
9.50 [j]	$\frac{3}{2}^+(\frac{1}{2}^+)$	0	$\frac{1}{2}^-$	≈ 100	
9.61	$\frac{3}{2}^-$	0	$\frac{1}{2}^-$	79	4.0
		5.24	$\frac{5}{2}^+$	19	1.0
		6.18	$\frac{3}{2}^-$	2	0.1
10.46	$(\frac{9}{2}^+)$	5.24	$\frac{5}{2}^+$	62 ± 6	18 ± 6 [n]
		6.86	$\frac{5}{2}^+$	< 4	< 1.5
		7.28	$\frac{7}{2}^+$	38 ± 6	11 ± 4 [n]
10.48	$(\frac{3}{2})^-$	0	$\frac{1}{2}^-$	60 ± 8	0.21 ± 0.07 [n]
		5.24	$\frac{5}{2}^+$	40 ± 6	0.14 ± 0.01 [n]
		6.18	$\frac{3}{2}^-$	< 4	< 0.02
		9.79	$\frac{3}{2}^+$	< 4	< 0.02
10.94	$\frac{1}{2}^+$	0	$\frac{1}{2}^-$	44 ± 8	14 ± 4
		5.18	$\frac{1}{2}^+$	34 ± 3	11 ± 2
		6.18	$\frac{3}{2}^-$	22 ± 8	7 ± 2

Table 15.18: Radiative decays in ^{15}O [a] (continued)

E_i (MeV)	J_i^π	E_f (MeV)	J_f^π	Branch (%)	δ [b]
		6.79	$\frac{3}{2}^+$	< 8	< 3
11.03 [a]	$\frac{1}{2}^-$	0	$\frac{1}{2}^-$	100	1.4 ± 0.4
11.22	$\frac{3}{2}^+$	0	$\frac{1}{2}^-$	74 ± 5	5.5 ± 0.5
		5.18	$\frac{1}{2}^+$	14 ± 5	1.0 ± 0.2
		5.24	$\frac{5}{2}^+$	12 ± 5	0.9 ± 0.2
		6.79	$\frac{3}{2}^+$	< 4	< 0.4
11.57	$\frac{5}{2}^-$	0	$\frac{1}{2}^-$	18 ± 9	0.3 ± 0.2
		5.24	$\frac{5}{2}^+$	63 ± 9	1.2 ± 0.1
		6.18	$\frac{3}{2}^-$	20 ± 9	0.4 ± 0.2
		6.79	$\frac{3}{2}^+$	< 3	< 0.1
11.75 [a]	$\frac{5}{2}^+$	5.24	$\frac{5}{2}^+$	47 ± 7	5 ± 1
		6.18	$\frac{3}{2}^-$	53 ± 7	5 ± 1
11.85 [a]	$\frac{5}{2}^-$	5.24	$\frac{5}{2}^+$	100	1.4 ± 0.6

[a] For references and other comments see Table 15.19 in (1981AJ01).
[b] δ = multipole mixing ratio.
[c] Branches to ^{15}O*(5.18, 5.24) are $< 2.5\%$ each.
[d] Branches to ^{15}O*(5.18, 5.24, 6.18) are $< 3\%$, $< 3\%$ and $< 7\%$, respectively.
[e] Branches to ^{15}O*(0, 5.18, 6.18) are $< 10\%$, $< 4\%$ and $< 0.4\%$, respectively.
[f] Branches to ^{15}O*(5.18, 6.18) are $< 4\%$ and $< 2\%$, respectively.
[g] Branchings shown to ^{15}O*(5.18, 6.18, 6.79) are weighted means of values shown in Table 15.19 of (1981AJ01), recalculated to sum to 100% for all the transitions.
[h] See, however, the comments in reaction 14 of (1981AJ01).
[i] Branchings to ^{15}O*(6.18, 6.86) are $< 1\%$ each.
[j] Unresolved doublet: see Table 15.21, and Table 15.23 in (1981AJ01).
[k] Weighted mean of values shown in Table 15.19 of (1981AJ01).
[l] Intensity $< 25\%$ of transition to ^{15}O*(6.79).
[m] Sum is 0.97 eV, but see Table 15.21 [$\Gamma_\gamma = 1.4$ eV].
[n] Γ_γ values assume J-values in column 2.

