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Energy Levels of Light Nuclei $A = 15$

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Abstract: An evaluation of A = 13–15 was published in Nuclear Physics A523 (1991), p. 1. This version of A = 15 differs from the published version in that we have corrected some errors discovered after the article went to press. Figures and introductory tables have been omitted from this manuscript. Also, reference key numbers have been changed to the NNDC/TUNL format.

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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: see (81AJ1A). It is then unstable with respect to decay into ^{14}Li + n and ^{13}Li + 2n by 1.2 and 5.1 MeV, respectively. (85PO1A) calculate [in a $(0+1)\ \hbar\omega$ model space] that the first four states of ^{15}Li at 0, 0.73, 2.39 and 2.77 MeV have, respectively, $J^\pi = \frac{3}{2}^-, \frac{1}{2}^-, \frac{7}{2}^-$ and $\frac{5}{2}^-$. See also (88PO1E; theor.).

^{15}Be
(Not illustrated)

^{15}Be has not been observed. The calculated mass excess is 51.18 MeV: see (81AJ1A). ^{15}Be is then unstable with respect to ^{14}Be+n and ^{13}Be+2n by 3.4 and 0.04 MeV, respectively. (85PO1A) calculate [in a $(0+1)\ \hbar\omega$ model space] that the first four states of ^{15}Be at 0, 0.07, 2.32, 3.10 MeV have, respectively, $J^\pi = \frac{5}{2}^+, \frac{3}{2}^+, \frac{9}{2}^+, \frac{7}{2}^+$. See also (87SA1E; theor.).

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

Mass of ^{15}B: Wapstra adopts 28970 ± 22 keV (88WA1C, and private communication) and so do we: see (86AJ1A). ^{15}B is then stable with respect to ^{14}B + n by 2.77 MeV.

Decay of ^{15}B: ^{15}B decays by β^- emission to ^{15}C: Q_{β^-} (max) = 19.10 MeV. The character of the decay is not known but measurements of the half-life are 11 ± 1 ms (84DU1D), 8.8 ± 0.6 ms (86CU1B), 10.4 ± 0.3 ms (88MU1B), 10.8 ± 0.5 ms (88SA2F), $10.3^{+0.6}_{-0.5}$ ms (89LE1E). The weighted mean of these five values is 10.3 ± 0.2 ms. Omitting the low value from (86CU1B) gives 10.5 ± 0.3 ms, which we adopt.

Upper limits have been set on the P_{0n} and P_{2n}: 5% and 1.5%, respectively (84DU1D). See also (89LE1E).

General: (85PO1A) calculate [in a $(0+1)\ \hbar\omega$ model space] that the first four states of ^{15}B at 0, 1.53, 2.06, 2.71 MeV have, respectively, $J^\pi = \frac{3}{2}^-, \frac{5}{2}^-, \frac{1}{2}^-$ and $\frac{7}{2}^-$.

Interaction cross sections at 790 MeV/A of ^{15}B ions with Be, C and Al are reported by (88TA1E). The interaction radius and the r.m.s. radius for the nucleon distributions in ^{15}B have also been derived (88TA1E). See also (89SA1N), (86DU1L, 89DE1X), (86GU1D, 88BA1J, 88MI1G, 89DO1I, 90LO1K) and (86AN1D, 89DO1K, 89PO1K, 89SI1H, 90RE1F; theor.).

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

GENERAL (See also (86AJ1A)).

Model calculations: (88MI1J, 89PO1K, 89WO1E).

Electromagnetic transitions: (84VA1A).

Astrophysical questions: (89KA1K).

Complex reactions involving ^{15}C: (85PO1D, 86AV1B, 86BI1A, 86DU1L, 86HA1P, 86HA1B, 86PO1A, 87RI1C, 87SA1F, 87SN1A, 87VI1A, 88CA1A, 88JO1B, 88MI1I, 88RU1A, 88SA2B, 89AS1B, 89OG1B, 89SA1N, 89SI1H, 89YO1D).

Hypernuclei: (88MA1G, 89TA1D).

Other topics: (85AN1A, 86AN1D).

Ground state of ^{15}C: (85AN1A, 86AS1B, 87SA1E, 87VA1F, 88VA1A, 89SA1N, 89WO1E).

$$|g| = 2.63 \pm 0.14 \text{ (88AS1A; prelim.)}$$

$$\mu_{\text{g.s.}} = 1.315 \pm 0.07 \text{ nm (89RA1I)}$$

$$\mu_{0.74} = -1.758 \pm 0.03 \text{ nm (89RA1I)}$$

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

The half-life of ^{15}C is 2.449 ± 0.005 s (79AL1E). Transitions have been observed to ^{15}N$_{\text{g.s.}}$ and to the upper of the 5.3 MeV states in ^{15}N which has $J^\pi = \frac{1}{2}^+$. The log ft to ^{15}N*(5.30) indicates an allowed transition: therefore J^π (^{15}C$_{\text{g.s.}}$) = $\frac{1}{2}^+$ or $\frac{3}{2}^+$. Weak transitions are observed to ^{15}N*(7.30, 8.31, 8.57, 9.05) (79AL1E): see Table 15.15. The shape of the ^{15}C$_{\text{g.s.}} \rightarrow {}^{15}N_{\text{g.s.}}$ transition differs appreciably from an allowed shape (84WA1A). See also (86AS1B, 88AS1A), (88WA1E) and (89BA2N, 89PO1K; theor.).

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

Observed proton groups are displayed in Table 15.2.

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

Observed groups are displayed in Table 15.3. See also (81AJ1A).

Table 15.1: Energy levels of ^{15}C[a]

E_x (MeV $\pm$ keV)	$J^\pi; T$	τ or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
g.s.	$\frac{1}{2}^+; \frac{3}{2}$	$\tau_{1/2} = 2.449 \pm 0.005$ s	β^-	1, 2, 3, 4, 6, 7, 9
		$\|g\| = 2.63 \pm 0.14$		
0.7400 ± 1.5	$\frac{5}{2}^+$	$\tau_m = 3.76 \pm 0.10$ ns	γ	2, 3, 4, 7, 8
		$g = -0.703 \pm 0.012$		
3.103 ± 4	$\frac{1}{2}^-$	$\Gamma_{c.m.} \leq 40$		2, 3, 9
4.220 ± 3	$\frac{5}{2}^-$	< 14		2, 3
4.657 ± 9	$\frac{3}{2}^-$			2, 3
4.78 ± 100	$\frac{3}{2}^+$	1740 ± 400		6
5.833 ± 20	$(\frac{3}{2}^+)$	64 ± 8		2, 6
5.866 ± 8	$\frac{1}{2}^-$			2, 3
6.358 ± 6	$(\frac{5}{2}, \frac{7}{2}^+, \frac{9}{2}^+)$	< 20		2, 3
6.417 ± 6	$(\frac{3}{2} \rightarrow \frac{7}{2})$	≈ 50		2, 3
6.449 ± 7	$(\frac{9}{2}^-, \frac{11}{2})$	< 14		2, 3
6.536 ± 4	[a]	< 14		2, 3
6.626 ± 8	$(\frac{3}{2})$	20 ± 10		2, 3
6.841 ± 4	[a]	< 14		2, 3
6.881 ± 4	$(\frac{9}{2})$[a]	< 20		2, 3
7.095 ± 4	$(\frac{3}{2})$	< 15		2, 3
7.352 ± 6	$(\frac{9}{2}, \frac{11}{2})$	20 ± 10		2, 4
7.414 ± 20				2
7.75 ± 30 [b]				2
8.01 ± 30				2
8.11 ± 10 [b]				2
8.47 ± 15	$(\frac{9}{2} \rightarrow \frac{13}{2})$	40 ± 15		2
8.559 ± 15	$(\frac{7}{2} \rightarrow \frac{13}{2})$	40 ± 15		2
9.00 ± 30				2
(9.73 ± 30)				2
9.789 ± 20	$(\frac{9}{2} \rightarrow \frac{15}{2})$	20 ± 15		2
10.248 ± 20	$(\frac{5}{2} \rightarrow \frac{9}{2})$	20 ± 15		2
11.015 ± 25				2
11.123 ± 20	$(\frac{11}{2} \rightarrow \frac{19}{2})$	30 ± 20		2

Table 15.1: Energy levels of ^{15}C[a] (continued)

E_x (MeV ± keV)	$J^\pi; T$	τ or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
(11.68 ± 30)				2
11.825 ± 20	$\geq \frac{13}{2}$	70 ± 30		2

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

[b] Broad or unresolved states.

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

See (81AJ1A).

5. ^{14}C(n, γ)^{15}C $Q_m = 1.2181$

$\sigma_\gamma < 1\ \mu$b (81MU1A).

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

At $E_{\vec{d}} = 16$ MeV angular distributions and A_y measurements are reported to a state at $E_x = 4.78 \pm 0.10$ MeV ($\Gamma_{c.m.} = 1.74 \pm 0.40$ MeV); $S = 0.5$. A narrow state at $E_x = 5.81 \pm 0.02$ MeV ($\Gamma_{c.m.} = 64.3 \pm 8.1$ keV), $S = 0.02$, is also observed. It is suggested that these are 1p2h and 3p4h $\frac{3}{2}^+$ states (85DA1C) [and S.E. Darden, private communication]. For the earlier work see Table 15.2.

7. ^{14}C(^{13}C, ^{12}C)^{15}C $Q_m = -3.7283$

Angular distributions have been studied at $E(^{13}\text{C}) = 20.0$ to 27.5 MeV to ^{15}C*(0, 0.74) (88BI1C). See also (90VO1E).

8. ^{15}N(π^-, γ)^{15}C $Q_m = 129.797$

Radiative pion capture shows evidence for $J^\pi = \frac{5}{2}^+$, $T = \frac{3}{2}$ giant magnetic quadrupole states: transitions are reported to ^{15}C*(0.74) as well as to ^{15}C*(6.7, 8.6, 12.0) (83ST1C).

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

^{9}Be(^{7}Li, p)^{15}C [b]			^{14}C(d, p)^{15}C [c]		
E_x (keV)	$\Gamma_{c.m.}$ (keV)	J^π [d]	E_x (keV)	$\Gamma_{c.m.}$ (keV)	J^π [e]
g.s.	bound		g.s.	bound	$\frac{1}{2}^+$ [o]
$\equiv 740$ [f]	bound		744.1 ± 2 [j]	bound	$\frac{5}{2}^+$ [p]
3100 ± 30	< 40	$(\frac{1}{2}^-)$ [h]	3105.3 ± 5 [k]	≈ 42	$(\frac{1}{2}^-)$
4223 ± 15	< 15	$(\frac{5}{2}^-)$	4221.1 ± 3 [k]	< 14	$(\frac{7}{2}^+, \frac{5}{2}^-)$
(4550 ± 30)					
			4657 [k]		
			4780 ± 100 [l]	1740 ± 400	$\frac{3}{2}^+$
5833 ± 20		[i]	5810 ± 20 [l]	64 ± 8	$(\frac{3}{2}^+)$ [q]
5858 ± 20		[i]			
6370 ± 15	< 20	$(\frac{5}{2})$	[k,m]	< 14	$(\frac{7}{2}, \frac{9}{2})^+$
6436 ± 20			6428.1 ± 7	≈ 50	$(\frac{3}{2}, \frac{5}{2}, \frac{7}{2})$
6461 ± 20			[m]	< 14	$(\frac{9}{2}^-, \frac{11}{2})$
6542 ± 15	< 20	$(\frac{3}{2})$	6539.8 ± 5	< 14	$(\frac{9}{2}^-, \frac{11}{2})$
6639 ± 15	20 ± 10	$(\frac{3}{2})$			
6847 ± 15	< 20	$(\frac{11}{2}, \frac{13}{2})$	6844.9 ± 5	< 14	$(\frac{13}{2}, \frac{11}{2})^+$
6894 ± 15	< 20	$(\frac{7}{2}, \frac{9}{2})$	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 [g]			7.81 ± 10 [n]		
8010 ± 30					
8130 ± 30 [g]			8.10 ± 10 [n]		
8491 ± 15	40 ± 15	$(\frac{9}{2}, \frac{11}{2}, \frac{13}{2})$	8.46 ± 10 [n]		
8559 ± 15	40 ± 15	$(\frac{7}{2} \to \frac{13}{2})$			
9000 ± 30					
(9730 ± 30)					
9789 ± 20	20 ± 15	$(\frac{9}{2} \to \frac{15}{2})$			
10248 ± 20	20 ± 15	$(\frac{5}{2}, \frac{7}{2}, \frac{9}{2})$			
11015 ± 25					

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

^{9}Be(^{7}Li, p)^{15}C [b]			^{14}C(d, p)^{15}C [c]		
E_x (keV)	$\Gamma_{c.m.}$ (keV)	J^{π} [d]	E_x (keV)	$\Gamma_{c.m.}$ (keV)	J^{π} [e]
11123 ± 20	30 ± 20	$(\frac{11}{2} \rightarrow \frac{19}{2})$			
(11680 ± 30)					
11825 ± 20	70 ± 30	$(\frac{13}{2} \rightarrow \frac{31}{2})$			

[a] For references see Table 15.2 in (81AJ1A).
[b] $E(^{7}\text{Li}) = 20$ MeV. E_x based on 740 keV for the first excited state.
[c] $E_d = 12 - 14$ MeV.
[d] Suggested J^{π} assignments based on angular distributions (and $2J_f + 1$ dependence) and l_{max} from Γ_n.
[e] Analysis of the two bound states is done using DWUCK. For the unbound states DOXY was used.
[f] $E_x = 739 \pm 1$ keV [from E_{γ}]; $\tau_m = 3.77 \pm 0.11$ ns.
[g] Broad or unresolved states.
[h] $\theta_n^2 = 0.0075 \pm 0.0015$.
[i] Sum of the J for these two states is 2 [based on $(2J_f + 1)$ dependence of cross section].
[j] $\tau_m = 3.73 \pm 0.23$ ns.
[k] See also (85DA1C).
[l] See text, reaction 6 (85DA1C).
[m] Observed but E_x not determined.
[n] Observed at $E_d = 27$ MeV.
[o] $S = 0.88$.
[p] $S = 0.69$ or 0.55. $g = -0.77 \pm 0.06$.
[q] May be unresolved.

9. ^{16}O(^{7}Li, ^{8}B)^{15}C $\qquad Q_m = -22.624$

At $E(^{7}\text{Li}) = 82$ MeV ^{15}C*(0, 3.1) are populated (85AL1G).

Table 15.3: Proton groups from ^{13}C(t, p)^{15}C [a]

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

[a] (83TR1D); $E_t = 18$ MeV; DWBA.
[b] Strong group.

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

GENERAL (See also (86AJ1A)).

Nuclear models: (85KW1A, 85PH1A, 87KA1H, 87KI1C, 87ME1D, 87ST1B, 88WO1A, 89WO1E, 90VA1H)

Special states: (85AR1H, 85GO1A, 85PH1A, 85SH1F, 87KI1C, 87ST1B, 88KW1A, 88ZH1B, 89OR1C)

Electromagnetic transitions and giant resonances: (85BL1H, 85GO1A, 86ER1A, 87KI1C, 87ST1B, 89AS1C)

Astrophysical questions: (82BU1A, 82CA1A, 82WO1A, 85PR1D, 86FR1G, 87AR1C, 87AU1A, 87LE1J, 87ZI1C, 88FE1A, 88KR1G, 88PI1C, 88WA1I, 89CH1X, 89GU1Q, 89GU1J, 89GU1L, 89JI1A , 89KA1K, 89KE1D, 89ME1C, 89NO1A, 89WY1A, 89YO1H, 90HA1W, 90RA1O)

Complex reactions involving ^{15}N: (85AR1H, 85BE1B, 85HA1N, 85PO1D, 85SI1C, 85UT1A, 86AI1A, 86CH2G, 86CO1Q, 86GR1A, 86HA1B, 86MA1F, 86MA1M, 86ME1B, 86PO1A, 86PO1L, 86SA1C, 86SC1B, 86SO1A, 86TO1H, 86UT1A, 86VA1B, 87BA1S, 87BE1I, 87BU1B, 87FE1A, 87MI1R, 87NA1B, 87OL1A, 87RI1C, 87ST1A, 87VI1A, 88AR1D, 88GO1L, 88JO1B, 88SA2B, 88UT1B, 89BA2N, 89GE1A, 89GR1J, 89KI1C, 89PA1E, 89SA1N, 89TE1C, 89YO1D, 90DA1C, 90GL1A, 90WE1A)

Applied work: (86AM1B, 86CO1Q, 86EN1A, 86HE1F, 86LE1L, 86NO1C, 86SA2H, 86ST1K, 87SI1D, 88GR1A, 88PI1D, 88PR1D, 88VI1A, 89KU1P, 89TA1Y, 89YO1H, 90AM1F)

Pion capture and reactions (See also reactions 15, 43, and 46.): (85LE1E, 85MA1K, 86BA1C, 86SI1A, 87KA1H, 87LE1B, 88LI1I, 88MI1K, 88RO1M, 88TA1M, 89CH2A, 89GE1C, 89JO1B, 89LE1L, 90ER1A, 90ER1E, 90OD1A, 90TA1K)

Reactions involving other mesons and hyperons: (85IA1A, 86FE1A, 89DO1I, 89DO1K)

Antiproton reactions: (85BA2C)

Hypernuclei: (84BO1H, 85IA1A, 86AN1R, 86DA1G, 86DA1B, 86FE1A, 86GA1H, 86KO1A, 86YA1F, 87MA2A, 87MI1A, 87PO1H, 87WU1A, 88MO1L, 89BA2N, 89BA1E, 89DO1K, 89KO1H, 89MI1E, 89TA1D)

Other topics: (85AN1A, 85PH1A, 85SH1F, 86AN1D, 86WI1F, 87CH1E, 88KW1A, 89OR1C, 89PO1K, 90MU1A)

Ground-state properties of ^{15}N: (85AN1A, 85AR1F, 85BL1H, 85GO1A, 86BA2X, 86BA2Y, 86MC1B, 86WI1F, 86WU1B, 87DE1E, 87FU1C, 87IC1A, 87KI1C, 87MI1R, 88AR1B, 88AR1I, 88CH1T, 88DE1C, 88FU1B, 88KE1B, 88NI1B, 88SH1C, 88VA1A, 88WA1D, 88WO1A, 89CH1N, 89FU1E, 89GO1H, 89NE1A, 89SA1N, 89WO1E, 90VA1G, 90VA1H)

