Energy Levels of Light Nuclei
$A = 15$

F. Ajzenberg-Selove

University of Pennsylvania, Philadelphia, Pennsylvania 19104-6396

Abstract: An evaluation of $A = 13$–15 was published in *Nuclear Physics A*268 (1976), 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}Li

(Not illustrated)

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

^{15}Be

(Not illustrated)

^{15}Be has not been observed. It is calculated to be particle unstable with respect to decay into ^{14}Be + n by 2.42 MeV. The binding energy of ^{13}Be + 2n is $+0.31$ MeV. The calculated mass excess is 51.18 MeV (1974TH01). See also (1975BE31; theor.).

^{15}B

(Fig. 13)

^{15}B has been observed in the 5.3 GeV proton bombardment of uranium (1966PO09) and in a study of the ^{14}C(^{9}Be, ^{8}B)^{15}B reaction at $E(^{9}\text{Be}) = 120$ MeV (1974CE1D). See also (1971AR02). It is particle stable. Its mass excess is calculated to be 29.89 MeV (1975JE02): the binding energies for ^{14}B + n and ^{13}B + 2n are then 1.84 and 2.82 MeV, respectively, based on the (1971WA37) masses except for ^{14}B [for which see "Mass of ^{14}B" in the "GENERAL" section of ^{14}B]. For other calculations of the mass of ^{15}B see (1970WA1G, 1972TH13, 1973BA34, 1974TH01, 1975BE31). See also (1972CE1A, 1973KO1D, 1973TO16).

^{15}C

(Figs. 10 and 13)

GENERAL: (See also (1970AJ04)):

Model calculations: (1973PH03, 1973RE17).

Special levels: (1973PH03, 1974VA24).

Muon and neutrino capture and reactions: (1973BE16, 1973BU20).

Pion capture and reactions: (1970JA11).

Special reactions: (1971AR02, 1973KO1D, 1973WI15, 1974KO25, 1975UD01).

Other topics: (1970SU1B, 1973PH03, 1973RE17, 1974VA24, 1975BE31).

Table 15.1: Energy levels of ^{15}C

E_x (MeV $\pm$ keV)	$J^\pi; T$	τ or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
g.s.	$\frac{1}{2}^+; \frac{3}{2}$	$\tau_{1/2} = 2.449 \pm 0.004$ sec	β^-	1, 2, 3, 6, 7
0.7400 ± 1.5	$\frac{5}{2}^+; \frac{3}{2}$	$\tau_m = 3.76 \pm 0.10$ nsec	γ	3, 6
		$g = -0.77 \pm 0.06$		
3.105 ± 5	$\frac{1}{2}^-; \frac{3}{2}$	$\Gamma_{c.m.} \leq 40$		3, 6
4.221 ± 3	$(\frac{7}{2}^+, \frac{5}{2}^-)$	< 14		3, 6
(4.55 ± 30)				3
5.833 ± 20	$\leq \frac{3}{2}$			3
5.858 ± 20	$\leq \frac{3}{2}$			3
6.370 ± 15	$(\frac{5}{2}, \frac{7}{2}^+, \frac{9}{2}^+)$	< 20		3, 6
6.429 ± 7	$(\frac{3}{2} \rightarrow \frac{7}{2})$	≈ 50		3, 6
6.461 ± 20	$(\frac{9}{2}^-, \frac{11}{2})$	< 14		3, 6
6.540 ± 5	[a]	< 14		3, 6
6.639 ± 15	$(\frac{3}{2})$	20 ± 10		3
6.845 ± 5	$(\frac{13}{2}, \frac{11}{2})^+$	< 14		3, 6
6.884 ± 5	$(\frac{9}{2})$ [a]	< 20		3, 6
7.098 ± 6	$(\frac{3}{2})$	< 15		3, 6
7.352 ± 6	$(\frac{9}{2}, \frac{11}{2})$	20 ± 10		3, 6
7.414 ± 20				3
7.75 ± 30 [b]				3, 6
8.01 ± 30				3
8.11 ± 10 [b]				3, 6
8.47 ± 15	$(\frac{9}{2} \rightarrow \frac{13}{2})$	40 ± 15		3, 6
8.559 ± 15	$(\frac{7}{2} \rightarrow \frac{13}{2})$	40 ± 15		3
9.00 ± 30				3
(9.73 ± 30)				3
9.789 ± 20	$(\frac{9}{2} \rightarrow \frac{15}{2})$	20 ± 15		3
10.248 ± 20	$(\frac{5}{2} \rightarrow \frac{9}{2})$	20 ± 15		3
11.015 ± 25				3
11.123 ± 20	$(\frac{11}{2} \rightarrow \frac{19}{2})$	30 ± 20		3
(11.68 ± 30)				3
11.825 ± 20	$\geq \frac{13}{2}$	70 ± 30		3

[a] See Table 15.3.
[b] Broad or unresolved states.

Table 15.2: Beta decay of ^{15}C [a]

Decay to ^{15}N* (keV)	J^π	Branch (%)	$\log f_0 t$ [d] (exp)	$\log ft$ [b] (theor)
g.s.	$\frac{1}{2}^-$	32 ± 2	5.99 ± 0.03	5.8 [c]
5298.87 ± 0.12	$\frac{1}{2}^+$	68 ± 2	4.08 ± 0.01	4.80
7301.1 ± 0.5	$\frac{3}{2}^+$	$(0.74 \pm 0.08) \times 10^{-2}$	6.89 ± 0.05	6.49
8312.9 ± 0.5	$\frac{1}{2}^+$	$(4.1 \pm 0.5) \times 10^{-2}$	5.18 ± 0.05	4.51
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] D.E. Alburger, private communication.

[b] See (1959AL97).

[c] See (1972TO03).

[d] Using $\tau_m = 2.449 \pm 0.004$ sec (D.E. Alburger).

1. ^{15}C$(\beta^-)^{15}$N $\qquad Q_m = 9.772$

The half-life is 2.449 ± 0.004 sec (D.E. Alburger, private communication). See also (1970AL21). Transitions have been observed to the ^{15}N$_{g.s.}$ and to the upper of the 5.3 MeV levels of ^{15}N. The latter transition (which is to a $\frac{1}{2}^+$ state) is clearly allowed: see Table 15.2. Therefore $J^\pi(^{15}\mathrm{C}_{g.s.}) = \frac{1}{2}^+$ or $\frac{3}{2}^+$ (1959AL06, 1959AL97, 1966AL12, 1969GA05). Weak transitions are observed to ^{15}N*(7.30, 8.31, 8.57, 9.05). See also (1970AS1C) and (1970HS02, 1972TO03; theor.).

2. ^{9}Be(^{6}He, α)^{11}Be $\qquad Q_m = 6.344 \qquad E_b = 19.072$

See (1970AJ04).

3. ^{9}Be(^{7}Li, p)^{15}C $\qquad Q_m = 9.094$

Observed proton groups and a γ-ray measurement are displayed in Table 15.3 (1974GA33, 1975HA42). τ_m for ^{15}C*(0.74) $= 3.77 \pm 0.11$ nsec (1968ME08). Angular distributions have been reported at $E(^7\mathrm{Li}) = 1.7$ to 1.9 MeV (1969KA1C; $p_1 \rightarrow p_4$), $5.6 - 6.2$ MeV (1969SN02; p_0, p_1) and 20 MeV (1974GA33; to states with $E_x < 8.6$ MeV, and partial distributions to ^{15}C*(9.79, 10.25, 11.13, 11.83). See also (1970AJ04).

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

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

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

4. ^{14}C(n, γ)^{15}C $\qquad Q_m = 1.218$

$\sigma_\gamma < 1\ \mu$b (1951YA1A, 1973MU14).

5. ^{14}C(n, n)^{14}C $\qquad E_b = 1.218$

See (1973PH03, 1974PH03; theor.).

6. ^{14}C(d, p)^{15}C $\qquad Q_m = -1.007$

Observed proton groups are displayed in Table 15.3 (1973GO28, 1975GO31) and compared with the results of reaction 3. The spectroscopic factors obtained for the bound states ^{15}C*(g.s., 0.74) [$J^\pi = \frac{1}{2}^+$ and $\frac{5}{2}^+$, respectively] are somewhat less than the value 1 predicted theoretically (1973PH03, 1973RE17) [see, however, (1975CE04)]. τ_m of ^{15}C*(0.74) $= 3.73 \pm 0.23$ nsec (1962LO02): the angular distribution of the 0.74 MeV γ-rays requires $J \geq \frac{5}{2}$; $l_n = 2$ stripping permits $J^\pi = \frac{3}{2}^+$ or $\frac{5}{2}^+$. Therefore $J^\pi = \frac{5}{2}^+$ for ^{15}C*(0.74) (1962CH14); g $= -0.77 \pm 0.06$ (1975HA42). See (1970AJ04) for a review of the earlier work.

7. ^{15}N(n, p)^{15}C $\qquad Q_m = -8.989$

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

8. ^{18}O(n, α)^{15}C $\quad Q_{\rm m} = -5.009$

See (1966BA1F).

The following light-particle induced reactions leading to ^{15}C have not been reported:

^{13}C(t, p)^{15}C	$Q_{\rm m} = 0.913$
^{14}C(t, d)^{15}C	$Q_{\rm m} = -5.039$
^{14}C(α, ^{3}He)^{15}C	$Q_{\rm m} = -19.360$

^{15}N
(Figs. 11 and 13)

GENERAL: (See also (1970AJ04)):

Shell model: (1968GO01, 1969UL03, 1970CO1H, 1970FR11, 1970GO1H, 1970HS02, 1970LI23, 1971BA2Y, 1971LI17, 1971NO02, 1972BA60, 1972GE05, 1972LE1L, 1973BA2L, 1973BE1V, 1973DE13, 1973HA49, 1973RE17, 1973WA35, 1974DI15, 1974SA06, 1975MA2H).

Collective and deformed models: (1974PU02).

Cluster and α-particle models: (1971NO02, 1972LE1L, 1972WE01, 1974PU02, 1975BU03).

Special levels: (1968GO01, 1969HA1F, 1970FR11, 1970FR1C, 1971BE59, 1971BE2D, 1971HS05, 1971LI17, 1971NO02, 1972WE01, 1973BA2L, 1974PU02, 1974SA06, 1974VA24, 1975BU03, 1975HS01).

Giant resonance: (1970AL1E, 1972BA60, 1972LE06, 1973DE1V, 1974DI15, 1974HA1C, 1975HA39, 1975MA2H).

Special reactions: (1969GA18, 1971AR02, 1973KO1D, 1973KU03, 1973WI15, 1975HU14, 1975KU01, 1975OS01, 1976YOZZ).

Electromagnetic transitions: (1969HA1F, 1970GO1H, 1970LI23, 1970SI1J, 1971LI17, 1973RE17, 1974HA1C, 1974SA06, 1975BU03, 1975HS01).

Astrophysical questions: (1972CL1A, 1973AR1E, 1973AU1B, 1973AU1D, 1973AU1C, 1973BO1R, 1973SM1A, 1973TA1D, 1973TR1B, 1974BE1R, 1975AR1E, 1975AU1D, 1975DW1A, 1975EN1A, 1975KE1A, 1975NO1D, 1975RA1M, 1975SC1H, 1975SN1A, 1975TR1A).

Muon and neutrino capture and reactions: (1970BU1B, 1970KA1E, 1970PR1H, 1972BL01, 1972BU29, 1972HI04, 1973BE16, 1973BU20, 1973ER06, 1973JO1G).

Pion capture and reactions: (1970DO04, 1970JA11, 1971KO23, 1973EI01, 1974LI15, 1975LI06).

Applied work: (1974MA1U).

Other topics: (1968GO01, 1969UL03, 1970CO1H, 1970LE1D, 1970RY04, 1970SI1C, 1971BA2Y, 1971BE59, 1971HS05, 1972AN05, 1972CA37, 1972LE1L, 1972SH32, 1973AR1K, 1973BE1V, 1973DE13, 1973HY1A, 1973JU2A, 1973KU03, 1973MA48, 1973RE17, 1973WA35, 1974CA1H, 1974SL1C, 1974VA24, 1975BE48, 1975HE10, 1975KU01, 1975SH1H, 1976MA04).

Ground state properties: (1964BA11, 1970SI1J, 1971SC29, 1971SH26, 1971TA1A, 1972GE05, 1972GL06, 1972LE1L, 1972LE1N, 1972VA36, 1972YO1B, 1973ARYL, 1973HI1A, 1973HO32, 1973RE17, 1973SU1B, 1973SU1C, 1974DE1E, 1974DIZR, 1974HA27, 1974SA06, 1975BE31, 1975BU03, 1975MI1N, 1975SC18).

$\mu = -0.2831892\ (3)$ nm (1974SHYR).

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

E_x (MeV ± keV)	$J^\pi; T$	τ_m (psec) or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
0	$\frac{1}{2}^-; \frac{1}{2}$		stable	2, 3, 4, 11, 12, 14, 16, 18, 19, 20, 21, 22, 31, 33, 34, 35, 39, 40, 42, 43, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88
5.27040 ± 0.17	$\frac{5}{2}^+$	$\tau_m = 2.6 \pm 0.2$ $g = +(0.9 \pm 0.3)$	γ	3, 4, 11, 12, 13, 16, 17, 18, 19, 21, 29, 30, 31, 33, 39, 40, 51, 64, 68, 69, 73, 76, 77, 84, 86, 87
5.29887 ± 0.12 [b]	$\frac{1}{2}^+$	$(2.5 \pm 0.7) \times 10^{-2}$	γ	3, 4, 11, 12, 13, 17, 18, 21, 29, 30, 31, 39, 40, 51, 60, 64, 68, 73, 76, 77, 87
6.32385 ± 0.12	$\frac{3}{2}^-$	$(0.22 \pm 0.03) \times 10^{-3}$	γ	3, 4, 11, 12, 14, 18, 29, 30, 39, 40, 51, 64, 68, 69, 73, 75, 76, 77, 82, 84, 87
7.15536 ± 0.11	$\frac{5}{2}^+$	0.028 ± 0.008	γ	3, 4, 11, 12, 18, 29, 30, 33, 39, 51, 64, 68, 69, 76, 84
7.30109 ± 0.17	$\frac{3}{2}^+$	$(0.25 \pm 0.10) \times 10^{-3}$	γ	3, 4, 11, 12, 18, 19, 29, 33, 39, 51, 60, 64, 68, 69, 76, 84
7.5671 ± 1.0	$\frac{7}{2}^+$	0.06 ± 0.02	γ	3, 4, 11, 12, 16, 17, 18, 19, 29, 30, 32, 39, 51, 56, 64, 68, 69, 73, 84
8.31279 ± 0.14	$\frac{1}{2}^+$	< 0.020	γ	3, 4, 11, 12, 18, 29, 30, 35, 39, 51, 60, 68, 69, 73, 84
8.5714 ± 1.0 [b]	$\frac{3}{2}^+$	$\lesssim 0.1$	γ	3, 4, 11, 12, 16, 17, 18, 29, 30, 39, 51, 60, 68, 69, 84
9.0500 ± 0.7 [b]	$\frac{1}{2}^+$	$\lesssim 0.1$	γ	3, 4, 11, 12, 29, 39, 51, 60, 73
9.15224 ± 0.22	$\frac{3}{2}^-$	< 0.040	γ	3, 4, 11, 12, 16, 17, 18, 29, 30, 35, 39, 51, 64, 68, 69
9.15527 ± 0.11	$\frac{5}{2}$	(< 0.010)	γ	3, 4, 11, 12, 16, 17, 18, 29, 30, 35, 39, 51, 68, 69
9.225 ± 3	$\frac{1}{2}^-$	< 0.13	γ	12, 29, 39, 51, 73
9.760 ± 5	$\frac{5}{2}^-$		γ	12, 13, 19, 29

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

E_x (MeV ± keV)	$J^\pi; T$	τ_m (psec) or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
9.829 ± 3	$\frac{7}{2}$	< 0.19	γ	3, 4, 12, 17, 18, 19, 29, 30, 32, 39, 51, 68, 69
9.928 ± 4	$(\frac{1}{2}, \frac{3}{2})^+$	$\lesssim 0.1$	γ	12, 18, 19, 29, 39, 51, 76
10.070 ± 3	$\frac{3}{2}^+$		γ	12, 18, 29, 51, 68, 69
10.4497 ± 0.3	$\frac{5}{2}^-$	$\Gamma < 0.5$	γ, p	4, 11, 12, 19, 29, 30, 39, 51
10.5333 ± 0.5	$\frac{5}{2}^+$		γ, p	4, 11, 12, 18, 29, 35, 39, 51
10.6932 ± 0.3	$\frac{9}{2}^+$		γ, p	4, 12, 16, 17, 18, 30, 31, 35, 36, 68
10.7019 ± 0.3 [c]	$\frac{3}{2}^-$	$\Gamma = 0.2$ keV	γ, p	12, 29, 30, 35, 36, 51, 68, 76
10.804 ± 2	$\frac{3}{2}^{(+)}$	$< 1 \times 10^{-3}$	γ, p	5, 12, 18, 35, 36, 37, 45, 46
11.235 ± 5	$\geq \frac{3}{2}$	3.3	n	39, 45
11.2929 ± 0.8	$\frac{1}{2}^-$	8 ± 3	γ, n, p	12, 35, 36, 37, 39, 45, 68
11.4375 ± 0.7	$\frac{1}{2}^+$	41.4 ± 1.1	γ, n, p, α	5, 12, 18, 35, 36, 37, 45, 46
(11.44)		$\ll 40$		39
11.615 ± 4	$\frac{1}{2}^+; T = \frac{3}{2}$	405 ± 6	γ, n, p	12, 35, 36, 37
11.778 ± 5	$\frac{3}{2}^+$	40	n, p, α	5, 36, 37, 45, 46
11.876 ± 3	$\frac{3}{2}^-$	25	n, p, α	5, 36, 37, 45, 46
11.942 ± 6	$\frac{11}{2}$	≤ 3.0	n, α	4, 5, 12, 18, 30, 32, 45, 68
11.965 ± 3	$\frac{1}{2}^-$	17	n, p	4, 12, 17, 18, 30, 32, 36, 37, 45, 46
12.095 ± 3	$\frac{5}{2}^+$	14 ± 5	n, p, α	5, 6, 36, 37, 38, 39, 45, 46, 50
12.145 ± 3	$\frac{3}{2}^-$	47 ± 7	n, p, α	5, 6, 36, 37, 45, 46, 50
12.327 ± 4	$\frac{5}{2}$	22	n, p	17, 18, 30, 36, 37, 45, 46
12.493 ± 4	$\frac{5}{2}^+; \frac{1}{2}$	40 ± 5	n, p, α	5, 6, 31, 36, 37, 38, 45, 46, 50
12.522 ± 8	$\frac{5}{2}^+; \frac{3}{2}$	58 ± 4	γ, p	35, 68
12.559 ± 10	$(\frac{9}{2})$			4, 12, 17, 18, 68
12.920 ± 4	$\frac{3}{2}^-$	56 ± 11	n, p, α	5, 6, 9, 18, 19, 36, 37, 38, 45, 46, 50
12.940 ± 10	$\frac{5}{2}^+$	81	p, α	6, 9, 36, 38
13.004 ± 10	$\frac{11}{2}^-$			4, 11, 12, 16, 18, 30, 31, 32
13.149 ± 10		7 ± 3	n, p, α	5, 6, 19, 50
13.173 ± 7	$(\frac{9}{2})$	7 ± 3	n, p, α	4, 5, 6, 12, 16, 17, 18, 31, 37, 45, 50

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

E_x (MeV $\pm$ keV)	$J^\pi; T$	τ_m (psec) or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
13.362 ± 8	$\frac{3}{2}^-$	16 ± 8	n, p, α	5, 6, 9, 36, 37, 38, 50
13.390 ± 10	$\frac{3}{2}^+$	56	γ, n, p, α	6, 9, 35, 36, 37, 38, 46
13.537 ± 10	$\frac{3}{2}^-$	85 ± 30	n, p, α	5, 9, 12, 36, 37, 38
13.608 ± 7	$\frac{5}{2}$	18 ± 4	n, p, α	5, 6, 18, 45, 46, 50
(13.612 ± 10)	$\frac{1}{2}^+$	90	n, p, α	9, 36, 37, 38
13.713 ± 10		26 ± 8	n, p, α	5, 46, 50
13.84 ± 30	$\frac{3}{2}^+$	75	n, p, α	4, 5, 9, 12, 45, 46, 50
13.9	$\frac{1}{2}^+$	930	γ, p	35, 36
13.99 ± 30		98 ± 10	n, p, α	5, 36, 38
14.090 ± 7		22 ± 6	n, p, α	4, 5, 12, 18, 38, 45, 46, 50, 68
14.10 ± 30	$\frac{3}{2}^+$	≈ 100	n, p, α	4, 5, 9, 12, 38, 45, 46, 50, 68
14.162 ± 10	$(\frac{3}{2})$	27 ± 6	n, α	4, 5, 12, 45, 46, 50, 68
14.24 ± 40	$\frac{5}{2}^+$	150	α	9
14.38 ± 40	$\frac{7}{2}^+$	100	α	9
14.4		≈ 1900	n, p, α	45, 46, 50
14.55 ± 20		74 ± 7	n, p, α	5, 36, 38, 45, 46, 50
14.647 ± 10		33 ± 6	n, α	5
14.71		750	γ, p	35
14.720 ± 10		140 ± 20	n, p, α	5, 11, 12, 18, 38, 45, 46, 50, 62
14.86 ± 20		48 ± 11	n, α	5, 9, 50
14.920 ± 10		13 ± 3	n, (p), α	5, 36
15.025 ± 10		13 ± 3	n, (p), α	5, 36
15.09 ± 20		80 ± 25	n, p, α	5, 9, 32, 36, 38, 45, 50, 68
15.288 ± 10		22 ± 6	n, p, α	5, 9, 35, 36, 38, 50
15.373 ± 10	$\frac{13}{2}^+, \frac{15}{2}^+$			4, 11, 12, 16, 17, 18, 31
15.38 ± 40		75 ± 25	n, t, α	5, 9, 15, 19
15.43 ± 20		≈ 100	n, α	5, 9
15.45		750	γ, p	35
15.53 ± 20		≈ 35	n, α	5
15.60 ± 20		95 ± 25	n, α	5, 62
(15.782 ± 10)				18
15.93 ± 20		35 ± 5	n, t, α	5, 15, 17

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

E_x (MeV $\pm$ keV)	$J^\pi; T$	τ_m (psec) or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
15.944 ± 15		21 ± 6	n, t, α	5, 15
16.026 ± 10		62 ± 12	n, t, α	5, 9, 15, 18, 32
16.190 ± 10			n, t, α	5, 17, 18, 32
16.26 ± 20		130 ± 14	n, p, t, α	5, 9, 15, 17, 19, 36, 38, 50
16.32 ± 20		≈ 30	n, p, t, α	5, 15
16.39 ± 20		44 ± 11	n, p, t, α	5, 15, 17, 50
16.46		560	γ, p	35
16.576 ± 15		27 ± 15	n, p, t, α	5, 15, 38, 50
16.677 ± 15	$\frac{3}{2}^+; \frac{1}{2}$	90 ± 10	γ, n, p, d, t, α	5, 15, 23, 24, 26, 35, 38, 45, 50, 62
16.76 ± 30			n, t, α	15, 17, 62
16.85 ± 30	$\frac{5}{2}$	110 ± 50	n, p, t, α	13, 15, 38, 45, 50
16.91		≈ 350	n, p, t, α	15, 23, 24
(17.05)			p, t	15
17.11		broad	d, t, α	15, 27
(17.16 ± 50)			t, α	15
17.23 ± 40		≈ 175	d, t	26
17.37 ± 40		≈ 250	n, p, t	15, 24, 26, 27, 45, 50
17.58 ± 40		≈ 175	n, d, t, α	26, 50
17.67 ± 40		≈ 500	γ, n, d, α	22, 23, 27
17.72 ± 10		48 ± 10	n, (p), d, t, α	19, 24, 26, 27, 50
17.81		167	n, α	19, 45, 50
18.06 ± 10		19 ± 4	(n), d, α	17, 23, 27
18.09 ± 20		≈ 40	(n), p, d, t	23, 24, 26
18.22		158	n, α	45, 50
18.28 ± 30		235 ± 60	n, p, d, α	23, 24, 27, 50
19.16	$(\frac{1}{2}^+; \frac{1}{2})$	≈ 130	(γ), n, p, d	23, 32, 35
19.5	$\frac{3}{2}^+; (\frac{3}{2})$	≈ 400	γ, p	35, 36
(19.77 ± 60)				17
20.5	$\frac{3}{2}^+$	≈ 400	γ, n, p	12, 23, 24, 35, 62
21.72			γ, p, d	22, 35, 62
22.9			γ, p	29, 35
25.5	$(T = \frac{3}{2})$		γ, p	35

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

E_x (MeV ± keV)	$J^\pi; T$	τ_m (psec) or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
(26.8)			t	15
≈ 37			γ, p	35

[a] See also Tables 15.5, 15.6 and 15.12.