4. (a) ^{12}C(^{3}He, γ)^{15}O $\quad Q_m = 12.0758$
   (b) ^{12}C(^{3}He, n)^{14}O $\quad Q_m = -1.1466$ $\quad E_b = 12.0758$
   (c) ^{12}C(^{3}He, p)^{14}N $\quad Q_m = 4.7789$

(d) ^{12}C(^{3}He, d)^{13}N $\quad Q_{\rm m} = -3.5500$

(e) ^{12}C(^{3}He, t)^{12}N $\quad Q_{\rm m} = -17.357$

(f) ^{12}C(^{3}He, ^{3}He)^{12}C

(g) ^{12}C(^{3}He, α)^{11}C $\quad Q_{\rm m} = 1.8563$

Excitation functions and polarization measurements for these reactions have been measured over a wide range of energies: see Tables 15.20 in (1970AJ04, 1976AJ04), (1981AJ01) and the text below. Observed resonances are displayed in Table 15.19 here.

The $90°$ yield and angular distributions of γ_0, measured from $E(^3\text{He}) = 5.24$ to 13.95 MeV show 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 3p4h admixture (1978DE33 [also for ω_γ], 1984DE09). See also (1983MAZZ, 1984MAZP). 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 (1981AJ01) [n_1 and n_{2+3+4} yields are also reported]. See also (1984SH04; Xn).

The yield of protons (reaction (d)) shows some clear resonances below $E(^3\text{He}) = 4.5$ MeV and some uncorrelated structures 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. 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: see (1976AJ04). At $E(^3\text{He}) = 33$ MeV A_y is measured for ^{14}N*(0, 2.31, 3.95) (1983LE17, 1983RO22). For reaction (d) see (1981AJ01) and (1983DR06; $E(^3\vec{\text{He}}) = 33$ MeV; g.s.; also dp). See also (1984AB1G; Xd). 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: see (1976AJ04). Resonance-like behavior is also reported for $E(^3\vec{\text{He}}) = 29$ MeV. Polarization measurments are also reported for $E(^3\vec{\text{He}}) = 20.5$ to 32.6 MeV: see (1981AJ01). Recently the elastic yield has been measured for $E(^3\text{He}) = 1.0$ to 2.7 MeV (1980VO1C). See also (1981AS04; n ^{3}He cross section at 910 MeV). 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: see (1981AJ01). For total cross sections see (1980DE28, 1981PE01). For a fragmentation study at 10.78 GeV/c see (1985AB1H). See also (1983CA07, 1984AA01), (1980TR02, 1981RO1H, 1985BL1B) and (1981LE01, 1984NA06; theor.).

5. ^{12}C(α, n)^{15}O $\quad Q_{\rm m} = -8.5019$

Angular distributions of the n_0 group have been measured for $E_\alpha = 18.4$ to 23.1 MeV: see (1976AJ04). At $E_\alpha = 41$ MeV angular distributions are reported to ^{15}O*(5.24, 6.89 + 7.26, 9.63, 10.48, 11.71, 12.85, 15.05). ^{15}O*(0, 8.91, 11.1, 12.3, 13.45, 13.72, 14.27, 15.65) are also

Table 15.19: Resonances in $^{12}C + ^{3}He$ [a]