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

E_x (MeV ± keV)	$J^\pi; T$	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
0	$\frac{1}{2}^-; \frac{1}{2}$	-	stable	3, 4, 5, 6, 13, 14, 16, 17, 18, 19, 20, 24, 25, 26, 27, 28, 31, 32, 33, 34, 35, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66
5.270155 ± 0.014 [b]	$\frac{5}{2}^+$	$\tau_m = 2.58 \pm 0.14$ ps $g = +(0.94 \pm 0.07)$	γ	4, 5, 16, 17, 24, 25, 31, 32, 35, 40, 45, 46, 49, 50, 56, 59, 60, 64, 65
5.298822 ± 0.014 [b]	$\frac{1}{2}^+$	25 ± 7 fs	γ	4, 5, 10, 11,12, 16, 18, 24, 25, 26, 31, 32, 35, 40, 42, 45, 49, 50, 56, 60, 64, 65
6.32378 ± 0.02 [b]	$\frac{3}{2}^-$	0.211 ± 0.012 fs	γ	4, 5, 10, 11, 12, 13, 16, 18, 24, 26, 31, 32, 35, 39, 40, 42, 44, 45, 46, 49, 50, 56, 57, 59, 60, 61, 63, 64, 65
7.15505 ± 0.02 [b]	$\frac{5}{2}^+$	18 ± 8 fs	γ	4, 5, 12, 16, 17, 18, 24, 25, 26, 31, 32, 35, 40, 45, 49, 50, 60
7.30083 ± 0.02 [b]	$\frac{3}{2}^+$	0.61 ± 0.05 fs	γ	4, 5, 12, 16, 18, 24, 25, 26, 31, 32, 35, 40, 42, 45, 49, 50, 60
7.5671 ± 1.0 [c]	$\frac{7}{2}^+$	12^{+11}_{-6} fs	γ	4, 5, 10, 11, 12, 16, 17, 18, 24, 25, 26, 31, 40, 45, 46, 49, 50, 60, 64
8.31262 ± 0.027 [b]	$\frac{1}{2}^+$	1.7 ± 1.1 fs	γ	4, 5, 18, 24, 25, 26, 31, 35, 39, 40, 42, 45, 49, 50, 56

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

E_x (MeV ± keV)	$J^\pi; T$	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
8.5714 ± 0.12	$\frac{3}{2}^+$	0.7 ± 0.7 fs	γ	4, 5, 10, 11, 12, 16, 17, 18, 24, 25, 26, 31, 40, 42, 45, 49, 50
9.04971 ± 0.07	$\frac{1}{2}^+$	0.50 ± 0.08 fs	γ	4, 5, 24, 25, 31, 35, 40, 42, 45, 56
9.15190 ± 0.12 [b]	$\frac{3}{2}^-$	1.40 ± 0.36 fs	γ	4, 5, 10, 11, 24, 25, 31, 35, 40, 45, 49, 50
9.15490 ± 0.03 [b]	$\frac{5}{2}^+$	7^{+6}_{-3} fs	γ	4, 5, 18, 24, 31, 35, 40, 49, 50
9.2221 ± 0.8	$\frac{1}{2}^-$	< 130 fs	γ	24, 26, 31, 35, 40, 56, 60
9.760 ± 1	$\frac{5}{2}^-$	2.6 ± 0.9 fs	γ	24, 40, 45
9.829 ± 3	$\frac{7}{2}^-$	17 ± 7 fs	γ	4, 5, 10, 11, 17, 18, 24, 26, 31, 40, 49, 50
9.9250 ± 0.2	$\frac{3}{2}^-$	0.31 ± 0.05 fs	γ	18, 24, 31, 35, 40, 45
10.0660 ± 0.2 [c]	$\frac{3}{2}^+$	0.100 ± 0.006 fs	γ	18, 35, 40, 44, 45, 49, 50
10.4497 ± 0.3	$\frac{5}{2}^-$	$\Gamma < 0.5$ keV	γ, p	5, 10, 11, 24, 28, 40
10.5333 ± 0.5	$\frac{5}{2}^+$		γ, p	5, 10, 11, 18, 24, 25, 28, 31, 40
10.6932 ± 0.3	$\frac{9}{2}^+$	$\tau_m = 18 \pm 9$ fs	γ, p	5, 11, 16, 28, 46
10.7019 ± 0.3	$\frac{3}{2}^-$	$\Gamma = 0.2$ keV	γ, p	10, 11, 17, 18, 24, 26, 28, 60
10.804 ± 2	$\frac{3}{2}^+$	$< 1 \times 10^{-3}$	γ, p	4, 5, 10, 11, 18, 24, 28, 40, 45
11.235 ± 5 [b]	$\geq \frac{3}{2}$	3.3	n	16, 31, 36, 40
11.2928 ± 0.7	$\frac{1}{2}^-$	8 ± 3	γ, n, p	16, 18, 28, 29, 30, 31, 36, 38, 49
11.4376 ± 0.7	$\frac{1}{2}^+$	41.4 ± 1.1	γ, n, p, α	6, 7, 10, 11, 18, 25, 28, 29, 30, 31, 36, 38, 64
11.615 ± 4	$\frac{1}{2}^+; T = \frac{3}{2}$	405 ± 6	γ, n, p	28, 29, 30
11.763 ± 3	$\frac{3}{2}^+$	40	n, p, α	7, 29, 30, 36, 38

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

E_x (MeV ± keV)	$J^\pi; T$	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
11.876 ± 3	$\frac{3}{2}^-$	25	γ, n, p, α	7, 29, 30, 36, 38, 48
11.942 ± 6	$\frac{9}{2}^-$	≤ 3.0	n, α	5, 16, 17, 18, 25, 26, 36
11.965 ± 3	$\frac{1}{2}^-$	17	n, p, α	5, 7, 10, 11, 29, 30, 36, 38
12.095 ± 3	$\frac{5}{2}^+$	14 ± 5	n, p, α	7, 25, 29, 30, 36, 38
12.145 ± 3	$\frac{3}{2}^-$	41 ± 5	n, p, α	7, 10, 11, 29, 30, 36, 38
12.327 ± 4	$\frac{5}{2}^{(+)}$	22	n, p	17, 18, 25, 29, 30, 36, 38
12.493 ± 4	$\frac{5}{2}^+; \frac{1}{2}$	40 ± 5	n, p, α	7, 18, 25, 29, 30, 36, 38
12.522 ± 8	$\frac{5}{2}^+; \frac{3}{2}$	58 ± 4	γ, p	28, 45
12.551 ± 10	$\frac{9}{2}^+$			5, 11, 16, 17, 25, 46
12.920 ± 4	$\frac{3}{2}^-$	56 ± 11	n, p, α	7, 9, 18, 29, 30, 36, 38
12.940 ± 10	$\frac{5}{2}^+$	81	p, α	7, 9, 29, 30
13.004 ± 10	$\frac{11}{2}^-$			5, 10, 11, 16, 18, 25, 26
13.149 ± 10		7 ± 3	n, p, α	7, 38
13.174 ± 7	$(\frac{9}{2})$	7 ± 3	n, p, α	5, 7, 11, 16, 17, 18, 29, 36, 38
13.362 ± 8	$\frac{3}{2}^-$	16 ± 8	n, p, α	7, 9, 29, 30, 38
13.390 ± 10	$\frac{3}{2}^+$	56	γ, n, p, α	7, 9, 28, 29, 30, 38
13.537 ± 10	$\frac{3}{2}^-$	85 ± 30	n, p, α	7, 9, 29, 30
13.608 ± 7	$\frac{5}{2}^{(+)}$	18 ± 4	n, p, α	7, 18, 36, 38
(13.612 ± 10)	$(\frac{1}{2}^+)$	90	n, p, α	9, 29, 30
13.713 ± 10		26 ± 8	n, p, α	7, 29, 38
13.84 ± 30	$\frac{3}{2}^+$	75	n, p, α	5, 7, 9, 11, 25, 36, 38
13.9	$\frac{1}{2}^+$	930	γ, p	28, 29
13.99 ± 30	$\frac{5}{2}^+$	98 ± 10	n, p, α	7, 11, 29, 30
14.090 ± 7	$(\frac{9}{2}^+, \frac{7}{2}^+)$	22 ± 6	n, p, α	5, 7, 10, 11, 18, 25, 36, 38, 46

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

E_x (MeV ± keV)	$J^\pi; T$	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
14.10 ± 30	$\frac{3}{2}^+$	≈ 100	n, α	5, 7, 9, 30
14.162 ± 10	$\frac{3}{2}^{(+)}$	27 ± 6	n, α	5, 7, 36, 38
14.24 ± 40	$\frac{5}{2}^+$	150	α	9, 10
14.38 ± 40	$\frac{7}{2}^+$	100	α	9
14.4		≈ 1900	n, p, α	36, 38
14.55 ± 20		200 ± 50	n, (p), α	7
14.647 ± 10		33 ± 6	n, p, α	7, 36, 38
14.71		750	γ, p	28
14.720 ± 10	$\frac{5}{2}^-$	110 ± 50	γ, n, (p), α	7, 10, 11, 18, 36, 38, 45
14.86 ± 20		48 ± 11	n, α	7, 9, 18
14.920 ± 10		12 ± 3	n, α	7, 10, 38
15.025 ± 10		13 ± 3	n, α	7, 18
15.09 ± 20		80 ± 25	n, α	7, 9, 49
15.288 ± 10		26 ± 6	n, α	7, 9
15.373 ± 10	$\frac{13}{2}^+$			5, 10, 11, 16, 17, 18
15.38 ± 20		75 ± 25	n, t, α	7, 9, 14
15.43 ± 20		≈ 100	n, (α)	7, 9
15.45		750	γ, p	28
15.53 ± 20		≈ 35	n, α	7, 10, 11, 38
15.60 ± 20		95 ± 25	n, α	7
15.782 ± 10			p, t, α	7, 14, 18
15.93 ± 20		35 ± 5	n, t, α	7, 14, 17
15.944 ± 15		21 ± 6	n, t, α	7, 14
16.026 ± 10		62 ± 12	n, p, t, α	7, 9, 14, 18, 38
16.190 ± 10	$\frac{3}{2}^+$	450 ± 100	γ, n, p, t, α	10, 14, 18
16.26 ± 20	$\frac{3}{2}^+$	150 ± 28	γ, n, t, α	6, 7, 9, 14, 17, 18
16.32 ± 20		≈ 30	n, p, t, α	7, 14
16.39 ± 20		44 ± 11	n, p, t, α	7, 14, 17, 38
16.46		560	γ, p, d	21, 28

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

E_x (MeV ± keV)	$J^\pi; T$	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
16.576 ± 15		27 ± 15	n, α	7, 38
16.59 ± 25	$\frac{3}{2}^-$	490	γ, n, p, t, α	14
16.677 ± 15	$\frac{1}{2}^+; \frac{1}{2}$	80 ± 20	γ, n, p, d, t, α	6, 7, 14, 17, 21, 23, 28, 30, 36, 38, 43
16.85 ± 30	$\frac{5}{2}$	110 ± 50	t, α	14
16.91		≈ 350	n, p, d, t, α	14, 21, 36, 38
(17.05)			p, t	14
17.11		broad	d, α	23
17.15 ± 50	$(\frac{1}{2}^+, \frac{3}{2}^+)$	250 ± 60	γ, t, α	6, 14
17.23 ± 40		≈ 175	d, t, (α)	23
17.37 ± 40		≈ 250	p, d, t, α	14, 21, 23, 36, 38
17.58 ± 40	$\frac{3}{2}^+$	450 ± 120	γ, d, t, α	14, 23, 38
17.67 ± 40	$\frac{3}{2}^+; \frac{1}{2}$	600 ± 80	γ, n, d, α	6, 20, 21, 23
17.72 ± 10		48 ± 10	n, (p), d, t, α	18, 21, 23, 38
17.95 ± 20		167	n, α	18
18.06 ± 10		19 ± 4	(n), d, α	17, 21, 23
18.09 ± 20		≈ 40	(n), p, d, t	21, 23
18.22		158	n, α	36, 38
18.27 ± 20		235 ± 60	n, p, d, α	18, 21, 23, 38
18.70 ± 20				11, 18
18.91 ± 150	$\frac{3}{2}^+ + \frac{1}{2}^+$	750 ± 70	γ, α	6
19.20 ± 35	$(\frac{1}{2}^+; \frac{1}{2})$	≈ 130	n, d	18, 21
19.5	$\frac{3}{2}^+; (\frac{3}{2})$	≈ 400	γ, p, t	14, 28, 29
19.72 ± 40		[d]		11, 17, 18
20.12 ± 50	$(T = \frac{3}{2})$			16, 46
20.5	$\frac{3}{2}^+$	≈ 400	γ, n, p, d	21, 28
20.96 ± 65	$\frac{3}{2}^+ + \frac{1}{2}^+$	1740 ± 150	γ, α	6, 18
21.82		≈ 600	γ, p, d	20, 28, 43
23.19 ± 60	$(T = \frac{3}{2})$		γ, p	28, 46
23.6		broad	γ, n, d	20, 43

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

E_x (MeV ± keV)	$J^\pi; T$	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
24.75 ± 150		d		18
25.5	$\frac{3}{2}^-; (T = \frac{3}{2})$		γ, n, p	28, 43
(26.8)			t	14
≈ 37			γ, p	28

[a] See also Tables 15.5 and 15.12 here, and Table 15.6 in (86AJ1A) [τ_m].

[b] Revisions in the values of the fundamental constants and of the binding energy of the deuteron, as well as a reevaluation of earlier work, lead (90WA1H) to suggest values for E_x which differ from the ones shown by, typically, 40 eV [lower].

[c] See also reaction 40.

[d] Wide or unresolved.

$$\langle r^2\rangle^{1/2} = 2.612 \pm 0.009 \text{ fm (88DE1C)}$$
$$\mu = -0.283188842\ (45) \text{ nm (see 89RA1I)}$$

Natural abundance: $(0.366 \pm 0.009)\%$ (84DE1A)

^{15}N*(5.27): $\mu = +(2.35 \pm 0.18)$ nm (see 89RA1I)

1. (a) ^{9}Be(^{6}Li, n)^{14}N $\quad Q_m = 14.4986 \quad E_b = 25.3319$
   (b) ^{9}Be(^{6}Li, p)^{14}C $\quad Q_m = 15.1245$
   (c) ^{9}Be(^{6}Li, t)^{12}C $\quad Q_m = 10.4835$
   (d) ^{9}Be(^{6}Li, α)^{11}B $\quad Q_m = 14.3403$

Thick target neutron yields are reported at $E(^6\text{Li}) = 40$ MeV (87SC1E). The yield of p_0 and p_1 (reaction (b)) for $E(^6\text{Li} = 3.84$ to 6.40 MeV shows some broad structure: analysis in terms of Ericson fluctuation theory gives a value of ≈ 0.4 MeV for the average level width at $E_x = 28$ MeV in ^{15}N. The excitation functions for t_0 (reaction (c)), α_0, α_1 and α_2 (reaction (d)) show broad structures for $E(^6\text{Li}) = 4$ to 14 MeV. See (76AJ1A) for the references.

2. ^{9}Be(^{7}Li, n)^{15}N $\quad Q_m = 18.0818$

See (85MC1C; applied).

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

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

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

E_i (MeV)	J_i^π	E_f (MeV)	J_f^π	Branch (%)	Mult. mixing ratio δ
9.22 [g]	$\frac{1}{2}^-$	0	$\frac{1}{2}^-$	22 ± 5	
		5.30	$\frac{1}{2}^+$	42 ± 8	
		6.32	$\frac{3}{2}^-$	35 ± 6	
		7.30	$\frac{3}{2}^+$	2.6 ± 0.7	
9.76 [h]	$\frac{5}{2}^-$	0	$\frac{1}{2}^-$	81.5 ± 2.8	
		$5.27 + 5.30$		7.5 ± 1.5	
		6.32	$\frac{3}{2}^-$	3.7 ± 0.8	
		7.16	$\frac{5}{2}^+$	2.3 ± 0.5	
		7.57	$\frac{7}{2}^+$	5.0 ± 0.6	
9.83 [i]	$\frac{7}{2}^-$	5.27	$\frac{5}{2}^+$	≈ 85	
		6.32	$\frac{3}{2}^-$	2.2 ± 0.9	
		7.16	$\frac{5}{2}^+$	2.4 ± 1.1	
		7.30	$\frac{3}{2}^+$	3.7 ± 0.9	
		7.57	$\frac{7}{2}^+$	7.3 ± 1.0	
9.93 [j]	$\frac{3}{2}^-$	0	$\frac{1}{2}^-$	77.6 ± 1.9	
		$5.27 + 5.30$		15.4 ± 1.5	
		6.32	$\frac{3}{2}^-$	4.9 ± 1.2	
		7.30	$\frac{3}{2}^+$	2.1 ± 0.8	
10.07 [k]	$\frac{3}{2}^+$	0	$\frac{1}{2}^-$	96.0 ± 0.7	
		$5.27 + 5.30$		4.0 ± 0.7	
10.45 [l]	$\frac{5}{2}^-$	5.27	$\frac{5}{2}^+$	55.0 ± 0.8	$+0.021 \pm 0.033$
		6.32	$\frac{3}{2}^-$	31.3 ± 1.7	-0.59 ± 0.13
		7.16	$\frac{5}{2}^+$	5.2 ± 0.1	$+0.13^{+0.03}_{-0.04}$
		8.57	$\frac{3}{2}^+$	3.8 ± 0.6	-0.3 ± 0.4
		9.152	$\frac{3}{2}^-$	4.7 ± 0.1	$-0.32^{+0.09}_{-0.10}$
10.53 [m]	$\frac{5}{2}^+$	0	$\frac{1}{2}^-$	< 0.1	
		5.27	$\frac{5}{2}^+$	38.7 ± 0.2	-0.27 ± 0.03
		6.32	$\frac{3}{2}^-$	7.7 ± 0.1	-0.028 ± 0.004
		7.16	$\frac{5}{2}^+$	19.4 ± 0.2	$+0.007^{+0.010}_{-0.008}$
		7.30	$\frac{3}{2}^+$	31.4 ± 0.5	$+0.066 \pm 0.005$

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

E_i (MeV)	J_i^π	E_f (MeV)	J_f^π	Branch (%)	Mult. mixing ratio δ
		8.57	$\frac{3}{2}^+$	2.4 ± 0.1	$+0.012^{+0.006}_{-0.005}$
		9.152	$\frac{3}{2}^-$	0.3 ± 0.1	$-0.20^{+0.03}_{-0.02}$
10.69 [m]	$\frac{9}{2}^+$	5.27	$\frac{5}{2}^+$	61.6 ± 0.3	
		7.16	$\frac{5}{2}^+$	2.1 ± 0.1	-0.03 ± 0.07
		7.57	$\frac{7}{2}^+$	36.3 ± 0.6	$+0.118 \pm 0.008$
10.70 [m]	$\frac{3}{2}^-$	0	$\frac{1}{2}^-$	52.6 ± 0.8	$+0.180^{+0.006}_{-0.002}$
		5.27	$\frac{5}{2}^+$	37.4 ± 0.6	$-0.24^{+0.004}_{-0.008}$
		5.30	$\frac{1}{2}^+$	0.8 ± 0.1	-0.13 ± 0.07
		6.32	$\frac{3}{2}^-$	3.8 ± 0.1	$+0.135 \pm 0.015$
		7.16	$\frac{5}{2}^+$	0.4 ± 0.1	0.3 ± 0.3
		7.30	$\frac{3}{2}^+$	2.3 ± 0.1	-0.027 ± 0.023
		8.31	$\frac{1}{2}^+$	0.8 ± 0.1	$-0.017^{+0.018}_{-0.016}$
		9.05	$\frac{1}{2}^+$	0.2 ± 0.1	-0.007 ± 0.12
		9.152	$\frac{3}{2}^-$	0.2 ± 0.1	-0.11 ± 0.03
		9.23	$\frac{1}{2}^-$	1.5 ± 0.1	$+0.049^{+0.006}_{-0.005}$
10.80 [n]	$\frac{3}{2}^+$	0	$\frac{1}{2}^-$	51.5 ± 0.4	-0.02 ± 0.01
		5.27	$\frac{5}{2}^+$	4.9 ± 0.1	-0.63 ± 0.04
		5.30	$\frac{1}{2}^+$	15.5 ± 0.2	-0.55 ± 0.02
		6.32	$\frac{3}{2}^-$	5.4 ± 0.2	-0.07 ± 0.05
		7.16	$\frac{5}{2}^+$	7.8 ± 0.1	$+0.14 \pm 0.03$
		7.30	$\frac{3}{2}^+$	5.8 ± 0.1	-0.12 ± 0.02
		8.31	$\frac{1}{2}^+$	3.6 ± 0.1	$+0.12 \pm 0.03$
		9.05	$\frac{1}{2}^+$	0.3 ± 0.1	
		9.152	$\frac{3}{2}^-$	0.9 ± 0.1	
		9.155	$\frac{5}{2}$	4.2 ± 0.1	
11.62 [o]	$\frac{1}{2}^+; T = \frac{3}{2}$	0	$\frac{1}{2}^-$	90.7 ± 3.0	
		5.27	$\frac{5}{2}^+$	< 1	
		5.30	$\frac{1}{2}^+$	7.4 ± 1.5	
		6.32	$\frac{3}{2}^-$	1.9 ± 1.5	
12.52	$\frac{5}{2}^+; T = \frac{3}{2}$	0	$\frac{1}{2}^-$	< 1	