[b] See Table 15.2.

[c] See, however, (1976KO11).

Mass of ^{15}N: The mass of ^{15}N derived from the work of (1975SM02) is $15.000108963\ (14)$ a.m.u. Using the conversion factor $931.5016\ (26)$ MeV/a.m.u., the mass excess of ^{15}N would be $101.50\ (2)$ keV. (1971WA37) quotes 101.8 ± 0.4 keV which we shall continue to assume. See also (1971KE01).

1. (a) ^{9}Be(^{6}Li, p)^{14}C $\quad Q_m = 15.127 \quad E_b = 25.334$
   (b) ^{9}Be(^{6}Li, t)^{12}C $\quad Q_m = 10.486$
   (c) ^{9}Be(^{6}Li, α)^{11}B $\quad Q_m = 14.343$
   (d) ^{9}Be(^{6}Li, 2n)^{13}N $\quad Q_m = 3.947$

The yield of p_0 and p_1 (reaction (a)) for $E(^6\text{Li}) = 3.84$ to 6.40 MeV shows some broad structure: analysis in terms of Ericson fluctuation theory gives a value of ≈ 0.4 MeV for the average level width at $E_x = 28$ MeV in ^{15}N (1967SE08). See also (1969KO1A, 1973AJ01) and ^{14}C. The excitation functions for α_0, α_1 and α_{2+3} (reaction (c)) [$E(^6\text{Li}) = 2$ to 4 MeV: (1961LE01)] and the yield of ^{13}N (reaction (d)) [$E(^6\text{Li}) = 1.5$ to 3.5 MeV: (1961NO05)] show a smooth increase in the cross section with energy. However, the excitation functions for t_0 (reaction (b)), α_0, α_1 and α_2 (reaction (c)) show broad structures for $E(^6\text{Li}) = 4$ to 14 MeV (1971WY01).

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

See (1970AJ04).

3. ^{10}B(^{6}Li, p)^{15}N $\quad Q_m = 18.749$

At $E(^6\text{Li}) = 4.9$ MeV, thirty proton groups are observed corresponding to ^{15}N states with $E_x < 16.8$ MeV. Angular distributions have been measured for the proton groups corresponding to ^{15}N*($5.27 + 5.30$, 6.32, $7.16 + 7.30$, 7.57, 8.31, 8.58, $9.05 + 9.15$) (1966MC05). See also (1970AJ04).

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

$E_{\rm i}$ (MeV)	$J^{\pi}_{\rm i}$	$E_{\rm f}$ (MeV)	$J^{\pi}_{\rm f}$	Branch (%)	Mult. mixing ratio δ	Refs. [1]
5.27	$\frac{5}{2}^+$	0	$\frac{1}{2}^-$	100	-0.131 ± 0.013	(1975BE23, 1976BE1B)
5.30	$\frac{1}{2}^+$	0	$\frac{1}{2}^-$	100		
6.32	$\frac{3}{2}^-$	0	$\frac{1}{2}^-$	100	$+0.122 \pm 0.006$ [b]	(1975MO28, 1976BE1B)
		5.27	$\frac{5}{2}^+$	< 1		(1965WA16, 1975MO28)
		5.30	$\frac{1}{2}^+$	< 0.5		(1975MO28)
7.16	$\frac{5}{2}^+$	0	$\frac{1}{2}^-$	< 0.1		(1976BE1B)
		5.27	$\frac{5}{2}^+$	100 ± 0.4 [c]	$-0.014^{+0.012}_{-0.015}$	(1976BE1B)
		5.30	$\frac{1}{2}^+$	< 4		(1966AL18, 1968GI11)
		6.32	$\frac{3}{2}^-$	< 0.5		(1965WA16)
7.30 [c]	$\frac{3}{2}^+$	0	$\frac{1}{2}^-$	99.3 ± 0.7	$-0.017^{+0.005}_{-0.008}$	(1976BE1B)
		5.27	$\frac{5}{2}^+$	0.6 ± 0.1	$+0.18 \pm 0.15$, or $+2.5 \pm 1.0$	(1976BE1B)
		5.30	$\frac{1}{2}^+$	0.2 ± 0.1	-0.31 ± 0.15, or $+4.6 \pm 3.4$	(1976BE1B)
		6.32	$\frac{3}{2}^-$	< 0.25		(1965WA16)
7.57	$\frac{7}{2}^+$	0	$\frac{1}{2}^-$	1.3 ± 0.6		(1975BE23, 1976BE1B)
		5.27	$\frac{5}{2}^+$	98.7 ± 1.0	-0.028 ± 0.012	(1976BE1B)
		5.30	$\frac{1}{2}^+$	< 4		(1966AL18)
		6.32	$\frac{3}{2}^-$	< 0.6		(1965WA16)
8.31	$\frac{1}{2}^+$	0	$\frac{1}{2}^-$	79 ± 2		(1965WA16, 1966WA08, 1967PH03)
		5.27	$\frac{5}{2}^+$	< 3		(1965WA16)
		5.30	$\frac{1}{2}^+$	10 ± 2		(1965WA16)
		6.32	$\frac{3}{2}^-$	7.8 ± 2		(1965WA16)
				4.4 ± 1.0		(1967PH03)
		7.16	$\frac{5}{2}^+$	1.2 ± 0.6		(1967PH03)
		7.30	$\frac{3}{2}^+$	2.2 ± 0.4		(1965WA16)
				4.4 ± 0.7		(1967PH03)
8.57	$\frac{3}{2}^+$	0	$\frac{1}{2}^-$	33 ± 2		(1965WA16, 1966WA08, 1967PH03)
					$-0.085^{+0.005}_{-0.009}$	(1976BE1B)
		5.27	$\frac{5}{2}^+$	65 ± 3		(1966WA08)
					-0.091 ± 0.007	(1976BE1B)
		5.30	$\frac{1}{2}^+$	< 12		(1965WA16)
		6.32	$\frac{3}{2}^-$	3 ± 1		(1965WA16)
				1.4 ± 0.6		(1967PH03)
		7.16	$\frac{5}{2}^+$	3.6 ± 0.5		(1967PH03)
		7.30	$\frac{3}{2}^+$	< 0.7		(1965WA16)
		7.57	$\frac{7}{2}^+$	< 3		(1965WA16, 1966WA08)

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	Refs. [1]
9.05	$\frac{1}{2}^+$	0	$\frac{1}{2}^-$	92 ± 3		(1965WA16, 1966WA08)
				91.6 ± 0.9		(1967PH03)
		5.27	$\frac{5}{2}^+$	3.5 ± 1		(1966WA08)
				4.7 ± 0.7		(1967PH03)
		6.32	$\frac{3}{2}^-$	4.5 ± 1		(1966WA08)
				3.7 ± 0.5		(1967PH03)
		7.16	$\frac{5}{2}^+$	< 10		(1965WA16)
		7.30	$\frac{3}{2}^+$	1.2 ± 0.4		(1965WA16)
		7.57	$\frac{7}{2}^+$	< 2		(1965WA16)
		8.31	$\frac{1}{2}^+$	< 0.5		(1965WA16)
9.152	$\frac{3}{2}^-$	0	$\frac{1}{2}^-$	100 ± 3		(1969SI04, 1976BE1B) [d]
					$+0.015^{+0.041}_{-0.034}$	(1976BE1B)
9.155	$\frac{5}{2}$	0	$\frac{1}{2}^-$	9 ± 9		(1968ST10)
		5.27	$\frac{5}{2}^+$	≈ 8		(1967TH05)
		5.30	$\frac{1}{2}^+$	≈ 10		(1967TH05)
		6.32	$\frac{3}{2}^-$	20 ± 2		(1967TH05, 1968ST10, 1969SI04)
		7.16	$\frac{5}{2}^+$	≈ 50		(1967TH05, 1968ST10, 1969SI04)
		7.30	$\frac{3}{2}^+$	8 ± 1		(1968ST10)
9.23	$\frac{1}{2}^-$	0	$\frac{1}{2}^-$	< 30		(1965WA16)
				41.5 ± 2.2		(1967PH03)
		5.27	$\frac{5}{2}^+$	< 25		(1965WA16)
		5.30	$\frac{1}{2}^+$	100		(1965WA16)
		$5.27 + 5.30$		31.2 ± 1.7		(1967PH03)
		6.32	$\frac{3}{2}^-$	≤ 25		(1965WA16)
				24.7 ± 1.5		(1967PH03)
		7.16	$\frac{5}{2}^+$	< 30		(1965WA16)
				< 1		(1967PH03)
		7.30	$\frac{3}{2}^+$	< 30		(1965WA16)
				2.6 ± 0.7		(1967PH03)
		7.57	$\frac{7}{2}^+$	< 20		(1965WA16)
		8.31	$\frac{1}{2}^+$	< 5		(1965WA16)
9.76 [e]	$\frac{5}{2}^-$	0	$\frac{1}{2}^-$	81.5 ± 2.8		(1967PH03)
		$5.27 + 5.30$		7.5 ± 1.5		(1967PH03)
		6.32	$\frac{3}{2}^-$	3.7 ± 0.8		(1967PH03)
		7.16	$\frac{5}{2}^+$	2.3 ± 0.5		(1967PH03)
		7.30	$\frac{3}{2}^+$	< 2		(1967PH03)
		7.57	$\frac{7}{2}^+$	5.0 ± 0.6		(1967PH03)

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	Refs. [1]
		8.31	$\frac{1}{2}^+$	< 1		(1967PH03)
		8.57	$\frac{3}{2}^+$	< 2		(1965WA16, 1967PH03)
9.83	$\frac{7}{2}$	0	$\frac{1}{2}^-$	< 4		(1967PH03)
		5.27	$\frac{5}{2}^+$	≈ 85		(1965WA16, 1967PH03)
		5.30	$\frac{1}{2}^+$	< 15		(1965WA16)
		6.32	$\frac{3}{2}^-$	2.2 ± 0.9		(1967PH03)
		7.16	$\frac{5}{2}^+$	2.4 ± 1.1		(1967PH03)
		7.30	$\frac{3}{2}^+$	3.7 ± 0.9		(1967PH03)
		7.57	$\frac{7}{2}^+$	7.3 ± 1.0		(1967PH03)
9.93 [e]	$(\frac{1}{2}, \frac{3}{2})^+$	0	$\frac{1}{2}^-$	77.6 ± 1.9		(1967PH03)
		$5.27 + 5.30$		15.4 ± 1.5		(1967PH03)
		6.32	$\frac{3}{2}^-$	4.9 ± 1.2		(1967PH03)
		7.16	$\frac{5}{2}^+$	< 1		(1967PH03)
		7.30	$\frac{3}{2}^+$	2.1 ± 0.8		(1967PH03)
		7.57	$\frac{7}{2}^+$	< 1		(1967PH03)
		8.31	$\frac{1}{2}^+$	< 1		(1967PH03)
		8.57	$\frac{3}{2}^+$	< 1		(1967PH03)
10.07 [e]	$\frac{3}{2}^+$	0	$\frac{1}{2}^-$	96.0 ± 0.7		(1967PH03)
		$5.27 + 5.30$		4.0 ± 0.7		(1967PH03)
		6.32, 7.16, 7.30, 7.57		< 2		(1966WA08)
		8.31	$\frac{1}{2}^+$	< 2		(1965WA16)
		8.57	$\frac{3}{2}^+$	< 3		(1965WA16)
10.45	$\frac{5}{2}^-$	0	$\frac{1}{2}^-$	< 12		(1976BE1B)
		5.27	$\frac{5}{2}^+$	55.0 ± 0.8	$+0.021 \pm 0.033$	(1976BE1B)
		5.30	$\frac{1}{2}^+$	< 2		(1976BE1B)
		6.32	$\frac{3}{2}^-$	31.3 ± 1.7	-0.59 ± 0.13	(1976BE1B)
		7.16	$\frac{5}{2}^+$	5.2 ± 0.1	$+0.13^{+0.03}_{-0.04}$	(1976BE1B)
		8.57	$\frac{3}{2}^+$	3.8 ± 0.6	-0.3 ± 0.4	(1976BE1B)
		9.152	$\frac{3}{2}^-$	4.7 ± 0.1	$-0.32^{+0.09}_{-0.10}$	(1976BE1B)
		9.83	$\frac{7}{2}$	< 0.1		(1976BE1B)
10.53	$\frac{5}{2}^+$	0	$\frac{1}{2}^-$	< 0.1		(1976BE1B)
		5.27	$\frac{5}{2}^+$	38.7 ± 0.2	-0.27 ± 0.03	(1976BE1B)
		6.32	$\frac{3}{2}^-$	7.7 ± 0.1	-0.028 ± 0.004	(1976BE1B)
		7.16	$\frac{5}{2}^+$	19.4 ± 0.2	$+0.007^{+0.010}_{-0.008}$	(1976BE1B)
		7.30	$\frac{3}{2}^+$	31.4 ± 0.5	$+0.066 \pm 0.005$	(1976BE1B)
		8.57	$\frac{3}{2}^+$	2.4 ± 0.1	$+0.012^{+0.006}_{-0.005}$	(1976BE1B)

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	Refs. [l]
		9.152	$\frac{3}{2}^-$	0.3 ± 0.1	$-0.20^{+0.03}_{-0.02}$	(1976BE1B)
10.69	$\frac{9}{2}^+$	5.27	$\frac{5}{2}^+$	61.6 ± 0.3	$\equiv 0$	(1975BE23, 1976BE1B)
		7.16	$\frac{5}{2}^+$	2.1 ± 0.1	-0.03 ± 0.07	(1975BE23, 1976BE1B)
		7.57	$\frac{7}{2}^+$	36.3 ± 0.6	$+0.118 \pm 0.008$	(1975BE23, 1976BE1B)
10.70 [f]	$\frac{3}{2}^-$	0	$\frac{1}{2}^-$	52.6 ± 0.8	$+0.180^{+0.006}_{-0.002}$	(1976BE1B)
		5.27	$\frac{5}{2}^+$	37.4 ± 0.6	$-0.024^{+0.004}_{-0.008}$	(1976BE1B)
		5.30	$\frac{1}{2}^+$	0.8 ± 0.1	-0.13 ± 0.07	(1976BE1B)
		6.32	$\frac{3}{2}^-$	3.8 ± 0.1	$+0.135 \pm 0.015$	(1976BE1B)
		7.16	$\frac{5}{2}^+$	0.4 ± 0.1	0.3 ± 0.3	(1976BE1B)
		7.30	$\frac{3}{2}^+$	2.3 ± 0.1	-0.027 ± 0.023	(1976BE1B)
		8.31	$\frac{1}{2}^+$	0.8 ± 0.1	$-0.017^{+0.018}_{-0.016}$	(1976BE1B)
		9.05	$\frac{1}{2}^+$	0.2 ± 0.1	-0.007 ± 0.12	(1976BE1B)
		9.152	$\frac{3}{2}^-$	0.2 ± 0.1	-0.11 ± 0.03	(1976BE1B)
		9.23	$\frac{1}{2}^-$	1.5 ± 0.1	$+0.049^{+0.006}_{-0.005}$	(1976BE1B)
10.80 [g]	$\frac{3}{2}^{(+)}$	0	$\frac{1}{2}^-$	51.5 ± 0.4	-0.02 ± 0.01 [f]	(1976BE1B)
		5.27	$\frac{5}{2}^+$	4.9 ± 0.1	-0.63 ± 0.04 [f]	(1976BE1B)
		5.30	$\frac{1}{2}^+$	15.5 ± 0.2	-0.55 ± 0.02 [f]	(1976BE1B)
		6.32	$\frac{3}{2}^-$	5.4 ± 0.2	-0.07 ± 0.05 [f]	(1976BE1B)
		7.16	$\frac{5}{2}^+$	7.8 ± 0.1	$+0.14 \pm 0.03$ [f]	(1976BE1B)
		7.30	$\frac{3}{2}^+$	5.8 ± 0.1	-0.12 ± 0.02 [f]	(1976BE1B)
		8.31	$\frac{1}{2}^+$	3.6 ± 0.1	$+0.12 \pm 0.03$ [f]	(1976BE1B)
		9.05	$\frac{1}{2}^+$	0.3 ± 0.1		(1976BE1B)
		9.152	$\frac{3}{2}^-$	0.9 ± 0.1		(1976BE1B)
		9.155	$\frac{5}{2}$	4.2 ± 0.1		(1976BE1B)
11.62 [h]	$\frac{1}{2}^+; T = \frac{3}{2}$	0	$\frac{1}{2}^-$	90.7 ± 3.0		(1971KU01)
		5.27	$\frac{5}{2}^+$	< 1		(1971KU01)
		5.30	$\frac{1}{2}^+$	7.4 ± 1.5		(1971KU01)
		6.32	$\frac{3}{2}^-$	1.9 ± 1.5		(1971KU01)
12.52	$\frac{5}{2}^+; T = \frac{3}{2}$	0	$\frac{1}{2}^-$	< 1		(1971KU01)
		5.27	$\frac{5}{2}^+$	94.2 ± 0.6 [i]		(1971YO03)
		5.30	$\frac{1}{2}^+$	< 1		(1971KU01)
		6.32	$\frac{3}{2}^-$	5.8 ± 0.6 [j]		(1971YO03)
13.42 [k]	$\frac{3}{2}^+$	0	$\frac{1}{2}^-$	100		(1976KU01)

[a] See also Table 15.10 in (1970AJ04).
[b] $\Gamma_{\gamma_0} = 3.1 \pm 0.3$ eV, δ(E2/M1) $= 0.137 \pm 0.005$ (1975MO28): see also Table 15.16.
[c] See also (1965WA16, 1966PE04, 1968GI11).
[d] See also (1968ST06) and reaction 44.
[e] See also (1965WA16).
[f] See (1969SI04 and private communication).
[g] See also (1965WA16, 1966WA08).
[h] $\Gamma_\gamma = 49 \pm 20, 4 \pm 2, 1.0 \pm 0.8$ for transitions to ^{15}N*(0, 5.30, 6.32) (1971KU01): see also Table 15.12.
[i] $\Gamma_\gamma = 4.3 \pm 0.7$ eV (1971YO03); $\delta = -0.02 \pm 0.04$ (E2/M1) (1971KU01).
[j] $\Gamma_\gamma = 0.27 \pm 0.05$ eV (1971YO03); $\delta = -0.02 \pm 0.04$ (E2/M1) (1971KU01).
[k] $\Gamma_{\gamma_0} = 3.0 \pm 0.9$ eV, $\Gamma_p\Gamma_{\gamma_0}/\Gamma = 1.70 \pm 0.5$ eV; $\delta = 0.00 \pm 0.04$ (M2/E1); B(E1) $= 1.2 \pm 0.4 \times 10^{-3}\ e^2 \cdot$ fm^2. Transitions to ^{15}N*(5.27, 5.30) $< 8\%$ and to ^{15}N*(6.32, 7.16, 7.30) $< 5\%$ (1976KU01). See also (1975HA39).
[l] And private communication with authors of (1969SI04).

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

At $E(^7\text{Li}) = 5.2$ MeV, thirty deuteron groups are observed corresponding to ^{15}N states with $E_x < 15.1$ MeV. Angular distributions have been measured for the deuterons to ^{15}N*(0, 5.27+5.30, 6.32, 7.16 + 7.30, 7.57, 8.31, 9.05 + 9.15, 9.83) (1966MC05). At $E(^7\text{Li}) = 24$ MeV, angular distributions have been studied to many of the ^{15}N states with $E_x < 15.5$ MeV: see reaction 12 (1976KO11). See also (1970AJ04).

5. ^{11}B(α, n)^{14}N $\qquad Q_m = 0.1574 \qquad E_b = 10.9911$

Reported resonances are displayed in Table 15.7: see (1970AJ04) for earlier references and (1975VA06: 0° excitation function for n_0, n_1, n_2; $E_\alpha = 3.7$ to 7.9 MeV). For angular distributions see ^{14}N. For polarization measurements see (1970CI02, 1970MO37; $E_\alpha = 3.6$ and 3.8 MeV).

6. ^{11}B(α, p)^{14}C $\qquad Q_m = 0.7837 \qquad E_b = 10.9911$

Reported resonances are listed in Table 15.7: see (1970AJ04) for the earlier references and (1976DA1U; $E_\alpha = 1.43$ to 2.94 MeV) and (1969SP02; p_0; $E_\alpha = 10$ to 25 MeV). The yield curve for ^{14}C [1.4 to 2.9 MeV] is dominated by two strong resonances at $E_\alpha = 1.57$ and 2.64 MeV (1976DA1U: CTR implications). The p_0 excitation functions at three angles [10 to 25 MeV] show broad uncorrelated structures (1969SP02). See also ^{14}C.