$E(^3He)$ (MeV ± keV)	Resonant for	$\Gamma_{c.m.}$	J^π	E_x (MeV)
1.21	p_0, p_2		$(\frac{5}{2})^-$	13.04
1.3	$p_0 \to p_3$			13.1
2.15	n, p_0		$(> \frac{5}{2})$	13.79
2.45 ± 40	$n_0, p_0 \to p_3$	160 ± 20	$(\frac{1}{2}^-, \frac{3}{2}^-)$	14.03
2.75 ± 40	$n_0, p_1, p_2, {}^3He, \alpha_0$	340 ± 30	$\frac{1}{2}^+$	14.27
(2.87)	p_0, p_2	240		(14.37)
2.990 ± 10	$n_0, p_0, p_1, p_2, p_4, p_5, p_8, {}^3He, \alpha_0$	100 ± 10	$\frac{3}{2}^+, \frac{5}{2}^+$	14.465
3.28 ± 40	$p_0, (p_1, p_2)$	180 ± 40		14.70
3.60 ± 40	p_0, p_1, p_2	400 ± 25		14.95
4.20 ± 10	p_5, p_6, α_0	65 ± 15		15.43
4.37 ± 40	$p_0, p_1, p_2, p_4, p_7, p_8, \alpha_0$	80 ± 25		15.57
4.65 ± 50	n_0			15.79
4.78 ± 50	${}^3He, \alpha_0$	350	$\frac{1}{2}^-, \frac{3}{2}^-$	15.90
4.97 ± 20	α_0			16.05
5.03 ± 20	$n_0, {}^3He, \alpha_0$			16.10
5.15 ± 20	$n_0, {}^3He, \alpha_0$			16.19
5.45 ± 50	${}^3He, \alpha_0$	170	$\frac{1}{2}^+$	16.43
5.85 ± 50	$n_0, {}^3He$			16.75
6.23 ± 70	γ_0	700 ± 70	$(\frac{1}{2}, \frac{3}{2})^+$	17.05 ± 0.06 [b]
6.80 ± 50	$n_0, {}^3He, \alpha_0$	600	$\frac{1}{2}^-, \frac{3}{2}^-$	17.51
7.40 ± 50	${}^3He$	200	$\frac{1}{2}^-, \frac{3}{2}^-$	17.99
7.70 ± 50	n_0, p_0			18.23
8.25 ± 70	γ_0	520 ± 110	$(\frac{1}{2}, \frac{3}{2})^+$	18.67 ± 0.06 [b]
8.70 ± 50	n_0			19.03
9.38 ± 100	γ_0	780 ± 270	$(\frac{1}{2}, \frac{3}{2})^+$	19.57 ± 0.08
9.80 ± 50	n_0			19.91
10.45 ± 90	$\gamma_0, (p_0)$	970 ± 240	$(\frac{3}{2}, \frac{1}{2})^+$	20.42 ± 0.07 [b]
11.87 ± 80	γ_0	730 ± 120	$(\frac{3}{2}, \frac{1}{2})^+$	21.56 ± 0.07 [b]
(17.0) [c]	${}^3He$	≈ 600	$(\frac{13}{2}^-)$	(26.0)
(20.0) [c]	${}^3He$	≈ 2500	$(\frac{9}{2}^-, \frac{11}{2}^-)$	(28.0)
(21.5)	${}^3He$ to ${}^{12}C^*(15.1)$	≈ 2500		(29.0)

[a] For references see Table 15.21 in (1976AJ04).
[b] (1978DE33, 1984DE09 [see p. 290]); $T = \frac{1}{2}$; $\Gamma_{^3He}/\Gamma_p = 0.17 \pm 0.07$ and 0.09 ± 0.04 for $^{15}O^*(17.05, 18.67)$.
[c] $\Gamma_p = 0.06$ and ≥ 0.1 MeV for $^{15}O^*(26, 28)$.

populated (1981OV01 [uncertainties in E_x are not shown; unresolved states are a problem]). See also (1981HAZV, 1983KOZD, 1984GO03) and ^{16}O in (1986AJ04).

6. ^{12}C(^{6}Li, t)^{15}O $\qquad Q_m = -3.7198$

States observed in this reaction are displayed in Table 15.20 (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 $(10.48 - 10.70)$, $(12.84 - 13.15(\text{u}))$ and $(15.05 - 15.49(\text{u}))$ [E_x in ^{15}O, E_x in ^{15}N; u = unresolved] (1975BI06). See also (1976AJ04) for the earlier work, ^{18}F in (1987AJ02) and (1980KR1F).