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

E_i (MeV)	J_i^π	E_f (MeV)	J_f^π	Branch (%)	Mult. mixing ratio δ
		5.27	$\frac{5}{2}^+$	94.2 ± 0.6	-0.02 ± 0.04
		5.30	$\frac{1}{2}^+$	< 1	
		6.32	$\frac{3}{2}^-$	5.8 ± 0.6	-0.02 ± 0.04
13.39 [p]	$\frac{3}{2}^+$	0	$\frac{1}{2}^-$	100	

[a] See also Tables 15.12 and 15.14, and 15.6 in 86AJ1A). For references see Table 15.4 in (81AJ1A). Please note that (76BE1B) is an unpublished Ph.D. thesis.
[b] Transitions to ^{15}N*(5.27, 5.30) are < 0.1 and < 0.05%, respectively (75MO1C).
[c] Transitions to ^{15}N*(0, 5.30, 6.32) are < 0.1, < 4 and < 0.5%.
[d] Transitions to ^{15}N*(5.30, 6.32) are < 4 and < 0.6%.
[e] Transitions to ^{15}N*(5.30, 7.30, 7.57) are < 12, < 0.7 and < 3%.
[f] Transitions to ^{15}N*(7.16, 7.57, 8.31) are < 10, < 2 and < 0.5%.
[g] Transitions to ^{15}N*(7.16, 7.57, 8.31) are < 1, < 20 and < 5%.
[h] Transitions to ^{15}N*(7.30, 8.31, 8.57) are < 2, < 1 and < 2%.
[i] Transitions to ^{15}N*(0, 5.30) are < 4 and < 15%.
[j] Transitions to ^{15}N*(7.16, 7.57, 8.31, 8.57) are each < 1%.
[k] For upper limits for transitions to other states see Table 15.4 in (81AJ1A).
[l] Transitions to ^{15}N*(0, 5.30, 9.83) are < 12, < 2 and < 0.1%. See also (90GO1H).
[m] See also (90GO1H).
[n] π is + because if π were − the Γ_γ and δ of the 10.80 → 5.30 MeV transition would lead to an unacceptably high M2 value (33 W.u.) (P.M. Endt, private communication). See also (90GO1H).
[o] See footnote [g] in Table 15.4 (81AJ1A).
[p] $\Gamma_{\gamma_0} = 3.0 \pm 0.9$ eV, $\Gamma_p\Gamma_{\gamma_0}/\Gamma = 1.70 \pm 0.5$ eV; $\delta = 0.00 \pm 0.04$ (M2/E1); $B(\mathrm{E1}) = (1.2 \pm 0.4)10^{-3}\ e^2 \cdot \mathrm{fm}^2$. Transitions to ^{15}N*(5.27, 5.30) are < 8% and to ^{15}N*(6.32, 7.16, 7.30) are < 5%.

3. ^{9}Be(^{12}C, ^{6}Li)^{15}N $\qquad Q_m = -2.8395$

See (88GO1H; $E(^{12}\mathrm{C}) = 65$ MeV; prelim.).

4. ^{10}B(^{6}Li, p)^{15}N $\qquad Q_m = 18.7462$

Table 15.6: Resonances in $^{11}B(\alpha, \gamma_0)^{15}N$ [a]

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

[a] For references and other information see Table 15.7 in (86AJ1A).
[b] These E_α may be 100 keV too high.
[c] There is indication of M1/E2 transitions interfering with the predominant E1 transitions.

At $E(^6Li) = 4.9$ Mev, thirty proton groups are observed corresponding to ^{15}N states with $E_x < 16.8$ MeV. Angular distributions have been measured for the proton groups corresponding to $^{15}N^*(5.27 + 5.30,\ 6.32,\ 7.16 + 7.30,\ 7.57,\ 8.31,\ 8.57,\ 9.05 + 9.15)$: see (76AJ1A).

5. $^{10}B(^7Li, d)^{15}N$ $\qquad Q_m = 13.7207$

At $E(^7Li) = 24$ MeV angular distributions have been studied to many of the ^{15}N states with $E_x < 15.5$ MeV: see (81AJ1A).

6. $^{11}B(\alpha, \gamma)^{15}N$ $\qquad Q_m = 10.9916$

The 90° differential cross section for γ_0 production has been measured for $E_\alpha = 5.74$ to 18.0 MeV: see (81AJ1A, 86AJ1A). For the observed resonances see Table 15.6. See also (88WA1J; prelim.).

7. (a) $^{11}B(\alpha, n)^{14}N$ $\qquad Q_m = 0.1583$ $\qquad E_b = 10.9916$
(b) $^{11}B(\alpha, p)^{14}C$ $\qquad Q_m = 0.7842$

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

E_α (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Particle out	J^π	E_x (MeV)
0.606 [b]		γ, n	$\frac{7}{2}$	11.436
01.07 ± 20 [c]		n, p		11.78
1.20 ± 10 [c]		n, p		11.87
1.32 ± 10 [c]		n, p		11.96
1.50 ± 10 [c]		n, p	$(\frac{5}{2}^+)$	12.09
1.57 ± 10 [c]	41 ± 5	n, p	$(\frac{3}{2}^-)$	12.14
2.056 ± 10	34 ± 5	n_0, p_0	$\frac{5}{2}^+$	12.499
2.610 ± 13	56 ± 11	n_0, p_0, α	$\frac{3}{2}^-$	12.905
2.66 ± 30	81	p_0, α	$\frac{5}{2}^+$	12.94
2.942 ± 10	7 ± 3	n_0, p_0		13.149
2.984 ± 10	7 ± 3	n_0, p_0		13.180
3.239 ± 15	16 ± 8	n_0, p, α	$\frac{3}{2}^-$	13.366
3.31 ± 30	61	p, α	$\frac{3}{2}^+$	13.42
3.46 ± 30	85 ± 30	n_0, α	$\frac{3}{2}^-$	13.53
3.560 ± 10	18 ± 4	n_0, p	$(\frac{5}{2}, \frac{7}{2})^-$	13.602
3.57 ± 30	94	α	$\frac{1}{2}^+$	13.61
3.712 ± 10	26 ± 8	n_0		13.713
(3.78 ± 30)	70	α	$(\frac{1}{2}^+)$	(13.76)
3.89 ± 30	≈ 70	n_1, α	$(\frac{3}{2}^+)$	13.84
4.09 ± 30	≈ 100	n_1		13.99
4.232 ± 10	22 ± 6	n_0		14.094
4.24 ± 30	≈ 100	n_1, α	$\frac{3}{2}^+$	14.10
4.324 ± 10	27 ± 6	n_0		14.162
4.43 ± 40	150	α	$\frac{5}{2}^+$	14.24
4.62 ± 40	100	α	$\frac{7}{2}^+$	14.38
4.85 ± 20	200 ± 50	n_0		14.55
4.986 ± 10	33 ± 6	n_0		14.647
5.11 ± 30	110 ± 50	n_0		14.74
5.28 ± 20	48 ± 11	n_0, α		14.86
5.358 ± 10	12 ± 3	n_0		14.920

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)
5.501 ± 10	13 ± 3	n_0		15.025
5.59 ± 20	80 ± 25	n_0, α		15.09
5.860 ± 10	22 ± 6	n_0, α		15.288
5.98 ± 20	75 ± 25	n_2, (α)		15.38
6.06 ± 20	≈ 100	n_0, (α)		15.43
6.19 ± 20	≈ 35	n_0		15.53
6.29 ± 20	95 ± 25	n_2		15.60
(6.65 ± 40)		(α)		(15.87)
6.73 ± 20	35 ± 10	n_0, n_2		15.93
6.755 ± 15	21 ± 6	n_1		15.944
6.83 ± 20	60 ± 20	n_2		16.00
6.884 ± 15	62 ± 12	n_0, α		16.039
(6.98 ± 40)		(α)		(16.11)
7.18 ± 20	≈ 100	n_0, α		16.26
7.27 ± 20	≈ 30	n_0		16.32
7.37 ± 20	44 ± 11	n_2		16.39
7.616 ± 15	27 ± 15	n_0, (n_2)		16.576
7.754 ± 15	60 ± 10	n_0, (n_2)		16.677

[a] For references see Table 15.7 in (81AJ1A).

[b] (88WA1J; prelim.): $\Gamma < 0.2$ keV.

[c] (87TU1A); $J^\pi = \frac{3}{2}^{(-)}, \frac{3}{2}^-, \frac{1}{2}^-, \frac{5}{2}^+, \frac{3}{2}^-$ [see also for partial widths].

Reported resonances are displayed in Table 15.7. Nine resonances have been observed in the total cross section for reaction (a) in the range $E_\alpha = 0.55$ to 2.40 MeV (88WA1J; prelim.) [astrophysical reaction rates will be derived]. For thick target neutron yields for $E_\alpha = 1.0$ to 9.8 MeV, see the review in (89HE1F). See also (87EL1B; applied).

The total cross section for reaction (b) has been measured for $E_\alpha = 0.9$ to 1.7 MeV: resonance information is deduced by (87TU1A). At higher energies (to 25 MeV) the p_0 excitation functions show broad features: see (81AJ1A).

8. (a) $^{11}B(\alpha, d)^{13}C$ $\quad Q_m = -5.1677$ $\quad E_b = 10.9916$

(b) $^{11}B(\alpha, t)^{12}C$ $\quad Q_m = -3.8568$

The yield of d_0 has been measured for $E_\alpha = 13.5$ to 25 MeV. The excitation functions for t_0 and t_1 (to 25 MeV) show strong uncorrelated structures: see (76AJ1A, 81AJ1A). See also (89VA1O).

9. $^{11}B(\alpha, \alpha)^{11}B$ $E_b = 10.9916$

Observed resonances are shown in Table 15.7.

10. $^{11}B(^6Li, d)^{15}N$ $Q_m = 9.5166$

At $E(^6Li) = 34$ MeV angular distributions are reported to the states with $5.3 < E_x < 16.3$ MeV: this reaction appears to be less selective than reaction 11. The most strongly populated states are $^{15}N^*(9.2, 10.5, 10.7, 13.1, 14.8, 15.5)$. See (81AJ1A). See also (90AZ1B).

11. $^{11}B(^7Li, t)^{15}N$ $Q_m = 8.5238$

At $E(^7Li) = 24$ and 34 MeV, angular distributions to states with $5.3 < E_x < 15.6$ MeV have been measured: $^{15}N^*(9.8, 10.5, 10.7, 15.4, 15.5)$ are particularly strongly populated at 34 MeV. $J^\pi = \frac{9}{2}^+, \frac{9}{2}, \frac{11}{2}, \frac{9}{2}, \frac{11}{2}, \frac{13}{2}, \frac{15}{2}$ are suggested for $^{15}N^*(10.69, 12.56, 13.03, 13.19, 13.84, 14.11, 15.37)$. Only $^{15}N^*(15.52)$ appears to have a large cluster component corresponding to $^{11}B + \alpha$. See (81AJ1A). For a study of the γ-decay, see (81AJ1A). At $E(^7Li) = 34$, 40, 45 and 55 MeV states at $E_x = 13.88$, 17.10, 18.67, 18.81, 19.70, 19.93 and 22.86 MeV are reported to be strongly populated (90AZ1B; prelim.). See also (90DA1C).

12. $^{11}B(^9Be, \alpha n)^{15}N$ $Q_m = 9.4181$

Gamma-ray cross sections involving $^{15}N^*(5.3, 6.32, 7.16, 7.30, 7.57, 8.57)$ are reported at $E_{c.m.} = 1.92$, 2.30 and 2.46 MeV (86CU1A). See (84DA1F) for cross sections and S-factors.

13. $^{11}B(^{16}O, ^{12}C)^{15}N$ $Q_m = 3.8297$

Angular distributions have been measured at $E(^{16}O) = 27$ to 60 MeV involving the two proton-hole states of $^{15}N[^{15}N^*(0, 6.32); J^\pi = \frac{1}{2}^-, \frac{3}{2}^-]$ and $^{12}C^*(0, 4.4, 9.6)$: see (76AJ1A). See also (89KA1N; theor.).

14. (a) ^{12}C(t, γ)^{15}N $Q_m = 14.8484$
(b) ^{12}C(t, n)^{14}N $Q_m = 4.0151$ $E_b = 14.8484$
(c) ^{12}C(t, p)^{14}C $Q_m = 4.6410$
(d) ^{12}C(t, t)^{12}C
(e) ^{12}C(t, α)^{11}B $Q_m = 3.8568$

The 90° excitation function for γ_0 in the range 1.0 to 6.5 MeV [see (81AJ1A, 86AJ1A)] shows one very strong resonance (at peak, 4.4 ± 0.5 μb/sr) corresponding to ^{15}N*(16.7) as well as two other strong (unresolved and/or broad) resonances at $E_t \approx 3.3$ and 6 MeV: Table 15.8 shows the derived parameters. Table 15.8 also displays the structures observed in reactions (b)→(e). At $E_{\vec{t}} = 17$ MeV the polarization and analyzing power for the transition to ^{14}C$_{g.s.}$ (reaction (c)) are shown to be the same, as required by the conservation of parity. The VAP for the elastic scattering (reaction (d)) has been measured at $E_t = 9$ and 11 MeV: see (84AJ1A). See (81AJ1A) for the earlier work. See also (85SA1L, 90HA1V; theor.).

15. ^{12}C(^{3}He, π^+)^{15}N $Q_m = -124.7387$

Individual states have not been resolved in this reaction. The cross section over the bound states of ^{15}N is < 0.03 nb at $E_{\pi^+} = 5$ MeV and 0.8 ± 0.2 nb at $E_{\pi^+} \approx 60$ MeV [E(^{3}He) = 170.2 and 236.3 MeV, respectively] (88HO1H). For the earlier work see (84BI1B, 86SC1K).

16. ^{12}C(α, p)^{15}N $Q_m = -4.9656$

Angular distributions have been measured at many energies for $E_\alpha = 13.4$ to 96.8 MeV: see (76AJ1A, 81AJ1A, 86AJ1A). See also (87MI1C, 88BR1C; $E_\alpha = 48$ MeV; prelim.), (87BI1C; $E_\alpha = 218$ MeV; prelim.) and (89BR1J).

17. ^{12}C(^{6}Li, ^{3}He)^{15}N $Q_m = -0.9471$

Observed ^{3}He groups are displayed in Table 15.9 of (81AJ1A). Comparisons of the angular distributions obtained in this reaction at E(^{6}Li) = 60.1 MeV and in the (^{6}Li, t) reaction shows analog correspondence for the following pairs of levels: 5.27 − 5.24, 7.16 − 6.86, 7.57 − 7.28, 8.57 − 8.28, 10.80 − 10.48, 13.15(u) − 12.84, 15.49(u) − 15.05 [first listed is E_x in ^{15}N-second in ^{15}O]. [E_x are nominal; u = unresolved.] For γ-decay measurements see Table 15.5. See also (90AZ1B).

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

E_t (MeV ± keV)	Particles out	J^π	Γ (keV)	E_x (MeV)
0.66	α_0			15.38
1.11	p_0, t_0, α_1			15.74
1.21	t_0			15.82
1.30 ± 20	n, α_0			15.89
1.39 ± 20	n, t_0, α_0			15.96
1.46	p_0			16.02
1.54	n, α_0, α_1			16.08
1.64 ± 40	γ_0, n, α_0	$\frac{3}{2}^+$	450 ± 100	16.16
1.78	α_0			16.27
1.85 ± 20	n, p_0, α_0, α_1			16.33
1.98 ± 20	n, p_0			16.43
2.05 ± 30	p_0, t_0, α_0			16.49
2.18 ± 25	γ_0, n, p_0, t_0, α_0, α_1	$\frac{3}{2}^-$	490	16.59
2.30	γ_0, n, p_0, α_0, α_1	$\frac{3}{2}^+$	130 ± 15	16.69 ± 0.01
2.39 ± 30	n, t_0, α_0, α_1			16.76
2.50 ± 30	α_0, α_1			16.85
2.60	α_0			16.93
2.75	p_0			17.05
2.82	γ_0, t_0, α_0, α_1	$\frac{3}{2}^-$		17.10
2.89 ± 50	α_0			17.16
3.14	α_1			17.36
3.30	γ_0	$\frac{3}{2}^+$	450 ± 120	17.49 ± 0.09
≈ 6	γ_0			19.6
15.0	t_0			26.8

[a] For references see Tables 15.8 in (76AJ1A, 81AJ1A) and 15.9 in (86AJ1A).

Table 15.9: States of ^{15}N from ^{12}C(^{7}Li, α)

E_x (MeV ± keV)		E_x (MeV ± keV)		E_x (MeV ± keV)	
(73TS1A) [a]	(80ZE1A) [b]	(73TS1A) [a]	(80ZE1A) [b]	(73TS1A) [a]	(80ZE1A) [b]
0		10.808		15.021	15.024
5.295	5.284		11.274	15.373	15.379
6.332	6.323	11.430	11.456	15.782	15.778
7.163	7.157	11.951	11.936	16.026	16.032
7.310	7.299	12.320 [a]	12.328	16.190	16.210
7.566	7.574	12.559 [a,c]	12.551		17.735
8.320		12.923			17.949 [b]
8.580 [a]	8.574	13.004 [a]	13.001		18.272
9.163 [a]	9.159	13.173 [a]	13.178		18.698 [b]
9.828 [a]	9.809	13.614			19.27 ± 40
9.932	9.921	14.087	14.097		19.68 ± 50 [b,d]
10.072	10.075	14.720	14.693		20.93 ± 50 [b,d]
10.524	10.518		14.874		24.75 ± 150 [b,d]
10.700 [a]	10.714				

[a] $E(^{7}\text{Li}) = 35$ MeV; angular distributions have been measured for the states labelled by this footnote; $E_x \pm 10$ keV.
[b] $E(^{7}\text{Li}) = 48$ MeV; angular distributions have been measured for the states labelled by this footnote; $E_x \pm 20$ keV unless otherwise shown.
[c] (73TS1A) suggest that this state is not the $T = \frac{3}{2}$ state at 12.52 MeV.
[d] Wide or unresolved.

18. ^{12}C(^{7}Li, α)^{15}N $\qquad Q_m = 12.3806$

Observed α-groups are shown in Table 15.9. Angular distributions have been measured to $E(^{7}\text{Li}) = 48$ MeV. Comparison of spectra from this reaction ($E(^{7}\text{Li}) = 34.9$ MeV) with those from ^{13}C(^{6}Li, α) (reaction 26) lead to configurations of $(\text{d})^3$ for ^{15}N*(10.7, 12.57, 13.20, 15.42) and suggest that ^{15}N*(12.57, 13.20) have lower J than ^{15}N*(10.7, 15.5), probably $J \leq \frac{7}{2}$. ^{15}N*(13.02) is shown to be p(d)^2 in agreement with $J^\pi = \frac{11}{2}^-$: see (81AJ1A).

