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Energy Levels of Light Nuclei
$A = 16$

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Abstract: An evaluation of $A = 16$–17 was published in *Nuclear Physics A*460 (1986), p. 1. This version of $A = 16$ differs from the published version in that we have corrected some errors discovered after the article went to press. Figures and introductory tables have been omitted from this manuscript. Reference key numbers have been changed to the NNDC/TUNL format.

(References closed June 01, 1986)

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^{16}He

(Not illustrated)

This nucleus has not been observed. See also (1982AV1A, 1983ANZQ; theor.).

^{16}Be

(Not illustrated)

This nucleus has not been observed. Its atomic mass excess is calculated to be 59.22 MeV. It is then unstable with respect to breakup into ^{14}Be + 2n by 2.98 MeV: see (1974TH01, 1986AJ01). The first three excited states with $J^\pi = 2^+, 4^+, 4^+$ are calculated to be at 1.90, 5.08 and 6.51 MeV in a $(0+1)\hbar\omega$ space shell model calculation (1985PO10). See also (1983ANZQ; theor.).

^{16}B

(Not illustrated)

This nucleus has not been observed in the 4.8 GeV proton bombardment of a uranium target: it is particle unstable. Its mass excess is predicted to be 37.97 MeV: it would then be unstable with respect to decay into ^{15}B + n by 0.93 MeV: see (1982AJ01, 1985WA02). The ground state is predicted to have $J^\pi = 0^-$ and the first three excited states are predicted to lie at 0.95, 1.10, and 1.55 MeV [$J^\pi = 2^-, 3^-, 4^-$] in a $(0+1)\hbar\omega$ space shell model calculation (1985PO10). See also (1983ANZQ; theor.).

^{16}C

(Figs. 1 and 5)

GENERAL: (See also (1982AJ01).)

Nuclear models: (1982LA26, 1984SA37).

Complex reactions involving ^{16}*C*: (1982FI10, 1983FR1A, 1983WI1A, 1984HI1A, 1985PO11, 1986CS1A).

Hypernuclei (States observed in the ^{16}O(K$^-$, π^+) reaction at $E_{\mathrm{K}^-} = 450$ MeV/c are interpreted as due to the recoil-less production of Σ^- particles in the $p_{3/2}$ and $p_{1/2}$ orbits of the $^{16}_{\Sigma}$C hypernucleus (1985BE31).): (1982DO1L, 1982PI02, 1983BA1Y, 1984AS1D, 1985BE31, 1986MI1N, 1986ZO1A).

Other topics: (1984PO11, 1985AN28, 1985BA51, 1985FL1D).

Ground state properties of ^{16}*C*: (1983ANZQ, 1984FR13, 1985AN28).

Table 16.1: Energy Levels of ^{16}C

E_x (MeV $\pm$ keV)	$J^\pi; T$	$\tau_{1/2}$ (sec) or Γ (keV)	Decay	Reactions
0	$0^+; 2$	$\tau_{1/2} = 0.747 \pm 0.008$	β^-	1, 2
1.766 ± 10	2^+		γ	2
3.027 ± 12	(0^+)		(γ)	2
3.986 ± 7	2		γ	2
4.088 ± 7	$3^{(+)}$		γ	2
4.142 ± 7	4^+		γ	2
6.109 ± 15	$(2^+, 3^-, 4^+)$	$\Gamma \leq 25$		2

Table 16.2: The β^- decay of ^{16}C

Decay to ^{16}N* (MeV)	J^π	Branch (%)	log f_0t
0.120	0^-	$0.68^{+0.09}_{-0.11}$ [a]	$6.70^{+0.07}_{-0.05}$
0.298	3^-	< 0.5 [b]	> 6.83
0.397	1^-	< 0.1 [a]	> 7.46
3.35	1^+	84.4 ± 1.7 [b]	3.551 ± 0.012
4.32	1^+	15.6 ± 1.7 [b]	3.83 ± 0.05

[a] (1983GA03). See also (1984GA1A).

[b] (1976AL02).

1. ^{16}C(β^-)^{16}N $\qquad Q_m = 8.012$

The half-life of ^{16}C is 0.747 ± 0.008 sec: it decays to ^{16}N*(0.12, 3.35, 4.32) $[J^\pi = 0^-, 1^+, 1^+]$: see Table 16.2. See also (1983SN03) for a discussion of the decay of ^{16}C to 1^+ states in ^{16}N and (1985KI06; theor.).

2. ^{14}C(t, p)^{16}C $\qquad Q_m = -3.013$

States of ^{16}C observed in this reaction are displayed in Table 16.3 of (1982AJ01) and in Table 16.1 here.

^{16}N

(Figs. 2 and 5)

GENERAL: (See also (1982AJ01).)