7. (a) ^{12}C(^{10}B, ^{7}Li)^{15}O $\qquad Q_m = -5.712$
(b) ^{12}C(^{11}B, ^{8}Li)^{15}O $\qquad Q_m = -15.133$

See (1981AJ01).

8. ^{12}C(^{12}C, ^{9}Be)^{15}O $\qquad Q_m = -14.2032$

At $E(^{12}\text{C}) = 187$ MeV, $\theta_{\text{lab}} = 8°$ the spectrum is dominated by ^{15}O*(12.84, 15.05) [assumed $J^\pi = \frac{1}{2}^-, \frac{13}{2}^+$, respectively]. ^{15}O*(7.28) [$J^\pi = \frac{7}{2}^+$] is populated but ^{15}O*(0, 6.79) are not observed. The situation is similar at $E(^{12}\text{C}) = 114$ MeV but at $E(^{12}\text{C}) = 72$ MeV ($\theta_{\text{lab}} = 11°$) ^{15}O*(0, 5.2, 7.28) are populated with comparable intensities: see (1976AJ04).

9. ^{13}C(^{3}He, n)^{15}O $\qquad Q_m = 7.1295$

Observed groups are displayed in Table 15.22 of (1981AJ01).

10. ^{14}C(p, π^-)^{15}O $\qquad Q_m = -132.1139$

At $E_{\vec{p}} = 183$ MeV differenatial cross sections and A_y are reported for the transitions to ^{15}O*(0, 7.3), the two states strongly excited in the reaction (1982JA05, 1982VI05). See also (1982GR1K, 1984JA1F), (1984BEZZ; theor.) and the "GENERAL" section here.

Table 15.20: 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	
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] $\Gamma_\gamma/\Gamma < 0.13$.

11. ^{14}N(p, γ)^{15}O $\qquad Q_m = 7.2970$

Observed resonances in the yield of γ-rays are listed in Table 15.21. Branching ratios are displayed in Table 15.18.

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. 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. 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.

The 90° yield γ_0 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. For $E_p = 18$ to 28 MeV the excitation function for γ_0 decreases smoothly with energy: there is no evidence for structures. $\tau_m = 8.2 \pm 1.0$, > 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 references and additional discussions see (1976AJ04, 1981AJ01). See also (1982KR05, BL84E), (1980WE1D, 1982WE01) and (1980BA2M, 1982BA80, 1984BO1Q, 1984MA67, 1984TR1C; astrophys.).

Table 15.21: Resonances in ^{14}N + p [a]

E_p (keV)	Γ_{lab} (keV)	$\omega\Gamma_\gamma$ (eV)	Particles out	J^π	E_x (MeV)
278.1 ± 0.4	1.3 ± 0.2	0.014 [b]	γ	$\frac{1}{2}^+$	7.5564
1058.0 ± 0.5	3.9 ± 0.7	0.95	γ	$\frac{3}{2}^+$	8.2839
1550 ± 6	34	0.16	γ	$\frac{1}{2}^+$	8.743
1742 ± 2 [c]	3.5 ± 0.3	0.16	γ, p_0	$\frac{5}{2}^+$	8.922
1742 ± 2 [c]	8	0.06	γ, p_0	$\frac{1}{2}^+$	8.922
1806.4 ± 1.5	4.2 ± 0.4	0.52	γ	$(\frac{3}{2})^-$	8.9821
2348 ± 3	10.8 ± 0.5	2.4	γ	$\frac{5}{2}^-$	9.488
2368 ± 32	300 ± 26		γ, p_0	$(\frac{3}{2}^+)$	9.506
2479 ± 1.7	9.4 ± 0.5	3.3	γ	$\frac{3}{2}^-$	9.609
2537 ± 4	2 ± 1		p_0	$(\frac{7}{2}, \frac{9}{2})^-$	9.664
3209	3 ± 1		p_0	$(\frac{5}{2}^-)$	10.291
3215	12 ± 2		p_0	$\frac{5}{2}^+$	10.296
3392 ± 5	< 2	0.029 ± 0.010	γ_2, γ_6	$(\frac{9}{2}^+)$	10.461
3410	27 ± 5		γ_0, γ_2, p_0	$(\frac{3}{2})^-$	10.478
3440	150 ± 45		γ, p_0	$(\frac{3}{2})^+$	10.506
3880 ± 15	97		p_0	$\frac{7}{2}^+$	10.916
		Γ_{γ_0} (eV)			
3903 ± 3	106 ± 5	14 ± 3	γ, p_0, p_1	$\frac{1}{2}^+$	10.938