^{15}N*(9.155) [$J = \frac{5}{2}$] decays to ^{15}N*(5.30) [$J = \frac{1}{2}^+$] by an E2 transition; therefore its parity is positive. It has a large triton cluster parentage. This is not true of ^{15}N*(9.152): see (81AJ1A). For γ-decay measurements see Table 15.5. See also (85SA1L; theor.).

19. (a) ^{12}C(^{11}B, ^{8}Be)^{15}N $\qquad Q_m = 3.6250$

(b) ^{12}C(^{13}C, ^{10}B)^{15}N $\quad Q_m = -9.0275$
(c) ^{12}C(^{18}O, ^{11}Bα)^{15}N $\quad Q_m = -11.9768$

For reaction (a) see (81AJ1A) and (88MA1C). For reaction (b) see (89VO1D). For reaction (c) see (84RA1A).

20. ^{13}C(d, γ)^{15}N $\quad Q_m = 16.1594$

The $90° - 95°$ yields of γ_0 have been measured for $E_d = 1$ to 10 MeV: observed resonances are displayed in Table 15.10. The γ-ray angular distributions are consistent with the emission of predominantly E1 radiation except for evidence of M1/E2 transitions in the region $E_x = 20 - 21.5$ MeV: see (81AJ1A). See also (90HA1V).

21. (a) ^{13}C(d, n)^{14}N $\quad Q_m = 5.3260 \quad E_b = 16.1594$
(b) ^{13}C(d, p)^{14}C $\quad Q_m = 5.9519$
(c) ^{13}C(d, 2p)^{13}B $\quad Q_m = -14.880$

Observed resonsnces are displayed in Table 15.10. Polarization measurements have been carried out at $E_{\vec{d}} = 12.3$ MeV (reaction (a)) and 13 and 56 MeV (reaction (b)): see (86AJ1A). See also (87AB1G). For VAP measurements (reaction (c)) at $E_{\vec{d}} = 70$ MeV to ^{13}B$_{\text{g.s.}}$ see (86MO1B).

22. ^{13}C(d, d)^{13}C $\quad E_b = 16.1594$

Excitation functions for elastically scattered deuterons have been measured in the range $E_d = 0.4$ to 5.7 MeV: see (76AJ1A). Polarization studies have been reported for $E_d = 12.5$ to 15 MeV and at $E_{\vec{d}} = 56$ MeV: see (81AJ1A, 86AJ1A).

23. (a) ^{13}C(d, t)^{12}C $\quad Q_m = 1.3109 \quad E_b = 16.1594$
(b) ^{13}C(d, ^{3}He)^{12}B $\quad Q_m = -12.040$
(c) ^{13}C(d, α)^{11}B $\quad Q_m = 5.1677$

Observed resonances are listed in Table 15.10. For polarization measurements to $E_{\vec{d}} = 29$ MeV [reactions (a), (b)] see (81AJ1A).

Table 15.10: Resonances in $^{12}C + d$ [a]

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

[a] See references listed in Tables 15.10 (76AJ1A, 81AJ1A).
[b] $J^\pi = \frac{1}{2}^-$ or $\frac{3}{2}^+$; $T = \frac{1}{2}$.

24. ^{13}C(^{3}He, p)^{15}N $\qquad Q_m = 10.6658$

Observed proton groups and γ-rays are listed in Table 15.11 of (81AJ1A). Angular distributions have been reported for $E(^{3}\text{He}) = 4.37$ to 20 MeV: see (81AJ1A).

25. ^{13}C(α, d)^{15}N $\qquad Q_m = -7.6874$

At $E_\alpha = 34.9$ MeV a ZRDWBA analysis has been made of the angular distributions to ^{15}N*(5.27, 5.30, 7.16, 7.30, 7.56, 8.31, 8.57, 9.05, 9.15, 10.07, 10.53, 10.69, 11.43, 11.94, 12.10, 12.33, 12.49, 12.56, 13.00, 13.83, 14.08). $L = 0$ for the group(s) to ^{15}N*(9.15, 10.69); $L = 2$ for ^{15}N*(12.56); $L = 3$ for ^{15}N*(5.27, 7.16, 7.56); $L = 4$ for ^{15}N*(11.94, 13.00); $L = 1$ for the remaining transitions (84YA1B). See also Table 15.11 of (76AJ1A).

26. ^{13}C(^{6}Li, α)^{15}N $\qquad Q_m = 14.6843$

Angular distributions have been measured at $E(^{6}\text{Li}) = 32$ MeV to ^{15}N*(0, 5.30, 6.32, 7.16, 7.30, 7.57, 8.31, 8.57, 9.15, 9.23, 9.83, 10.07, 10.70, 11.94, 13.00): the results are consistent with the previously known J^π, with (odd) parity for ^{15}N*(9.83) and with $J^\pi = \frac{9}{2}^-$ for ^{15}N*(11.94): see (81AJ1A).

27. (a) ^{13}C(^{10}B, ^{8}Be)^{15}N $\qquad Q_m = 10.1328$
(b) ^{13}C(^{11}B, ^{9}Be)^{15}N $\qquad Q_m = 0.3440$

For reaction (a) see (88MA1C). For reaction (b) see (81AJ1A).

28. ^{14}C(p, γ)^{15}N $\qquad Q_m = 10.2074$

Observed resonances are displayed in Table 15.11; the branching ratios are shown in Table 15.5. Narrow anamolies (in the γ_0 yield for $E_p = 2.8$ to 30 MeV) are reported at $E_p = 10.0$, 11.0, 12.35, 13.6, 16.4 MeV. A good fit to the total cross section ($E_{\vec{p}} = 7.5$ to 19 MeV) is obtained with the GDR split into peaks at $E_x = 21.0$ and 25.5 MeV with $\Gamma = 6$ and 2 MeV, respectively. The integrated E2 cross section for $E_x = 19.5$ to 27.0 MeV is $(6.8 \pm 1.4)\%$ of the isoscalar sum rule. The reaction thus shows no sign of a collective E2 resonance in that E_x region. [Another study shows no appreciable E2 strength concentration for $E_x = 14.3$ to 23.3 MeV.] Above the GDR region the 90° γ_0 cross section decreases smoothly with energy except for a small peak which would correspond to ^{15}N*(37.0). See (81AJ1A, 86AJ1A) for the references. See also (85CA1A, 88CA1N, 90GO1H; astrophysics) and (90HA1V; theor.).

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

E_p (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Γ_n (keV)	Γ_p (keV)	Γ_α (keV)	Γ_γ (eV)	J^π	E_x (MeV ± keV)
0.261 ± 0.6 [f]	< 0.5		$(0.08 \pm 0.01) \times 10^{-6}$		(0.29 ± 0.05) meV [b]	$\frac{5}{2}^-$	10.4497 ± 0.3 [d]
0.352 ± 1 [f]					37 ± 6 meV [b]	$\frac{5}{2}^+$	10.5333 ± 0.5 [d]
0.519 ± 1 [f]			$(0.49 \pm 0.10) \times 10^{-6}$		3.1 ± 0.5 meV [b]	$\frac{9}{2}^+$	10.6932 ± 0.3 [d]
0.527 ± 1 [f]			0.2		0.37 ± 0.07 [g]	$\frac{3}{2}^-$	10.7019 ± 0.3 [d]
0.634 ± 1 [f]			$(0.22 \pm 0.10) \times 10^{-3}$		0.27 ± 0.14 [h]	$\frac{3}{2}^{(+)}$	10.804 ± 2 [d]
1.162 ± 2	7.9 ± 3	2.3	5.6	< 0.3	0.29 [c]	$\frac{1}{2}^-$	11.291
1.3188 ± 0.5	41.4 ± 1.1	34.6 ± 0.9	6.8 ± 0.5	< 0.3	4.2 ± 0.7 [c]	$\frac{1}{2}^+$	11.4376
1.509 ± 4	404.9 ± 6.3	4.0 ± 0.2	400.9 ± 6.3	< 0.3	19.2 ± 0.4 [c]	$\frac{1}{2}^+; T = \frac{3}{2}$	11.615
1.668 ± 3	37	36.5	0.5	< 0.3		$\frac{3}{2}^+$	11.763
1.788 ± 3	24.5	24.5	0.03	< 0.3		$\frac{3}{2}^-, (\frac{5}{2}^-)$	11.875
1.884 ± 3	21.5	21.2	0.3	< 0.3		$\frac{1}{2}^-$	11.965
2.025 ± 4	14 ± 5	12.0	1.7	0.6		$\frac{5}{2}^+$	12.096
2.077 ± 3	47 ± 7	30.2	16.6	2.2		$\frac{3}{2}^-$	12.145
2.272 ± 4	22	21.7	0.3	< 0.3		$\frac{5}{2}^{(+)}$	12.327
2.450 ± 4	44 ± 3	28	0.3	5.5		$\frac{5}{2}^+; T = \frac{1}{2}$	12.493
2.482 ± 8	58 ± 4				4.6 ± 0.7	$\frac{5}{2}^+; T = \frac{3}{2}$	12.523
2.908 ± 4	70	25	9.0	15		$\frac{3}{2}^-$	12.920
2.93 ± 10	81	n.r.	0.5	80		$\frac{5}{2}^+$	12.940
3.19	5.5	r					13.18
3.38 ± 10	24	6	6.0	12		$\frac{3}{2}^-$	13.360
3.421 ± 10	57	20.6	35	5.5	3.0 ± 0.9	$\frac{3}{2}^+$	13.390
3.57 ± 10	124	≈ 75	8.0	≈ 40		$\frac{3}{2}^-$	13.537

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

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

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

E_p (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Γ_n (keV)	Γ_p (keV)	Γ_α (keV)	Γ_γ (eV)	J^π	E_x (MeV ± keV)
≈ 29					r		≈ 37

r = resonant

n.r. = non-resonant

[a] See Tables 15.5 in (59AJ1A), 15.11 in (70AJ1A) and 15.12 in (81AJ1A) for references and additional comments.

[b] $\omega\gamma$.

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

[d] E_x measured directly: see (81AJ1A).

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

[f] Resonances are observed at E_p = 262, 351, 520, 528 and 635 keV [±1 keV] (90GO1H). See also Table 15.5. I am indebted to Drs. J. Gorres and M. Wiescher for sending me these results prior to publication.

[g] $\omega\gamma = 840 \pm 130$ meV (90GO1H).

[h] $\omega\gamma = 270 \pm 40$ meV (90GO1H).

29. ^{14}C(p, n)^{14}N $Q_m = -0.6259$ $E_b = 10.2074$

Observed resonances are displayed in Table 15.11. Cross sections have recently been measured for $E_p = 0.67$ to 1.20 MeV (89KE1B; prelim.). Polarization measurements are reported at $E_{\vec{p}} = 160$ MeV (84TA1C, 87RA1G; A_y; $D_{NN}(0°)$; n to ^{14}N*(0, 2.31, 3.95, 13.72)). Forward-angle differential cross sections have been measured at $E_p = 200$, 300, (400), 450 MeV (86AL1C, 89AL1C; $n_1 + n_2$) and at 492 MeV (89RA1E; n_1, n_2). See (86AJ1A) for the earlier work. See also (85TA1J), (86TA1E, 87TA1J, 89SU1J), (85CA1A, 88CA1N; astrophysics) and (87BE1D, 87LO1D; theor.).

30. (a) ^{14}C(p, p)^{14}C $E_b = 10.2074$
(b) ^{14}C(p, α)^{11}B $Q_m = -0.7842$

Observed resonances and anomalies are displayed in Table 15.11. For polarization measurements see (81AJ1A, 86AJ1A). See also (89AM1B; theor.).

31. ^{14}C(d, n)^{14}N $Q_m = 7.9829$

Angular distributions have been measured for $E_d = 1.3$ to 6.5 MeV: see (76AJ1A).

32. ^{14}C(^{3}He, d)^{15}N $Q_m = 4.7139$

Angular distributions have been studied at $E(^3\mathrm{He}) = 23$ MeV to ^{15}N*(0, 5.27 + 5.30, 6.32, 7.16, 7.30): see (81AJ1A). See also (76AJ1A).

33. ^{14}C(^{7}Li, ^{6}He)^{15}N $Q_m = 0.2328$

See (88AL1G); $E(^7\mathrm{Li}) = 27$ MeV; prelim.).

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

See (76AJ1A, 86AJ1A).

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

Transition in ^{15}N	E_γ [b] (keV)	E_x [b] (keV)	I_γ [c]
C→ 0	10829.087 (46)	10833.302 (12)	13.65 (21)
C→ 5.27	5562.062 (17)		10.65 (12)
C→ 5.30	5533.379 (13)		19.75 (21)
C→ 6.32	4508.783 (14)		16.54 (17)
C→ 7.16	3677.772 (17)		14.89 (15)
C→ 7.30	3532.013 (13)		9.24 (9)
C→ 8.31	2520.418 (15)		5.79 (7)
C→ 9.05			[a]
C→ 9.152	1681.117 (171)		1.54 (15)
C→ 9.155	1678.174 (55)		7.23 (18)
5.27 → 0	5269.169 (12)	5270.155 (10)	30.03 (20)
5.30 → 0	5297.817 (15)	5298.822 (11)	21.31 (18)
6.32 → 0	6322.337 (14)	6323.775 (15)	18.67 (14)
7.16 → 0		7155.051 (16)	
7.16 → 5.27	1884.879 (21)		18.66 (25)
7.16 → 5.30			0.8 (2)
7.30 → 0	7298.914 (33)	7300.832 (16)	9.73 (9)
7.30 → 5.30			[a]
8.31 → 0	8310.143 (29)	8312.620 (25)	4.22 (5)
8.31 → 5.30	3013.494 (73)		0.69 (2)
8.31 → 6.32	1988.507 (239)		0.37 (9)
8.57 → 0	8568.920 (230)	8571.412 (120)	0.073 (4)
8.57 → 5.27	3300.728 (113)		0.16 (2)
9.05 → 0	9046.802 (69)	9049.713 (69)	0.186 (5)
9.152 → 0		9151.895 (120)	
	9149.222 (47)		1.62 (2)
9.155 → 0		9154.895 (23)	
9.155 → 5.27	3884.184 (39)		0.57 (2)
9.155 → 5.30	3855.579 (45)		0.70 (1)
9.155 → 6.32	2830.809 (70)		1.75 (3)

Table 15.12: Gamma radiation from ^{14}N(n, γ) [a] (continued)

Transition in ^{15}N	E_γ [b] (keV)	E_x [b] (keV)	I_γ [c]
9.155 → 7.16	1999.708 (86)		3.99 (9)
9.212 → 0	9219.022 (763)	9222.06 (76)	0.024 (5)
9.925 → 0	9921.511 (166)	9925.033 (166)	0.127 (4)
10.066 → 0	10062.345 (197)	10065.969 (197)	0.062 (4)

C = capturing state.

[a] See also Tables 15.13 in (81AJ1A, 86AJ1A) for earlier references, comments and reports. The previously reported transition to ^{15}N*(9.76) has not been confirmed: $I_\gamma < 0.01\%$ (T.J. Kennett, private communication). (90WA1H) [see footnote [b] in Table 15.4] recommends different values for E_γ and E_x.

[b] Error in Q_m not included. Adjustments due to it require the addition in quadrature of the Q_m error: see (86KE1M).

[c] In units of photons/100 captures (86KE1M): errors are statistical only but these are predominant.

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

The thermal cross section is 79.8 ± 1.4 mb (90IS1A). See also (88MC1F).

Observed γ-rays from thermal neutron capture are displayed in Table 15.12. See also Table 15.5. The 90° γ_0 yield and angular distributions have been measured for $E_n = 5.6$ to 15.3 MeV. The cross section shows two prominent dips at $E_x = 16.7$ and 18.1 MeV [compare with ^{14}N(p, γ); reaction 9 in ^{15}O] and broad structures at $E_x \approx 17$ and 19 MeV. The angular distribution data are consistent with essentially pure E1 radiation in the region $E_x = 17$ to 24 MeV (82WE1E). See also (89WO1C) and (89GU1J; astrophys.).

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

The scattering amplitude (bound) $a = 9.37 \pm 0.03$ fm, $\sigma_{free} = 10.05 \pm 0.12$ b, σ_{inc}^{spin} (bound nucleus) $= 0.49 \pm 0.11$ b (79KO1A). Observed resonances are displayed in Table 15.13: for a discussion of the evidence leading to J^π assignments see (59AJ1A). Cross section curves and a listing of references can be found in (88MC1F). Recent measurements are reported at $E_n = 0.14$, 1.3 and 2.1 MeV (88KO1L; σ_t), 7.67 to 13.50 MeV (86CH2F; el and inel; prelim.). 10.96, 13.96 and 16.95 MeV (85TE1B; elastic). The (n, n′γ) cross section has been

Table 15.13: Resonances in ^{14}N + n [a]

$E_{\rm res}$ (MeV ± keV)	$\Gamma_{\rm lab}$ (keV)	$\Gamma_{\rm n}$ (keV)	$\Gamma_{\rm p}$ (keV)	Γ_{α} (keV)	J^{π}	^{15}N* (MeV)
0.430 ± 5	3.5	< 3	< 0.01		$\geq \frac{3}{2}$	11.235
0.4926 ± 0.65	7.5	< 3	< 10		$\frac{1}{2}^-$	11.2928
0.639 ± 5	43	34	9		$\frac{1}{2}^+$	11.429
0.998 ± 5	46	45	0.8		$\frac{3}{2}^+$	11.764
1.120 ± 6	19	19	0.20		$\frac{3}{2}^-$	11.878
1.188 ± 6	≤ 3.2	< 2	< 0.1		$\geq \frac{3}{2}$	11.942
1.211 ± 7	13	12	0.4		$\frac{1}{2}^-$	11.963
1.350 ± 7	21	20	0.9	0.4	$\frac{5}{2}^{(+)}$	12.093
1.401 ± 8	54	41	11	1.8	$\frac{5}{2}^{(+)}$	12.140
1.595 ± 8	22	21	0.2	< 0.1	$\frac{5}{2}^{(-)}$	12.321
1.779 ± 10	47	37	0.5	9.0	$(\frac{5}{2}^+)$	12.493
2.23	65	39	7.8	18	$\frac{3}{2}^-$	12.91
2.47	< 3			r		13.14
2.52	≈ 7	r		r		13.18
2.71	40			r	$\frac{3}{2}^-$	13.36
2.74	95		r		$\frac{5}{2}^+$	13.39
2.95	20	16	1.1	3.2	$\frac{5}{2}^+$	13.59
3.09	60		r	r		13.72
3.21	85	r	r	r	$\frac{3}{2}^+$	13.83
3.51	≈ 20	r	r	r		14.11
3.57	30	r	r	r	$\frac{3}{2}^{(+)}$	14.16
≈ 3.8	≈ 2000	≈ 1000	200	≈ 1000		14.4
4.09	50	r	r	r		14.65
≈ 4.2	≈ 300	r	r	r		14.8
4.38	40			r		14.92
4.60		r		r		15.12
5.03				r		15.52
5.60	100			r		16.06
5.94				r		16.37
6.16	75			r		16.58

Table 15.13: Resonances in ^{14}N + n [a] (continued)

E_{res} (MeV ± keV)	Γ_{lab} (keV)	Γ_n (keV)	Γ_p (keV)	Γ_α (keV)	J^π	^{15}N* (MeV)
6.26	100	r		r		16.67
6.55	170	r		r		16.94
6.94	200	r		r		17.31
7.16				r		17.51
7.34	120			r		17.68
7.48	180	r		r		17.81
7.92	170	r		r		18.22
8.00	120			r		18.29

r = resonant.