7. ^{11}B(α, d)^{13}C $\qquad Q_m = -5.1686 \qquad E_b = 10.9911$

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

E_x (MeV)	τ_m (psec)	Reaction	Refs.
5.27	2.9 ± 0.5	^{14}N(d, p)	(1967BI11)
	2.6 ± 0.2	^{12}C(^{3}He, p)	(1975FO06)
	2.5 ± 0.5	^{13}C(^{14}N, ^{12}C)	(1975SE04)
	2.6 ± 0.2	mean	
5.30	$(4.3 \pm 1.8) \times 10^{-2}$	^{14}N(d, p)	(1965AL19)
	$(2.2 \pm 0.7) \times 10^{-2}$	^{14}N(n, γ)	(1969WE07)
	$(2.5 \pm 0.7) \times 10^{-2}$	mean	
6.32	< 0.040	^{14}N(n, γ)	(1969WE07)
	$(0.35 \pm 0.07) \times 10^{-3}$	^{15}N(e, e)	(1975KI08)
	$(0.21 \pm 0.02) \times 10^{-3}$	^{15}N(γ, γ)	(1975MO28)
7.16 [b]	0.155 ± 0.025	^{13}C(^{3}He, p)	(1966LI07)
	0.028 ± 0.008 [A]	^{13}C(^{14}N, ^{12}C)	(1975SE04)
7.30 [c]	< 0.025	^{14}N(d, p)	(1968GI11)
	< 0.050	^{13}C(^{14}N, ^{12}C)	(1975SE04)
	$(0.25 \pm 0.10) \times 10^{-3}$	^{15}N(e, e)	(1975KI09)
7.57 [b]	0.15 ± 0.05	^{13}C(^{3}He, p)	(1966LI07)
	0.06 ± 0.02 [A]	^{14}N(d, p)	(1968GI11)
8.31 [c]	< 0.020	^{14}N(n, γ), (d, p)	(1968GI11, 1969WE07)
8.58	$\lesssim 0.1$	^{13}C(^{3}He, p)	(1972ST22)
9.05	$\lesssim 0.1$	^{13}C(^{3}He, p)	(1972ST22)
9.152	< 0.040	^{13}C(^{3}He, p)	(1972ST22)
9.155	(< 0.010)	^{14}N(n, γ)	(1969WE07)
9.23	< 0.13	^{13}C(^{3}He, p)	(1972ST22)
9.83	< 0.19	^{12}C(^{7}Li, α)	(1969TH01)
9.93	$\lesssim 0.1$	^{13}C(^{3}He, p)	(1972ST22)

A = adopted.

[a] See also Table 15.7 in (1970AJ04) and Table 15.16 here.

[b] See also (1975KI09).

[c] See also (1972ST22).

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

E_{α} (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Particle out	J^{π}	E_x (MeV)	Refs.
0.60		n		11.43	(1954BE08) [b]
1.03		n		11.75	(1954BE08)
1.18		n		11.86	(1954BE08)
1.30		n		11.94	(1954BE08)
1.51		n, p	$(\frac{5}{2}^{+})$	12.10	(1955SH46, 1976DA1U)
1.58		n, p	$(\frac{3}{2}^{-})$	12.15	(1955SH46, 1976DA1U)
2.056 ± 10	34 ± 5	n_0, p_0	$\frac{5}{2}^{+}$	12.499	A, (1975VA06, 1976DA1U)
2.610 ± 13	56 ± 11	n_0, p_0, α	$\frac{3}{2}^{-}$	12.905	A, (1972RA03, 1975VA06, 1976DA1U)
2.66 ± 30	81	p_0, α	$\frac{5}{2}^{+}$	12.94	A, (1972RA03, 1976DA1U)
2.942 ± 10	7 ± 3	n_0, p_0		13.149	A, (1975VA06)
2.984 ± 10	7 ± 3	n_0, p_0		13.179	A, (1975VA06)
3.239 ± 15	16 ± 8	n_0, p, α	$\frac{3}{2}^{-}$	13.366	A, (1972RA03, 1975VA06)
3.31 ± 30	61	p, α	$\frac{3}{2}^{+}$	13.42	A, (1972RA03)
3.46 ± 30	85 ± 30	n_0, α	$\frac{3}{2}^{-}$	13.53	(1972RA03, 1975VA06)
3.560 ± 10	18 ± 4	n_0, p	$(\frac{5}{2}, \frac{7}{2})^{-}$	13.602	A, (1975VA06)
3.57 ± 30	94	α	$\frac{1}{2}^{+}$	13.61	(1972RA03)
3.712 ± 10	26 ± 8	n_0		13.713	A, (1975VA06)
(3.78 ± 30)	70	α	$(\frac{1}{2}^{+})$	(13.76)	(1972RA03)
3.89 ± 30	≈ 70	n_1, α	$(\frac{3}{2}^{+})$	13.84	(1972RA03, 1975VA06)
4.09 ± 30	≈ 100	n_1		13.99	(1975VA06)
4.232 ± 10	22 ± 6	n_0		14.094	(1975VA06)
4.24 ± 30	≈ 100	n_1, α	$\frac{3}{2}^{+}$	14.10	(1972OT04, 1975VA06)
4.324 ± 10	27 ± 6	n_0		14.162	A, (1975VA06)
4.43 ± 40	150	α	$\frac{5}{2}^{+}$	14.24	(1972OT04)
4.62 ± 40	100	α	$\frac{7}{2}^{+}$	14.38	(1972OT04)
4.85 ± 20	200 ± 50	n_0		14.55	(1975VA06)
4.986 ± 10	33 ± 6	n_0		14.647	(1975VA06)
5.11 ± 30	110 ± 50	n_0		14.74	(1975VA06)
5.28 ± 20	48 ± 11	n_0, α		14.86	(1972OT04, 1975VA06)
5.538 ± 10	12 ± 3	n_0		14.920	(1975VA06)
5.501 ± 10	13 ± 3	n_0		15.025	(1975VA06)
5.59 ± 20	80 ± 25	n_0, α		15.09	(1972OT04, 1975VA06)
5.860 ± 10	22 ± 6	n_0, α		15.288	(1972OT04, 1975VA06)

Table 15.7: Resonances in $^{11}B + \alpha$ [a] (continued)

E_α (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Particle out	J^π	E_x (MeV)	Refs.
5.98 ± 20	75 ± 25	n_2, (α)		15.38	(1972OT04, 1975VA06)
6.06 ± 20	≈ 100	n_0, (α)		15.43	(1972OT04, 1975VA06)
6.19 ± 20	≈ 35	n_0		15.53	(1975VA06)
6.29 ± 20	95 ± 25	n_2		15.60	(1975VA06)
(6.65 ± 40)		(α)		(15.87)	(1972OT04)
6.73 ± 20	35 ± 10	n_0, n_2		15.93	(1975VA06)
6.755 ± 15	21 ± 6	n_1		15.944	(1975VA06)
6.83 ± 20	60 ± 20	n_2		16.00	(1975VA06)
6.884 ± 15	62 ± 12	n_0, α		16.039	(1972OT04, 1975VA06)
(6.98 ± 40)		(α)		(16.11)	(1972OT04)
7.18 ± 20	≈ 100	n_0, α		16.26	(1975VA06)
7.27 ± 20	≈ 30	n_0		16.32	(1975VA06)
7.37 ± 20	44 ± 11	n_2		16.39	(1975VA06)
7.616 ± 15	27 ± 15	n_0, (n_2)		16.575	(1975VA06)
7.754 ± 15	60 ± 10	n_0, (n_2)		16.676	(1975VA06)

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

[a] See also Table 15.5 in (1970AJ04).

[b] And private communication.

The yield of d_0 has been measured for $E_\alpha = 17$ to 22 MeV (1967AL16).

8. $^{11}B(\alpha, t)^{12}C$ $\quad Q_m = -3.8574 \quad E_b = 10.9911$

Excitation functions for t_0 ($E_\alpha = 14$ to 25 MeV) and t_1 ($E_\alpha = 17$ to 25 MeV) show strong uncorrelated structures (1972VA34, 1974DM01). See also ^{12}C.

9. $^{11}B(\alpha, \alpha)^{11}B$ $\quad E_b = 10.9911$

Observed resonances for $E_\alpha = 2.1$ to 7.9 MeV are shown in Table 15.7 (1972OT04, 1972RA03): the yield curves have been fitted by R-matrix analysis. See also ^{11}B in (1975AJ02).

10. $^{11}B(\alpha, 2\alpha)^{7}Li$ $\quad Q_m = -8.666 \quad E_b = 10.9911$

See (1969FU09, 1974JE1A) and ^{7}Li in (1974AJ01).

11. ^{11}B(^{6}Li, d)^{15}N $Q_{\rm m} = 9.517$

At $E(^{6}\text{Li}) = 4.72$ MeV, angular distributions are reported for the deuteron groups corresponding to ^{15}N*(0, $5.27 + 5.30$, 6.32, $7.16 + 7.30$, 7.57, 8.31, 8.58, $9.05 + 9.15$) (1966MC05). At $E(^{6}\text{Li}) = 34$ MeV this reaction appears to be less selective than reaction 12. The most strongly populated states are ^{15}N*(10.5, 13.05, 14.76, 15.52) (1976NO01). See also (1970AJ04).

12. ^{11}B(^{7}Li, t)^{15}N $Q_{\rm m} = 8.524$

At $E(^{7}\text{Li}) = 5.00$ MeV angular distributions have been reported to the states listed in reaction 11 (1966MC05). At $E(^{7}\text{Li}) = 12$ MeV, angular distributions have been measured to states at $E_{\rm x} = 0$, 5.288 [$3 + 1$], 6.324 [(0)], 7.160, 7.306, 7.565, 8.313 [1]. 8.576 [3], 9.052 [1]. 9.154 [$2 + 1$], 9.224 [2], 9.765 [(2)], 9.827 [2], 9.925 [2], 10.073 [3], 10.458 [2], 10.535 [3], 10.701 [3] and 10.799 [2] MeV (± 0.007 MeV) [the numbers on brackets are reported L-values] (1975EL04). At $E(^{7}\text{Li}) = 24$ and 34 MeV, angular distributions to many of the same states have been measured (1976KO11, 1976NO01): ^{15}N*(10.69, 13.01, 13.84, 15.37) are particularly strongly populated and $J^{\pi} = \frac{9}{2}^{+}, \frac{11}{2}^{-}, \frac{11}{2}^{+}, \frac{15}{2}^{+}$, respectively (1976KO11). (1976NO01: $E(^{7}\text{Li}) = 34$ MeV) suggest that only ^{14}N*(15.4) has a large cluster component corresponding to $^{11}\text{B} + \alpha$.

13. ^{11}B(^{11}B, ^{7}Li)^{15}N $Q_{\rm m} = 2.326$

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

14. ^{11}B(^{16}O, ^{12}C)^{15}N $Q_{\rm m} = 3.829$

Angular distributions have been measured at $E(^{16}\text{O}) = 27$, 30, 32.5, 35 and 60 MeV involving $^{15}\text{N}_{\rm g.s.} + {}^{12}\text{C}_{\rm g.s.}$, $^{15}\text{N}_{\rm g.s.} + {}^{12}\text{C}^{*}_{4.4}$, $^{15}\text{N}^{*}_{6.32} + {}^{12}\text{C}_{\rm g.s.}$ and $^{15}\text{N}_{\rm g.s.} + {}^{12}\text{C}^{*}_{9.6}$ (1972SC03, 1972SC17, 1975SC35): the reaction selectivity populates the two proton-hole states of ^{15}N: ^{15}N*(0, 6.32) [$J^{\pi} = \frac{1}{2}^{-}$ and $\frac{3}{2}^{-}$, respectively]. See also (1970AJ04), ^{12}C in (1975AJ02), (1972MO1E) and (1970AN1D, 1970SC1G, 1972BO21, 1973DE1W, 1973DE35, 1973OS03, 1974FL1A, 1974OS1A, 1975OS01; theor.).

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

E_t (MeV $\pm$ keV)	E_x (MeV)	Particles out	Refs. [a]
0.66	15.38	α_0	(1963NI04, 1969ET01)
1.11	15.74	p_0, t_0, α_1	(1962GU01, 1962KU09, 1963NI04, 1969ET01)
1.21	15.82	t_0	(1969ET01)
1.30 ± 20	15.89	n, α_0	(1961VA13, 1969ET01)
1.39 ± 20	15.96	n, t_0, α_0	(1961VA13, 1969ET01)
1.46	16.02	p_0	(1969ET01)
1.54	16.08	n, α_0, α_1	(1961VA13, 1969ET01)
1.65 ± 40	16.17	n, α_0	(1961VA13, 1965SE05, 1969ET01)
1.78	16.27	α_0	(1969ET01)
1.85 ± 20	16.33	n, p_0, α_0, α_1	(1961VA13, 1965SE05, 1969ET01)
1.98 ± 20	16.43	n, p_0	(1961VA13, 1969ET01)
2.05 ± 30	16.49	p_0, t_0, α_0	(1965SE05, 1969ET01)
2.18 ± 25	16.59	n, p_0, t_0, α_0, α_1	(1961VA13, 1969ET01)
2.28 ± 30	16.67	(γ), n, p_0, α_0, α_1	(1961VA13, 1965SE05, 1969ET01, 1973SC1G)
2.39 ± 30	16.76	n, t_0, α_0, α_1	(1961VA13, 1965SE05, 1969ET01)
2.50 ± 30	16.85	α_0, α_1	(1965SE05, 1969ET01)
2.60	16.93	α_0	(1969ET01)
2.75	17.05	p_0	(1969ET01)
2.82	17.10	t_0, α_0, α_1	(1969ET01)
2.89 ± 50	17.16	α_0	(1965SE05, 1969ET01)
3.14	17.36	α_1	(1969ET01)
15.0	26.8	t_0	(1972KE02)

[a] And private communication with authors of (1969ET01).

15. (a) ^{12}C(t, γ)^{15}N $\quad Q_{\rm m} = 14.8485$

(b) ^{12}C(t, n)^{14}N $\quad Q_{\rm m} = 4.0149 \quad E_{\rm b} = 14.8485$

(c) ^{12}C(t, p)^{14}C $\quad Q_{\rm m} = 4.6412$

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

(e) ^{12}C(t, α)^{11}B $\quad Q_{\rm m} = 3.8574$

Reported resonances are listed in Table 15.8. The $90°$ excitation function for γ_0 (reaction (a)) in the range $E_{\rm t} = 1$ to 3 MeV shows one very strong resonance (at peak, 8 μb/sr) corresponding to ^{15}N*(16.7): the angular distributions show interference between at least two levels (1973SC1G). For reaction (b) see Table 15.8. See also (1971MA46). The excitation function for p_0 (reaction (c)) has been measured for $E_{\rm t} = 14$ to 17 MeV, and the polarization of p_0 has been studied at $E_{\rm t} = 16$ MeV (1972KE02). See also (1973BA1R; applied). For reaction (c) see Table 15.8, (1970AJ04) and (1972KE02; $E_{\rm t} = 13.5$ to 17.2 MeV; t_0): an anomaly in the elastic scattering is reported at $E_{\rm t} = 15$ MeV. For reaction (d) see Table 15.8. See also ^{11}B and ^{12}C in (1975AJ02) and ^{14}C and ^{14}N here.

16. ^{12}C(α, p)^{15}N $\quad Q_{\rm m} = -4.9661$

Angular distributions have been measured for $E_\alpha = 13.4$ to 42 MeV [see (1970AJ04)], at $E_\alpha = 11.2$ to 17.9 MeV (1971ZE01; p_0) and at 96.8 MeV (1975FA07: see Table 15.9; reduced widths are calculated). At 97 MeV the spectrum at $10.5°$ is dominated by ^{15}N*(15.40) [$J^\pi = \frac{13}{2}^+$]: DWBA calculations have been carried out using a semi-microscopic three-nucleon form factor and several different sets of wave functions (1975FA07). See also (1971AU1E, 1975SP04, 1975VA1K), (1971BU1K, 1971TE10, 1975AR1J; theor.) and ^{16}O in (1977AJ02).

17. ^{12}C(^{6}Li, ^{3}He)^{15}N $\quad Q_{\rm m} = -0.946$

Angular distributions have been measured at $E(^6{\rm Li}) = 30.8$ MeV (1971CH1R) and 60.1 MeV (1975BI06: see Table 15.9). Comparison of the distributions obtained in this reaction and in the (^{6}Li, t) reaction shows analog correspondence for the following pairs of levels, $5.27 - 5.24$, $7.16 - 6.86$, $7.57 - 7.28$, $8.58 - 8.28$, $10.80 - 10.48$, 13.15 (u)–12.84, 15.49 (u)–15.05 [first listed is $E_{\rm x}$ in ^{15}N–second in ^{15}O] (1975BI06). [$E_{\rm x}$ are nominal; u = unresolved.] See also (1974HO1P), (1973OG1A) and (1973ST1D; theor.).

18. ^{12}C(^{7}Li, α)^{15}N $\quad Q_{\rm m} = 12.382$

Angular distributions have been measured at $E(^7Li) = 3.2$ to 4 MeV (1962HO06), 30.3 MeV (1969GL07) and at 35 MeV (1973TS02: see Table 15.9). The mean lifetime of $^{15}N^*(9.83) < 190$ fsec: see Table 15.6 [$E_\gamma = 4562.6 \pm 4.0$ keV for the $(9.83 \rightarrow 5.27)$ transition] (1969TH01). Comparison of spectra from this reaction ($E(^7Li) = 34.9$ MeV) with those from $^{13}C(^6Li, \alpha)$ [reaction 31] lead to configurations of $(d)^3$ for $^{15}N^*$(10.7, 12.57, 13.20, 15.42) and suggest that $^{15}N^*$(12.57, 13.20) have lower J than $^{15}N^*$(10.7, 15.5), probably $J \leq \frac{7}{2}$. $^{15}N^*(13.00)$ is shown to be $p(d)^2$ in agreement with $J^\pi = \frac{11}{2}^-$ (1976HAZR and private communication). See also (1970CA14, 1972CR1B), (1970OG1A, 1971BA2V, 1973OG1A, 1974FO1J) and ^{19}F in (1978AJ03).

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

E_x (MeV ± keV)			L [a]	J^π [a]
(1975FA07) [a]	(1975BI06) [b]	(1973TS02) [c]		
0		0	1	$\frac{1}{2}^-$
$5.27 + 5.30$	5.27 ± 60	5.295 ± 10 [c]	$2 + 0$	
		6.332 ± 10		
		7.163 ± 10		
	7.24 ± 60			
		7.310 ± 10		
7.57	7.61 ± 60	7.566 ± 10	4	$\frac{7}{2}^+$
		8.320 ± 10		
8.58	8.59 ± 60	8.580 ± 10 [c]	2	$\frac{3}{2}^+$
$9.15 + 9.16$	9.17 ± 60	9.163 ± 10 [c]	$1 + 2$	
	9.84 ± 60	9.828 ± 10 [c]		
		9.932 ± 10		
		10.072 ± 10		
		10.524 ± 10		
10.70	10.73 ± 60	10.700 ± 10 [c]	4	$\frac{9}{2}^+$
		10.808 ± 10		
		11.430 ± 10		
	12.05 ± 60	11.951 ± 10		
	12.36 ± 60	12.320 ± 10 [c]		
	12.64 ± 60	12.559 ± 10 [c,d]		
		12.923 ± 10		
13.01		13.004 ± 10 [c,e]	5	$(\frac{11}{2}^-)$

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

E_x (MeV $\pm$ keV)			L [a]	J^{π} [a]
(1975FA07) [a]	(1975BI06) [b]	(1973TS02) [c]		
13.19	13.15 ± 60	13.173 ± 10 [c,e]	2	
		13.614 ± 10		
		14.087 ± 10		
		14.720 ± 10		
		15.021 ± 10		
15.40	15.49 ± 60	15.373 ± 10 [e]	6	$\frac{13}{2}^+$
		15.782 ± 10		
	15.88 ± 60			
		16.026 ± 10		
	16.18 ± 60	16.190 ± 10		
	16.41 ± 60			
	16.74 ± 60			
	18.02 ± 60			
	19.77 ± 60			

[a] $E_\alpha = 96.8$ MeV. E_x are nominal.
[b] $E(^{6}\text{Li}) = 60.1$ MeV: angular distributions measured for states with $E_x < 16.2$ MeV.
[c] $E(^{7}\text{Li}) = 35$ MeV: angular distributions have been measured for the states labeled by this footnote.
[d] (1973TS02) suggest that this state is not the $T = \frac{3}{2}$ state at 12.52 MeV. (1976HAZR and private communication) report a state at 12.57 ± 0.02 MeV with $J \leq \frac{7}{2}$.
[e] See also (1976HAZR and private communication).

19. (a) ^{12}C(^{10}B, ^{7}Be)^{15}N $Q_m = -3.820$
(b) ^{12}C(^{11}B, 2α)^{15}N $Q_m = 3.716$

At $E(^{10}\text{B}) = 100$ MeV angular distributions have been measured for ^{15}N*(5.27, 7.57, 9.87, 10.87, 13.15, 15.72, 16.26, 17.83) and comparisons have been attempted with those to states in ^{15}O, in the mirror reaction (1973NA09) [see ^{15}O]. (1974AN36: $E(^{10}\text{B}) = 100$ MeV), on the other hand, report population of ^{15}N*(0, 5.24, 7.28, 9.64, 10.47, 12.89, 15.36, 15.88). ^{15}N*(12.89, 15.36) are the most intense groups (1974AN36). See also (1973BR1C, 1973SC1B). For reaction (b) see (1974EY01).

20. ^{12}C(^{18}O, ^{15}N)^{15}N $\quad Q_m = -0.986$

See (1974CH1Q).

21. ^{12}C(^{19}F, ^{16}O)^{15}N $\quad Q_m = 3.149$

At $E(^{19}\text{F}) = 40$, 60 and 68.8 MeV angular distributions have been measured for the transitions involving ^{15}N*(0, 5.3) and various ^{16}O states: ^{15}N*(5.3) is veryy strongly excited (1972SC17). See also (1975PU02), (1969VO1D, 1972MO1E, 1973SC1J) and (1972BO21; theor.).

22. ^{13}C(d, γ)^{15}N $\quad Q_m = 16.1597$

The 90° yields of the γ_0 have been measured for $E_d = 1$ to 4.2 MeV (1973WE12) and 3 to 10 MeV (1975DE1M). In the lower energy region, a resonance is observed at $E_d = 1.73 \pm 0.05$ MeV, $\Gamma_{lab} \approx 600$ keV, peak cross section ≈ 1.6 μb/sr; assuming E1, ^{15}N*(17.7) has $J^\pi = \frac{1}{2}^+$ or $\frac{3}{2}^+$ (1973WE12). A resonance is reported at $E_d = 6.63$ MeV over a generally monotonic decrease in cross section for $E_p = 3$ to 10 MeV (1975DE1M): see Table 15.10.

23. ^{13}C(d, n)^{14}N $\quad Q_m = 5.3260 \quad E_b = 16.1597$

Observed resonances are displayed in Table 15.10: see (1970AJ04) for the earlier references and (1973BO10: $E_d = 4.75 \rightarrow 5.35$ MeV; n_1). Polarization measurements have been carried out at $E_d = 2.65$ to 3.90 MeV (1972ME06; n_0, n_1, n_2). See also (1970LI1R) and ^{14}N.