Table 15.21: Resonances in ^{14}N + p [a] (continued)

E_p (keV)	Γ_{lab} (keV)	$\omega\Gamma_\gamma$ (eV)	Particles out	J^π	E_x (MeV)
3996 ± 3	27 ± 2	1.4 ± 0.4	γ, p_0, p_1	$\frac{1}{2}^-$	11.025
4130 ± 15	< 10		p_0		11.150
4203 ± 3	43 ± 4	5.2 ± 0.4	γ, p_0	$\frac{3}{2}^+$	11.218
4575 ± 15	< 10		p_0		11.565
4580 ± 15	21 ± 15	0.7 ± 0.2	γ, p_0	$\frac{5}{2}^-$	11.569
4580	150		γ		11.57
4630 ± 15	86 ± 50		γ, p_0	$(\frac{3}{2}, \frac{1}{2})^-$	11.616
4740 ± 15	< 10		p_0		11.718
4772 ± 3	106 ± 5		γ, p_0, p_1	$\frac{5}{2}^+$	11.748
4877 ± 3	70 ± 3		γ, p_0, p_1	$\frac{5}{2}^-$	11.846
5025 ± 15	21 ± 5		p_0, p_1	$\frac{5}{2}^-$	11.984
5180 ± 15	214 ± 50		p_0, p_1	$\frac{5}{2}^+$	12.129
5280 ± 20	106 ± 50		p_1 [d]		12.222
5547 ± 3	82 ± 4		p_1, p_2	$\frac{5}{2}^-(\frac{3}{2}^-)$	12.471
5900	≈ 250		γ		12.80
5937 ± 3	17 ± 1		p_2 [e]		12.835
(6100)	30		$p_0 \to p_2$, α_0	$\frac{5}{2}^+$	(12.99)
6123 ± 3	230 ± 30		p_2 [e]		13.008
6141 ± 3	43 ± 30		p_2 [e]		13.025
6600	≈ 1000		γ, (p_2, α_0)	$(\frac{1}{2}, \frac{3}{2})^+$	13.45
6640			(p_0), (p_2)	$(\frac{3}{2}^+)$	13.49
6760			α_0	$\frac{5}{2}^+$	13.60
6870			p_2	$\frac{3}{2}^-$	13.70
6960			p_1, p_2, p_4, α_0	$\frac{3}{2}^-$	13.79
7050	≈ 150		γ		13.87
7370			α_0	$\frac{5}{2}^-$	14.17
7500	≈ 500		n, $p_0 \to p_2$, ^{3}He, α		14.29
7550			α_0	$\frac{5}{2}^+$	14.34
7700			n, p_0, α_0		14.48
7950	170 ± 50		n		14.71
8200			n, $p_2 \to p_6$, ^{3}He, α_0, α_1		14.94

Table 15.21: Resonances in ^{14}N + p [a] (continued)