[a] See references in Tables 15.14 in (70AJ1A, 76AJ1A).

measured for E_n = 2.5 to 3.5 MeV (89ST1I; prelim.; applied). Analyzing powers for the n_0 group have been measured for $E_{\vec{n}}$ = 10 to 17 MeV (89LI10). See also ^{14}N, (88BA2F, 86LI1M) and (88MA1H).

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

Cross sections have been measured for E_n = 10 to 37 MeV [see (88MC1F)] and at E_n = 13.40 to 14.87 MeV (89KA1S). See also (89KA2B).

38. (a) ^{14}N(n, p)^{14}C $\qquad Q_m = 0.6259 \qquad E_b = 10.8333$
(b) ^{14}N(n. d)^{13}C $\qquad Q_m = -5.3260$
(c) ^{14}N(n, t)^{12}C $\qquad Q_m = -4.0151$
(d) ^{14}N(n, ^{3}He)^{12}B $\qquad Q_m = -12.7436$
(e) ^{14}N(n, α)^{11}B $\qquad Q_m = -0.1583$

(89KO1N), using the "white" neutron source LANSCE, have measured the (n, p) cross section from 61 meV to 34.6 keV. Their results support the role of this reaction as a "poison" during s-process nucleosynthesis. [See (89KO1N) for a discussion of other measurements.] See also (88BR1G, 89KE1B). For a display of the measured cross sections for (a) and (c), see (88MC1F). See also (88SU1F; E_n = 5.0 to 10.6 MeV; σ = 11 to 30 mb; prelim.) for reaction

(c) and (88MA1H). For resonances in reactions (a) and (e), see Table 15.13. (86SU1F) report double-differential cross sections at $E_n = 27.4$, 39.7 and 60.7 MeV for all five reactions. See also (89CH2E).

39. ^{14}N(p, π^+)^{15}N $\qquad Q_m = -129.518$

At $E_{\vec{p}} = 200$ MeV, angular distributions and A_y have been measured for the transitions to ^{15}N*(0, 6.32, 8.31) as well as for a number of unresolved transitions. A sharp group at $E_x = 21.5$ MeV is suggested to correspond to a $\frac{15}{2}^-$ state (88AZ1D, 87AZ1A; Ph.D. thesis and abstract).

40. ^{14}N(d, p)^{15}N $\qquad Q_m = 8.6087$

Proton groups (and γ-rays) from this reaction are displayed in Table 15.15 of (81AJ1A). The results include $E_x = 7567.1 \pm 1.0$ keV for ^{15}N*(7.57). Newer values, derived from measurements of proton groups in a spectrograph, are 5270.2 ± 1.3, 6324.0 ± 1.0, 7154.85 ± 0.17, 7300.80 ± 0.09, 7563.25 ± 0.19, 8312.79 ± 0.12, 8571.53 ± 0.25, 9050.24 ± 0.33, 10064.34 ± 0.31 and 11235.5 ± 0.5 keV (90PI1E). Angular distributions have been meausred for $E_d = 0.32$ to 52 MeV and lead to l_n, J^π and spectroscopic factors: see Table 15.15 in (81AJ1A). Branching ratios and multipolarities are shown in Table 15.14. See also (85LI1H, 85ME1E, 87SI1D, 88LI1E, 88VI1A, 89VI1E; appliactions).

41. ^{14}N(^{14}N, ^{13}N)^{15}N $\qquad Q_m = 0.2799$

See (81AJ1A) and (88DA1G; theor.).

42. ^{15}C(β^-)^{15}N $\qquad Q_m = 9.7717$

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

43. (a) ^{15}N(γ, n)^{14}N $\qquad Q_m = -10.8333$
(b) ^{15}N(γ, 2n)^{13}N $\qquad Q_m = -21.3868$
(c) ^{15}N(γ, p)^{14}C $\qquad Q_m = -10.2074$
(d) ^{15}N(e, ep$_0$)^{14}C $\qquad Q_m = -10.2074$
(e) ^{15}N(γ, d)^{13}C $\qquad Q_m = -16.1594$
(f) ^{15}N(γ, t)^{12}C $\qquad Q_m = -14.8484$
(g) ^{15}N(γ, π^-)^{15}O $\qquad Q_m = -142.322$

Table 15.14: Radiative widths [a] from ^{15}N(γ, γ') and ^{15}N(e, e′) [a]

E_x (MeV ± keV)	J^{π}	Mult.	Γ_{γ_0} (eV)
5.27	$\frac{5}{2}^+$	C3	$(4.2 \pm 0.3) \times 10^{-6}$
		M2	$(1.2 \pm 0.7) \times 10^{-4}$
5.30	$\frac{1}{2}^+$	C1	2.2 ± 2.3
6.323 ± 1 [b]	$\frac{3}{2}^-$	C2	0.050 ± 0.004
		M1	1.9 ± 0.4 [c]
		M1 + E2	3.12 ± 0.18 [b,d,e]
7.16	$\frac{5}{2}^+$	C3	$(0.86 \pm 0.10) \times 10^{-5}$
7.301 ± 1 [b]	$\frac{3}{2}^+$	C1	2.6 ± 1.0
		M2	$(0.3 \pm 0.2) \times 10^{-5}$
		E1 + M2	1.08 ± 0.08 [b]
7.57	$\frac{7}{2}^+$	C3	$(1.84 \pm 0.16) \times 10^{-5}$
8.310 ± 4 [b]	$\frac{1}{2}^+$	E1	0.3 ± 0.2 [b]
8.575 ± 4 [b]	$\frac{3}{2}^+$	E1 + M2	0.3 ± 0.3 [b]
9.048 ± 1 [b]	$\frac{1}{2}^+$	E1	1.2 ± 0.2 [b]
9.150 ± 1 [b]	$\frac{3}{2}^-$	C2	0.095 ± 0.005[f]
		M1	0.2 ± 0.8
		M1 + E2	0.47 ± 0.12 [b,g]
9.760 ± 1 [b]	$\frac{5}{2}^-$	C2	0.20 ± 0.05
		E2	0.21 ± 0.07 [b]
9.924 ± 1 [b]	$\frac{3}{2}^-$	M1	1.6 ± 0.2 [b]
10.064 ± 1 [b]	$\frac{3}{2}^+$	E1	6.3 ± 0.4 [b]
10.8	$\frac{3}{2}^+$	M2	$(1.8 \pm 0.8) \times 10^{-2}$
11.88	$\frac{3}{2}^-$	C2	0.44 ± 0.10
		M1	4.4 ± 3.8
12.5	$\frac{5}{2}^+$	M2	$(5.2 \pm 2.0) \times 10^{-2}$
(13.98)			
14.7	$\frac{5}{2}^-$	C2	1.8 ± 0.2
20.10			
23.25			

[a] For references and $B(\lambda)\uparrow$ see Table 15.17 in (81AJ1A). See also Tables 15.5 and 15.6 here. Form factors have also been measured to ^{15}N*(9.23, 11.29 [both $\frac{1}{2}^-$], 10.45 [$\frac{5}{2}^-$], 12.1[u], 12.9[u]) (87DE1Q) [unpublished Ph.D. thesis].

[b] (81MO1A): (γ, γ).

[c] See note added in proof in (75MO1C).

[d] $\delta(\mathrm{E2/M1}) = 0.137 \pm 0.005$. See, however, Table 15.5.

[e] Using $\delta(\mathrm{E2/M1}) = 0.132 \pm 0.004$ [see Table 15.5] $\Gamma_{\gamma_0} = 3.07 \pm 0.18$ eV (M1) and $(5.34 \pm 0.44) \times 10^{-2}$ eV (E2) (D.J. Millener, private communication.)

[f] $\delta(\mathrm{E2/M1}) > 0.3$.

[g] Mixing ratio is very small [see Table 15.5] and the transition is almost purely M1 (D.J. Millener, private communication).

The total photoneutron cross section from threshold to 38 MeV shows a very broad GDR which extends from ≈ 16 to 30 MeV. Maxima are observed at $E_\gamma \approx 23.5$ and 25.5 MeV ($\sigma \approx 11$ mb): see (88DI1A) [based on (82JU1A; monoenergetic photons)]. However, (89BA1I) report a sharper single peak at $E_\gamma = 25.5$ MeV in the $(\gamma$, Sn) reaction with a cross section of ≈ 16 mb. See (89BA1I) for a discussion of the $T_<$ and $T_>$ components of the GDR.

The (γ, n_0) cross section for $E_\mathrm{x} = 13$ to 24 MeV shows a broad structure centered at $E_\mathrm{x} \approx 14.5$ MeV and a resonance at $E_\mathrm{x} = 17.3 \pm 0.1$ MeV. A large fraction of the photoabsorption strength leading to $^{14}\mathrm{N}_{\mathrm{g.s.}}$ is due to the formation of $\frac{3}{2}^+$, $T = \frac{1}{2}$ states in ^{15}N which decay by d-wave emission. The absorption is essentially pure E1 (83WA1K). See also (81AJ1A).

The $(\gamma, 2\mathrm{n})$ reaction has been studied from threshold to 38 MeV [see (88DI1A)] and more recently from 20 to 28 MeV by (88MC1B). The cross section remains near zero for 3 MeV above threshold and then rises sharply at about 24 MeV to a maximum value of 1.7 mb (88MC1B) [see, however, (82JU1A)]. For discussions of the results in terms of the density of $T_>$ states in ^{14}N, see (88MC1B, 89BA1I (p.511)).

For discussions of the (γ, p) reaction see (81AJ1A) and (89BA1I). The latter show a curve for the total absorption cross section $[(\gamma, \mathrm{n}) + (\gamma, \mathrm{p})]$ from 10 and 27 MeV dominated by a peak (see above) at $E_\gamma \approx 25$ MeV with $\sigma \approx 23$ mb.

A study at $E_\mathrm{e} = 18.8$, 20.8, 25.7 and 29.7 MeV (reaction (d)) shows a "pigmy" resonance at $E_\mathrm{x} = 14.8$ 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 $14 < E_\mathrm{x} < 28$ 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: see (81AJ1A).

The cross section for for d_0 [reaction (e)] is reported at 90° for $E_\gamma \approx 20.5$ to 28.5 MeV: a resonance is observed at $E_\mathrm{x} \approx 21.9$ MeV. The (γ, t_0) cross section (reaction (f)) at 90° decreases from a value of 30 μb/sr at 20 MeV to 5μb/sr at 22 MeV and remains flat out to 25 MeV. Comparison of this cross section, and those of the other photonuclear reactions,

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

Decay to ^{15}N* (keV)	J^{π}	Branch (%)	log ft
g.s.	$\frac{1}{2}^-$	36.8 ± 0.8 [c]	5.99 ± 0.03 [c]
5298.87 ± 0.15 [b]	$\frac{1}{2}^+$	63.2 ± 0.8 [c]	4.11 ± 0.01
6323.3 ± 0.6	$\frac{3}{2}^-$	$\leq 0.4 \times 10^{-2}$	≥ 7.8
7301.1 ± 0.5	$\frac{3}{2}^+$	$(0.74 \pm 0.08) \times 10^{-2}$	6.89 ± 0.05
8312.9 ± 0.5	$\frac{1}{2}^+$	$(4.1 \pm 0.5) \times 10^{-2}$	5.18 ± 0.05
8571.4 ± 1.0	$\frac{3}{2}^+$	$(1.3 \pm 0.2) \times 10^{-2}$	5.34 ± 0.07
9050.0 ± 0.7	$\frac{1}{2}^+$	$(3.4 \pm 0.3) \times 10^{-2}$	4.05 ± 0.04

[a] (79AL1E).
[b] (76AL1C). 5297.794 ± 0.035 keV: see (81WA1E).
[c] (84WA1A).

suggest an isospin splitting of ≈ 6 MeV with the $T = \frac{1}{2}$ strength concentrated between 16 and 21 MeV and the $T = \frac{3}{2}$ strength between 21 and 28 MeV. ^{15}N*(21.9) is not observed. See (81AJ1A) for references. For reaction (g) [to $^{15}O_{g.s.}$] see (88LI1I, 89KO1X). See also (85GO1A, 87KI1C; theor.).

44. ^{15}N(γ, γ)^{15}N

See Table 15.14 and (81AJ1A). See also (87MO1D).

45. ^{15}N(e, e)^{15}N

The charge r.m.s. radius of ^{15}N is 2.612 ± 0.009 fm. The C0 elastic scattering form factor of ^{15}N has been measured over $q = 0.4 - 3.2$ fm^{-1} (88DE1C). Inelastic groups are displayed in Table 15.14.

The giant resonance is split into two main peaks at $E_x = 22$ and 25.5 MeV with some structure around 20 MeV. $\Gamma_{\gamma_0}(C1) = (1.1 \pm 0.3) \times 10^3$ eV (14−18.5 MeV), $\Gamma_{\gamma_0}(C2) = 12.5 \pm 2.0$ eV assuming the states responsible are $\frac{3}{2}^+$ and $\frac{3}{2}^-$, respectively. For $E_x = 18.5$ to 30 MeV, $\Gamma_{\gamma_0}(C1) = (1.96 \pm 0.04) \times 10^4$ eV while $\Gamma_{\gamma_0} < 0.1$ eV for any C2 strength. See (81AJ1A, 86AJ1A) for references. See also (88MU1F; (e, e′γ); prelim.), (86PA1C, 87DE1A, 88LI1I, 88PA1S, 89KO1X, 90PA1H) and (86JE1A, 87DO1J, 88FU1B, 88GO1B, 88SH1C, 89FU1E, 89WO1E, 90BL1E, 90FU1E; theor.).

46. $^{15}N(\pi^{\pm}, \pi^{\pm})^{15}N$

At $E_{\pi^{\pm}} = 164$ MeV angular distributions have been studied to states at $E_x = 10.68 \pm 0.03$, 12.52 ± 0.02, 14.04 ± 0.03 and 17.19 ± 0.03 MeV: $J^{\pi} = \frac{9}{2}^+, \frac{9}{2}^+, (\frac{9}{2}^+, \frac{7}{2}^+)$ and $(\frac{9}{2}^+, \frac{7}{2}^+)$, respectively, as well as to the $^{15}N_{g.s.}$. Additional π^+ cross sections were measured at 120 and 260 MeV: peaks were observed at $E_x = 20.11 \pm 0.06$ and 23.19 ± 0.06 MeV [both are probably $T = \frac{3}{2}$ states]. $^{15}N^*(5.27, 6.32, 7.57)$ were also populated (85SE1E). At $E_{\pi^+} = 164$ MeV, elastic scattering has been studied from $^{15}\vec{N}$: A_y for $\theta = 60° - 100°$ is consistent with zero (89TA1X, 90TA1L). See also (90TA1H) and (88GO1B; theor.).

47. $^{15}N(n, n)^{15}N$

See ^{16}N in (86AJ1B). See also (89FU1J).

48. $^{15}N(p, p)^{15}N$

Angular distributions of elastically scattered protons have been measured at E_p to 44.2 MeV: see (81AJ1A, 86AJ1A). For measurements of $K_y^{y'}$ at $E_{\vec{p}} = 65$ MeV see (90NA1A). See also ^{16}O in (86AJ1B) and (90DU1A; theor.).

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

Angular distributions of elastically scattered deuterons have been measured at $E_d = 5-6$ MeV. Elastic and inelastic ^{3}He distributions have been studied for $E(^3He) = 11$ to 39.8 MeV: see (76AJ1A). Elastic distributions and A_y have also been measured at $E(^3\vec{He}) = 33$ MeV (86DR1A).

50. $^{15}N(\alpha, \alpha)^{15}N$

At $E_{\alpha} = 40.5$ MeV, a number of particle groups have been observed and angular distributions have been measured: see Table 15.17 of (76AJ1A). At $E_{\alpha} = 48.7$ and 54.1 MeV elastic angular distributions have been reported by (87AB1D). See also (81AJ1A) for additional information and (85SH1D; theor.).

51. $^{15}N(^{7}Li, ^{7}Li)^{15}N$

The elastic scattering has been studied at $E(^{7}Li) = 28.8$ MeV: see (86AJ1A).

52. (a) $^{15}N(^{12}C, ^{12}C)^{15}N$
(b) $^{15}N(^{13}C, ^{13}C)^{15}N$
(c) $^{15}N(^{14}C, ^{14}C)^{15}N$

Angular distributions of elastic scattering have been measured at $E(^{15}N) = 31.5$ to 47 MeV [reaction (a)] and $E(^{13}C) = 105$ MeV [reaction (b)]: see (81AJ1A, 86AJ1A) [also for yield measurements]. See also (86HA1F, 89BE2C) and (85HU1A, 86BA1I, 86HA1D; theor.).

53. $^{15}N(^{16}O, ^{16}O)^{15}N$

Elastic angular distributions have been measured at $E(^{16}O) = 35.1$ and 42.6 MeV: see (86AJ1A). For fusion cross sections and yields see (76AJ1A, 86AJ1A) and (85NO1C, 86HA1F). See also (85HU1A; theor.).

54. (a) $^{15}N(^{27}Al, ^{27}Al)^{15}N$
(b) $^{15}N(^{28}Si, ^{28}Si)^{15}N$

Elastic distributions have been measured in the range $E(^{15}N) = 32.8$ to 69.8 MeV [reaction (a)] and at 44 MeV [reaction (b)]: see (81AJ1A, 86AJ1A). See also (88SN1A).

55. $^{15}O(\beta^{+})^{15}N$ $\qquad Q_m = 2.7539$

See ^{15}O.

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

Over the giant resonance region in ^{16}O, the decay takes place to the odd-parity states ^{15}N*(0, 6.32) and less strongly to the even-parity states ^{15}N*(5.27, 5.30, 8.31, 9.05) and to ^{15}N*(9.22): see (70AJ1A, 76AJ1A). At E_e = 500 MeV most of the 1p hole strength is concentrated in the groups to ^{15}N*(0, 6.32). The 1s state shows up as a very wide asymmetric structure centered at $E_x \approx 41$ MeV: see (81AJ1A). See also (90LE1P). In the range E_γ = 101.5 to 382 MeV differential cross sections are reported for the p_0, (p_{1+2}) and p_3 groups at θ = 45°, 90° and 135° (85LE1D). Differential cross sections have also been measured at E_γ = 196, 257, 312, 316 MeV for the p_0 and $p_{1\to3}$ groups [the latter not at 316 MeV] (88AD1D, 85TU1C). ^{15}N*(0, 6.3, 10.8) have been populated at E_e = 500 MeV (82BE1G). See also (86AJ1A), (87VO1A, 88LE1A, 89LE1F; prelim.), (87MA1K) and (85CA1H, 85GO1B, 86CH1U, 86LU1A, 86PO1C, 87RY1A, 88CA1D, 88DU1D, 88HO1C, 88JI1B, 88LO1D, 88MC1C, 88RY1A, 89RY1B, 90BR1R, 90FL1A, 90OW1A; theor.).

57. ^{16}O(μ^-, νn)^{15}N $\qquad Q_m = 92.7492$

Gamma rays from the decay of one of the states at 5.3 MeV and from ^{15}N*(6.3) are reported by (83VA1E).