Model calculations: (1984BA24, 1984KA1H, 1984VA06).

Complex reactions involving ^{16}*N*: (1981ME13, 1981OL1C, 1983EN04, 1983FR1A, 1983MA06, 1983OL1A, 1983PL1A, 1983SA06, 1983WI1A, 1984GR08, 1984HI1A, 1984HO23, 1984KA1H, 1985BE40, 1985PO11, 1986HA1P).

Reactions involving muons nad neutrinos (See also reaction 14.): (1981GM02, 1981TO16, 1983EG03, 1983JA10, 1984JA06, 1984KI09, 1984NO03, 1984SR05, 1985CH04, 1985DO04, 1985NO10, 1986GM03, 1986MC02, 1986NO04, 1986RO06).

Reactions involving pions (See also reaction 15.): (1981GM03, 1981RA16, 1982DE14, 1982GI12, 1983AS01, 1983ER02, 1983ER06, 1983MO1J, 1984AS05, 1984KA31).

Hypernuclei: (1982KA1D, 1983CH1T, 1983FE07, 1983SH1E, 1984AS1D, 1984CH1G, 1984ZH1B).

Other topics: (1982BR08, 1985AN28).

Ground state properties of ^{16}*N*: (1983ANZQ, 1985AN28).

For a comparison of analog states in ^{16}N and ^{16}O, see (1983KE06, 1983SN03).

1. ^{16}N(β^-)^{16}O $\qquad Q_m = 10.419$

The half-life of ^{16}N is 7.13 ± 0.02 sec: see Table 16.3 in (1971AJ02). From the character of the beta decay [see Table 16.21] it is concluded that ^{16}N$_{\rm g.s.}$ has $J^\pi = 2^-$: see ^{16}O. The β-decay of ^{16}N*(0.12) $[J^\pi = 0^-]$ to ^{16}O$_{\rm g.s.}$ has been studied. The β-decay rate $\lambda_\beta = 0.45 \pm 0.05$ sec^{-1} which implies g$_{\rm P}$/g$_{\rm A}$ $= 11 \pm 2$ (1983GA18); $\lambda_\beta = 0.48 \pm 0.024$ sec^{-1}, g$_{\rm P}$/g$_{\rm A}$ $= 11 - 12$ (1985HA22). (1985HE08) recalculate $\lambda_\beta = 0.489 \pm 0.02$ sec^{-1} and suggest that pion exchange currents must be included in the nucleon exchange current. See also (1982AJ01, 1982GA05) and (1983MI20). The half-life of ^{16}N*(0.12) is 5.26 ± 0.06 μsec [see (1982AJ01)], 5.40 ± 0.05 μsec (1983MI20). See also (1984GA1A, 1985MI1A) and (1981TO16, 1983JA10, 1983RH1A, 1984HO1L, 1984JA06, 1984NO03, 1985DO04, 1985TO20, 1986MC02, 1986NO04, 1986RO06; theor.).

2. ^{7}Li(^{11}B, pn)^{16}N $\qquad Q_m = 2.532$

Gamma rays with $E_\gamma = 120.42 \pm 0.12$, 298.22 ± 0.08 and 276.85 ± 0.10 keV from the ground state decays of ^{16}N*(0.12, 0.30) and the decay of the state at 397.27 ± 0.10 keV to the first excited state have been studied. $\tau_{\rm m}$ for ^{16}N*(0.30, 0.40) are, respectively, 133 ± 4 and 6.60 ± 0.48 psec (1983KO01).