E_p (keV)	Γ_{lab} (keV)	$\omega\Gamma_\gamma$ (eV)	Particles out	J^π	E_x (MeV)
8400	≈ 1000		γ	$(\frac{1}{2}, \frac{3}{2})^+$	15.1
9050			n		15.74
[f]					
9370 ± 20	≈ 200		n, p_2, p_8, α_1		16.04
9580 ± 20	≈ 150		p_0, p_1, $p_3 \rightarrow p_7$, p_9, ^{3}He, α_1		16.23
9850 ± 50	600 ± 100		n, ^{3}He		16.48
10300	≈ 1000		γ	$(\frac{1}{2}, \frac{3}{2})^+$	16.9
10600			$p_4 \rightarrow p_9$, α_0, α_1		17.2
11900	≈ 1000		γ	$(\frac{1}{2}, \frac{3}{2})^+$	18.4
14200	≈ 2000		γ	$(\frac{1}{2}, \frac{3}{2})^+$	20.5
15800	≈ 2000		γ	$(\frac{1}{2}, \frac{3}{2})^+$	22.0

[a] For references see (1970AJ04, 1976AJ04, 1981AJ01). See also Table 15.18 here.
[b] ± 0.001 (1982BE29).
[c] Separated by 0.5 ± 0.5 keV: see, however, reaction 14 in (1981AJ01).
[d] Weak.
[e] Strong.
[f] See footnote [e] in Table 15.23 of (1981AJ01).

12. ^{14}N(p, n)^{14}O $\qquad Q_m = -5.9255 \qquad E_b = 7.2970$

The excitation function has been measured for $E_p = 6.3$ to 12 MeV: see (1970AJ04). Observed resonances are displayed in Table 15.21. The cross section [obtained by measuring the 2.31 MeV γ-rays from the ^{14}O(β^+) decay] is reported at 12 energies in the range $E_p = 7$ to 22 MeV (1981DY03). The ratio of the cross section to ^{14}O$_{g.s.}$ to that for the analog state ^{14}N*(2.31) [from the (p, p′) reaction] has been determined at $E_p = 35$ MeV (1984TA02). See also ^{14}O.

13. (a) ^{14}N(p, p)^{14}N $\qquad E_b = 7.2970$
(b) ^{14}N(p, d)^{13}N $\qquad Q_m = -8.3289$

The yields of elastic and inelastic protons, and of 2.31 MeV γ-rays, have been studied at many energies: see (1959AJ76, 1970AJ04, 1976AJ04). Observed resonances are displayed in Table

15.21. 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. 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. See (1981AJ01) 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_y measurements have also been reported at $E_{\vec{p}} = 21$ MeV (1982AO05; to ^{14}N*(0, 2.31, 3.95) and ^{13}N*(0, 3.51)) and at 159.4 MeV (1983TA12; p_0, p_1, p_2). See also (1980LE28), (1981DY03, 1984RE14) and (1984AN1M; theor.).

14. ^{14}N(p, ^{3}He)^{12}C $\qquad Q_m = -4.7789 \qquad E_b = 7.2970$

Excitation functions for the ground-state group have been measured at $E_p = 7$ to 11 MeV: some resonant structure is indicated [see Table 15.21]. See also (1976AJ04).

15. ^{14}N(p, α)^{11}C $\qquad Q_m = -2.9226 \qquad E_b = 7.2970$

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: see Table 15.21 here and footnote [e] in Table 15.23 of (1981AJ01).

16. ^{14}N(d, n)^{15}O $\qquad Q_m = 5.0724$

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). $\tau_m = 3.2 \pm 0.5$ psec, < 28 fsec, 0.70 ± 0.15 psec, respectively for ^{15}O*(5.24, 6.79, 7.28): see (1970AJ04). $K_y^{y'}(0°)$ have been measured for $E_{\vec{d}} \approx 7.5$ to ≈ 14 MeV for the $\vec{n}$ to an unresolved group involving at least ^{15}O*(6.79, 7.55) (1981LI23). See also Table 15.22, (1983MU13; theor.) and ^{16}O in (1986AJ04).

17. ^{14}N(^{3}He, d)^{15}O $\qquad E_m = 1.8034$

See Table 15.22 and (1976AJ04). See also (1985HA01) and ^{16}F in (1986AJ04).

18. ^{14}N(α, t)^{15}O $\qquad Q_m = -12.5171$

See (1976AJ04).