24. ^{13}C(d, p)^{14}C $\quad Q_m = 5.9524 \quad E_b = 16.1597$

Observed resonances are displayed in Table 15.10: see (1970AJ04) for the earlier references and (1971PU01: $E_d = 0.4$ to 0.85 MeV; p_0) and (1973BO10: $E_d = 4.75$ to 5.3 MeV). See also (1970LI1E, 1971LI1K), (1972FI1E, 1973FI1C) and ^{14}C.

25. ^{13}C(d, d)^{13}C $\quad E_b = 16.1597$

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

E_d (MeV)	Particles out	Γ_{lab} (keV)	$^{15}N^*$ (MeV)	Refs.
0.37	p		16.48	(1956VA17)
0.64	n, p_0, t_0	≈ 100	16.71	(1950CU13, 1950RI57, 1953KO42, 1956MA46, 1956VA17, 1971PU01)
0.85	n, p_0	≈ 400	16.90	(1950RI57, 1971PU01)
1.10	α_0	broad	17.11	(1956MA35, 1966KL06, 1966KL1A)
1.24 ± 0.04	t_0, (α_0)	≈ 200	17.23	(1956MA46, 1966KL1A)
1.40 ± 0.04	p_0, t_0, α_0	≈ 400	17.37	(1956MA35, 1956MA46, 1966KL1A)
1.55 [a]	n	≈ 100		(1941BE1A, 1950RI57, 1966KL06)
1.64 ± 0.04	t_0	≈ 200	17.58	(1956MA35)
1.75 ± 0.04	γ_0, n, α_0	≈ 600	17.67	(1950RI57, 1955MA76, 1956MA35, 1973WE12)
1.80 ± 0.01	(p_0), t_0, α_1	55 ± 10	17.72	(1956MA35, 1956MA46)
2.20 ± 0.01	(n), α_0, α_1	22 ± 4	18.06	(1956MA35, 1963AL21)
2.23 ± 0.02	(n), p_0, t	≈ 50	18.09	(1956MA35, 1956MA46, 1963AL21)
2.45 ± 0.03	n, p_0, α_0	270 ± 70	18.28	(1955MA76, 1956MA35, 1956MA46)
3.46 ± 0.03	n	≈ 150	19.16	(1955MA76, 1963DE19)
5.1	n_1, p_0	≈ 50	20.6	(1973BO10)
6.63	γ_0		21.90	(1975DE1M)

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

Excitation functions for elastically scattered deuterons have been measured for $E_d = 0.4$ to 0.85 MeV (1971PU01) and 4.5 to 5.7 MeV (1968CO04). A polarization study is reported at $E_d = 15$ MeV (1974BU06; d_0). See also (1970LI1E), (1970GU01; theor.) and ^{13}C.

26. $^{13}C(d, t)^{12}C$ $Q_m = 1.3112$ $E_b = 16.1597$

Observed resonances are listed in Table 15.10 (1956MA35). In the t_0 yield for $E_d = 0.4$ to 0.85 there appears to be some indication of the 0.6 MeV resonance (1971PU01). Polarization measurements have been carried out a $E_d = 12.1$ MeV (1971DE03; t_0, t_1) and 15 MeV (1974LU06; t_0). See also (1970LI1E, 1971LI1K) and ^{12}C in (1975AJ02).

27. $^{13}C(d, \alpha)^{11}B$ $Q_m = 5.1686$ $E_b = 16.1597$

Observed resonances are listed in Table 15.10 (1956MA35, 1966KL1A). The yield of α_0 and α_1 shows a monotonic increase for $E_d = 0.4$ to 0.85 MeV (1971PU01). See also (1970LI1E, 1971LI1K) and ^{11}B in (1975AJ02).

28. $^{13}C(t, n)^{15}N$ $Q_m = 9.9021$

Not reported.

29. $^{13}C(^3He, p)^{15}N$ $Q_m = 10.6659$

Observed proton groups and γ-rays are listed in Table 15.11. Gamma ray branching ratios are displayed in Table 15.5 which also shows J^π values obtained from angular correlation measurements: see (1970AJ04) for the earlier measurements and (1971ST1F, 1972ST22). The two states at $E_x = 9.16$ MeV are separated by 2.5 ± 0.5 keV (1968ST10). Lifetimes are displayed in Table 15.6 (1966LI07, 1972ST22, 1975FO06).

Angular distributions have been measured at $E(^3He) = 5$ MeV for the proton groups to ^{15}N*(0, 5.27 + 5.30, 6.32, 7.16, 7.30, 7.57, 9.05, 9.15, 9.22). This study, in conjunction with angular correlation measurements, leads to an assignment of $J^\pi = \frac{1}{2}^-$ for ^{15}N*(9.22) and is consistent with $J = \frac{5}{2}$ for ^{15}N*(9.152) (1972ST22). The p_0 angular distribution has also been measured for $E(^3He) = 15$ MeV (1975HA33). The g-factor for ^{15}N*(5.27) [$J^\pi = \frac{5}{2}^+$] has been measured to be $+(0.9 \pm 0.3)$ (1975FO06). See also ^{16}O in (1977AJ02).

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

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

[a] E_γ, except for $E_x = 10.94$ MeV; errors for E_γ are nominal.
[b] ^{13}C(α, d)^{15}N: $E_\alpha = 40.1$ MeV.
[c] (1969LU07) also reports levels at $E_x = 11.950 \pm 0.020$ ($J^\pi = (\frac{9}{2}^-)$), 12.318 ± 0.030 and 13.028 ± 0.020 MeV ($J^\pi = (\frac{11}{2}^-)$).

30. ^{13}C(α, d)^{15}N $\qquad Q_m = -7.6879$

This reaction has been studied at $E_\alpha = 40.1$ MeV: see Table 15.11 (1969LU07). Angular distributions for the d_0 group have been measured at $E_\alpha = 18.7$, 20.4 and 25.8 MeV (1973LE28). See also (1971BU1K; theor.).

31. ^{13}C(^{6}Li, α)^{15}N $\qquad Q_m = 14.686$

Angular distributions have been measured for $E(^6\text{Li}) = 3.2$ to 3.8 MeV (1964BL1B; α_0, α_{1+2}). This reaction has also been studied at $E(^6\text{Li}) = 32$ MeV (1976HAZR and private communication): see reaction 18 for discussion. See also (1974CO13) and ^{19}F in (1978AJ03).

32. ^{13}C(^{11}B, ^{9}Be)^{15}N $\qquad Q_m = 0.343$

At $E(^{11}\text{B}) = 114$ MeV, strong population of ^{15}N*(7.57, 9.83, 11.95, 13.03, 15.1, 16.1, 18.7, 19.2) is reported by (1974AN36, 1975PO10): the dominant group is ^{15}N*(13.03). See also (1970AJ04).

33. ^{13}C(^{14}N, ^{12}C)^{15}N $\qquad Q_m = 5.887$

The mean lifetimes of ^{15}N*(5.27, 7.16, 7.30) are 2.5 ± 0.5 psec, 28 ± 8 fsec and < 50 fsec, respectively (1975SE04): see Table 15.6. See also (1975SE03).

34. ^{13}C(^{17}O, ^{15}N)^{15}N $\qquad Q_m = 2.114$

See (1974CH1Q).

35. ^{14}C(p, γ)^{15}N $\qquad Q_m = 10.2073$

Observed resonances are displayed in Table 15.12; the branching ratios are shown in Table 15.5: see the earlier references in (1970AJ04) and (1970RA22, 1971KU01, 1971YO03, 1972RA03, 1972WE07, 1973WE04, 1974WE01, 1975BE23, 1975HA39, 1976BE1B, 1976KU01). The angular distribution of the $(10.81 \rightarrow 8.31)$ γ-ray fixes $J = \frac{1}{2}$ for ^{15}N*(8.31). A triple correlation measurement of the decay of ^{15}N*(10.81) to $E_x = 9.15$ MeV leads to $J = \frac{3}{2}$ for the lower and $J = \frac{5}{2}$ for the upper of these two states (1969SI04 and private communication). Besides the sharp resonances seen at $E_p < 2.5$

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

E_p (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Γ_n (keV)	Γ_p (keV)	Γ_α (keV)	Γ_γ (eV)	J^π	E_x (MeV ± keV)	Refs.
0.261 ± 0.6	< 0.5		$(0.08 \pm 0.01) \times 10^{-6}$		> 21 meV	$\frac{5}{2}^-$	10.4497 ± 0.3 [f]	A, (1975BE23, 1976BE1B)
0.352 ± 1					$(3.4 \pm 0.4) \times 10^{-2}$ [b]	$\frac{5}{2}^+$	10.5333 ± 0.5 [f]	A, (1975BE23, 1976BE1B)
0.519 ± 1			$(0.49 \pm 0.10) \times 10^{-3}$		> 40 meV	$\frac{9}{2}^+$	10.6932 ± 0.3 [f]	(1975BE23, 1976BE1B)
0.527 ± 1			0.2		0.37 ± 0.07	$\frac{3}{2}^-$	10.7019 ± 0.3 [f]	A, (1976BE1B)
0.634 ± 1			$(0.22 \pm 0.10) \times 10^{-3}$		0.27 ± 0.14	$\frac{3}{2}^{(+)}$	10.804 ± 2 [f]	A, (1975BE23, 1976BE1B)
1.162 ± 2	7.9 ± 3	2.3	5.6	< 0.3	0.29	$\frac{1}{2}^-$	11.291	A
1.3188 ± 0.5	41.4 ± 1.1	34.6 ± 0.9	6.8 ± 0.5	< 0.3	4.2 ± 0.7	$\frac{1}{2}^+$	11.4375	A
1.509 ± 4	404.9 ± 6.3	4.0 ± 0.2	400.9 ± 6.3	< 0.3	19.2 ± 0.4	$\frac{1}{2}^+; T = \frac{3}{2}$	11.615	A, (1971KU01, 1975HA39)
1.688 ± 3	37	36.5	0.5	< 0.3		$\frac{3}{2}^+$	11.782	A
1.788 ± 3	24.5	24.5	0.03	< 0.3		$\frac{3}{2}^-, (\frac{5}{2}^-)$	11.875	A
1.884 ± 3	21.5	21.2	0.3	< 0.3		$\frac{1}{2}^-$	11.965	A
2.025 ± 4	14 ± 5	12.0	1.7	0.6		$\frac{5}{2}^+$	12.096	A
2.077 ± 3	47 ± 7	30.2	16.6	2.2		$\frac{3}{2}^-$	12.145	A
2.272 ± 4	22	21.7	0.3	< 0.3		$\frac{5}{2}^{(+)}$	12.327	A
2.450 ± 4	44 ± 3	28	0.3	5.5		$\frac{5}{2}^+; T = \frac{1}{2}$	12.493	A, (1971YO03)
2.482 ± 8	58 ± 4				4.6 ± 0.7	$\frac{5}{2}^+; T = \frac{3}{2}$	12.522	A, (1971KU01, 1971YO03, 1975HA39)
2.908 ± 4	70	25	9.0	15		$\frac{3}{2}^-$	12.920	A, (1972RA03, 1974WE06)
2.93 ± 10	81	n.r.	0.5	80		$\frac{5}{2}^+$	12.940	(1972RA03)
3.19	5.5						13.18	A
3.38 ± 10	24	6	6.0	12		$\frac{3}{2}^-$	13.360	A, (1972RA03, 1974WE06)
3.42 ± 10	57	20.6	35	5.5	3.0 ± 0.9	$\frac{3}{2}^+$ [d]	13.390	A, (1970RA22, 1972RA03, 1974WE06, 1975HA39, 1976KU01)
3.57 ± 10	124	≈ 75	8.0	≈ 40		$\frac{3}{2}^-$	13.537	(1972RA03, 1974WE06)
3.65 ± 10	88	≈ 16	12.0	≈ 60		$\frac{1}{2}^+$	13.612	(1972RA03, 1974WE06)
3.71 [c]							13.67	A
4.0 [c]	930		500		r	$\frac{1}{2}^+$	13.9	(1974WE06, 1975HA39)
4.1 ± 100	98 ± 10		25	r		$\frac{5}{2}^+$	14.0	(1974WE06, 1975WE09)
4.2 ± 100				r		$(\frac{3}{2})$	14.1	(1975WE09)
4.6 ± 150	74 ± 7		20	r	(r)	$\frac{3}{2}^-$	14.5	(1974WE06, 1975WE09)
4.8	149 ± 18		39	r	(r)	$\frac{3}{2}^+$	14.7	(1972WE07, 1974WE06, 1975WE09)
4.83	750				r		14.71	(1975HA39)
5.08	158 ± 19		20			$\frac{3}{2}^+$	14.95	(1974WE06, 1975WE09)
5.16 ± 130	28 ± 3		9.0	r		$\frac{3}{2}^+$	15.0	(1974WE06, 1975WE09)
5.54 ± 130	39 ± 5		12	r	(r)	$\frac{3}{2}^-$	15.4	(1972WE07, 1974WE06, 1975WE09)
5.62	750				r		15.45	(1975HA39)
6.4 ± 150	130 ± 14		19	r		$\frac{3}{2}^+$	16.2	(1974WE06, 1975WE09)
6.70	560				r		16.46	(1975HA39)
6.85 ± 180	100 ± 50			r		$\frac{5}{2}, \frac{3}{2}^+$	16.6	(1975WE09)
6.925	90 ± 10			r	r	$\frac{3}{2}^+; \frac{1}{2}$	16.67	(1975HA39)
7.18 ± 180	110 ± 50			r		$\frac{5}{2}$	16.9	(1975WE09)
≈ 9					r	$\frac{1}{2}^+; \frac{1}{2}$	19	(1973WE04, 1974WE01)
10.0	sharp		(1000)		r	$\frac{3}{2}^+; (T = \frac{3}{2})$	19.5 [e]	(1973WE04, 1974WE01, 1974WE07, 1975HA39)
11.0	sharp				r	$\frac{3}{2}^+$	20.5	(1973WE04, 1974WE01, 1975HA39)
12.35					r		21.72	(1975HA39)
13.65					r		22.94	(1975HA39)
16.4					r	$(T = \frac{3}{2})$	25.5 [e]	(1975HA39)
≈ 29							≈ 37	(1975HA39)

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

r = resonant.

n.r. = non-resonant.

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

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

[c] See also (1972RA1C).

[d] (1970RA22, 1972RA03) suggest that this state has $T = \frac{3}{2}$: however, no analog state has been observed in ^{15}C (see, e.g., Fig. 13). See also (1971KU1B, 1972WE07, 1975HA39).

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

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

MeV, broad structures are observed at $E_p \approx 4.8$ and 5.8 MeV in the $60°$ yield for $E_p = 3.2$ to 12 MeV (1972WE07): the angular distributions are isotropic. In the $90°$ γ_0 yield a shoulder in the cross section is observed at $E_p \approx 9$ MeV and two large structures are reported at $E_p \approx 10$ and 10.8 MeV (1973WE04). Studies of angular distributions by (1973WE04) and a study using polarized protons ($E_p = 4.85$ to 12.45 MeV (1974WE01)) lead to $J^\pi = \frac{1}{2}^+, \frac{3}{2}^+$ and $\frac{3}{2}^+$ respectively for the corresponding ^{15}N states. Both E2 and M1 transitions are present in the giant dipole resonance region (1974WE01). (1975HA39: γ_0 yield for $E_p = 2.8$ to 30 MeV) find that the $T = \frac{1}{2}$ and $\frac{3}{2}$ components of the GDR are located near $E_x = 20$ and 26 MeV. Narrow anomalies are reported at $E_p = 10.0$ and 11.0 MeV (relative strength is not in agreement with (1973WE04)), 12.35, 13.6 and 16.4 MeV. Above the giant dipole resonance region the $90°$ γ_0 cross scetion decreases smoothly with energy except for a small peak which would correspond to ^{15}N*(37.0) (1975HA39). See also (1973PA1P, 1973SU1E) and (1970TI1A, 1974DI15, 1975MA2H; theor.).

36. ^{14}C(p, p)^{14}C $\qquad E_b = 10.2073$

Observed anomalies in the elastic scattering are displayed in Table 15.12. See (1970AJ04) for the earlier work and (1970RA22, 1972RA03: $E_p = 2.7$ to 4.0 MeV) and (1974WE06, 1974WE07: $E_p = 4$ to 12.5 MeV). Polarization measurements have been carried out for $E_p = 3.2$ to 5.7 MeV (1974WE06). See also (1969IW1A, 1974DI15; theor.).

37. ^{14}C(p, n)^{14}N $\qquad Q_m = -0.6263 \qquad E_b = 10.2073$

Observed resonances are listed in Table 15.12: see (1970AJ04) for the earlier references and (1971YO03: $E_p = 2.3$ to 2.6 MeV; n_0) and (1970RA22, 1972RA03: $E_p = 2.6$ to 3.9 MeV for n_0 and 3.3 to 4.4 MeV for n_1). Polarization measurements are reported at several energies in the range $E_p = 7.2$ to 13.3 MeV (1971WO03; n_0, n_1, n_2). See also ^{14}N and (1970TI1A, 1971DU1B; theor.).

38. ^{14}C(p, α)^{11}B $\qquad Q_m = -0.7837 \qquad E_b = 10.2073$

Observed resonances are displayed in Table 15.12: see (1970RA22, 1972RA03: $E_p = 2.8$ to 4.0 MeV; α_0) and (1975WE09: $E_p = 3.9$ to 7.5 MeV; α_0). See also ^{11}B in (1975AJ02).

39. ^{14}C(d, n)^{15}N $\qquad Q_m = 7.9827$

Angular distributions have been measured at $E_d = 1.3$ to 6.5 MeV: see (1970AJ04) and (1975BO34, 1975BO35: $E_d = 6.5$ MeV; for $E_x < 12.1$ MeV; see for spectroscopic factors). The transitions to ^{15}N*(5.30, 9.05) involve $l_p = 0$: therefore $J^\pi = \frac{1}{2}^+$ (1967LA11, 1975BO34, 1975BO35); while $l = 2$ is involved in the population of ^{15}N*(9.23) (1975BO34, 1975BO35): see, however, reaction 29. For studies of the γ-decay of states observed in this reaction see Table 15.5. See also ^{16}N in (1977AJ02).

40. ^{14}C(^{3}He, d)^{15}N $\qquad Q_m = 4.7136$

Angular distributions have been measured at $E(^3\text{He}) = 14$ MeV (1969AL04; $d_0 \rightarrow d_3$) and for 1 to 9 MeV (d_0: see (1970AJ04)).

41. ^{14}C(α, t)^{15}N $\qquad Q_m = -9.6073$

Not reported.

42. ^{14}C(^{14}N, ^{13}C)^{15}N $\qquad Q_m = 2.657$

See (1975VO1B).

43. (a) ^{14}C(^{16}O, ^{15}N)^{15}N $\qquad Q_m = -1.920$
(b) ^{14}C(^{18}O, ^{17}N)^{15}N $\qquad Q_m = -5.735$

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

44. ^{14}N(n, γ)^{15}N $\qquad Q_m = 10.8337$
$Q_0 = 10833.64 \pm 0.13$ keV (1974GR37);
$Q_0 = 10833.395 \pm 0.030$ keV (1975SM02); see also (1969JO1G).

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

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

Transition in ^{15}N	E_γ [a] (keV) (1974GR37)	E_x (keV) (1974GR37)	I_γ [c] (1967TH05)	(1969JO1G)	(1971BE34)
C → 0	10829.44 ± 0.13	10833.64 ± 0.13	13.3 ± 2.0		13.8 ± 0.2
C → 5.27	5562.18 ± 0.10		10.3 ± 0.5	10.4 ± 0.7	10.3 ± 0.4
C → 5.30	5533.38 ± 0.12		18.8 ± 0.9	18.5 ± 1.3	18.9 ± 0.4
C → 6.32	4509.06 ± 0.11		16.6 ± 0.8	16.5 ± 1.2	15.3 ± 0.4
C → 7.16	3677.80 ± 0.09		15.9 ± 0.8	15.0 ± 1.4	16.2 ± 0.3
C → 7.30	3532.10 ± 0.15		9.9 ± 0.5	9.3 ± 0.6	10.2 ± 0.1
C → 8.31	2520.62 ± 0.11		6.1 ± 0.3	6.0 ± 0.4	5.8 ± 0.3
C → 9.05					0.7 ± 0.4
C → 9.152	1681.30 ± 0.19		1.4 ± 0.3 [d]	1.7 ± 0.4	
C → 9.155	1678.27 ± 0.05		9.2 ± 0.5	8.0 ± 1.0	9.5 ± 0.3
C → 9.76		9757.5 ± 3 [f]			0.2 ± 0.05
C → 9.93		9927.5 ± 3 [e]		0.2 ± 0.1	0.1 ± 0.04
5.27 → 0	5269.36 ± 0.10	5270.35 ± 0.10	30.6 ± 1.5	31.4 ± 2.2	31.2 ± 0.7
5.30 → 0	5298.16 ± 0.12	5299.16 ± 0.17	21.4 ± 1.1	21.4 ± 1.5	22.2 ± 0.4
6.32 → 0	6322.42 ± 0.12	6323.85 ± 0.12	18.8 ± 0.9	18.4 ± 1.3	18.1 ± 1.3
7.16 → 0		7155.36 ± 0.11			
7.16 → 5.27	1884.88 ± 0.12		19.7 ± 1.0	18.3 ± 1.5	20.5 ± 0.2
7.16 → 5.30	1857 ± 2 [b]		0.8 ± 0.2	0.4 ± 0.2	
7.30 → 0	7299.18 ± 0.17	7301.09 ± 0.17	10.0 ± 0.5	9.2 ± 1.0	9.2 ± 0.2
7.30 → 5.30					1.2 ± 0.4
8.31 → 0	8310.32 ± 0.14	8312.79 ± 0.14	4.4 ± 0.4	3.8 ± 0.4	3.6 ± 0.1
8.31 → 5.30	3013.7 ± 0.6 [e]			0.7 ± 0.2	1.1 ± 0.4
8.31 → 6.32	1989 ± 2 [b]		1.5 ± 0.3	0.5 ± 0.2	1.5 ± 0.2
8.57 → 0	8570 ± 4 [b]	8573 ± 4 [b]	0.2 ± 0.03	0.1 ± 0.05	0.2 ± 0.04
8.57 → 5.27	3299.7 ± 1.5 [e]			0.2 ± 0.1	
9.05 → 0	9047 ± 4 [b]	9050 ± 4 [b]	0.2 ± 0.03	0.2 ± 0.1	0.3 ± 0.05
9.152 → 0	9149.24 ± 0.22	9152.24 ± 0.22	1.7 ± 0.2	1.6 ± 0.2	
9.155 → 0		9155.27 ± 0.11			1.6 ± 0.07
9.155 → 5.27	3884.38 ± 0.10		0.8 ± 0.1	0.9 ± 0.2	0.8 ± 0.2
9.155 → 5.30	3855 ± 2 [b]		1.0 ± 0.1	1.0 ± 0.2	0.4 ± 0.04

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

Transition in ^{15}N	E_γ [a] (keV) (1974GR37)	E_x (keV) (1974GR37)	I_γ [c] (1967TH05)	(1969JO1G)	(1971BE34)
$9.155 \rightarrow 6.32$	2831.13 ± 0.11		2.0 ± 0.2	2.0 ± 0.3	2.4 ± 0.4
$9.155 \rightarrow 7.16$	1999.78 ± 0.09		4.6 ± 0.2	4.2 ± 0.3	3.9 ± 0.4
$9.155 \rightarrow 7.30$					0.9 ± 0.2

C = capturing state.