58. ^{16}O(n, d)^{15}N $\qquad Q_m = -9.9030$

Angular distributions of the d_0 group have been reported at E_n = 14 and 14.4 MeV: see (76AJ1A). See also (88YO1C; E_n = 60 MeV; prelim.) and (90MC1E; applied).

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

At $E_{\pi^\pm}$ = 240 MeV, the spectra are dominated by ^{15}N*(0, ≈ 6.5). The π^+/π^- ratio has been measured for the ground-state transitions (84KY1A). At E_{π^+} = 2.0 GeV/c differential cross sections have been determined for the transition to ^{15}N*(6.3) (83KI1C).

At E_p = 505 MeV the summed proton spectrum shows two peaks corresponding to the knockout of $p_{1/2}$ and $p_{3/2}$ protons with binding energies of 12.12 and 18.44 MeV [^{15}N*(0, 6.32)]. Differential cross sections and (p, 2p)/(p, pn) ratios are also reported (86MC1A). For work at 1 GeV involving the knockout of $s_{1/2}$ protons see (85BE1J). For γ-ray production (^{15}N*(5.27)) at E_p = 30 − 40 MeV see (88LE1C). See also (85KI1A, 86CH1J, 87VD1A), (87LA1B, 88LE1C; astrophys.) and (86BO1A; theor.). For earlier work see (76AJ1A).

60. ^{16}O(d, ^{3}He)^{15}N $\qquad Q_m = -6.6340$

Angular distributions of ^{3}He groups have been measured for $E_d = 20$ to 82 MeV: see (76AJ1A, 81AJ1A). The spectra are dominated by the transitions to ^{15}N*(0, 6.32). A ZRDWBA analysis leads to $C^2S = 2.25$ and 3.25 for these two states [and to 2.37 and 3.31 for the analog states in ^{15}O studied with the (d, t) reaction]. $J^\pi = \frac{3}{2}^-$ for both ^{15}N*(9.93, 10.70): see (81AJ1A). See also (87MO1D) for a re-analysis of C^2S.

61. ^{16}O(α, αp)^{15}N $\qquad Q_m = -12.1276$

At $E_\alpha = 139.2$ MeV the absolute spectroscopic factors $S = 5.4$ and 6.9 for ^{15}N*(0, 6.32) (87SA1B).

62. (a) ^{16}O(^{6}Li, ^{7}Be)^{15}N $\qquad Q_m = -6.522$
(b) ^{16}O(^{7}Li, ^{8}Be)^{15}N $\qquad Q_m = 5.1268$
(c) ^{16}O(^{16}O, ^{17}F)^{15}N $\qquad Q_m = -11.5274$

For reaction (a) see (86GL1E). For reaction (b) see (88MA1C) and for (c) see (88AU1B). For other heavy-ion reactions see (81AJ1A, 86AJ1A).

63. ^{17}O(p, ^{3}He)^{15}N $\qquad Q_m = -8.5529$

At $E_p = 39.8$ MeV angular distributions of the groups to ^{15}N*(0, 6.32) have been compared with those to the analog states in ^{15}O reached in the (p, t) reaction: see (76AJ1A).

64. ^{18}O(p, α)^{15}N $\qquad Q_m = 3.9804$

Angular distributions of α_0 have been measured for $E_p = 0.125$ to 42.2 MeV: see (76AJ1A, 81AJ1A) and ^{19}F in (87AJ1B). At $E_p = 40.9$ MeV angular distributions have also been studied to ^{15}N*(0, 5.27 + 5.30, 6.32, 7.57, 9.15[u], 9.83[u], 10.7[u], 11.24[u], 11.44, 12.52[u] (87CA1L; see for C^2S).

For ^{15}N*(5.27), $\tau_m = 2.49 \pm 0.24$ ps, $|g| = 0.94 \pm 0.07$ (83BI1D). See also (86CO1F), (88FI1C, 89NW1A, 90MI1I; applied) and (86BA1F, 88CA1N; astrophys.).

65. ^{19}F(d, ^{6}Li)^{15}N $\qquad Q_m = -2.5388$

Angular distributions involving ^{15}N*(0, 5.3, 6.3) have been measured in the range E_d = 9.0 to 28 MeV [see (76AJ1A, 81AJ1A)].

66. ^{19}F(^{3}He, ^{7}Be)^{15}N $\qquad Q_m = -2.4265$

See (76AJ1A) and (86HA1E; theor.).

^{15}O
(Figs. 12 and 13)

GENERAL (See also (86AJ1A)).

Nuclear models: (87ST1B)

Special states: (85SH1F, 86LI1B, 87ST1B, 88AN1E, 89WU1C)

Electromagnetic transitions: (84VA1A, 87HO1L, 87ST1B)

Astrophysical questions: (85TA1A, 87RA1D, 89JI1A , 89ST1J, 90RA1O)

Complex reactions involving ^{15}O: (85FI1A, 85HU1C, 85PO1D, 85SI1C, 86GR1A, 86ME1B, 86PO1A, 86TO1H, 86UT1A, 87BA1S, 87BE1I, 87BU1B, 87NA1B, 87RI1C, 87ST1A, 88BE1C, 88BE2H, 88MI1I, 89BA2N, 89CA1B, 89DR1B, 89KI1C, 89PO1H, 89SA1N, 89TA1O, 89YO1D)

Applied work: (85BO1P, 85HA1L, 87HI1B, 88HI1F, 88VO1D, 89AR1J, 89WO1B)

Pion and other mesons capture and reactions (See also reactions 8, 16, 17 and 21.): (86LI1B, 87LE1B, 88CH1H, 88MI1K, 89LE1L, 90OD1A)

Hypernuclei: (84ZH1B, 86DA1G, 89BA1E, 89KO1H, 89TA1D)

Other topics: (85AN1A, 85SH1F, 86AN1D, 86WI1F, 87CH1E, 89WU1C, 90MU1A)

Ground-state properties of ^{15}O: (85AN1A, 85AR1F, 86MC1B, 86WI1F, 86WU1B, 87FU1C, 87SA1E, 88AR1B, 88CH1T, 88FU1B, 88NI1B, 88SH1C, 88VA1A, 88WA1D, 89CH1N, 89FU1E, 89NE1A, 89SA1N)

$\mu = 0.7189$ (8) nm (78LE1A). See also (89RA1I).

^{15}O*(5.24): $\mu = +(0.65 \pm 0.07)$ nm: see (89RA1I).

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

The half-life of ^{15}O is 122.24 ± 0.16 s: see (81AJ1A); log $f_0t = 3.637$. The K/β^+ ratio is $(10.7 \pm 0.6) \times 10^{-4}$: see (76AJ1A). The β-anisotropy has been measured by (89SE1B, 88SE1H). See also (86AJ1A), (90ST1E), (85BA1N, 85BA1M, 86GR1E, 87BA1U, 87FR1C, 87RI1E, 87WE1C, 88BA1H, 88BA1Y, 89BA2P, 89DA1H; astrophysics) and (88TA1L, 88TO1C, 89WO1E; theor.).

2. (a) ^{11}B(^{7}Li, 3n)^{15}O $\qquad Q_m = -3.494$
(b) ^{11}B(^{9}Be, t2n)^{15}O $\qquad Q_m = -13.932$

Table 15.16: Energy levels of ^{15}O [a]

E_x in ^{15}O (MeV ± keV)	J^π; T	τ or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
0	$\frac{1}{2}^-$; $\frac{1}{2}$	$\tau_{1/2} = 122.24 \pm 0.16$ s	β^+	1, 3, 4, 5, 6, 7, 8, 9, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 27, 28
5.183 ± 1	$\frac{1}{2}^+$	$\tau_m = 8.2 \pm 1.0$ fs	γ	5, 7, 9, 14, 15, 19, 20, 23, 24, 25
5.2409 ± 0.3	$\frac{5}{2}^+$	3.25 ± 0.30 ps $g = +0.248 \pm 0.026$	γ	4, 5, 6, 7, 9, 14, 15, 18, 19, 20, 23, 24, 25, 27
6.1763 ± 1.7	$\frac{3}{2}^-$	< 2.5 fs	γ	5, 7, 9, 14, 15, 18, 19, 20, 21, 22, 23, 24, 25, 27
6.7931 ± 1.7	$\frac{3}{2}^+$	< 28 fs	γ	5, 7, 9, 14, 15, 19, 25
6.8594 ± 0.9	$\frac{5}{2}^+$	16.0 ± 2.5 fs	γ	4, 5, 7, 9, 14, 15, 19, 20, 25, 27
7.2759 ± 0.6	$\frac{7}{2}^+$	0.70 ± 0.15 ps	γ	4, 5, 6, 7, 8, 14, 15, 18, 19, 23, 25, 27
7.5565 ± 0.4	$\frac{1}{2}^+$	$\Gamma = 0.99 \pm 0.10$ keV	γ, p	7, 9, 14, 15, 18, 19, 23, 25
8.2840 ± 0.5	$\frac{3}{2}^+$	3.6 ± 0.7	γ, p	5, 7, 9, 14, 15, 25
8.743 ± 6	$\frac{1}{2}^+$	32	γ, p	7, 9, 25
8.922 ± 2	$\frac{5}{2}^+$	3.3 ± 0.3	γ, p	4, 5, 7, 9, 23, 25
8.922 ± 2	$\frac{1}{2}^+$	7.5	γ, p	4, 7, 9, 23, 25
8.9821 ± 1.7	$(\frac{1}{2})^-$	3.9 ± 0.4	γ, p	5, 7, 9, 25
9.484 ± 8	$(\frac{3}{2})^+$	≈ 200	γ, p	9, 25
9.488 ± 3	$\frac{5}{2}^-$	10.1 ± 0.5	γ, p	5, 7, 9, 25
9.609 ± 2	$\frac{3}{2}^-$	8.8 ± 0.5	γ, p	4, 5, 7, 9, 25
9.662 ± 3	$(\frac{7}{2}, \frac{9}{2})^-$	2 ± 1	p	4, 5, 7, 11, 25
10.29 [b]	$(\frac{5}{2}^-)$	3 ± 1	p	5, 7, 11, 25
10.30 [b]	$\frac{5}{2}^+$	11 ± 2	p	5, 7, 11, 25

Table 15.16: 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
10.461 ± 5	$(\frac{9}{2}^+)$	< 2	γ, p	4, 5, 6, 7, 9, 25
10.48	$(\frac{3}{2}^-)$	25 ± 5	γ, p	4, 7, 9, 11, 24
(10.506)	$(\frac{3}{2})^+$	140 ± 40	γ, p	9, 11
10.917 ± 12	$\frac{7}{2}^+$	90	p	11, 25
10.938 ± 3	$\frac{1}{2}^+$	99 ± 5	γ, p	9, 11, 25
11.025 ± 3	$\frac{1}{2}^-$	25 ± 2	γ, p	9, 11, 25
11.151 ± 7		< 10	p	5, 11, 25
11.218 ± 3	$\frac{3}{2}^+$	40 ± 4	γ, p	9, 11, 25
11.565 ± 15		< 10	p	5, 11, 25
11.569 ± 15	$\frac{5}{2}^-$	20 ± 15	γ, p	5, 9, 11
11.616 ± 15	$(\frac{3}{2}, \frac{1}{2})^-$	80 ± 50	γ, p	9, 11
11.719 ± 8		< 10	p	4, 5, 11, 25
11.748 ± 3	$\frac{5}{2}^+$	99 ± 5	γ, p	9, 11
11.846 ± 3	$\frac{5}{2}^-$	65 ± 3	γ, p	9, 11
11.980 ± 10	$\frac{5}{2}^-$	20 ± 5	p	5, 11, 25
12.129 ± 15	$\frac{5}{2}^+$	200 ± 50	p	11
12.222 ± 20		100 ± 50	p	11
12.255 ± 13	$\frac{5}{2}^+; \frac{3}{2}$	135 ± 15	p	27
12.295 ± 10				5
12.471 ± 3	$\frac{5}{2}^-, (\frac{3}{2}^-)$	77 ± 4	p	11
12.60 ± 10				5
12.80		≈ 250	γ, p	9
12.835 ± 3		16 ± 1	p	4, 5, 6, 11
13.008 ± 3		215 ± 3	p	11
13.025 ± 3		40 ± 30	p, (^{3}He)	3, 11
13.45	$(\frac{1}{2}, \frac{3}{2})^+$	≈ 1000	γ, p, (α)	9, 11, 13
(13.49)	$(\frac{3}{2}^+)$		(p)	11
13.60	$\frac{5}{2}^+$		p, α	13
13.70	$\frac{3}{2}^-$		p	11
13.79	$\frac{3}{2}^-$		n, p, ^{3}He, α	3, 11, 13

Table 15.16: 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
13.87		≈ 150	γ, p	9
14.03 ± 40	$(\frac{1}{2}^-, \frac{3}{2}^-)$	160 ± 20	n, p, ^{3}He	3
14.17	$\frac{5}{2}^-$		p, α	13
14.27 ± 10	$\frac{1}{2}^+$	340 ± 30	n, p, ^{3}He, α	3, 4, 5, 10, 11, 12, 13
14.34	$\frac{5}{2}^+$	(240)	p, (^{3}He), α	3, 13
14.465 ± 10	$\frac{3}{2}^+, \frac{5}{2}^+$	100 ± 10	n, p, ^{3}He, α	3, 10, 11, 13
14.70 ± 40		170 ± 35	n, p, ^{3}He	3, 10
14.95 ± 40		400 ± 25	n, p, ^{3}He, α	3, 10, 11, 12, 13
15.05 ± 10	$((\frac{13}{2}^+))$			4, 5, 6
15.1	$(\frac{1}{2}, \frac{3}{2})^+$	≈ 1000	γ, p	9
15.45 ± 30		70 ± 20	p, ^{3}He, α	3
15.54 ± 10			(p, ^{3}He, α)	3, 5
15.60 ± 10			(p, ^{3}He, α)	3, 5
15.65 ± 10				4, 5
15.80 ± 10			n, ^{3}He	3, 5
15.90 ± 15	$\frac{1}{2}^-, \frac{3}{2}^-$	350	^{3}He, α	3
16.05 ± 20		≈ 185	n, p, ^{3}He, α	3, 10, 11, 13
16.10 ± 20			(n), ^{3}He, α	3
16.21 ± 20		≈ 140	(n), p, ^{3}He, α	3, 11, 12, 13
16.43 ± 75	$\frac{1}{2}^+$	560 ± 100	n, ^{3}He, α	3, 10, 12
16.75 ± 50			n, ^{3}He	3, 25
17.05 ± 60	$(\frac{1}{2}, \frac{3}{2})^+; \frac{1}{2}$	700 ± 70	γ, p, ^{3}He	3, 9, 11, 13
17.46 ± 20				5
17.51 ± 20	$\frac{1}{2}^-, \frac{3}{2}^-$	640 ± 120	γ, n, ^{3}He, α	3, 5
17.99 ± 50	$\frac{1}{2}^-, \frac{3}{2}^-$	200	^{3}He	3
18.23 ± 50			n, p, ^{3}He	3
18.67 ± 60	$(\frac{1}{2}, \frac{3}{2})^+; \frac{1}{2}$	520 ± 110	γ, ^{3}He	3, 9
19.03 ± 50		1120 ± 300	γ, n, ^{3}He	3, 23
19.57 ± 80	$(\frac{1}{2}, \frac{3}{2})^+; \frac{1}{2}$	780 ± 270	γ, ^{3}He	3

Table 15.16: Energy levels of ^{15}O [a] (continued)

E_x in ^{15}O (MeV ± keV)	J^π; T	τ or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
19.91 ± 50			n, ^{3}He	3
20.42 ± 70	$(\frac{3}{2}, \frac{1}{2})^+; \frac{1}{2}$	970 ± 240	γ, p, ^{3}He	3, 9
21.56 ± 70	$(\frac{3}{2}, \frac{1}{2})^+; \frac{1}{2}$	730 ± 120	γ, p, ^{3}He	3, 9, 23
23.8 ± 0.1		$\lesssim 500$	γ, ^{3}He	3
(26.0)	$(\frac{13}{2}^-)$	≈ 600	^{3}He	3
(28.0)	$(\frac{9}{2}^-, \frac{11}{2}^-)$	≈ 2500	^{3}He	3
(29.0)		≈ 2500	^{3}He	3

[a]See also Table 15.17.

[b] It is possible that these two are in fact a single state: see (76AJ1A).

For reaction (a) see (86BE2E); for reaction (b) see (86BE1A). For other heavy-ion reactions see (86AJ1A).

3. (a) ^{12}C(^{3}He, γ)^{15}O $\quad Q_m = 12.0759$
   (b) ^{12}C(^{3}He, n)^{14}O $\quad Q_m = -1.1466$ $\quad E_b = 12.0759$
   (c) ^{12}C(^{3}He, p)^{14}N $\quad Q_m = 4.7789$
   (d) ^{12}C(^{3}He, d)^{13}N $\quad Q_m = -3.5500$
   (e) ^{12}C(^{3}He, t)^{12}N $\quad Q_m = -17.357$
   (f) ^{12}C(^{3}He, ^{3}He)^{12}C
   (g) ^{12}C(^{3}He, α)^{11}C $\quad Q_m = 1.8560$

Excitation functions and polarization measurements for these reactions have been measured over a wide range of energies: see Tables 15.20 in (70AJ1A, 76AJ1A, 81AJ1A) and the text below. Observed resonances are displayed in Table 15.18 here.

The 90° yield and the angular distributions of γ_0, measured from $E(^3\mathrm{He}) = 5.24$ to 13.95 MeV show five resonances attributed to E1 transitions from $J^\pi = \frac{1}{2}^+$ or $\frac{3}{2}^+$, $T = \frac{1}{2}$ states in the GDR characterized by a considerable 3p4h admixture (78DE1B [also for ω_γ], 84DE1K). Yields of γ_{1+2} at 90° have also been reported at $E(^3\mathrm{He}) = 5.3$ to 16.7 MeV: the cross section is some eight times greater than that for (^{3}He, γ_0) and is similar to that for the ^{14}N(p, γ_0)^{15}O reaction over the same excitation range. Three resonances are reported [see Table 15.18 (89KI1G)]: it is suggested that they are due to cluster states with a large 3p4h component. See also (88BL1D; prelim.; $E(^3\mathrm{He}) = 12.0$ to 24.6 MeV; γ to many states of ^{15}O).