Table 15.22: Levels of ^{15}O from ^{14}N(d, n) and ^{14}N(^{3}He, d)

E_x in ^{15}O [a] (MeV $\pm$ 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).

19. (a) ^{14}N(^{11}B, ^{10}Be)^{15}O $\qquad Q_m = -3.9319$
(b) ^{14}N(^{13}C, ^{12}B)^{15}O $\qquad Q_m = -10.237$

Differential cross sections are reported for ^{15}O*(0, 6.86, 7.28) at $E(^{11}\text{B}) = 115$ MeV and for $^{15}\text{O}_{\text{g.s.}}$ at $E(^{13}\text{C}) = 105$ MeV (1980PR09).

20. ^{15}N(π^+, π^0)^{15}O $\qquad Q_m = 1.850$

Angular distributions to $^{15}\text{O}_{\text{g.s.}}$ have been studied at $E_{\pi^+} = 48$ MeV (1984CO04) and 165 MeV (1982DO10). At 48 MeV a deep forward-angle minimum is observed. It appears to reflect the analogous minimum in the free-nucleon cross section which is caused by cancellation between the s- and p-wave π-nucleon amplitudes (1984CO04).

21. ^{15}N(p, n)^{15}O $\qquad Q_m = -3.5363$

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 (1981AJ01) for the earlier work, (1981MU01: $E_p = 5.5$ to 9.3 MeV) and (1981BY01; 9.1 to 15.6 MeV). At $E_p = 160$ MeV transitions are observed to ^{15}O*(0, 6.2, (9.6)): the transition to ^{15}O*(6.2) [$\frac{3}{2}^-$] is significantly more quenched than the $\frac{1}{2} \rightarrow \frac{1}{2}$ transition, as is also the case in ^{13}C(p, n) (1985GO02). At $E_p = 135$ MeV ^{15}O*(10.5) is weakly populated (1985PAZV). See also (1981BY1B, 1981WA1F, 1984TAZS, 1985KI1L), and (1983BY03) in ^{16}O (1986AJ04).

22. ^{15}N(^{3}He, t)^{15}O $\quad\quad Q_m = -2.7726$

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).

23. ^{16}O(γ, n)^{15}O $\quad\quad Q_m = -15.6639$

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 (1970AJ04, 1976AJ04). Differential cross sections for the n_0 group have been measured from threshold to $E_\gamma = 28$ MeV [see (1976AJ04)] and at $E_\gamma = 60$ to 160 MeV (1980GO13, 1982GO09, 1982SC02 [also ^{15}O*(6.18); no appreciable strength in the 5.2 MeV doublet]). In the energy range $E_\gamma = 30 - 35$ MeV, $\approx 4\%$ of the isovector energy-weighted sum rule is found in the (γ, n_0) channel (1984KU21). See also (1981AJ01), ^{16}O in (1986AJ04) and (1981GA1M, 1982LO1B).

24. (a) ^{16}O(π^+, p)^{15}O $\quad\quad Q_m = 124.6857$
(b) ^{16}O(π^+, π^+n)^{15}O $\quad\quad Q_m = -15.6639$

For reaction (a) see (1982DO01). At $E_{\pi^+} = 2.0$ GeV/c differential cross sections have been determined for the transition to ^{15}N*(6.2) (1983KI01). See also (1982LO1B).

25. ^{16}O(p, d)^{15}O $\quad\quad Q_m = -13.4393$

Angular distributions have been reported at many energies for $E_p = 18.5$ to 155.6 MeV [see Table 15.30 in (1970AJ04), and (1976AJ04)] and at $E_{\vec{p}} = 65$ MeV (1980HO18; d_0). At those energies ^{15}O*(0, 6.18) are primarily populated. At $E_{\rm p} = 800$ MeV (1984SM04) report the population of ^{15}O*(0, $5.18 + 5.24$, 6.18, $7.28 + 7.56$, $8.84 + 0.15$, 10.42 ± 0.15, 10.87 ± 0.15, 12.21 ± 0.15, 13.59 ± 0.15, 19.0 ± 0.2, 21.1 ± 0.2) [the last states have $\Gamma \geq 0.8$ MeV]. See also (1981LI1B), (1982LO1B) and ^{17}F in (1986AJ04).