[a] See also (1969JO1G, 1969VA1B, 1971BE34, 1974IS06).

[b] (1967TH05).

[c] In units of photons/100 captures.

[d] (1968GR14).

[e] (1969JO1G).

[f] (1971BE34).

Observed γ-rays are displayed in Table 15.13 (1967TH05, 1968GR14, 1969JO1G, 1971BE34, 1974GR37). The very accurate γ-ray measurements of (1968GR14, 1974GR37) show that two states at $E_x = 9.1$ and 9.155 MeV are involved in this reaction. The lower state decays preferentially to the ground state. The state at 9.155 MeV is fed preferentially in this reaction and decays primarily via cascades: see Tables 15.5 and 15.13. For τ_m measurements see Table 15.6. See also (1967RA24, 1972LO26, 1975SH18) and (1968FOZY, 1973CL1E; astrophys. considerations).

45. ^{14}N(n, n)^{14}N $\qquad E_b = 10.8337$

The thermal (bound) scattering cross section is 5.51 b (1961WI1A). The scattering amplitude (bound) is $a = 9.38 \pm 0.03$ fm [recommended by (1973MU14)]. The coherent scattering cross section is 10.6 ± 0.5 b (1973MU14).

Older cross section data are summarized in (1964ST25, 1970GA1A) and the older measurements are displayed in Table 15.13 of (1970AJ04) [$E_n = 0.01 \rightarrow 152$ MeV]. Recent measurements of the total cross section include those by (1970CA1F: high resolution; $E_n = 0.5$ to 9.0 MeV), (1974SC1C: high resolution; $E_n = 0.5$ to 25 MeV), (1971FO1P, 1971FO24: 2.5 to 15 MeV), (1971AN16: 14.7 MeV) and (1972AU01: 36.3, 46.2, 49.1, 54.4 and 58.9 MeV). The elastic cross section has been measured at forward angles for $E_n = 7.40$ to 9.50 MeV (1974BU19). For polarization measurements see (1969IV1A: 0.01 to 40 eV). See also (1970KN1B) and (1970AJ04).

Observed resonances are shown in Table 15.14: for a discussion of the evidence leading to J^π assignments see (1959AJ76).

Cross sections for production of γ-rays due to the decay of excited states of ^{14}N have been measured in the range $E_n = 4 - 20$ MeV (1974ROXP; σ_t), 4.2, 5.9 and 6.9 MeV (1972NY02), 8.6 to 11.0 MeV (1970DI1A) and 15 MeV (1971NY03). For a discussion of non-elastic cross sections in the range $E_n = 7 - 9$ MeV, see (1971PE19). See also (1970SU01) and ^{14}N.

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

E_{res} (MeV $\pm$ keV)	Γ_{lab} (keV)	Γ_n (keV)	Γ_p (keV)	Γ_α (keV)	J^π	^{15}N* (MeV)	Refs. [b]
0.430 ± 5	3.5	< 3	< 0.01		$\geq \frac{3}{2}$	11.235	A
0.4926 ± 0.65	7.5	< 3	< 10		$\frac{1}{2}^-$	11.2932	A, (1974SC1C)
0.639 ± 5	43	34	9		$\frac{1}{2}^+$	11.430	A, (1974SC1C)
0.998 ± 5	46	45	0.8		$\frac{3}{2}^+$	11.765	A, (1974SC1C)
1.120 ± 6	19	19	0.20		$\frac{3}{2}^-$	11.878	A, (1974SC1C)
1.188 ± 6	≤ 3.2	< 2	< 0.1		$\geq \frac{3}{2}$	11.942	(1952HI12, 1974SC1C)
1.211 ± 7	13	12	0.4		$\frac{1}{2}^-$	11.963	(1952HI12, 1974SC1C)
1.350 ± 7	21	20	0.9	0.4	$\frac{5}{2}^{(+)}$	12.093	A, (1974SC1C)
1.401 ± 8	54	41	11	1.8	$\frac{5}{2}^{(+)}$	12.141	A, (1974SC1C)
1.595 ± 8	22	21	0.2	< 0.1	$\frac{5}{2}^{(-)}$	12.321	A, (1974SC1C)
1.779 ± 10	47	37	0.5	9.0	$(\frac{5}{2}^+)$	12.493	A, (1974SC1C)
2.23	65	39	7.8	18	$\frac{3}{2}^-$	12.91	A, (1974SC1C)
2.47	< 3			r		13.14	(1959GA14)
2.52	≈ 7	r		r		13.18	(1959GA14, 1974SC1C)
2.71	40			r	$\frac{3}{2}^-$	13.36	(1959GA14)
2.74	95		r		$\frac{5}{2}^+$	13.39	(1959GA14)
2.95	20	16	1.1	3.2	$\frac{5}{2}^+$	13.59	A, (1974SC1C)
3.09	60		r	r		13.72	(1959GA14)
3.21	85	r	r	r	$\frac{3}{2}^+$	13.83	A, (1970CA1F, 1974SC1C)
3.51	≈ 20	r	r	r		14.11	(1959GA14, 1970CA1F, 1974SC1C)
3.57	30	r	r	r	$\frac{3}{2}^{(+)}$	14.16	A, (1970CA1F, 1974SC1C)
≈ 3.8	≈ 2000	≈ 1000	200	≈ 1000		14.4	(1959GA14)
4.09	50	r	r	r		14.65	A, (1974SC1C)

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

E_{res} (MeV ± keV)	Γ_{lab} (keV)	Γ_n (keV)	Γ_p (keV)	Γ_α (keV)	J^π	^{15}N* (MeV)	Refs. [b]
≈ 4.2	≈ 300	r	r	r		14.8	(1959GA14, 1974SC1C)
4.38	40			r		14.92	A
4.60		r		r		15.12	A, (1970CA1F, 1974SC1C)
5.03				r		15.52	A
5.60	100			r		16.06	A
5.94				r		16.37	A
6.16	75			r		16.58	A
6.26	100	r		r		16.67	A, (1974SC1C)
6.55	170	r		r		16.94	A, (1974SC1C)
6.94	200	r		r		17.31	(1959GA14, 1959HA13)
7.16				r		17.51	(1959GA14)
7.34	120			r		17.68	(1959GA14)
7.48	180	r		r		17.81	A
7.92	170	r		r		18.22	(1959HA13, 1970CA1F)
8.00	120			r		18.29	A

A: See references for this state in Table 15.14 (1970AJ04).

r = Resonant channel.

[a] See also (1959AJ76) and (1973MU14).

[b] References to (1970CA1F, 1974SC1C) made by inspection of curves by reviewer.

46. ^{14}N(n, 2n)^{13}N $\qquad Q_m = -10.554 \qquad E_b = 10.8337$

Older measurements of cross sections [$E_n = 10$ to 37 MeV] are llisted in Table 15.13 of (1970AJ04). Recent experiments give $\sigma = 8.2 \pm 1.1$ mb at $E_n = 14.7$ MeV (1970IS1B) and 7.45 ± 0.4 mb at 14.78 MeV (1973RO29). See also (1971NY03) and (1973BO1K, 1974KO35).

47. ^{14}N(n, p)^{14}C $\qquad Q_m = 0.6263 \qquad E_b = 10.8337$

The thermal cross section is 1.81 ± 0.05 b (1973MU14). Reported resonances are displayed in Table 15.14. See also Table 15.13 in (1970AJ04) for a listing of the older cross section measurements.

Differential cross sections have been measured at $E_n = 9.0$ to 11.0 MeV for the production of γ-rays from excited states of ^{14}C (1970DI1A). See also (1971NY03, 1972NY02) and ^{14}C. See also (1971CU1B, 1972ED01) and (1971DU1B; theor.).

48. (a) ^{14}N(n, d)^{13}C $\qquad Q_m = -5.3260 \qquad E_b = 10.8337$
(b) ^{14}N(n, np)^{13}C $\qquad Q_m = -7.5507$

Differential cross sections for production of γ-rays from ^{13}C*(3.09, 3.68) have been measured for $E_n = 10$ to 11 MeV by (1970DI1A). See also (1971NY03, 1974ROXP). For reaction (b) see Table 15.13 in (1970AJ04). See also ^{13}C.

49. (a) ^{14}N(n, t)^{12}C $\qquad Q_m = -4.0149 \qquad E_b = 10.8337$
(b) ^{14}N(n, t)^{4}He^{4}He^{4}He $\qquad Q_m = -11.2897$
(c) ^{14}N(n, 2α)^{7}Li $\qquad Q_m = -8.823$

For cross section measurements see Table 15.13 in (1970AJ04). See also (1971NY03), ^{7}Li in (1974AJ01) and ^{11}B and ^{12}C in (1975AJ02).

50. (a) ^{14}N(n, α)^{11}B $\qquad Q_m = -0.1574 \qquad E_b = 10.8337$
(b) ^{14}N(n, nα)^{10}B $\qquad Q_m = -11.6134$

Earlier cross section measurements are displayed in Table 15.13 of (1970AJ04): observed resonances are listed in Table 15.14 here.

Recent work on reaction (a) includes measurements of differential cross sections for the α_0 and α_1 groups for $E_n = 14.8$ to 18.8 MeV (1971SA31), for the 4.4 MeV γ-ray (1974ROXP: $E_n = 6$ to 19 MeV) and for various γ-rays from ^{11}B states with $E_x < 8$ MeV (1970DI1A: $E_n = 9$ to 11 MeV). See also (1971NY03, 1972NY02, 1973BO26) and ^{11}B in (1975AJ02).

51. ^{14}N(d, p)^{15}N $\qquad Q_m = 8.6090$

Proton groups corresponding to levels of ^{15}N are listed in Table 15.15. The J^π assignments are based on PWBA and DWBA analyses: see Tables 15.9 in (1959AJ76) and 15.16 in (1970AJ04) for the earlier angular distribution studies in the range $E_d = 0.5$ to 27 MeV. Recent measurements have been carried out at $E_d = 3.0$ and 3.6 MeV (1971BE2A, 1972AM06, 1973AM1A), 7, 8 and 9 MeV (1969PH02: see also for spectroscopic factors) and 13.6 MeV (1967GO27; p_0). E_x derived form very accurate γ-ray measurements are shown in column B of Table 15.15.

Branching ratios and multipolarities are shown in Table 15.5 and lifetime measurements in Table 15.6. The two states of ^{15}N at $E_x = 9.15$ MeV [see Table 15.5 for branching ratios] are separated by 2.8 ± 0.5 keV (1968ST10, 1970RE04): see also ^{14}N(n, γ).

The probability p_j for transfer of a neutron with $j = \frac{3}{2}$ has been determined for the p_0 group using vector polarized deuterons at $E_d = 10$ and 12 MeV (1970FI07). See also (1967SP09, 1975ZA06), (1975OL1A; applications), (1973DO02, 1974BA19, 1975HS01; theor.) and ^{16}O in (1977AJ02).

52. ^{14}N(t, d)^{15}N $\qquad Q_m = 4.5761$

The d_0 angular distributions have been measured at $E_t = 1.50$, 1.83 and 1.98 MeV (1964SC09).

53. ^{14}N(α, ^{3}He)^{15}N $\qquad Q_m = -9.7448$

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

54. ^{14}N(^{9}Be, ^{8}Be)^{15}N $\qquad Q_m = 9.169$

See (1970AJ04).

55. ^{14}N(^{11}B, ^{10}B)^{15}N $\qquad Q_m = -0.622$

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

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

A: (1950MA65, 1956DO41, 1966GA08).

B: (1965AL19, 1965WA16, 1966AL18, 1967CH19).

[a] 7307, 8319 and 8577 keV (±8 keV) (1956DO41).

[b] For earlier references see Table 15.15 in (1970AJ04).

[c] Isotropic: no clear stripping pattern.

[d] See (1969PH02) for absolute spectroscopic factors.

[e] (1957WA01) find a possible $l = 0$ component.

[f] This is a doublet: see text.

[g] (1972AM06): $E_d = 3.0$ and, in some cases, 3.6 MeV; see for spectroscopic factors.

[h] See (1972AM06): no clear pattern.

See (1967PO13, 1970GO1B).

56. ^{14}N(^{12}C, ^{11}C)^{15}N $\quad Q_m = -7.888$

At $E(^{12}C) = 114$ MeV, the strongly populated states are ^{15}N*(0, 7.5) (1974AN36). See also (1973SC1J).

57. ^{14}N(^{14}N, ^{13}N)^{15}N $\quad Q_m = 0.280$

Angular distributions of the transition to the ground state of ^{15}N have been measured for $E(^{14}N)$ (cm) $= 5.5$ to 16 MeV (1961TO07, 1964JO1A, 1965BE1B, 1965HI1A). Below ≈ 6.5 MeV, the tunneling theory of neutron transfer gives a good account of the data. At higher energies, nuclear absorption of the incident ^{14}N ions occurs (1965HI1A, 1966GA04). See also (1970GO1B) and (1968TO1C, 1970AN1D, 1970KA41, 1970MA57, 1970TR1B, 1971AL1D, 1971AN12, 1971BU23, 1972AN25, 1973OS03, 1974OS1A, 1975OS01; theor.). For earlier theoretical discussions see (1970AJ04).

58. ^{14}N(^{18}O, ^{17}O)^{15}N $\quad Q_m = 2.787$

See (1974SW04).

59. ^{14}N(^{19}F, ^{18}F)^{15}N $\quad Q_m = 0.403$

See (1968GA03, 1971GA13).

60. ^{15}C(β^-)^{15}N $\quad Q_m = 9.772$

The β^- decay takes place to ^{15}N*(0, 5.30, 7.30, 8.31, 8.57, 9.05): see Table 15.2 also for E_x in ^{15}N. Older measurements of γ-ray energies gave $E_\gamma = 5299.03 \pm 0.43$ keV (1967CH19), 8315 ± 6 and 9048 ± 4 keV (1966AL12). See also ^{15}C.

61. ^{15}N(γ, n)^{14}N $\quad Q_m = -10.8337$

See (1971DE1P, 1972GO23; theor.). See also (1970AJ04).

62. (a) ^{15}N(γ, p)^{14}C $\qquad Q_{\rm m} = -10.2073$

(b) ^{15}N(e, p$_0$e$'$)^{14}C $\qquad Q_{\rm m} = -10.2073$

The integrated cross section for transitions to ^{14}C(0) for E_γ up to 30.5 MeV $= 22 \pm 3$ MeV$\cdot$mb, assuming an isotropic angular distribution. Pronounced maxima are observed at $E_\gamma = 19.5$, 20.4, 22.7 and 24.5 MeV. In addition a "pigmy" resonance at $E_\gamma = 15.2$ MeV and less pronounced structures at $E_\gamma = 13.6$ and 17.0 MeV are observed (1964KO10).

A study at $E_{\rm e} = 18.8$, 20.8, 25.7 and 29.7 MeV (reaction (b)) shows a "pigmy" resonance at $E_{\rm x} = 14.8$ 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 $14 < E_{\rm x} < 28$ MeV the reaction goes predominantly via $\frac{1}{2}^+$ or $\frac{3}{2}^+$ (E1) states in ^{15}N; the $T = \frac{3}{2}$ strength is concentrated above 18 MeV (1975MU07) [see also (1975HA39)]. See also (1973DE30) and (1970FR11, 1970HS03, 1972GO23; theor.).

63. ^{15}N(γ, d)^{13}C $\qquad Q_{\rm m} = -16.1597$

For $E_\gamma < 25$ MeV the ^{13}C ground state is reported to be preferentially populated (1973DE30).

64. (a) ^{15}N(γ, γ)^{15}N

(b) ^{15}N(e, e)^{15}N

^{15}N*(6.32) has been excited in reaction (a). Measurements of the angular distribution and polarization confirm $J^\pi = \frac{3}{2}^-$. See Tables 15.5 and 15.16 (1973MO15).

The r.m.s. radius of ^{15}N is 2.580 ± 0.026 fm (1973FE13, 1975SC18) (reaction (b)). See also (1969DA21, 1970DA20). The inelastic scattereing of ^{15}N*(5.27, 5.30, 6.32, 7.16, 7.30, 7.57, 9.15) has been reported by (1975KI08, 1975KI09): see Table 15.16 for Γ_{γ_0}, B(E3) and mixing ratios. See also (1970DA20).

See also (1971FL1B, 1973FL1B), (1972THZF, 1973TH1B, 1974DE1E) and (1973GA19; theor.).

65. ^{15}N(n, n)^{15}N

Table 15.16: Ground state radiative widths from ^{15}N(e, e$'$)^{15}N [a]

State in ^{15}N	J^π	Transition	Γ_{γ_0} (eV)	B(E3)↑ ($e^2 \cdot$ fm^6)	Mixing ratio δ(E2/M1)
5.27	$\frac{5}{2}^+$	E3	$(4.2 \pm 0.3) \times 10^{-6}$	293 ± 20	
		M2	$(1.2 \pm 0.7) \times 10^{-4}$		
5.30	$\frac{1}{2}^+$	E1	2.2 ± 2.3		
6.32 [b]	$\frac{3}{2}^-$	E2	0.050 ± 0.004		0.16 ± 0.03 [c]
		M1	1.9 ± 0.4		
7.16	$\frac{5}{2}^+$	E3	$(0.86 \pm 0.10) \times 10^{-5}$	71 ± 8	
7.30	$\frac{3}{2}^+$	E1	2.6 ± 1.0		
		M2	$(0.3 \pm 0.2) \times 10^{-5}$		
7.57	$\frac{7}{2}^+$	E3	$(1.84 \pm 0.16) \times 10^{-5}$	136 ± 12	
9.15	$\frac{3}{2}^-$	E2	0.095 ± 0.005		> 0.3
		M1	0.2 ± 0.8		

[a] (1975KI08, 1975KI09). See also Tables 15.5 and 15.6.

[b] See also (1968BE14).

[c] 0.137 ± 0.005 (1975MO28: (γ, γ)).

For angular distributions see (1971ZE02: $E_n = 0.8$ to 3.1 MeV) and ^{16}N in (1971AJ02). See also (1974HO1L; theor.) and ^{16}N in (1977AJ02).

66. ^{15}N(p, p)^{15}N

The angular distribution of inelastically scattered protons has been measured at $E_p = 39.8$ MeV (1969SN04) and 22.4, 24.5, 26 and 39.8 MeV (1974PI05). See also (1971RO1H, 1971RO1J; unpublished) for distributions to excited states of ^{15}N and (1972FR1G, 1972PA1A).

67. ^{15}N(d, d)^{15}N

Angular distributions of the elastic deuterons have been measured at $E_d = 5.0$, 5.5 and 6 MeV (1972BO49) and at 5.5 MeV (1970BU15). See also ^{17}O in (1977AJ02).

68. ^{15}N(^{3}He, ^{3}He)^{15}N

Angular distributions have been studied at $E(^3\text{He}) = 11$ MeV (1969BO13, 1970BO21, 1970BO25; elastic), 16.5, 20.0 and 24.4 MeV (1975PI01; elastic), 30.2, 34.4, 37.7 MeV (1975PI01: ^{15}N*(5.27+5.30, 6.32, 7.16+7.30+7.57) and 39.8 MeV (1969BA06: see Table 15.17). See also (1970LE1G).

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

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

[a] (^{3}He, ^{3}He′): (1969BA06).
[b] (α, α') (1966HA19). The E_x were determined.
[c] Weakly excited. See also (1965BU05, 1969BA06).

69. ^{15}N(α, α)^{15}N

The surface thickness $a = 0.36$ fm, as determined from analysis of the scattering of 44 MeV α-particles from ^{15}N (1968FA1A). At $E_\alpha = 40.5$ MeV, a number of particle groups have been observed, and angular distributions have been measured: see Table 15.17 (1966HA19). B(E2)↓

$/e^2 = 4.7$ fm^4 for ^{15}N*(6.32); B(E3)$\downarrow$ $/e^2 = 60$ fm ^{6} for both ^{15}N*(5.27, 7.57) (1966HA19). At $E_\alpha = 22$, 24 and 28 MeV, the intensity of the back scattering is greatly enhanced over pure Coulomb scattering (1972OE01, 1973OE01). See also (1971TE10, 1972DM01, 1974CH58, 1974KU15; theor.).

70. ^{15}N(^{16}O, ^{16}O)^{15}N

See (1970SI09). See also (1971GO1T, 1975VO1B).

71. ^{15}N(^{19}F, ^{19}F)^{15}N

Elastic angular distributions have been studied at $E(^{15}$N$) = 23$, 26 and 29 MeV (1973GA14). See also (1975VO1B).

72. ^{15}O(β^+)^{15}N $\qquad Q_m = 2.7538$

See ^{15}O.

73. (a) ^{16}O(γ, p)^{15}N $\qquad Q_m = -12.1277$
(b) ^{16}O(e, ep)^{15}N $\qquad Q_m = -12.1277$

Over the giant resonance region in ^{16}O, the decay takes place to the odd parity states ^{15}N*(0, 6.32) and less strongly to the even-parity states ^{15}N*(5.27, 5.30, 8.31, 9.05) and to ^{15}N*(9.22): see (1970HO21) and the earlier references in (1970AJ04). See also (1971AD05, 1975MA2G), (1970FI1D, 1974HA1C, 1975MA1E), (1973CL1E; astrophys. questions), (1969VA1A, 1970MU1D, 1973SP03; theor.) and ^{16}O in (1977AJ02).

74. ^{16}O(n, d)^{15}N $\qquad Q_m = -9.9031$

Angular distributions of the d_0 groups have been measured at $E_n = 14$ MeV (1963GA10) and 14.4 MeV (1964PA11, 1965VA05). See also (1971MI12; theor.).

75. ^{16}O(p, 2p)^{15}N $\qquad Q_m = -12.1277$

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)] (1966TY01). The ground state angular correlation has been studied at $E_p = 45$ MeV (1971EI06). See also (1973GO27), (1973WA1E), (1972LI1J; theor.) and (1970AJ04).