Table 15.17: Radiative decays in ^{15}O [a]

E_i (MeV)	J_i^π	E_f (MeV)	J_f^π	Branch (%)	δ [b]
5.24	$\frac{5}{2}^+$	0	$\frac{1}{2}^-$	100	$+0.10 \pm 0.04$ (E3/M2)
6.18 [c]	$\frac{3}{2}^-$	0	$\frac{1}{2}^-$	100	-0.125 ± 0.007 (E2/M1) [k]
6.79 [d]	$\frac{3}{2}^+$	0	$\frac{1}{2}^-$	100	-0.02 ± 0.02 (M2/E1)
6.86 [e]	$\frac{5}{2}^+$	5.24	$\frac{5}{2}^+$	100	$+0.04 \pm 0.03$ (E2/M1)
7.28 [f]	$\frac{7}{2}^+$	0	$\frac{1}{2}^-$	3.8 ± 1.2	
		5.24	$\frac{5}{2}^+$	96.2 ± 1.2	
7.56 [g]	$\frac{1}{2}^+$	0	$\frac{1}{2}^-$	3.5 ± 0.5	
		5.18	$\frac{1}{2}^+$	15.8 ± 0.6	
		6.18	$\frac{3}{2}^-$	57.5 ± 0.4	
		6.79	$\frac{3}{2}^+$	23.2 ± 0.6	
		6.86	$\frac{5}{2}^+$	[l]	Γ_γ (eV)
8.28 [h]	$\frac{3}{2}^+$	0	$\frac{1}{2}^-$	53.2 ± 0.25 [m]	0.24
		5.18	$\frac{1}{2}^+$	1.2 ± 0.1	0.006
		5.24	$\frac{5}{2}^+$	42.2 ± 0.5 [m]	0.20
		6.18	$\frac{3}{2}^-$	2.2 ± 0.6 [m]	0.01
		6.86	$\frac{5}{2}^+$	1.2 ± 0.3 [m]	0.006
8.74 [h]	$\frac{1}{2}^+$	5.18	$\frac{1}{2}^+$	64 ± 3	0.18
		6.18	$\frac{3}{2}^-$	36 ± 3	0.10
8.922 [i]	$\frac{5}{2}^+$	0	$\frac{1}{2}^-$	9 ± 4	
		5.18	$\frac{1}{2}^+$	39 ± 3	
		6.18	$\frac{3}{2}^-$	24 ± 3	
		6.86	$\frac{5}{2}^+$	28 ± 3	
8.922 [i]	$\frac{1}{2}^-$	0	$\frac{1}{2}^-$	50 ± 25	
		5.18	$\frac{1}{2}^+$	20 ± 10	
		6.18	$\frac{3}{2}^-$	20 ± 10	
		6.86	$\frac{5}{2}^+$	(10 ± 10)	
8.982 [j]	$(\frac{3}{2})^-$	0	$\frac{1}{2}^-$	94 ± 1	
		5.18	$\frac{1}{2}^+$	6 ± 1	
9.48 [h]	$(\frac{3}{2}^+)$	0	$\frac{1}{2}^-$	100	9.1 ± 2.0 [n]
9.49	$\frac{5}{2}^-$	0	$\frac{1}{2}^-$	86	2.1

Table 15.17: Radiative decays in ^{15}O [a] (continued)

E_i (MeV)	J_i^π	E_f (MeV)	J_f^π	Branch (%)	δ [b]
		5.24	$\frac{5}{2}^+$	6.5	0.15
		6.18	$\frac{3}{2}^-$	0.7	0.22
		6.86	$\frac{5}{2}^+$	3.4	0.08
		7.28	$\frac{7}{2}^+$	5.1	0.11
9.61	$\frac{3}{2}^-$	0	$\frac{1}{2}^-$	79	4.0
		5.24	$\frac{5}{2}^+$	19	1.0
		6.18	$\frac{3}{2}^-$	2	0.1
10.46	$(\frac{9}{2}^+)$	5.24	$\frac{5}{2}^+$	62 ± 6	18 ± 6 [n]
		6.86	$\frac{5}{2}^+$	< 4	< 1.5
		7.28	$\frac{7}{2}^+$	38 ± 6	11 ± 4 [n]
10.48	$(\frac{3}{2})^-$	0	$\frac{1}{2}^-$	60 ± 8	0.21 ± 0.07 [n]
		5.24	$\frac{5}{2}^+$	40 ± 6	0.14 ± 0.01 [n]
		6.18	$\frac{3}{2}^-$	< 4	< 0.02
		9.79	$\frac{3}{2}^+$	< 4	< 0.02
10.94	$\frac{1}{2}^+$	0	$\frac{1}{2}^-$	44 ± 8	14 ± 4
		5.18	$\frac{1}{2}^+$	34 ± 3	11 ± 2
		6.18	$\frac{3}{2}^-$	22 ± 8	7 ± 2
		6.79	$\frac{3}{2}^+$	< 8	< 3
11.03 [a]	$\frac{1}{2}^-$	0	$\frac{1}{2}^-$	100	1.4 ± 0.4
11.22	$\frac{3}{2}^+$	0	$\frac{1}{2}^-$	74 ± 5	5.5 ± 0.5
		5.18	$\frac{1}{2}^+$	14 ± 5	1.0 ± 0.2
		5.24	$\frac{5}{2}^+$	12 ± 5	0.9 ± 0.2
		6.79	$\frac{3}{2}^+$	< 4	< 0.4
11.57	$\frac{5}{2}^-$	0	$\frac{1}{2}^-$	18 ± 9	0.3 ± 0.2
		5.24	$\frac{5}{2}^+$	63 ± 9	1.2 ± 0.1
		6.18	$\frac{3}{2}^-$	20 ± 9	0.4 ± 0.2
		6.79	$\frac{3}{2}^+$	< 3	< 0.1
11.75 [a]	$\frac{5}{2}^+$	5.24	$\frac{5}{2}^+$	47 ± 7	5 ± 1
		6.18	$\frac{3}{2}^-$	53 ± 7	5 ± 1
11.85 [a]	$\frac{5}{2}^-$	5.24	$\frac{5}{2}^+$	100	1.4 ± 0.6

[a] For references and other comments see Table 15.19 in (81AJ1A).
[b] δ =multipole mixing ratio.
[c] Branches to ^{15}O*(5.18, 5.24) are $< 2.5\%$ each.
[d] Branches to ^{15}O*(5.18, 5.24, 6.18) are < 3, < 3 and $< 7\%$, respectively.
[e] Branches to ^{15}O*(0, 5.18, 6.18) are < 10, < 4 and $< 0.4\%$, respectively.
[f] Branches to ^{15}O*(5.18, 6.18) are < 4 and $< 2\%$, respectively.
[g] Branchings shown to ^{15}O*(5.18, 6.18, 6.79) are weighted means of values shown in Table 15.19 of (81AJ1A), recalculated to sum to 100% for all the transitions.
[h] (87SC1H).
[i] See, however, the comments in reaction 14 of (81AJ1A).
[j] Branchings to ^{15}O*(6.18, 6.86) are $< 1\%$ each.
[k] Weighted mean of values shown in Table 15.19 of (81AJ1A).
[l] Intensity $< 25\%$ of transition to ^{15}O*(6.79).
[m] Recalculated because of new transition to ^{15}O*($\frac{1}{2}^+$) (87SC1H).
[n] Γ_γ values assume J-values in column 2.

The yield of n_0 (reaction (b)) shows resonances for $E(^3\text{He}) < 10$ MeV and little structure above, to 30.6 MeV: see (81AJ1A) [n_1 and n_{2+3+4} yields are also reported].

The yield of protons (reaction (c)) shows some clear resonances below $E(^3\text{He}) = 4.5$ MeV and some uncorrelated structures at higher energies (to $E(^3\text{He}) = 12$ MeV) with the possible exception of states at $E_{\text{res}} = 7.8$, $9.2-9.6$ and (10.5) MeV. For $E(^3\text{He}) = 16$ to 30.6 MeV no appreciable structure is observed in the p_0, p_1 and p_2 yields: see (76AJ1A). At $E(^3\vec{\text{He}}) = 33$ MeV A_y has been measured for ^{14}N*(0, 2.31, 3.95): see (86AJ1A). For polarization effects in the (^{3}He, 2p) reaction at $E(^3\vec{\text{He}}) = 33$ MeV see (86KA1X). For reactions (d) and (e) see (76AJ1A, 81AJ1A, 86AJ1A).

The elastic scattering (reaction (f)) shows some resonant structure near 3, 5 and 6 MeV and some largely uncorrelated structures in the range $E(^3\text{He}) = 16.5$ to 24 MeV. There is some suggestion, however, of two resonances at $E(^3\text{He}) = 17$ and 20 MeV: see (76AJ1A). Resonance-like behavior is also reported at $E(^3\vec{\text{He}}) = 29$ MeV. Polarization measurements are reported for $E(^3\vec{\text{He}}) = 20.5$ to 32.6 MeV: see (81AJ1A). See also (86AJ1A). The yield of α-particles displays resonance structure below 8 MeV, and broad fluctuations for $E(^3\text{He}) = 12$ to 18.6 MeV: see (76AJ1A). Polarization measurements are reported for $E(^3\vec{\text{He}}) = 33.3$ MeV for the α_0 and α_1 groups: see (81AJ1A). For A_y measurements of the (^{3}He, ^{7}Be) and (^{3}He, ^{6}Li) reactions see (89SI1A, 86CL1B). For $\pi^\pm$ production see (86MI1L). For a search for subthreshold K^+ production see (85IA1A). For work at very high energies see (85AB1B, 85AD1C). See also (86AJ1A), (84NA1F), (90TO1E; applied) and (86EV1B, 86SI1F; theor.).

4. ^{12}C(α, n)^{15}O $\qquad Q_m = -8.5019$

Table 15.18: Resonances in $^{12}C + ^{3}He$ [a]

$E(^3He)$ (MeV ± keV)	Resonant for	$\Gamma_{c.m.}$ (keV)	J^π	E_x (MeV)
1.21	p_0, p_2		$(\frac{5}{2})^-$	13.04
1.3	$p_0 \rightarrow p_3$			13.1
2.15	n, p_0		$(> \frac{5}{2})$	13.79
2.45 ± 40	n_0, $p_0 \rightarrow p_3$	160 ± 20	$(\frac{1}{2}^-, \frac{3}{2}^-)$	14.03
2.75 ± 40	n_0, p_1, p_2, ^3He, α_0	340 ± 30	$\frac{1}{2}^+$	14.27
(2.87)	p_0, p_2	240		(14.37)
2.990 ± 10	n_0, p_0, p_1, p_2, p_4, p_5, p_8, ^3He, α_0	100 ± 10	$\frac{3}{2}^+, \frac{5}{2}^+$	14.465
3.28 ± 40	p_0, (p_1, p_2)	180 ± 40		14.70
3.60 ± 40	p_0, p_1, p_2	400 ± 25		14.95
4.20 ± 10	p_5, p_6, α_0	65 ± 15		15.43
4.37 ± 40	p_0, p_1, p_2, p_4, p_7, p_8, α_0	80 ± 25		15.57
4.65 ± 50	n_0			15.79
4.78 ± 50	^3He, α_0	350	$\frac{1}{2}^-, \frac{3}{2}^-$	15.90
4.97 ± 20	α_0			16.05
5.03 ± 20	n_0, ^3He, α_0			16.10
5.15 ± 20	n_0, ^3He, α_0			16.19
5.45 ± 50	^3He, α_0	170	$\frac{1}{2}^+$	16.43
5.85 ± 50	n_0, ^3He			16.75
6.23 ± 70	γ_0	700 ± 70	$(\frac{1}{2}, \frac{3}{2})^+$	17.05 ± 0.06 [b]
6.83 ± 40	γ_{1+2}, n_0, ^3He, α_0	640 ± 120	$\frac{1}{2}^-, \frac{3}{2}^-$	17.53 [c]
7.40 ± 50	^3He	200	$\frac{1}{2}^-, \frac{3}{2}^-$	17.99
7.70 ± 50	n_0, p_0			18.23
8.25 ± 70	γ_0	520 ± 110	$(\frac{1}{2}, \frac{3}{2})^+$	18.67 ± 0.06 [b]
8.70 ± 50	γ_{1+2}, n_0	1120 ± 300		19.03 [c]
9.38 ± 100	γ_0	780 ± 270	$(\frac{1}{2}, \frac{3}{2})^+$	19.57 ± 0.08
9.80 ± 50	n_0			19.91
10.45 ± 90	γ_0, (p_0)	970 ± 240	$(\frac{3}{2}, \frac{1}{2})^+$	20.42 ± 0.07 [b]

Table 15.18: Resonances in $^{12}C + {}^{3}He$ [a] (continued)

$E(^3He)$ (MeV ± keV)	Resonant for	$\Gamma_{c.m.}$ (keV)	J^π	E_x (MeV)
11.87 ± 80	γ_0	730 ± 120	$(\frac{3}{2}, \frac{1}{2})^+$	21.56 ± 0.07 [b]
14.7	γ_{1+2}	$\lesssim$ 0.5 MeV [e]		23.8 ± 0.1 [c]
(17.0) [d]	^3He	≈ 600	$(\frac{13}{2}^-)$	(26.0)
(20.0) [d]	^3He	≈ 2500	$(\frac{9}{2}^-, \frac{11}{2}^-)$	(28.0)
(21.5)	^3He to $^{12}C^*(15.1)$	≈ 2500		(29.0)

[a] For references see Table 15.21 in (76AJ1A).
[b] (78DE1B, 84DE1K [see p.290]); $T = \frac{1}{2}$; $\Gamma_{^3He}/\Gamma_p = 0.17 \pm 0.07$ and 0.09 ± 0.04 for $^{15}O^*(17.05, 18.67)$.
[c] (89KI1G). See also for ω_γ. See also Table 15.19 in (86AJ1A); $T = \frac{1}{2}$ if they are 3p4h cluster states.
[d] $\Gamma_p = 0.06$ and ≥ 0.1 MeV for $^{15}O^*(26, 28)$.
[e] Estimated by reviewer.

Angular distributions of the n_0 group have been measured for $E_\alpha = 18.4$ to 23.1 MeV: see (76AJ1A). At $E_\alpha = 41$ MeV angular distributions are reported to $^{15}O^*(5.24, 6.86+7.28, 9.63[u], 10.48[u], 11.72[u], 12.85[u], 15.05[u])$. $^{15}O^*(8.92, 11.1, 12.3, 13.45, 13.72, 14.27, 15.65)$ are also populated (81OV1B [uncertainties in E_x are not shown; unresolved states are a problem]). At $E_\alpha = 47.4$ MeV groups are populated at $\theta = 0°$ corresponding to $^{15}O_{g.s.}$ and to unresolved states at 5.2, 7.3, 10.0, 12.5 and 15.3 MeV (88LU1B). See also (88CA1N; astrophys.).

5. $^{12}C(^6Li, t)^{15}O$ $\qquad Q_m = -3.7196$

States observed in this reaction are displayed in Table 15.19 (75BI1B: $E(^6Li) = 59.8$ MeV). Comparisons of angular distributions of the triton groups in this reaction and of the ^3He groups to analog states in ^{15}N have been made: analog correspondence is established for (10.48 – 10.70), (12.84 – 13.15 (u)) and (15.05 – 15.49 (u)) [E_x in ^{15}O, E_x in ^{15}N; u = unresolved] (75BI1B). See also (76AJ1A) for the earlier work.

6. $^{12}C(^{12}C, {}^9Be)^{15}O$ $\qquad Q_m = -14.2031$

Table 15.19: Levels of ^{15}O from ^{12}C(^{6}Li, t)^{15}O [a]

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

[a] (75BI1B): $E(^{6}\text{Li}) = 59.8$ MeV.
[b] Angular distributions measured and compared with those of the (^{6}Li, ^{3}He) reaction to analog states in ^{15}N.
[c] Angular distribution measured: analog states in ^{15}N not known.
[d] Unresolved in angular distribution.
[e] $\Gamma_\gamma/\Gamma < 0.13$.

At $E(^{12}C) = 187$ MeV, $\theta_{lab} = 8°$, the spectrum is dominated ny $^{15}O^*(12.84, 15.05)$ [assumed $J^\pi = \frac{1}{2}^-, \frac{13}{2}^+$, respectively]. $^{15}O^*(7.28)$ [$J^\pi = \frac{7}{2}^+$] is populated but $^{15}O^*(0, 6.79)$ are not observed. The situation is similar at $E(^{12}C) = 114$ MeV but at $E(^{12}C) = 72$ MeV ($\theta_{lab} = 11°$) $^{15}O^*(0, 5.2, 7.28)$ are populated with comparable intensities: see (76AJ1A).

At $E(^{12}C) = 480$ MeV the three most strongly excited states in the forward direction are $^{15}O^*(10.46, 12.83[u], 15.05[u])$ [$J^\pi = \frac{9}{2}^+, \frac{11}{2}^-, \frac{13}{2}^+$] and forward angle $\sigma(\theta)$ have been measured. $^{15}O^*(0, 5.24, 7.3, 8.9[u], 16.7[u], 18.2[u], 21.1[u], 22.1[u])$ are also populated (88KR1F).

7. $^{13}C(^3He, n)^{15}O$ $\qquad Q_m = 7.1296$

Observed groups are displayed in Table 15.22 of (81AJ1A).

8. $^{14}C(p, \pi^-)^{15}O$ $\qquad Q_m = -132.115$

At $E_{\vec{p}} = 183$ MeV differential cross sections and A_y are reported for the transitions to $^{15}O^*(0, 7.3)$, the two states strongly populated in the reaction (82JA1A, 82VI1A). See also (86JA1H) and (86KU1J, 90KU1H; theor.).

9. $^{14}N(p, \gamma)^{15}O$ $\qquad Q_m = 7.2971$

Observed resonances in the yield of γ-rays are listed in Table 15.20. Branching ratios are displayed in Table 15.17. Measurements of E_γ lead to $E_x = 5183 \pm 1$, 5240.9 ± 0.4, 6175 ± 2, 6794 ± 2, 6858 ± 2, 8284.1 ± 0.8, 8922 ± 2 and 8978 ± 2 keV: see 81AJ1A). For τ_m see (81AJ1A).

(87SC1H) have studied absolute cross sections, γ-ray angular distributions and excitation functions for $E_p = 0.2$ to 3.6 MeV: $S(0)$ is determined to be 3.20 ± 0.54 keV · b. C^2S are derived for the first eight states of ^{15}O (87SC1H).

The 90° γ_0 yield has been measured for $E_p = 2.2$ to 19 MeV: resonances are observed over most of the range. The $(\gamma_1+\gamma_2)$ yield is relatively weak. For $E_p = 18$ to 28 MeV the excitation function for γ_0 decreases smoothly with energy: there is no evidence for structures [see (81AJ1A)]. See also (85CA1A, 87KR1J, 87WE1C, 88CA1J, 88CA1N, 89BA2P, 89TH1C, 90MA1P; astrophysics) and (90HA1V; theor.).