26. ^{16}O(d, t)^{15}O $\quad Q_{\rm m} = -9.4066$

Angular distributions have been reported at a number of energies in the range $E_{\rm d} = 20$ to 52 MeV: see (1981AJ01) and reaction 62 in ^{15}N here. See also ^{18}F in (1983AJ01).

27. (a) ^{16}O(^{3}He, α)^{15}O $\quad Q_{\rm m} = 4.9139$
(b) ^{16}O(^{3}He, tp)^{15}O $\quad Q_{\rm m} = -14.9002$

The $p_{1/2}$ and $p_{3/2}$ hole states ^{15}O*(0, 6.18) are strongly populated. Information on these and other states are displayed in Table 15.25 of (1981AJ01). Angular distributions have been measured at energies up to $E(^3{\rm He}) = 217$ MeV: see (1981AJ01). Branching ratios and multipole mixing ratios are displayed in Table 15.18. (1978BE73) report $\tau_{\rm m}$ of ^{15}O*(5.24) $= 3.25 \pm 0.30$ psec, $|{\rm g}| = 0.260 \pm 0.028$. (1983BI10) determine g $= +0.17 \pm 0.07$. For reaction (b) see (1984ST10; $E(^3{\rm He}) = 81$ MeV) and ^{16}O. See also ^{19}Ne in (1983AJ01), (1982AB04), (1983GO2D; applied) and (1982LO1B).

28. (a) ^{16}O(^{10}B, ^{11}B)^{15}O $\quad Q_{\rm m} = -4.2098$
(b) ^{16}O(^{12}C, ^{13}C)^{15}O $\quad Q_{\rm m} = -10.7176$

Angular distributions involving ^{15}O$_{\rm g.s.}$ have been investigated at $E(^{10}{\rm B}) = 100$ MeV: see (1981AJ01). See also (1983OS08; theor.). For reaction (b) see (1984FL1B; theor.).

29. ^{17}O(p, t)^{15}O $\quad Q_{\rm m} = -11.3257$

At $E_{\rm p} = 39.8$ 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. At $E_{\rm p} = 45$ 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 $E_{\rm x} = 12.255 \pm 0.013$ MeV, $\Gamma_{\rm c.m.} = 135 \pm 15$ keV. The state decays by proton emission to the $T = 1$, 0^+ state ^{14}N*(2.31) [the population of some $T = \frac{1}{2}$ states is also reported]: see (1981AJ01). See also (1984VOZY).

30. ^{19}F(^{3}He, ^{7}Li)^{15}O $\qquad Q_m = -4.318$

See (1976AJ04).

^{15}F
(Fig. 13)

GENERAL: (See also (1981AJ01).)

See (1982AW02, 1983ANZQ; theor.). See the latter also for discussions of higher Z, $A = 15$ nuclei.

Mass of ^{15}F: The atomic mass excess of ^{15}F is 16.77 ± 0.13 MeV. ^{15}F is unstable with respect to breakup into ^{14}O + p by 1.47 MeV: see (1981AJ01).

1. ^{12}C(^{3}He, π^-)^{15}F $\qquad Q_m = -141.41$

This reaction is not observed at $E(^3\text{He}) = 235$ MeV, $\theta_{\text{lab}} = 20°$: the differential cross section (c.m.) is $\leq 4 \times 10^{-11}$ b (1984BI08).

Table 15.23: Energy levels of ^{15}F

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

2. ^{20}Ne(^{3}He, ^{8}Li)^{15}F $\qquad Q_m = -29.83$

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 [$\Gamma_{\text{c.m.}} = 0.8 \pm 0.3$ 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 $E_x = 1.3 \pm 0.1$ MeV (1978KE06), 1.2 ± 0.2 MeV (1978BE26) and $\Gamma_{\text{c.m.}} = 0.5 \pm 0.2$ 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).

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