76. ^{16}O(d, ^{3}He)^{15}N $\qquad Q_m = -6.6340$

Angular distributions of ^{3}He groups have been measured at $E_d = 20$ MeV (1969PU04: to ^{15}N*(0, 5.27, 5.30)), 28 MeV [(1968GA13: to $^{15}N_{g.s.}$), (1970IN1A, 1971IN1C; unpublished: to ^{15}N*(0, $5.27 + 5.30$, 6.32), also elastic at $E_d = 20$ and 24 MeV)], 29 MeV (1974FI1F; abstract: to ^{15}N*(0, 5.27, 5.30, 6.32, 7.16, 7.57), 34.4 MeV (1967HI06: to ^{15}N*(0, $5.27 + 5.30$, 6.32)), 52 MeV (1969KA1A: to $^{15}N_{g.s.}$) and 82 MeV (1969DO04: to ^{15}N*(0, $5.27+5.30$, 6.32)). At $E_d = 52$ MeV the spectrum at $11°$ is dominated by ^{15}N*(0, 6.32): states at 9.94 ± 0.02 and 10.705 ± 0.010 MeV are also populated (1973MA21). See also the mirror reaction ^{16}O(d, t)^{15}O, (1973WA1E), (1973FA02; theor.) and ^{18}F in (1978AJ03).

77. ^{16}O(t, α)^{15}N $\qquad Q_m = 7.6869$

Angular distributions have been measured at $E_t = 13$ MeV (1965AJ01; α_0, α_{1+2}, α_3). See also (1970AJ04).

78. ^{16}O(^{10}B, ^{11}C)^{15}N $\qquad Q_m = -3.436$

The ground state angular distribution has been studied at $E(^{10}\text{B}) = 100$ MeV (1975NA15).

79. ^{16}O(^{14}N, ^{15}O)^{15}N $\qquad Q_m = -4.830$

See reaction 33 in ^{15}O (1975NA15, 1975VO05).

80. ^{16}O(^{16}O, ^{17}F)^{15}N $\qquad Q_m = -11.527$

See (1974RO04).

81. ^{16}O(^{19}F, ^{20}Ne)^{15}N $\qquad Q_m = 0.717$

Angular distributions are reported at $E(^{19}\text{F}) = 36$ MeV involving $^{15}\text{N}_{\text{g.s.}}$ and ^{20}Ne*(0, 1.63) (1973GA14).

82. ^{17}O(p, ^{3}He)^{15}N $Q_{\text{m}} = -8.552$

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

83. ^{17}O(d, α)^{15}N $Q_{\text{m}} = 9.802$

See (1954PA39).

84. (a) ^{18}O(p, α)^{15}N $Q_{\text{m}} = 3.9799$

(b) ^{18}O(p, tp)^{15}N $Q_{\text{m}} = -15.8347$

Angular distributions of α_0 have been measured at $E_{\text{p}} = 0.84$ to 2.00 MeV (1961CA02) and at 20.6, 26.1, 34.2, 42.2 MeV (1974PI05). Angular correlation measurements lead to $J = \frac{5}{2}$, $\frac{3}{2}$, $\frac{5}{2}$, $\frac{3}{2}$, $\frac{7}{2}$, ($\frac{1}{2}$) and ($\frac{3}{2}$), respectively for ^{15}N*(5.27, 6.32, 7.16, 7.30, 7.57, 8.31, 8.58) (1965WA06, 1966HA30, 1966LO02). $J = \frac{5}{2}$ for ^{15}N*(5.27) and the mixing parameter fix $J = \frac{5}{2}$ for ^{15}N*(10.54) which feeds ^{15}N*(5.27) [as observed in ^{14}C(p, γ)^{15}N] (1965WA06).

At $E_{\text{p}} = 46$ MeV the first $T = 2$ state [$J^{\pi} = 0^{+}$] in ^{16}O at $E_{\text{x}} = 22.72$ MeV (reaction (b)) decays by proton emission with branching ratios of $(25 \pm 6)\%$, $(22 \pm 5)\%$ and $(15 \pm 5)\%$ to ^{15}N*(0, $5.27 + 5.30$, 6.32) (1973KO02). See also (1973CL1E, 1975FO19, 1975RO20; astrophys. questions), (1974NI1A; theor.) and ^{19}F in (1978AJ03).

85. ^{18}O(^{18}O, ^{20}F)^{15}N $Q_{\text{m}} = -1.651$

See (1972EY01).

86. (a) ^{19}F(γ, α)^{15}N $Q_{\text{m}} = -4.0129$

(b) ^{19}F(p, pα)^{15}N $Q_{\text{m}} = -4.0129$

(c) ^{19}F(α, 2α)^{15}N $Q_{\text{m}} = -4.0129$

In reaction (a) the yields of 5.27 MeV γ-rays have been measured at $E_{\rm bs} = 19$, 21.5 and 25 MeV (1972TH15). See also (1972SP1B) and (1970AJ04).

87. ^{19}F(d, ^{6}Li)^{15}N $\qquad Q_{\rm m} = -2.539$

Angular distributions of the ^{6}Li ions corresponding to ^{15}N$_{\rm g.s.}$ have been measured at $E_{\rm d} = 9.0$ to 12.5 MeV (1967DE14), 14.5–14.9 MeV (1964DA1B, 1966DE09), 19.5 MeV (1971GU07: also to ^{15}N*(5.3, 6.3)) and 28 MeV (1972BE1T, 1972BE29). See also (1972GA1E).

88. ^{19}F(^{3}He, ^{7}Be)^{15}N $\qquad Q_{\rm m} = -2.426$

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

^{15}O

(Figs. 12 and 13)

GENERAL: (See also (1970AJ04)):

Shell model: (1970FR11, 1970GO1H, 1970GU1E, 1970LI23, 1971HS02, 1971LE30, 1971LI17, 1972BA78, 1972LE1L, 1973DE13, 1973HA49, 1973RE17, 1973WA35, 1974SA06).

Collective and deformed nuclei: (1974PU02).

Cluster and deformed models: (1972LE1L, 1972WE01, 1974PU02).

Special levels: (1970FR11, 1971BE59, 1971HS02, 1971LI17, 1972WE01, 1974PU02, 1974SA06, 1974VA24, 1975BU03, 1975HS01).

Giant resonance: (1973DE1V).

Special reactions: (1969HI1A, 1971AR02, 1974HA61, 1975HU14).

Electromagnetic transitions: (1970AL1D, 1970GO1H, 1970LI23, 1970SI1J, 1971LI17, 1973RE17, 1974SA06, 1975HS01).

Astrophysical questions: (1973BA1H, 1975RA1M).

Muon and neutrino capture and reactions: (1972BL01).

Pion capture and reactions: (1970HO12, 1971LI1M, 1973AR1B, 1974AM01, 1974LI15, 1975LI06).

Applied physics: (1973PH1B, 1973WE1N, 1975AL1B).

Other topics: (1970RY03, 1970RY04, 1970SI1C, 1970SU1B, 1971BE59, 1971ER1C, 1971LA1D, 1972AN05, 1972BA78, 1972CA37, 1972LE1L, 1972SH32, 1973DE13, 1973RE17, 1973RO1R, 1973RO1P, 1973SP1A, 1973WA35, 1974SA05, 1974SL1C, 1974VA24, 1975BE48, 1975MI02, 1975SH20, 1975SH1H).

Ground state properties: (1970AL1D, 1970RY03, 1970SI1J, 1971SH26, 1971TA1A, 1972LE1L, 1972VA36, 1972YO1B, 1973RE17, 1973RO1P, 1974DIZR, 1974HA27, 1974SA06, 1975BE31, 1975MI02, 1975MI1N).

Mass of ^{15}O: A re-determination of the mass of ^{15}O has resulted from studies of the ^{14}N(p, γ)^{15}O (1972NE05) and ^{15}N(p, n)^{15}O (1972JE02, 1972SH08) reactions. Based on the (1971WA37) masses for n, p, ^{14}N and ^{15}N, the mass excesses are 2854.2 ± 1.1 keV (1972JE02), 2856.4 ± 0.9 keV (1972SH08) and 2855.9 ± 1.0 keV (1972NE05): the weighted mean of these three values is 2855.6 ± 0.6 keV (1972SH08) and we adopt it for ^{15}O. The mass of ^{15}O is then 15.0030656 (7) a.m.u., based on the conversion factor 931.502 (3) MeV/a.m.u.

Table 15.18: 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, 6, 7, 10, 11, 12, 14, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34
5.183 ± 1	$\frac{1}{2}^+$	< 0.1 psec	γ	3, 7, 10, 12, 14, 22, 25, 26, 28, 29, 34
5.2409 ± 0.3	$\frac{5}{2}^+$	3.2 ± 0.5 psec	γ	3, 7, 8, 10, 12, 13, 14, 21, 22, 24, 25, 26, 28, 29, 34
6.1763 ± 1.7	$\frac{3}{2}^-$	< 47 fsec	γ	3, 7, 12, 14, 21, 22, 25, 26, 27, 28, 29, 32, 34
6.7931 ± 1.7	$\frac{3}{2}^+$	< 28 fsec	γ	3, 7, 12, 21, 22, 25, 29
6.8594 ± 0.9	$\frac{5}{2}^+$	0.10 ± 0.06 psec	γ	3, 7, 12, 14, 21, 22, 25, 26, 29
7.2759 ± 0.6	$\frac{7}{2}^+$		γ	7, 8, 9, 10, 12, 13, 21, 22, 25, 29
7.5568 ± 0.8	$\frac{1}{2}^+$	$\Gamma = 1.6 \pm 0.5$ keV	γ, p	14, 21, 22, 25, 29
8.2843 ± 0.9	$\frac{3}{2}^+$	3.6 ± 0.7	γ, p	7, 12, 14, 21, 22, 25, 29
8.743 ± 6	$\frac{1}{2}^+$	32	γ, p	12, 14, 29
8.922 ± 2	$(\frac{5}{2}^+)$	≈ 4	γ, p	7, 12, 14, 15, 25, 29
8.927 ± 2	$(\frac{1}{2}^-)$	≈ 4	γ, p	14, 15, 25, 29
8.9824 ± 1.7	$(\frac{1}{2})^-$	3.9 ± 0.4	γ, p	7, 12, 14, 25, 29
9.487 ± 3	$\frac{5}{2}^-$	10.1 ± 0.5	γ, p	7, 12, 14, 25, 29
9.527 ± 17	$(\frac{1}{2})^+$	280 ± 25	γ, p	12, 14, 29
9.610 ± 2	$\frac{3}{2}^-$	8.8 ± 0.5	γ, p	7, 8, 12, 14, 25, 28, 29
9.662 ± 3	$(\frac{7}{2}, \frac{9}{2})^-$	2 ± 1	p	7, 8, 12, 15, 25, 29
9.72 ± 50	$(\frac{1}{2}, \frac{3}{2})^+$	1185 ± 50	γ, p	7, 14, 29
10.291 [b]	$(\frac{5}{2}^-)$	3 ± 1	(γ), p	7, 12, 15, 25, 29
10.296 [b]	$\frac{5}{2}^+$	11 ± 2	(γ), p	7, 15, 25
10.478 [b]	$(\frac{3}{2})^-$	25 ± 5	γ, p	7, 8, 9, 12, 14, 15, 25, 28, 29

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

E_x in ^{15}O (MeV ± keV)	$J^\pi; T$	τ or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
10.506 [b]	$(\frac{3}{2})^+$	140 ± 40	γ, p	14, 15, 25, 28
10.917 ± 12	$\frac{7}{2}^+$	90	p	15, 29
10.938 ± 3	$\frac{1}{2}^+$	99 ± 5	γ, p	14, 15, 25, 29
11.025 ± 3	$\frac{1}{2}^-$	25 ± 2	γ, p	14, 15, 25, 29
11.151 ± 7		< 10	p	7, 15, 29
11.218 ± 3	$\frac{3}{2}^+$	40 ± 4	γ, p	14, 15, 25, 29
11.565 ± 15		< 10	p	7, 15, 29
11.569 ± 15	$\frac{5}{2}^-$	20 ± 15	γ, p	14, 15, 29
11.616 ± 15	$(\frac{3}{2}, \frac{1}{2})^-$	80 ± 50	γ, p	14, 15
11.719 ± 8		< 10	p	7, 15, 25
11.748 ± 3	$\frac{5}{2}^+$	99 ± 5	γ, p	14, 15, 29
11.846 ± 3	$\frac{5}{2}^-$	65 ± 3	γ, p	14, 15
11.980 ± 10	$\frac{5}{2}^-$	20 ± 5	p	7, 15, 29
12.129 ± 15	$\frac{5}{2}^+$	200 ± 50	p	15
12.222 ± 20		100 ± 50	p	15
12.295 ± 10				7, 25
12.471 ± 3	$\frac{5}{2}^-(\frac{3}{2}^-)$	77 ± 4	p	15
12.60 ± 10				7
12.80		≈ 250	γ, p	14
12.835 ± 3	$(\frac{1}{2}^-)$	16 ± 1	p	7, 8, 9, 10, 15
13.008 ± 3		215 ± 30	p, ^{3}He	5, 8, 9, 15
13.025 ± 3		40 ± 30	p, (^{3}He)	5, 15
13.45	$(\frac{1}{2}, \frac{3}{2})^+$	≈ 1000	γ, p, (α)	14, 15, 20
13.49	$(\frac{3}{2}^+)$		p	7, 15
13.60	$\frac{5}{2}^+$		p, α	7, 20
13.70	$\frac{3}{2}^-$		p	7, 15
13.79	$\frac{3}{2}^-$		n, p, ^{3}He, α	5, 7, 15, 20, 25
13.87		≈ 150	γ, p	14
14.03 ± 40	$(\frac{1}{2}^-, \frac{3}{2}^-)$	160 ± 20	n, p, ^{3}He	5
14.17	$\frac{5}{2}^-$		p, α	20

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

E_x in ^{15}O (MeV ± keV)	$J^\pi; T$	τ or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
14.27 ± 10	$\frac{1}{2}^+$	340 ± 30	n, p, ^{3}He, α	5, 7, 15, 16, 19, 20
14.34	$\frac{5}{2}^+$	(240)	p, (^{3}He), α	5, 20
14.465 ± 10	$\frac{3}{2}^+, \frac{5}{2}^+$	100 ± 10	n, p, ^{3}He, α	5, 15, 16, 20
14.70 ± 40		170 ± 35	n, p, ^{3}He	5, 16
14.95 ± 40		400 ± 25	n, p, ^{3}He, α	5, 15, 16, 19, 20
15.05 ± 10	$((\frac{13}{2}^+))$			7, 9, 10
15.1	$(\frac{1}{2}, \frac{3}{2})^+$	≈ 1000	γ, p	14
15.45 ± 30		70 ± 20	p, ^{3}He, α	5, 7, 8
15.54 ± 10			(p, ^{3}He, α)	5, 7
15.60 ± 10			(p, ^{3}He, α)	5, 7
15.65 ± 10				7
15.80 ± 10			n, p, ^{3}He	5, 7, 8, 16
15.90 ± 5	$\frac{1}{2}^-, \frac{3}{2}^-$	350	^{3}He, α	5
16.05 ± 20		≈ 185	n, p, ^{3}He, α	5, 15, 16, 20
16.10 ± 20			(n) ^{3}He, α	5
16.21 ± 20		≈ 140	(n), p, ^{3}He, α	5, 15, 19, 20
16.43 ± 50	$\frac{1}{2}^+$	560 ± 100	^{3}He, α	5, 15, 16, 19
16.75 ± 50			n, ^{3}He	5
16.9	$(\frac{1}{2}, \frac{3}{2})^+$	≈ 1000	γ, p	14
17.2			p, α	8, 15, 20
17.46 ± 20				7
17.51 ± 20	$\frac{1}{2}^-, \frac{3}{2}^-$	600	n, ^{3}He, α	5, 7
17.99 ± 50	$\frac{1}{2}^-, \frac{3}{2}^-$	200	^{3}He	5
18.23 ± 50			n, p, ^{3}He	5
18.4	$(\frac{1}{2}, \frac{3}{2})^+$	≈ 1000	γ, p	14
19.03 ± 50			n, ^{3}He	5
19.91 ± 50			n, ^{3}He	5
20.5	$(\frac{1}{2}, \frac{3}{2})^+$	≈ 2000	γ, p, ^{3}He	5, 14
22.0	$(\frac{1}{2}, \frac{3}{2})^+$	≈ 2000	γ, p	14
(26.0)	$(\frac{13}{2}^-)$	≈ 600	^{3}He	5

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

E_x in ^{15}O (MeV ± keV)	$J^\pi; T$	τ or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
(28.0)	$(\frac{9}{2}^-, \frac{11}{2}^-)$	≈ 2500	^{3}He	5
(29.0)		≈ 2500	^{3}He	5

[a] See also Table 15.26 in (1970AJ04) and Table 15.19 here.

[b] It is not excluded that $(10.29 + 10.30)$ and $(10.47 + 10.51)$ each correspond to a single state: see Table 15.24 in (1970AJ04) and Tables 15.22 and 15.25 here.

1. ^{15}O(β^+)^{15}N $\qquad Q_m = 2.7538$

Reported half-lives are listed in Table 15.19 of (1970AJ04): the weighted mean is 122.24 ± 0.16 sec. See also (1972LE33). Using this value of $\tau_{1/2}$ and Q_m, $\log f_0 t = 3.636$ [see (1972JE02)]. The K/β^+ ratio is $(10.7 \pm 0.6) \times 10^{-4}$ (1972LE33). See also (1970DA21, 1970KO41, 1970ST04, 1972KO1A (also astrophys.), (1973MU1D, 1973WI04, 1973WI11, 1974LE1G, 1974WI1M, 1975BA59, 1975BL1G, 1975KR14; theor.).

2. ^{10}B(^{6}Li, n)^{15}O $\qquad Q_m = 15.213$

See (1957NO17).

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

At $E(^{14}\text{N}) = 100$ MeV, angular distributions have been measured to ^{15}O*(0, $5.18 + 5.24$, $6.79 + 6.86$) (1975NA15). See also (1975KL1A).

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

Elastic angular distributions have been studied at $E(^{14}\text{N}) = 41$, 77 and 113 MeV (1971LI11). See also (1967PO13, 1973SC1J) and (1973DE35; theor.).

Table 15.19: Radiative decays in ^{15}O [a]

E_i (MeV)	J^π_i	E_f (MeV)	J^π_f	Branch (%)	δ [b]	Refs.
5.24	$\frac{5}{2}^+$	0	$\frac{1}{2}^-$	100	$+0.08 \pm 0.08$	(1971AV04)
					(E3/M2)	
6.18	$\frac{3}{2}^-$	0	$\frac{1}{2}^-$	100	-0.141 ± 0.016	(1965WA16, 1974KE02)
					-0.121 ± 0.008	(1971AV04)
					(E2/M1)	
		5.18	$\frac{1}{2}^+$	< 2.5		(1965WA16)
		5.24	$\frac{5}{2}^+$	< 2.5		(1965WA16)
6.79	$\frac{3}{2}^+$	0	$\frac{1}{2}^-$	100	-0.02 ± 0.02	(1965WA16, 1968GI11, 1971AV04)
					(M2/E1)	
		5.18	$\frac{1}{2}^+$	< 3		(1968GI11)
		5.24	$\frac{5}{2}^+$	< 3		(1968GI11)
		6.18	$\frac{3}{2}^-$	< 7		(1965WA16)
6.86	$\frac{5}{2}^+$	0	$\frac{1}{2}^-$	< 10		(1965WA16)
		5.18	$\frac{1}{2}^+$	< 4		(1968GI11)
		5.24	$\frac{5}{2}^+$	100	$+0.04 \pm 0.03$	(1965WA16, 1968GI11, 1971AV04)
					(E2/M1)	
		6.18	$\frac{3}{2}^-$	< 0.4		(1965WA16)
7.28	$\frac{7}{2}^+$	0	$\frac{1}{2}^-$	< 30		(1965WA16)
				< 12		(1968GI11)
				3.8 ± 1.2		(1969KU01)
		5.18	$\frac{1}{2}^+$	< 10		(1965WA16)
				< 4		(1968GI11)
		5.24	$\frac{5}{2}^+$	100		(1965WA16, 1968GI11)
				96.2 ± 1.2		(1969KU01)
		6.18	$\frac{3}{2}^-$	< 2		(1965WA16)
7.56	$\frac{1}{2}^+$	0	$\frac{1}{2}^-$	≈ 3		(1960TA17)
				3.5 ± 0.5		(1963HE11)
		5.18	$\frac{1}{2}^+$	16.2 ± 2		(1960TA17)
				15.8 ± 0.6		(1963HE11)
		6.18	$\frac{3}{2}^-$	57.9 ± 0.6		(1960TA17)
				57.4 ± 0.6		(1963HE11)
		6.79	$\frac{3}{2}^+$	22.9 ± 2		(1960TA17)
				23.3 ± 0.6		(1963HE11)

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

E_i (MeV)	J^π_i	E_f (MeV)	J^π_f	Branch (%)	δ [b]	Refs.
		6.86	$\frac{5}{2}^+$	[d]	Γ_γ (eV)	
8.28	$\frac{3}{2}^+$	0	$\frac{1}{2}^-$	53.8 ± 0.25	0.531	(1966EV01)
		5.24	$\frac{5}{2}^+$	42.7 ± 0.5	0.405	(1966EV01)
		6.18	$\frac{3}{2}^-$	2.2 ± 0.6	0.021	(1966EV01)
		6.86	$\frac{5}{2}^+$	1.2 ± 0.3	0.011	(1966EV01)
8.74 [c]	$\frac{1}{2}^+$	5.18	$\frac{1}{2}^+$	67	0.32	(1966EV01)
		6.18	$\frac{3}{2}^-$	33	0.16	(1966EV01)
8.922 [e]	$(\frac{5}{2}^+)$	0	$\frac{1}{2}^-$	9 ± 4		(1972KR14)
		5.18	$\frac{1}{2}^+$	39 ± 3		(1972KR14)
		6.18	$\frac{3}{2}^-$	24 ± 3		(1972KR14)
		6.86	$\frac{5}{2}^+$	28 ± 3		(1972KR14)
8.927 [e]	$(\frac{1}{2}^-)$	0	$\frac{1}{2}^-$	50 ± 25		(1972KR14)
		5.18	$\frac{1}{2}^+$	20 ± 10		(1972KR14)
		6.18	$\frac{3}{2}^-$	20 ± 10		(1972KR14)
		6.86	$\frac{5}{2}^+$	10 ± 10		(1972KR14)
8.982 [e]	$(\frac{3}{2})^-$	0	$\frac{1}{2}^-$	94 ± 1		(1972KR14)
		5.18	$\frac{1}{2}^+$	6 ± 1		(1972KR14)
		6.18	$\frac{3}{2}^-$	< 1		(1972KR14)
		6.86	$\frac{5}{2}^+$	< 1		(1972KR14)
9.49	$\frac{5}{2}^-$	0	$\frac{1}{2}^-$	86	2.1	(1967EV02)
		5.24	$\frac{5}{2}^+$	6.5	0.15	(1967EV02)
		6.18	$\frac{3}{2}^-$	0.7	0.22	(1967EV02)
		6.86	$\frac{5}{2}^+$	3.4	0.08	(1967EV02)
		7.28	$\frac{7}{2}^+$	5.1	0.11	(1967EV02)
9.50 [f]	$\frac{3}{2}^+(\frac{1}{2}^+)$	0	$\frac{1}{2}^-$	≈ 100		(1967EV02)
9.61	$\frac{3}{2}^-$	0	$\frac{1}{2}^-$	79	4.0	(1967EV02)
		5.24	$\frac{5}{2}^+$	19	1.0	(1967EV02)
		6.18	$\frac{3}{2}^-$	2	0.1	(1967EV02)
10.29 [f]		γ mainly to ^{15}O*(5.24, 6.18, 6.79, 6.86)				(1972KU1J, 1971SH1D; abstracts)
10.48	$(\frac{3}{2})^-$	γ mainly to ^{15}O*(5.24)				(1972KU1J, 1971SH1D; abstracts)
10.51	$(\frac{3}{2})^+$	γ mainly to ^{15}O*(5.24)				(1972KU1J, 1971SH1D; abstracts)
10.94	$\frac{1}{2}^+$	0	$\frac{1}{2}^-$	44 ± 8	14 ± 4	(1972PH02)
		5.18	$\frac{1}{2}^+$	34 ± 3	11 ± 2	(1972PH02)

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

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

[a] See also Table 15.23 in (1970AJ04) and Table 15.25 here.
[b] δ = multipole mixing ratio.
[c] See also (1959HE47).
[d] Intensity $< 25\%$ of transition to ^{15}O*(6.79) (1959PO79).
[e] See also (1966EV01).
[f] Unresolved doublet: see Table 15.25.