10. $^{14}N(p, n)^{14}O$ $\qquad Q_m = -5.9255$ $\qquad E_b = 7.2971$

Table 15.20: Resonances in $^{14}N + p$ [a]

E_p (keV)	Γ_{lab} (keV)	$\omega\Gamma_\gamma$ (eV)	Particles out	J^π	E_x (MeV)
278.1 ± 0.4	1.06 ± 0.11 [b]	$(14 \pm 1) \times 10^{-3}$ [a,b]	γ	$\frac{1}{2}^+$	7.5565
1058.0 ± 0.5	3.9 ± 0.7	0.31 ± 0.04 [a,b]	γ	$\frac{3}{2}^+$	8.2840
1550 ± 6	34	$(93 \pm 20) \times 10^{-3}$ [a,b]	γ	$\frac{1}{2}^+$	8.743
1742 ± 2 [c]	3.5 ± 0.3	0.16	γ, p_0	$\frac{5}{2}^+$	8.922
1742 ± 2 [c]	8	0.06	γ, p_0	$\frac{1}{2}^+$	8.922
1806.4 ± 1.5	4.2 ± 0.4	0.52	γ	$(\frac{3}{2})^-$	8.9821
2344 ± 8 [b]	205 [b]	6.1 ± 1.3 [b]	γ, p_0	$(\frac{3}{2}^+)$	9.484
2348 ± 3	10.8 ± 0.5	2.4	γ	$\frac{5}{2}^-$	9.488
2.479 ± 1.7	9.4 ± 0.5	3.3	γ	$\frac{3}{2}^-$	9.609
2537 ± 4	2 ± 1		p_0	$(\frac{7}{2}, \frac{9}{2})^-$	9.664
3209	3 ± 1		p_0	$(\frac{5}{2}^-)$	10.291
3215	12 ± 2		p_0	$\frac{5}{2}^+$	10.296
3392 ± 5	< 2	0.029 ± 0.010	γ_2, γ_6	$(\frac{9}{2}^+)$	10.461
3410	27 ± 5		γ_0, γ_2, p_0	$(\frac{3}{2})^-$	10.478
3440	150 ± 45		γ, p_0	$(\frac{3}{2})^+$	10.506
3880 ± 15	97		p_0	$\frac{7}{2}^+$	10.916
		Γ_{γ_0} (eV)			
3903 ± 3	106 ± 5	14 ± 3	γ, p_0, p_1	$\frac{1}{2}^+$	10.938
3996 ± 3	27 ± 2	1.4 ± 0.4	γ, p_0, p_1	$\frac{1}{2}^-$	11.025
4130 ± 15	< 10		p_0		11.150
4203 ± 3	43 ± 4	5.2 ± 0.4	γ, p_0	$\frac{3}{2}^+$	11.218
4575 ± 15	< 10		p_0		11.565
4580 ± 15	21 ± 15	0.7 ± 0.2	γ, p_0	$\frac{5}{2}^-$	11.569
4580	150		γ		11.57
4630 ± 15	86 ± 50		γ, p_0	$(\frac{3}{2}, \frac{1}{2})^-$	11.616
4740 ± 15	< 10		p_0		11.718
4772 ± 3	106 ± 5		γ, p_0, p_1	$\frac{5}{2}^+$	11.748
4877 ± 3	70 ± 3		γ, p_0, p_1	$\frac{5}{2}^-$	11.846
5025 ± 15	21 ± 5		p_0, p_1	$\frac{5}{2}^-$	11.984
5180 ± 15	214 ± 50		p_0, p_1	$\frac{5}{2}^+$	12.129

Table 15.20: Resonances in $^{14}N + p$ [a] (continued)

E_p (keV)	Γ_{lab} (keV)	$\omega\Gamma_\gamma$ (eV)	Particles out	J^π	E_x (MeV)
5280 ± 20	106 ± 50		p_1 [d]		12.222
5547 ± 3	82 ± 4		p_1, p_2	$\frac{5}{2}^-(\frac{3}{2}^-)$	12.471
5900	≈ 250		γ		12.80
5937 ± 3	17 ± 1		p_2 [e]		12.835
(6100)	30		$p_0 \rightarrow p_2$, α_0	$\frac{5}{2}^+$	(12.99)
6123 ± 3	230 ± 30		p_2 [e]		13.008
6141 ± 3	43 ± 30		p_2 [e]		13.025
6600	≈ 1000		γ, (p_2, α_0)	$(\frac{1}{2}, \frac{3}{2})^+$	13.45
6640			(p_0), (p_2)	$(\frac{3}{2}^+)$	13.49
6760			α_0	$\frac{5}{2}^+$	13.60
6870			p_2	$\frac{3}{2}^-$	13.70
6960			p_1, p_2, p_4, α_0	$\frac{3}{2}^-$	13.79
7050	≈ 150		γ		13.87
7370			α_0	$\frac{5}{2}^-$	14.17
7500	≈ 500		n, $p_0 \rightarrow p_2$, ^3He, α		14.29
7550			α_0	$\frac{5}{2}^+$	14.34
7700			n, p_0, α_0		14.48
7950	170 ± 50		n		14.71
8200			n, $p_2 \rightarrow p_6$, ^3He, α_0, α_1		14.94
8400	≈ 1000		γ	$(\frac{1}{2}, \frac{3}{2})^+$	15.1
9050 [f]			n		15.74
9370 ± 20	≈ 200		n, p_2, p_8, α_1		16.04
9580 ± 20	≈ 150		p_0, p_1, p_3 $\rightarrow p_7$, p_9, ^3He, α_1		16.23
9850 ± 50	600 ± 100		n, ^3He		16.48
10300	≈ 1000		γ	$(\frac{1}{2}, \frac{3}{2})^+$	16.9
10600			$p_4 \rightarrow p_9$, α_0, α_1		17.2

Table 15.20: Resonances in $^{14}N + p$ [a] (continued)

E_p (keV)	Γ_{lab} (keV)	$\omega\Gamma_\gamma$ (eV)	Particles out	J^π	E_x (MeV)
11900	≈ 1000		γ	$(\frac{1}{2}, \frac{3}{2})^+$	18.4
14200	≈ 2000		γ	$(\frac{1}{2}, \frac{3}{2})^+$	20.5
15800	≈ 2000		γ	$(\frac{1}{2}, \frac{3}{2})^+$	22.0

[a] For references see (70AJ1A, 76AJ1A, 81AJ1A). See also Table 15.17 here.
[b] (87SC1H). See also (87KR1J; theor.).
[c] Separated by 0.5 ± 0.5 keV: see, however, reaction 14 in (81AJ1A).
[d] Weak.
[e] Strong.
[f] See footnote [e] in Table 15.23 of (81AJ1A).

The excitation function has been measured for $E_p = 6.3$ to 12 MeV: see (70AJ1A). Observed resonances are displayed in Table 15.20. The cross section [obtained by measuring the 2.31 MeV γ-rays from the ^{14}O (β^+) decay] is reported at 12 energies in the range $E_p = 7$ to 22 MeV (81DY1A). Production cross sections for the 2.31 MeV γ-rays have been measured at $E_p = 8.9$, 20, 30, 33 and 40 MeV by (88LE1C). The ratio of the cross section to $^{14}O_{g.s.}$ to that for the analog state $^{14}N^*(2.31)$ [from the (p, p′) reaction] has been determined at $E_p = 35$ MeV (84TA1H). Forward-angle differential cross sections (n_0) are reported by (79MO1C) at $E_p = 144$ MeV. See also (85CA1A; astrophys.) and ^{14}O.

11. $^{14}N(p, p)^{14}N$ $\qquad E_b = 7.2971$

The yields of elastic and inelastic protons, and of 2.31 MeV γ-rays, have been studied at many energies: see (59AJ1A, 70AJ1A, 76AJ1A). Observed resonances are displayed in Table 15.20. At higher energies excitation functions have been measured for the p_0, p_1 and p_2 groups for $E_p = 17$ to 26.5 MeV: there is no evidence for resonant behavior but the p_1 yield shows a large increase between $E_p = 20$ and 23 MeV. Total cross sections for the $p_0 \rightarrow p_9$ groups have been measured at $E_p = 8.6$, 10.6, 12.6 and 14.6 MeV [see (81AJ1A)]. Total reaction cross sections have also been measured in the range $E_p = 22.9$ to 49.0 MeV by (85CA1D). (88LE1C) report 2.31–MeV γ-ray production cross sections at $E_p = 8.9$, 20, 30, 33 and 40 MeV. For measurements at $E(^{14}N) = 516$ MeV/A see (90WE1A).

Polarization measurements have been carried out at $E_p = 3.0$ to 159.4 MeV [see (70AJ1A, 76AJ1A, 86AJ1A)] and at $E_{\vec{p}} = 35$ MeV (90IE1A; p_1) and 0.8 GeV (85BL1G; A_y; elastic). See also ^{14}N, (86BA2U), (86BA1N, 87HU1D) and (89AM1B; theor.).

12. ^{14}N(p, ^{3}He)^{12}C $\quad Q_m = -4.7789 \quad E_b = 7.2971$

Excitation functions for the ground-state group have been measured at $E_p = 7$ to 11 MeV: some resonant structure is indicated [see Table 15.20]. See also (76AJ1A).

13. ^{14}N(p, α)^{11}C $\quad Q_m = -2.9228 \quad E_b = 7.2971$

Excitation functions and total cross-section measurements have been measured for the α_0 group for $E_p = 3.8$ to 45 MeV: see (76AJ1A). Fairly sharp structures persist until $E_p = 15$ MeV: see Table 15.20 here and footnote [e] in Table 15.23 of (81AJ1A). See also (86HA1H; applied) and (85CA1A; astrophys.).

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

Angular distributions have been studied at many energies in the range $E_d = 0.9$ to 11.8 MeV: see Tables 15.27 and 15.28 in (70AJ1A) and Table 15.26 in (76AJ1A). For τ_m measurements see (70AJ1A). See also Table 15.21 here, ^{16}O in (86AJ1B), (87HI1B; applied) and (84BL1C; theor.).

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

See Table 15.28 in (70AJ1A). See also Table 15.21 here.

16. ^{15}N(γ, π^-)^{15}O $\quad Q_m = -142.322$

At $E_\gamma = 170$ MeV four-point angular distributions of the π^- to ^{15}O$_{\rm g.s.}$ have been measured by (88LI1I) and (89KO1X): the two studies are not in good agreement. See also (90ER1A; theor.).

17. ^{15}N(π^+, π^0)^{15}O $\quad Q_m = 1.850$

Angular distributions of the π^0 to ^{15}O$_{\rm g.s.}$ have been studied at $E_{\pi^+} = 32.4$ and 55.5 MeV (85IR1B), at 48 MeV (84CO1G, 86LE1K) and at 165 MeV (82DO1B). Forward-angle differential cross sections of the π^0 to ^{15}O$_{\rm g.s.}$ have also been measured at $E_{\pi^+} = 20$ MeV (87IR1A) and at 40.7 and 63.6 MeV (85IR1B). See also (89LE1L).

Table 15.21: Levels of ^{15}O from ^{14}N(d, n) and ^{14}N(^{3}He, d) [a]

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

[a] See Tables 15.28 in (70AJ1A) and 15.26 in (76AJ1A) for references and additional information.
[b] Nominal energies if uncertainty is not indicated.
[c] From γ-ray measurements.
[d] From both (d, n) and (^{3}He, d) work: see (76AJ1A).
[e] From (^{3}He, d).

18. ^{15}N(p, n)^{15}O $\qquad E_m = -3.5363$

Angular distributions have been measured for $E_p = 3.95$ to 18.5 MeV [see (81AJ1A, 86AJ1A)], at 35 MeV (87OR1A; ^{15}O*(7.56) [$J^\pi = \frac{1}{2}^+$]), at 135 MeV (85WA1B; ^{15}O*(0, 6.2)) and at 200 and 494 MeV (88CI1A; prelim.; also A_y). Forward-angle differential cross sections at $E_p = 200$, 300 and 400 MeV to ^{15}O*(0, 6.2) are reported by (87AL1A; prelim.). The ratio of the population of ^{15}O$_{\rm g.s.}$ to that of ^{15}O*(6.2) has been determined at $E_p = 800$ MeV (86KI1F). ^{15}O*(6.2) contains only about $\frac{1}{3}$ of the expected GT strength (85GO1N). [I am indebted to Prof. C.D. Goodman for his comments.] For a discussion of GT strengths, see (87TA1G). ^{15}O*(5.2[u], 6.8[u], 7.28) have also been populated (87OR1A). For the earlier work see (86AJ1A). See also ^{16}O in (86AJ1B), (85GO1Q, 86VO1G, 87BE1T, 88RO1O, 88WA1Q), (86MA1P, 87HI1B, 88HI1F; applied) and (89RA1A; theor.).

19. ^{15}N(^{3}He, t)^{15}O $\qquad Q_m = -2.7725$

Angular distributions for the t$_0$, t$_{1+2}$, t$_3$, t$_{4+5}$, t$_6$ and t$_7$ groups have been studied for $E(^3\text{He}) = 16.5$ to 44.6 MeV: see (76AJ1A).

20. ^{16}O(γ, n)^{15}O $\qquad Q_m = -15.6638$

The spectrum of photoneutrons has been investigated at many energies. Measurements over the giant dipole resonance region show the predominant strength is to the $J^\pi = \frac{1}{2}^-$ and $\frac{3}{2}^-$ states $E_x = 0$ and 6.18 MeV, consistent with the basic validity of the single-particle, single-hole theory of photoexcitation in ^{16}O. However, the positive-parity states at $E_x = 5.18$, 5.24, 6.86 MeV are also populated suggesting some more complicated excitations in ^{16}O: see (70AJ1A, 76AJ1A). Differential cross sections for the n$_0$ group have been measured from threshold to $E_\gamma = 28$ MeV [see (76AJ1A)], at $E_\gamma = 60$ to 160 MeV (also ^{15}O*(6.18); no appreciable strength in the 5.2 MeV doublet) [see (86AJ1A)] and at 150, 200 and 250 MeV (89BE1L). See also ^{16}O in (86AJ1B) and (87RY1A, 88CA1D, 88DU1D, 88RY1A, 90BR1R, 90FL1A; theor.).

21. (a) ^{16}O(π^+, p)^{15}O $\qquad Q_m = 124.687$
(b) ^{16}O(π^+, π^+n)^{15}O $\qquad Q_m = -15.6638$
(c) ^{16}O(π^+, π^0p)^{15}O $\qquad Q_m = -10.277$

For reaction (a) see (82DO1A). At $E_{\pi^+} = 2.0$ GeV/c differential cross sections have been determined for the transition to ^{15}N*(6.2) (83KI1C) in reaction (b). For reaction (c), see (86GI1A).

22. ^{16}O(p, pn)^{15}O $\qquad Q_m = -15.6638$

At $E_p = 505$ MeV the summed spectra show two peaks corresponding to the $p_{1/2}$ and $p_{3/2}$ knockouts [^{15}O*(0, 6.18)] (binding energies of 15.64 and 21.82 MeV). Differential cross sections are also reported (86MC1A) [see also reaction 59 in ^{15}N]. For work at 1 GeV, see (85BE1J). See also (83WA1C) and (87HI1B; applied).

23. ^{16}O(p, d)^{15}O $\qquad Q_m = -13.4392$

Angular distributions have been reported at many energies for $E_p = 18.5$ to 155.6 MeV [see Table 15.30 in (70AJ1A), (76AJ1A), (86AJ1A)]: at those energies ^{15}O*(0, 6.18) are preferentially populated. At $E_p = 200$ MeV angular distributions have been studied for ^{15}O*(0, 6.18) (89AB1F) [also A_y and C^2S]. At $E_p = 800$ MeV ^{15}O*(0, 5.2[u], 6.18, 7.4[u], 9.0[u], 10.42 ± 0.15, 10.87 ± 0.15, 12.21 ± 0.15, 13.59 ± 0.15, 19.0 ± 0.2, 21.1 ± 0.2) [the last two states have $\Gamma \geq 0.8$ MeV] have been populated (84SM1A).

For γ-ray production [^{15}O*(5.24)] see (88LE1C). See also ^{17}F in (86AJ1B), (89KI1D) and (87LA1B, 88LE1C, 89GU1I; astrophysics).

24. ^{16}O(d, t)^{15}O $\qquad Q_m = -9.4065$

Angular distributions have been reported at a number of energies in the range $E_d = 20$ to 52 MeV [see (81AJ1A) and reaction 60 in ^{15}N here] and at $E_{\vec{d}} = 89$ MeV (90SA1C; ^{15}O*(0, 6.18)). See also ^{18}F in (83AJ1A).

25. ^{16}O(^{3}He, α)^{15}O $\qquad Q_m = 4.9140$

The $p_{1/2}$ and $p_{3/2}$ hole states ^{15}O*(0, 6.18) are strongly populated. Information on these and other states are displayed in Table 15.25 of (81AJ1A). Angular distributions have been measured at energies up to $E(^3\text{He}) = 217$ MeV: see (81AJ1A). Branching ratios and multipole mixing ratios are displayed in Table 15.17. (78BE1E) report τ_m of ^{15}O*(5.24) = 3.25 ± 0.30 ps, $|g| = 0.260 \pm 0.028$. (83BI1D) determine $g = +0.17 \pm 0.07$. See also (86AJ1A), ^{19}Ne in (83AJ1A) and (90AB1G; applied).

26. ^{16}O(^{6}Li, ^{7}Li)^{15}O $\qquad Q_m = -8.414$

See (86GL1E; prelim.).

27. ^{17}O(p, t)^{15}O $Q_m = -11.3254$

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. At $E_p = 45$ MeV a state, assumed to be the $J^\pi = \frac{5}{2}^+$, $T = \frac{3}{2}$ analog of ^{15}C*(0.74), is observed at $E_x = 12.255 \pm 0.013$ MeV, $\Gamma_{c.m.} = 135 \pm 15$ keV. The state decays by proton emission to the $T = 1$, 0^+ state ^{14}N*(2.31) [the population of some $T = \frac{1}{2}$ states is also reported]: see (81AJ1A).

$E_{\vec{p}} = 89.7$ MeV angular distributions and A_y measurements have been reported to ^{15}O*(0, 5.24[u], 6.18, 6.86, 7.28) (85VO1A).

28. ^{19}F(^{3}He, ^{7}Li)^{15}O $Q_m = -4.3185$

See (76AJ1A). See also (86HA1E; theor.).

^{15}F
(Fig. 13)

GENERAL (See also (86AJ1A)).

See (89AY1B, 89OG1B) and (85AN1A, 86AN1D, 88CO1F; theor.). See (86AN1D) for comments on ^{15}Ne.

Mass of ^{15}F: The atomic mass excess of ^{15}F is 16.77 ± 0.13 MeV. ^{15}F is unstable with respect to breakup into ^{14}O + p by 1.47 MeV: see (81AJ1A).

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

This reaction is not observed at $E(^3\text{He}) = 235$ MeV, $\theta_{lab} = 20°$: the differential cross section (c.m.) is $\leq 4 \times 10^{-11}$ b (84BI1B).

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

This reaction has been studied at $E(^3\text{He}) = 74.5$ MeV (78BE1D) and 75.4 and 87.8 MeV (78KE1A). Two groups are observed: the ground state [$\Gamma_{c.m.} = 0.8 \pm 0.3$ MeV (78KE1A), 1.2 ± 0.3 MeV (78BE1D)] and a relatively strongly populated state, presumed to be the mirror of ^{15}C*(0.74) [$J^\pi = \frac{5}{2}^+$], with $E_x = 1.3 \pm 0.1$ MeV (78KE1A), 1.2 ± 0.2 MeV (78BE1D) and $\Gamma_{c.m.} = 0.5 \pm 0.2$ MeV (78KE1A), 0.24 ± 0.03 MeV (78BE1D). The differential cross section for populating ^{15}F*(1.3) is 250 ± 20 nb/sr at 10° and $E(^3\text{He}) = 74.5$ MeV (78BE1D) and 80 ± 25 nb/sr at 9°, 87.8 MeV (78KE1A). At $E(^3\text{He}) = 75.4$ MeV, $\theta = 9°$, the ground state is populated with a differential cross section of 8 ± 4 nb/sr (78KE1A).

Table 15.22: Energy levels of ^{15}F

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

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(Closed July 1, 1990)

(i) Abstracts of contributed papers to the Int. Conf. on Nuclear Physics, Florence, Italy, August 29-September 3, 1983, published by Tipografia Compositori, Bologna; referred to herein as "FLORENCE".
(ii) Abstracts of contributed papers to the 35th Meeting on Nuclear Spectroscopy and the Structure of the Atomic Nucleus, Leningrad, USSR, April 16-18, 1985, published by "Nauka"; referred to herein as "LENINGRAD".
(iii) Abstracts of contributed papers to the 36th Meeting on Nuclear Spectroscopy and the Structure of the Atomic Nucleus, Kharkov, USSR, April 15-18, 1986, published by "Nauka"; referred to herein as "KHARKOV".
(iv) "Nuclear Data for Basic and Applied Science", Editors: P.G. Young et al., published by Gordon and Breach (1986), referred to herein as "SANTA FE 1985".
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