5. (a) ^{12}C(^{3}He, n)^{14}O $\quad Q_m = -1.1486 \quad E_b = 12.0761$
   (b) ^{12}C(^{3}He, p)^{14}N $\quad Q_m = 4.7787$
   (c) ^{12}C(^{3}He, d)^{13}N $\quad Q_m = -3.550$
   (d) ^{12}C(^{3}He, t)^{12}N $\quad Q_m = -17.362$
   (e) ^{12}C(^{3}He, ^{3}He)^{12}C

(f) $^{12}C(^3He, \alpha)^{11}C$ $Q_m = 1.857$

(g) $^{12}C(^3He, ^7Li)^8B$ $Q_m = -22.899$

(h) $^{12}C(^3He, ^8Be)^7Be$ $Q_m = -5.780$

Excitation functions for these reactions have been measured over a wide range of energies: see Table 15.20 in (1970AJ04) and Table 15.20 here. Observed resonances are displayed in Table 15.21. For angular distributions see the writeups of the residual nuclei in (1974AJ01, 1975AJ02) and in ^{13}N, ^{14}N and ^{14}O.

The yield of n_0 (reaction (a)) shows a resonance for $E(^3He) < 10$ MeV [see, e.g., (1964OS01)] and little structure above, to 30.6 MeV (1970SI15). The yield of protons (to many final states in ^{14}N) (reaction (b)) shows some clear resonances below $E(^3He) = 4.5$ MeV and some uncorrelated structures [see Fig. 3 in (1973SO04) for a summary of the (1969HA49, 1973SO04) work for $E(^3He) = 4$ to 12 MeV] at higher energies, with the possible exception of states at $E_{res} = 7.8$, 9.2–9.6 and (10.5) MeV (1973SO04). The reaction proceeds predominantly via the compound nucleus up to $E(^3He) = 12$ MeV. The p_0, p_1 and p_2 yields show no appreciable structure for $E(^3He) = 16$ to 30.6 MeV (1970SI15). See also (1973HE09), (1970VY1A; theor.) and the earlier references in (1970AJ04).

The activation cross section for ^{13}N (reaction (c)) shows no structure for $E(^3He) = 6.5$ to 30.6 MeV (1970SI15). A structure at $E(^3He) = 29.5$ MeV is reported by (1970SI16: $E(^3He) = 22.3$ to 30.6 MeV) in reaction (d). The elastic scattereing (reaction (e)) shows some resonant structure near 3, 5 and 6 MeV (see Table 15.21) and some largely uncorrelated structures in the range $E(^3He) = 16.5$ to 24 MeV (1972MC01). There is some suggestion, however, of two resonances at $E(^3He) = 17$ and 20 MeV (1972MC01). The 90° yield of reaction (d) to ^{12}C*(15.1) [$J^\pi = 1^+$; $T = 1$] shows a strong peak at 21.5 MeV, $\Gamma \approx 2.5$ MeV (1970SI16). See also (1975WA1N; theor.).

The yield of α-particles has been measured at many energies to $E(^3He) = 18.6$ MeV. Below $E(^3He) = 8$ MeV resonances are observed † : see Table 15.21. Broad fluctuations are observed in the excitation functions for α_0, α_1 and α_3 for $E(^3He) = 12$ to 18.6 MeV (1970GR08). For reaction (g) see (1971DE37: 37.7 to 41 MeV). For spallation reactions see (1975FU01, 1976WA1P).

For polarization measurements see Table 15.20 in (1970AJ04) and Table 15.20 here.

6. $^{12}C(\alpha, n)^{15}O$ $Q_m = -8.5024$

Angular distributions of the n_0 group have been measured at $E_\alpha = 18.4$ to 23.1 MeV (1973CO04) and at 21.9 MeV (1975SK1B: also to some (unlisted) excited states). See also (1972DA32, 1974SH06) and (1970AJ04).

7. $^{12}C(^6Li, t)^{15}O$ $Q_m = -3.7185$

† I am indebted to Prof. H.R. Weller for pointing out errors in Table 15.21 in (1970AJ04).

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

(a) *Excitation functions* [b]

$E(^3\text{He})$ (MeV)	Yield of	Refs.
2 – 30.6	n_0	(1970SI15)
2.2 – 3.6	p_0, p_1, p_2	(1969SC1G, 1973SC1U)
7.0 – 11.0	p_0	(1973SO04)
16 – 30.6	p_0, p_1, p_2	(1970SI15)
6.5 – 30.6	^{13}N [d or (p + n)]	(1970SI15)
22.3 – 30.6	t_0	(1970SI16)
2.3 – 3.3	^{3}He (elastic)	(1971JA01)
16.5 – 24	^{3}He (elastic)	(1972MC01)
18.6 – 23.9	^{3}He (elastic)	(1968WA1E)
thresh. – 30.6	^{3}He [to ^{12}C*(15.1)]	(1970SI16)
2.3 – 3.3	α_0	(1971JA01)
12 – 18.6	α_0, α_1, α_3	(1970GR08)

(b) *Polarization measurements* [d]

$E(^3\text{He})$ (MeV)	Yield of	Refs.
4.1 – 5.9	n	(1971SO07)
10 – 22	n_0	(1973RH1A)
2.4 – 3.6	p_0	(1970OE02, 1971OE1A)
18, 20	^{3}He (elastic)	(1970MC10, 1972MC01)
28	^{3}He (elastic)	(1975BO06)
30	^{3}He (elastic)	(1970BU26)
31.6	^{3}He (elastic)	(1971EN03)
32.6	$^3\text{He} \rightarrow {}^{12}\text{C}^*(0, 4.4)$	(1975BU11)

[a] See Table 15.20 in (1970AJ04) for earlier measurements.
[b] See also (1968TO09, 1970AD02, 1970CL1D, 1971KL1C).
[c] And some additional data to $E(^3\text{He}) = 17$ MeV. (This footnote is not labeled in the table.)
[d] See also (1971TH1E).

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

$E(^3\text{He})$ (MeV ± keV)	Resonant for	$\Gamma_{\text{c.m.}}$ (keV)	J^π	E_x (MeV)	Refs.
1.21	p_0, p_2		$(\frac{5}{2})^-$	13.04	(1957BR18)
1.3	$p_0 \rightarrow p_3$			13.1	(1957BR18)
2.15	n, p_0		$(> \frac{5}{2})$	13.79	(1957BR18)
2.45 ± 40 [a]	n_0, $p_0 \rightarrow p_3$	160 ± 20	$(\frac{1}{2}^-, \frac{3}{2}^-)$	14.03	A
2.75 ± 40 [a]	n_0, p_1, p_2, ^{3}He, α_0	340 ± 30	$\frac{1}{2}^+$	14.27	A, (1971JA01)
(2.87)	p_0, p_2	240		(14.37)	(1973SC1U)
2.990 ± 10 [a]	n_0, p_0, p_1, p_2, p_4, p_5, p_8, ^{3}He, α_0	100 ± 10	$\frac{3}{2}^+, \frac{5}{2}^+$	14.465	A, (1971JA01)
3.28 ± 40 [a]	p_0, (p_1, p_2)	180 ± 40		14.70	(1964KU05)
3.60 ± 40	p_0, p_1, p_2	400 ± 25		14.95	(1958JO20, 1964KU05)
4.20 ± 10	p_5, p_6, α_0	65 ± 15		15.43	(1964KU05)
4.37 ± 40	p_0, p_1, p_2, p_4, p_7, p_8, α_0	80 ± 25		15.57	A [d]
4.65 ± 50	n_0			15.79	A
4.78 ± 50	^{3}He, α_0	350	$\frac{1}{2}^-, \frac{3}{2}^-$	15.90	(1969WE03)
4.97 ± 20	α_0			16.05	(1969WE08)
5.03 ± 20	n_0, ^{3}He, α_0			16.10	A, (1969WE08)
5.15 ± 20	n_0, ^{3}He, α_0			16.19	A, (1969WE08)
5.45 ± 50	^{3}He, α_0	170	$\frac{1}{2}^+$	16.43	(1969WE03)
5.85 ± 50	n_0, ^{3}He			16.75	(1964OS01, 1966SC12)
6.80 ± 50	n_0, ^{3}He, α_0	600	$\frac{1}{2}^-, \frac{3}{2}^-$	17.51	(1964OS01, 1969WE03)
7.40 ± 50	^{3}He	200	$\frac{1}{2}^-, \frac{3}{2}^-$	17.99	(1969WE03)
7.70 ± 50	n_0, p_0			18.23	(1964OS01, 1973SO04)
8.70 ± 50	n_0			19.03	(1964OS01)
9.80 ± 50	n_0			19.91	(1964OS01)
(10.5)	p_0			(20.5)	(1973SO04)
(17.0) [b]	^{3}He	≈ 600	$(\frac{13}{2}^-)$	(26.0)	(1968FO06, 1972MC01)
(20.0) [c]	^{3}He	≈ 2500	$(\frac{9}{2}^-, \frac{11}{2}^-)$	(28.0)	(1972MC01)
(21.5)	^{3}He to ^{12}C*(15.1)	≈ 2500		(29.0)	(1970SI16)

A: See references listed in Table 15.21 (1970AJ04) for this state.
[a] See also (1973SC1U).
[b] $\Gamma_p = 0.06$ MeV (1972MC01).
[c] $\Gamma_p =\geq 0.1$ MeV (1972MC01).
[d] Omit (1969WE03).

States observed in this reaction are displayed in Table 15.22 (1975BI06: $E(^6\text{Li}) = 59.8$ MeV). Comparisons of angular distributions of the triton groups in this reaction and of the ^{3}He groups to analog states in ^{15}N have been made: analog correspondence is established for (10.48–10.80), (12.84–13.15 [u]) and (15.05–15.49 [u]) [E_x in ^{15}O–E_x in ^{15}N; u = unresolved]. Previous suggestions of analog pairs in ^{12}C(^{10}B, ^{7}Li) and ^{12}C(^{10}B, ^{7}Be) seem doubtful in view of this high resolution study which shows that some of the states involved in the previous comparisons were unresolved doublets (1975BI06). See also the work of (1970JO09, 1970JO1D: 12, 13, 14 MeV; t_0) and of (1971CH1R: 30.8 MeV; many states, comparisons with analogs). See also (1971LA1B, 1971BA2Q, 1972BA2B, 1974HO1P) and (1971BA2V, 1973OG1A).

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

At $E(^{10}\text{B}) = 100$ MeV angular distributions have been measured for groups to ^{15}O*(5.24, 7.28, 9.64, 10.47, 12.89, 15.36, 15.88, 17.13) and comparisons have been attempted with those for the reaction (^{10}B, ^{7}Be) to analog states in ^{15}N [but see reaction above]. ^{15}O*(12.89, 15.36) are very strongly populated (1973NA09). See also (1973BR1C, 1973SC1B).

9. ^{12}C(^{11}B, ^{8}Li)^{15}O $\qquad Q_m = -15.135$

At $E(^{11}\text{B}) = 114$ MeV, $\theta_{\text{lab}} = 7°$ the spectrum is dominated by ^{15}O*(12.84, 15.05). ^{15}O*(7.28, 10.48) are also populated (1974AN36). See also (1975VO1H).

10. ^{12}C(^{12}C, ^{9}Be)^{15}O $\qquad Q_m = -14.204$

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 (1974AN36, 1974SC1M). 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 (1974AN36). See also (1971SC1F, 1972SC21, 1973SC1J, 1973SC1B, 1973VO1E, 1975HA1P, 1975VO1H) and (1972BR21, 1975KU1L; theor.).

11. ^{12}C(^{14}N, ^{11}B)^{15}O $\qquad Q_m = -8.6597$

See (1973SC1J).

12. ^{13}C(^{3}He, n)^{15}O $\qquad Q_m = 7.1297$

Table 15.22: 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	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	3
9.485 ± 5		15.48 ± 10	
9.610 ± 5	[c,d]	15.54 ± 10	
9.658 ± 5	[c,d]	15.60 ± 10	[c,d]
9.76 ± 5		15.65 ± 10	[c,d]
10.27 ± 5		15.80 ± 10	
10.45 ± 5	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.

Table 15.23: Levels of ^{15}O from ^{13}C(^{3}He, n)^{15}O

E_x [a] (MeV)	J^π [b]	L [c]	L [d]	S [e]
g.s.	$\frac{1}{2}^-$	0	0	1 [g]
5.18 [f]	$\frac{1}{2}^+$	1	1	0.15
5.24 [f]	$\frac{5}{2}^+$	3	3	0.17
6.18	$\frac{3}{2}^-$	2	2	0.10 [h]
6.79 [f]	$\frac{3}{2}^+$	1	1	0.12
6.86 [f]	$\frac{5}{2}^+$	3	3	0.29
7.28	$\frac{7}{2}^+$	3	3	(< 0.03)
7.56	$\frac{1}{2}^+$	1	1	0.02
8.28	$\frac{3}{2}^+$	1	1	(0.38)
8.74	$\frac{1}{2}^+$	1	1	
8.92 [l]		1		0.55 [i]
8.98	$(\frac{1}{2})^-$	0		0.44 [j]
9.49	$\frac{5}{2}^-$	2		
9.53	$(\frac{1}{2})^+$	1		
9.61	$\frac{3}{2}^-$	2		1.05 [j]
9.66	$(\frac{7}{2}, \frac{9}{2})^-$	0 [k]		
10.29 [l]			≥ 3	
10.48 [l]			2	

[a] Nominal energies: see Table 15.18.

[b] Known J^π: see Table 15.18.

[c] (1971ET1A, 1972ET01): $E(^3\text{He}) = 5.5$ and 6.2 MeV; used codes DWUCK and MANDY. See also (1971HI04, 1971HI1F: $E(^3\text{He}) = 6$ MeV).

[d] (1972GE02): $E(^3\text{He}) = 6$ MeV.

[e] (1971HI04); see also (1972GE02).

[f] These states were unresolved.

[g] $(p_{1/2})^2$.

[h] $(p_{3/2}, p_{1/2})$.

[i] $(p_{1/2}, d_{3/2})$.

[j] $(d_{5/2})^2$.

[k] (1971HI04) report $L = 4$.

[l] Known to be a doublet: see Table 15.19.

Angular distributions of the n_0 group have previously been measured at $E(^3He) = 1.70$ to 10.1 MeV: see (1970AJ04). Recent measurements of the distributions to most states of ^{15}O with $E_x < 10.5$ MeV are displayed in Table 15.23 (1971HI04, 1972ET01, 1972GE02: $E(^3He) = 5.5 - 6.2$ MeV). At these energies it is necessary to combine direct interaction and compound nuclear calculations: these suggest that ^{15}O*(5.18, 5.24, 7.28, 8.28(?)) have large 3p-4h strengths (1972GE02). See also (1973RH1A).

Branching ratio measurements by (1965WA16) are listed in Table 15.19. The measured E_γ lead to $E_x = 6180 \pm 4$, 6857 ± 3.2 and 7284 ± 7 keV (1965WA16).

13. $^{13}C(^{11}B, ^9Li)^{15}O$ $\qquad Q_m = -16.028$

At $E(^{11}B) = 114$ MeV the states which are strongly populated are ^{15}O*(5.24, 7.28, 11.2, 11.7) (1974AN36). See also (1973SC1J).

14. $^{14}N(p, \gamma)^{15}O$ $\qquad Q_m = 7.2974$

Observed resonances and states observed in the γ-decay are listed in Tables 15.24 and 15.25. Branching ratios are displayed in Table 15.19: see (1970AJ04) and (1972KR14, 1972PH02, 1974KE02). See also (1971SH1D, 1972KU1J).

The cross section increases from $(8.5 \pm 3.7) \times 10^{-12}$ b at 100 keV to $(140 \pm 30) \times 10^{-12}$ b at 135 keV (1957LA13). Extrapolation from the $E_p = 0.28$ MeV resonance gives $S(0) = 2.75 \pm 0.50$ keV · b, with zero slope to $E_p = 0.05$ MeV (1963HE11). For astrophysical implications see (1970AJ04, 1971BA1A, 1972CA1N, 1973CL1E, 1973TR1E).

(1972NE05) has measured accurately both the energy of the second resonance $[1058.0 \pm 0.5$ keV$]$ and the excitation energy of the corresponding state in ^{15}O ($E_x = 8284.1 \pm 0.8$ keV): this leads to a mass excess for ^{15}O of 2855.9 ± 1.0 keV. For a comparison of this value and of two others which have led to a new mass of ^{15}O see the "GENERAL" section here.

The $90°$ yield curve has been measured for $E_p = 2.2$ to 19.0 MeV: resonances are observed over most of the range in the γ_0 yield. The $(\gamma_1 + \gamma_2)$ yield is relatively weak (1970KU09). For $E_p = 18$ to 28 MeV the excitation function for γ_0 decreases smoothly with energy: there is no evidence for structures (1975HA39). The (p, γ_0) reaction populates the $T = \frac{1}{2}$ component of the giant dipole resonance: in ^{15}N, $^{14}C(p, \gamma_0)$ can populate both the $T = \frac{1}{2}$ and the $T = \frac{3}{2}$ components (1973PA1P). See also (1972SN1A, 1974MA1U), (1973HA1X, 1973SU1E) and (1970FR11; theor.).

15. (a) $^{14}N(p, p)^{14}N$ $\qquad E_b = 7.2974$

(b) $^{14}N(p, 2p)^{13}C$ $\qquad Q_m = -7.5507$

Table 15.24: Energies of states of ^{15}O from ^{14}N(p, γ)^{15}O [a]

E_x in keV		J^{π} [c]
(1972KR14)	(1972NE05)	
5183 ± 1		
$\equiv 5241$ [b]	5240.9 ± 0.4 [d]	
6175 ± 2		
6794 ± 2		
6858 ± 2		
8919 ± 2		$(\frac{5}{2}^{+})$
8924 ± 2		$(\frac{1}{2}^{-})$
8978 ± 2		$(\frac{1}{2}, \frac{3}{2})^{-}$

[a] See also reaction 9 in (1970AJ04) and Table 15.25 here.

[b] Other energies based on this value. (1972KR14) used 5241.5 keV as the standard.

[c] (1972KR14).

[d] $E_{\gamma} = 5240.0 \pm 0.8$ keV.

The yields of elastic and inelastic protons, and of γ-rays, have been studied at many energies: see (1959AJ76) and Table 15.25 in (1970AJ04).

The scattering anomalies are superposed on a background which decreases less rapidly than the Rutherford cross section; for $E_p < 2.3$ MeV, the background is largely s-wave with some p-wave contribution above $E_p = 1.5$ MeV.

Observed resonances are displayed in Table 15.25. The J^{π} assignments shown arise from considerations of branching ratios (see Table 15.19), measurements of angular distributions of γ-rays in the (p, γ) reaction, angular correlation studies and the work discussed in this section. See (1970AJ04) for the earlier references.

The recent work of (1969WE02, 1971LA23, 1972CH28, 1972PH02) has given us a much clearer picture of the resonances in this reaction below $E_p = 6.2$ MeV. These results, together with those obtained in the (p, γ) reaction, lead to a good understanding of the correspondence of the analog states in ^{15}N and ^{15}O below $E_x \approx 13$ MeV: see (1972PH02) and Fig. 13.

Excitation functions have also been measured for the p_0, p_1 and p_2 groups for $E_p = 17$ to 26.5 MeV: there is no evidence for resonant behavior but the p_1 yield shows a large increase between $E_p = 20$ and 23 MeV (1972LU10). Total cross sections for the $p_0 \rightarrow p_9$ groups have been measured at $E_p = 8.6$, 10.6, 12.6 and 14.6 MeV by (1973HA54). See also (1971ES1A, 1971OD01).

Table 15.25: Resonances in ^{14}N + p

E_p (keV)	Γ_{lab} (keV)	$\omega\Gamma_\gamma$ (eV)	Particles out	J^π	E_x (MeV)	Refs.
278.1 ± 0.4	1.7 ± 0.5	0.014	γ	$\frac{1}{2}^+$	7.5568	A
1058.0 ± 0.5	3.9 ± 0.7	0.95	γ	$\frac{3}{2}^+$	8.2843	A, (1972NE05)
1550 ± 6	34	0.16	γ	$\frac{1}{2}^+$	8.743	A
1742 ± 2	≈ 4	0.16	γ, p_0	$(\frac{5}{2}^+)$	8.922	(1971LA23, 1972KR14)
1747 ± 2	≈ 4	0.06	γ, p_0	$(\frac{1}{2}^-)$	8.927	(1971LA23, 1972KR14)
1806.4 ± 1.5	4.2 ± 0.4	0.52	γ	$(\frac{1}{2}, \frac{3}{2})^-$	8.9824	A, (1966EV01, 1972KR14)
2348 ± 3	10.8 ± 0.5	2.4	γ	$\frac{5}{2}^-$	9.488	A, (1970KU09)
2368 ± 32	300 ± 26		γ	$(\frac{1}{2}^+)$	9.506	A, (1970KU09)
2479 ± 1.7	9.4 ± 0.5	3.3	γ	$\frac{3}{2}^-$	9.610	A, (1970KU09)
2537 ± 4	2 ± 1		p_0	$(\frac{7}{2}, \frac{9}{2})^-$	9.664	(1967LA05, 1967LA10)
2600 ± 50	1270 ± 50	46	γ	$(\frac{1}{2}, \frac{3}{2})^+$	9.72	(1951DU08)
3209 [a]	3 ± 1		p_0	$(\frac{5}{2}^-)$	10.291	(1970DI1D, 1972CH28)
3215 [a]	12 ± 2 [b]		p_0	$\frac{5}{2}^+$	10.296	(1970DI1D, 1972CH28)
3410 [c]	27 ± 5		γ, p_0	$(\frac{3}{2})^-$	10.478	(1970DI1D, 1972CH28)
3440 [c]	150 ± 45		γ, p_0	$(\frac{3}{2})^+$	10.506	(1970DI1D, 1972CH28)
3880 ± 15	97		p_0	$\frac{7}{2}^+$	10.916	A
		$\Gamma_{\gamma 0}$ (eV)				A, (1970KU09, 1972PH02)
3903 ± 3	106 ± 5	14 ± 3	γ, p_0, p_1	$\frac{1}{2}^+$	10.938	A, (1972PH02)
3996 ± 3	27 ± 2	1.4 ± 0.4	γ, p_0, p_1	$\frac{1}{2}^-$	11.025	(1969WE02)
4130 ± 15	< 10		p_0		11.150	(1969WE02, 1970KU09, 1972PH02)
4203 ± 3	43 ± 4	5.2 ± 0.4	γ, p_0	$\frac{3}{2}^+$	11.218	(1969WE02)
4575 ± 15	< 10		p_0		11.565	(1969WE02, 1972PH02)
4580 ± 15	21 ± 15	0.7 ± 0.2	γ, p_0	$\frac{5}{2}^-$	11.569	(1970KU09)

Table 15.25: Resonances in ^{14}N + p (continued)

E_p (keV)	Γ_{lab} (keV)	$\omega\Gamma_\gamma$ (eV)	Particles out	J^π	E_x (MeV)	Refs.
4580	150		γ		11.57	(1969WE02, 1972PH02)
4630 ± 15	86 ± 50		γ, p_0	$(\frac{3}{2}, \frac{1}{2})^-$	11.616	(1969WE02)
4740 ± 15	< 10		p_0		11.718	A, (1972PH02)
4772 ± 3	106 ± 5		γ, p_0, p_1	$\frac{5}{2}^+$	11.748	A, (1972PH02)
4877 ± 3	70 ± 3		γ, p_0, p_1	$\frac{5}{2}^-$	11.846	(1969WE02, 1972PH02)
5025 ± 15	21 ± 5		p_0, p_1	$\frac{5}{2}^-$	11.984	(1969WE02, 1972PH02)
5180 ± 15	214 ± 50		p_0, p_1	$\frac{5}{2}^+$	12.129	(1972PH02)
5280 ± 20	106 ± 50		p_1 ^{d}		12.222	(1969WE02, 1972PH02)
5547 ± 3	82 ± 4		p_1, p_2	$\frac{5}{2}^-(\frac{3}{2}^-)$	12.471	(1970KU09)
5900	≈ 250		γ		12.80	(1972PH02)
5937 ± 3	17 ± 1		p_2 ^{e}		12.835	(1968SH11)
(6100)	30		$p_0 \rightarrow p_2$, α_0	$\frac{5}{2}^+$	(12.99)	(1972PH02)
6123 ± 3	230 ± 30		p_2 ^{e}		13.008	(1972PH02)
6141 ± 3	43 ± 30		p_2 ^{e}		13.025	(1968SH11, 1970KU09)
6600	≈ 1000		γ, (p_2, α_0)	$(\frac{1}{2}, \frac{3}{2})^+$	13.45	(1968SH11)
6640			(p_0), (p_2)	$(\frac{3}{2}^+)$	13.49	(1968SH11)
6760			α_0	$\frac{5}{2}^+$	13.60	(1968SH11)
6870			p_2	$\frac{3}{2}^-$	13.70	(1968SH11)
6960			p_1, p_2, p_4, α_0	$\frac{3}{2}^-$	13.79	(1970KU09)
7050	≈ 150		γ		13.87	(1968SH11)
7370			α_0	$\frac{5}{2}^-$	14.17	(1964KU06, 1968SH11, 1970ME30)
7500	≈ 500		n, $p_0 \rightarrow p_2$, ^{3}He, α		14.29	(1968SH11)
7550			α_0	$\frac{5}{2}^+$	14.34	(1964KU06, 1970ME30)

Table 15.25: Resonances in ^{14}N + p (continued)

E_p (keV)	Γ_{lab} (keV)	$\omega\Gamma_\gamma$ (eV)	Particles out	J^π	E_x (MeV)	Refs.
7700			n, p_0, α_0		14.48	(1964KU06)
7950	170 ± 50		n		14.71	(1964KU06, 1970ME30)
8200			n, $p_2 \rightarrow p_6$, ^{3}He, α_0, α_1		14.94	(1970KU09)
8400 [f]	≈ 1000		γ	$(\frac{1}{2}, \frac{3}{2})^+$	15.1	(1964KU06)
9050 [f]			n		15.74	(1964KU06)
[g]						
9370 ± 20	≈ 200		n, p_2, p_8, α_1		16.04	(1964KU06, 1970ME30)
9580 ± 20	≈ 150		p_0, p_1, $p_3 \rightarrow p_7$, p_9, ^{3}He, α_1		16.23	(1970ME30)
9850 ± 50	600 ± 100		n, ^{3}He		16.48	(1964KU06, 1970ME30)
10300 [f]	≈ 1000		γ	$(\frac{1}{2}, \frac{3}{2})^+$	16.9	(1970KU09)
10600			$p_4 \rightarrow p_9$, α_0, α_1		17.2	(1970ME30)
11900	≈ 1000		γ	$(\frac{1}{2}, \frac{3}{2})^+$	18.4	(1970KU09)
14200	≈ 2000		γ	$(\frac{1}{2}, \frac{3}{2})^+$	20.5	(1970KU09)
15800	≈ 2000		γ	$(\frac{1}{2}, \frac{3}{2})^+$	22.0	(1970KU09)

A: See earlier references for this resonance in (1970AJ04).

[a] Previously [see (1970AJ04)] a single resonance at $E_{\rm p} = 3200 \pm 8$ keV was reported [$\Gamma_{\rm lab} = 17 \pm 4$ keV].

[b] (1971SH1D, 1972KU1J; abstracts) report $\Gamma_{\rm lab} = 9 \pm 2$ keV, $\Gamma_{\rm p}/\Gamma \approx 1.0$.

[c] Previously [see (1970AJ04)] a single resonance at $E_{\rm p} = 3390 \pm 10$ keV was reported [$\Gamma_{\rm lab} = 50$ keV]. See also (1970KU09). (1971SH1D, 1972KU1J; abstracts) report that one of these states has $\Gamma \leq 2$ keV and the other [$J^\pi = (\frac{3}{2}, \frac{5}{2})^-$] has $\Gamma = 30 \pm 5$ keV.

[d] Weak.

[e] Strong.

[f] See also (1970ME30).

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

The polarization of the p_0 group has been measured at $E_p = 49.4$ MeV (1970CL10). The depolarization parameter, D, has been determined for the elastic transition at $E_p = 16.15$ MeV (1974CL1H). For other polarization measurements [$E_p = 3.0$ to 155 MeV] see Table 15.25 in (1970AJ04). See also (1971ES1A).

See also ^{14}N, (1970JU05; astrophys. implications) and (1974OD01, 1975BA05; theor.). For spallation studies see (1970JU05, 1971EP1D, 1972HE06, 1973LA19, 1974RA09, 1975WE1E). For reaction (b) see ^{13}C.

16. ^{14}N(p, n)^{14}O $Q_m = -5.9272$ $E_b = 7.2974$

The excitation function has been measured for $E_p = 6.3$ to 12 MeV. Broad resonances are observed for $E_p = 7.5$ to 9.85 MeV: see Table 15.25 (1964KU06). See also (1970AJ04), (1973CL1E; astrophys. questions) and (1970AL1J; theor.).

17. ^{14}N(p, d)^{13}N $Q_m = -8.329$ $E_b = 7.2974$

See ^{13}N.

18. ^{14}N(p, t)^{12}N $Q_m = -22.141$ $E_b = 7.2974$

See ^{12}N in (1975AJ02).

19. ^{14}N(p, ^{3}He)^{12}C $Q_m = -4.7787$ $E_b = 7.2974$

Excitation functions for the ground state group have been measured at $E_p = 7$ to 11 MeV: some resonant structure is indicated (see Table 15.25) (1970ME30). Total cross section for the transitions to ^{12}C*(0, 4.4) have been measured in the range $E_p = 20.5$ to 44.6 MeV (1974PI05). See also (1970AJ04) and ^{12}C in (1975AJ02).

20. (a) ^{14}N(p, α)^{11}C $Q_m = -2.922$ $E_b = 7.2974$
(b) ^{14}N(p, 2α)^{7}Be $Q_m = -10.467$

Excitation functions and total cross section measurements have been carried out for the α_0 group for $E_p = 3.78$ to 6.38 MeV (1976IN01), 5 to 22 MeV (1974JA11), 6 to 10.5 MeV (1968SH11; also α_1 in the range $8.2-10.5$ MeV), 7 to 11 MeV (1970ME30; also α_1), 9 to 12 MeV (1974HU02) and 20 to 45 MeV (1974PI05; also α_1, α_{2+3}, α_{4+5+6}). Fairly sharp structures persist until $E_p = 15$ MeV (1974JA11): see Table 15.25 for the parameters of observed resonances, and in particular footnote [g]. Reaction (b) whose cross section has been measured for $E_p = 14$ to 24 MeV displays a broad peak at ≈ 20 MeV (1974JA11). For astrophysical questions see (1974JA11, 1976IN01). See also (1975AJ02).

21. ^{14}N(d, n)^{15}O $\qquad Q_m = 5.0728$

Angular distribution studies have been carried out at many energies in the range $E_d = 0.9$ to 11.8 MeV: see Table 15.27 in (1970AJ04) and (1970RI01: $E_d = 2.80 - 5.35$ MeV; $E_x < 7.6$ MeV), (1970BU15: 4.35, 5.5 MeV; n_0), (1972FO07: 5.2 MeV; pol. n to $E_x < 7.6$ MeV), (1971BO35: 5.6 and 6 MeV; $E_x < 8.3$ MeV) and (1971HI09: $E_{\vec{d}} = 10.0, 11.8$ MeV; n_0). See also (1970ME25, 1975HS01; theor.). The latter experiment shows that j_p in the ground state transition is predominantly $\frac{1}{2}$. Information derived from DWBA analysis of the angular distributions, and from the very accurate γ-ray measurements of (1965WA16, 1966AL18, 1967CH19) are shown in Table 15.26. See also (1973HI1C).

Neutron thresholds have been observed at $E_d = 0.143 \pm 0.004$, 0.206 ± 0.005 (1963CS02), 1.24 ± 0.02, 1.967 ± 0.004 and 2.044 ± 0.004 MeV (1955MA85), corresponding to ^{15}O*(5.198, 5.253, 6.16, 6.792, 6.859).

Gamma ray branching ratios are shown in Table 15.19 (1965WA16, 1968GI11); lifetime measurements are listed in Table 15.18. For polarization measurements see ^{16}O in (1971AJ02) and (1977AJ02).

22. ^{14}N(^{3}He, d)^{15}O $\qquad Q_m = 1.8037$

Angular distributions have been obtained at $E(^3\text{He}) = 11$ MeV (1968BO14) and 14 MeV (1969AL04): see Table 15.26. See also (1970AJ04) and (1971DZ07; theor.).

23. ^{14}N(α, t)^{15}O $\qquad Q_m = -12.5172$

Angular distributions of the t_0 group have been studied at $E_\alpha = 56$ MeV (1969GA11). See also (1970AJ04).

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

Table 15.26: Levels of ^{15}O from ^{14}N(d, n)^{15}O and ^{14}N(^{3}He, d)^{15}O

E_x in ^{15}O [a] (MeV)	l_p [b]	S [c]	E_x [d] (MeV $\pm$ keV)	l_p [e]	J^π
0	1	0.87		1	$\frac{1}{2}^-$
5.18		0		(0)	$\frac{1}{2}^+$
5.24	2	(0.03)	5.2410 ± 0.5 [f]	2	$\frac{5}{2}^+$
6.18	1	0.04	6.180 ± 4	1	$\frac{3}{2}^-$
6.79	0	≤ 0.3		0	$\frac{3}{2}^+$
6.86	2	0.4	6.8598 ± 1.0	2	$\frac{5}{2}^+$
7.28	2	0.42	7.2762 ± 0.6	2	$\frac{7}{2}^+$
7.56	0	≤ 0.4		0	$\frac{1}{2}^+$
8.28	1			0	$\frac{3}{2}^+$

[a] Nominal energies.
[b] (d, n): (1970RI01, 1971BO35). See also Table 15.27 in (1970AJ04).
[c] (d, n): (1971BO35); determined at $E_d \approx 6$ MeV; $\pm 30\%$. (1971BO35) reviews the spectroscopic factors derived in this and in other papers. See also (1970RI01).
[d] (d, nγ): (1965WA16, 1966AL18, 1967CH19).
[e] (^{3}He, d): (1968BO14, 1969AL04).
[f] See also p. 215 in (1972NE05).

$$E_{\text{thresh}} = 3772.7 \pm 1.1 \text{ keV (1972JE02)};$$
$$E_{\text{thresh}} = 3775.1 \pm 0.8 \text{ keV (1972SH08)}.$$

Angular distributions have been measured for the n_0 group at $E_p = 3.95$ to 18.5 MeV [and for the n_2 group at $E_p = 5.5$ MeV]: see (1970AJ04) for a listing of the references. See also (1971TH1D) and (1969HA1J, 1969SC1H; theor.). The threshold measurements listed above have led to a redetermination of the mass of ^{15}O: see the "GENERAL" section here. See also ^{16}O in (1977AJ02).

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

Angular distributions for the t_0, t_{1+2}, t_3, t_{4+5}, t_6 and t_7 groups have been studied in great detail for $E(^3\text{He}) = 16.5$ to 37.7 MeV by (1975PI01) and 39.8 and 44.6 MeV (1969BA06: see Table 15.27). (1975PI01) report evidence that a tensor term is needed in the effective interaction and that

Table 15.27: Levels of ^{15}O from ^{15}N(^{3}He, t)^{15}O [a]

E_x (MeV ± keV)	L [b]	E_x (MeV ± keV)
0	0	9.63 ± 40
5.24 ± 30	1, 3	10.30 ± 40
6.18	0	10.49 ± 40
6.84 ± 40	1, 3	10.97 ± 50
7.28	3	11.21 ± 60
7.56	3	11.69 ± 40
8.28	1	12.34 ± 40
8.94 ± 40		13.78 ± 40
9.47 ± 50		

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

[b] See general discussion in (1975PI01).

all transitions show a similar decreasing trend with energy, while the cross sections for populating the analog states in ^{15}N (in ^{15}N(^{3}He, ^{3}He)) is increasing: this is consistent with DWBA with an energy-independent interaction (1975PI01). For other states of ^{15}O observed in this reaction see Table 15.27.

26. ^{16}O(γ, n)^{15}O $Q_m = -15.6640$

The spectrum of photoneutrons has been investigated at many energies. Meaurements over the giant dipole resonance region show the predominant strength is to the $J^\pi = \frac{1}{2}^-$ and $\frac{3}{2}^-$ states at $E_x = 0$ and 6.18 MeV, consistent with the basic validity of the single-particle, single-hole theory of photoexcitation in ^{16}O. However, the positive parity states at $E_x = 5.18$, 5.24, 6.86 MeV are also populated suggesting some more complicated excitations in ^{16}O: see (1970HO21) and the earlier references in (1970AJ04). The angular distributions of the ground state neutrons have been measured from threshold to $E_\gamma = 28$ MeV (1970JU02). See also (1969NA1D, 1970CO1G, 1971AD05, 1974SC23), (1970FI1D), (1969VA1A, 1970MU1D, 1973BA2H, 1973SP03, 1973WA1H; theor.) and ^{16}O in (1977AJ02). For τ_m measurements see Table 15.18 (1969MU07).

27. (a) ^{16}O(p, d)^{15}O $Q_m = -13.4393$

(b) ^{16}O(p, pn)^{15}O $Q_m = -15.6640$

Reaction (a) goes primarily to ^{15}O*(0, 6.18). Angular distributions have been reported at many energies for $E_p = 18.5$ to 155.6 MeV: see Table 15.30 in (1970AJ04) and (1975RO27: $E_p = 65$ MeV; d_0, d_3). See (1975RO27) for a review of spectroscopic factors. See also (1969SN1B, 1972KA1A, 1973FA10, 1975KA1A), (1972PA1A) and (1970DE38, 1970PR1A, 1971JO22, 1971MC15, 1972PR01, 1973BL04, 1973SA1A, 1973TA27; theor.). For reaction (b) see (1973GO27) and (1970AJ04).

28. ^{16}O(d, t)^{15}O $\qquad Q_m = -9.4064$

Angular distributions have been reported at $E_d = 20$ MeV (1969PU04; $t_0 \to t_3$; $l_n = 1, 0, 2, 1$) and 28 MeV [(1968GA13; t_0), (1970IN1A, 1971IN1C; unpublished; t_0, t_{1+2}, t_3; also t_0 at $E_d = 20$ and 24 MeV)]. See (1970AJ04) for earlier references. At $E_d = 28$ MeV detailed comparison is made with the results from the mirror reaction ^{16}O(d, ^{3}He)^{15}N (1968GA13). At $E_d = 52$ MeV the spectrum at $\theta_{lab} = 11°$ is dominated by ^{15}O*(0, 6.18); ^{15}O*(9.61, 10.48) are also populated (1973MA21). See also (1972PA1A), (1971BO50, 1974DA1D; theor.) and ^{18}F in (1978AJ03).

29. ^{16}O(^{3}He, α)^{15}O $\qquad Q_m = 4.9145$

The $p_{1/2}$ and $p_{3/2}$ hole states at $E_x = 0$ and 6.18 MeV are strongly populated in this reaction. Information on these and other states of ^{15}O observed in this reaction is shown in Table 15.28. Angular distributions have been measured at $E(^3\text{He}) = 5.2$ to 36.6 MeV [see Table 15.32 of (1970AJ04)], and more recently at $E(^3\text{He}) = 15$ MeV (1974EL09), 16 MeV (1969DE06), 24 and 28 MeV (1973FU02) [see Table 15.28] and at 216 MeV (1974GE09; α_0, α_3). Branching ratios and multipole mixing ratios are displayed in Table 15.19 (1965WA16, 1969KU01, 1971AV04). For lifetime measurements see Table 15.18 (1965AL19).

^{15}O*(7.28) has an excitation energy of 7274.2 ± 1.4 keV (1967HE1A) (which is 23.2 keV below the E_b of ^{14}N + p) and $J^\pi = \frac{7}{2}^+$: thus it plays no significant role in determining that rate of the ^{14}N(p, γ)^{15}O reaction (1967HE1A). See also (1971BA1A). See also (1970CA28) and (1970LI1K, 1971MC15; theor.).

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

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

31. ^{16}O(^{10}B, ^{11}B)^{15}O $\qquad Q_m = -4.213$

Angular distributions involving ^{15}O(0) have been investigated at $E(^{10}\text{B}) = 100$ MeV (1975NA15).

Table 15.28: States of ^{15}O from ^{16}O(^{3}He, α)^{15}O

E_x (MeV ± keV)		l_n [a]	l_n [b]	S [c]	J [d]
(1974EL09)	A				
0	0	1	1	0.9	
5.182 ± 10	5.174 ± 10	0	0	≤ 0.10	
	5.167 ± 15				
	5.193 ± 11				
5.241 ± 10	5.233 ± 10	2	2	0.04	$\frac{5}{2}$
	5.243 ± 10				
6.175 ± 10		1	1	1	$\frac{3}{2}$
6.791 ± 10		2	2		$\frac{3}{2}$
6.861 ± 10		2	2		$\frac{5}{2}$
7.278 ± 10	7.2742 ± 1.4	(4)			$\frac{7}{2}$
7.557 ± 10		0			
8.290 ± 10		2			
8.744 ± 10		0			
8.924 ± 10		2			
8.985 ± 10		1			
9.493 ± 20					
9.535 ± 20					
9.611 ± 10		1			
9.668 ± 10		1			
10.286 ± 10		(2)			
10.469 ± 10					
10.900 ± 20					
10.945 ± 20					
11.010 ± 10					
11.158 ± 10					
11.217 ± 20					
11.578 ± 10					
11.740 ± 20 [f]					
11.960 ± 20					
11.995 ± 20					

Table 15.28: States of ^{15}O from ^{16}O(^{3}He, α)^{15}O (continued)

E_x (MeV ± keV)		l_n [a]	l_n [b]	S [c]	J [d]
(1974EL09)	A				
16.8 [e]					
23.0 [e]					

A: Older values: see Table 15.30 in (1970AJ04) for references.
[a] $E(^{3}\text{He}) = 15$ MeV (1974EL09).
[b] $E(^{3}\text{He}) = 11$ MeV (1968BO14), 16 MeV (1969DE06), 24 and 28 MeV (1973FU02).
[c] $E(^{3}\text{He}) = 28$ MeV (1973FU02).
[d] From angular correlation measurements: see (1966GA19, 1966GO15, 1967GO07, 1967HE1A, 1968GI01, 1971AV04).
[e] Structures observed at $E(^{3}\text{He}) = 216$ MeV (1975GE16).
[f] F. El Bedewi, private communication.

32. ^{16}O(^{14}N, ^{15}N)^{15}O $\qquad Q_m = -4.8303$

The ground state angular distribution has been studied at $E(^{14}\text{N}) = 155$ MeV (1975NA15, 1975VO05). See also (1965GA1B).

33. ^{17}O(p, t)^{15}O $\qquad Q_m = -11.324$

At $E_p = 39.8$ MeV angular distributions of t_0 and t_3 groups have been compared to those of the ^{3}He groups to the analog states in ^{15}N (1970OL1B, 1971OL04).

34. ^{19}F(^{3}He, ^{7}Li)^{15}O $\qquad Q_m = -4.319$

Angular distributions are reported at $E(^{3}\text{He}) = 40.7$ MeV invloving ($^{15}\text{O}_{\text{g.s.}} + {}^{7}\text{Li}^{*}_{\text{g.s.},0.48}$), ($^{15}\text{O}^{*}_{5.19+5.24} + {}^{7}\text{Li}^{*}_{\text{g.s.},0.48}$) and ($^{15}\text{O}^{*}_{6.18} + {}^{7}\text{Li}_{\text{g.s.}}$) (1971DE04, 1971DE37): see also the analog reaction ^{19}F(^{3}He, ^{7}Be)^{15}N [reaction 88 in ^{15}N].

^{15}F

(Not illustrated)

^{15}F has not been observed. It is predicted to be unstable with respect to proton emission by 2.32 MeV: the mass excess of ^{15}F is then 17.62 MeV (1966KE16). See also (1972WA07).

References

(Closed 31 January 1976)

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

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