Table 16.3: Energy Levels of ^{16}N

E_x (MeV $\pm$ keV)	$J^\pi; T$	τ or $\Gamma_{\text{c.m.}}$ (keV)	Decay	Reactions
0	$2^-; 1$	$\tau_{1/2} = 7.13 \pm 0.02$ sec	β^-	1, 2, 4, 5, 7, 9, 10, 12, 15, 16, 17, 18, 19, 21, 22
0.12042 ± 0.12	0^-	$\tau_m = 7.58 \pm 0.09$ μsec	γ, β^-	1, 2, 4, 5, 7, 9, 12, 13, 14, 15, 16, 17, 18, 21, 22
0.29822 ± 0.08	3^-	131.7 ± 1.9 psec $\lvert g \rvert = 0.532 \pm 0.020$	γ	2, 4, 5, 7, 8, 9, 12, 15, 16, 17, 18, 19, 21, 22
0.39727 ± 0.10	1^-	$\tau_m = 5.63 \pm 0.05$ psec $g = -1.83 \pm 0.13$	γ	2, 4, 5, 7, 9, 12, 14, 15, 16, 17, 18, 21, 22
3.3528 ± 2.6	1^+	$\Gamma = 15 \pm 5$	n	4, 5, 7, 9, 11, 12, 13, 18, 19, 21
3.5227 ± 2.6	2^+	3	n	4, 5, 7, 9, 11, 12, 18, 19, 21
3.9627 ± 2.6	3^+	≤ 2	n	4, 5, 7, 8, 9, 11, 12, 18, 19, 21
4.3204 ± 2.7	1^+	20 ± 5	n	4, 7, 9, 11, 12, 13
4.3914 ± 2.7	1^-	82 ± 20	n	4, 5, 7, 9, 11, 12
4.76 ± 50	1^-	250 ± 50	n	9, 11, 12
4.7828 ± 2.7	2^+	59 ± 8	n	4, 5, 7, 9, 11, 12
5.0537 ± 2.7	2^-	19 ± 6	n	4, 7, 9, 11, 12
5.129 ± 7	≥ 2 [a]	$\leq 7 \pm 4$	n	4, 5, 7, 9, 11, 12, 19
5.150 ± 7	$(2,3)^-$ [a]	$\leq 7 \pm 4$	n	4, 5, 7, 9, 11, 12, 19
5.2301 ± 2.6	3^+	≤ 4	n	4, 7, 9, 11, 12, 21
5.25 ± 70	2^-	320 ± 80	n	9, 12
5.318 ± 3	1^+	(260)	n	4, 11
5.5216 ± 2.5	3^+	$\leq 7 \pm 4$	n	4, 5, 7, 9, 11, 12, 18, 19, 21
5.7317 ± 2.5	(5^+)	$\leq 7 \pm 4$	n	4, 5, 7, 8, 9, 11, 12, 18, 19, 21
6.003 ± 3	1^-	270 ± 30	n	4, 9, 11, 21
6.1707 ± 2.4	(4^-) [a]	$\leq 7 \pm 4$	n	4, 5, 7, 9, 12, 16, 18, 19, 21

Table 16.3: Energy Levels of ^{16}N (continued)

E_x (MeV ± keV)	$J^\pi; T$	τ or $\Gamma_{\text{c.m.}}$ (keV)	Decay	Reactions
6.3739 ± 2.8	(3^-)	30 ± 6	n	4, 5, 9, 11, 12, 19, 21
6.426 ± 7		300 ± 30		9, 12
6.5054 ± 2.8	1^+	34 ± 6	(n)	4, 9, 11, 12, 21
6.6085 ± 2.8	(4)	$\leq 7 \pm 4$		4, 5, 9, 12, 21
6.845 ± 4		$\leq 7 \pm 4$		5, 7, 9, 12, 21
(6.84)	≥ 2	> 140	n	11
7.02 ± 20	1^+	22 ± 5	n	9, 11, 12, 21
7.134 ± 7		$\leq 7 \pm 4$		7, 9, 12, 21
7.250 ± 7	≥ 2	17 ± 5	n	5, 9, 11, 12, 21
7.572 ± 4	≥ 3 [b]	$\leq 7 \pm 4$	n	5, 7, 8, 9, 11, 12, 21
7.637 ± 4	$(3, 4, 5)^+$ [b]	$\leq 7 \pm 4$		5, 7, 8, 9, 12, 21
7.674 ± 4	(b)	$\leq 7 \pm 4$	n	5, 7, 9, 11, 12, 19, 21
7.877 ± 9	≥ 4	100 ± 15	n	5, 9, 11, 12, 16, 21
8.048 ± 9		85 ± 15	n	9, 11, 21
8.199 ± 5	$(3, 2)^+$	28 ± 8		7, 9, 21
8.282 ± 8		24 ± 8		9, 21
8.365 ± 8	≥ 1	18 ± 8	n	5, 9, 11, 21
8.49 ± 30	≥ 1	≤ 50	n	11, 21
8.72	≥ 1	40	n	11
8.819 ± 15		≤ 50	n	5, 11, 21
9.035 ± 15		≤ 50		21
9.16 ± 30	≥ 2	100	n	11, 21
9.34 ± 30		≤ 50	n	11, 21
9.459 ± 15	≥ 2	100	n	5, 11, 19, 21
9.760 ± 10	$T = 1$	15 ± 8		5, 7, 21
9.813 ± 10	$T = 1$			7
9.928 ± 7	$0^+; T = 2$	< 12		7, 20
10.055 ± 15	≥ 3	30	n	5, 11, 21
10.37 ± 40	≥ 2	165	n	5, 11
10.71	≥ 2	120	n	11
11.16 ± 40				5

Table 16.3: Energy Levels of ^{16}N (continued)

E_x (MeV ± keV)	$J^\pi; T$	τ or $\Gamma_{\text{c.m.}}$ (keV)	Decay	Reactions
11.49	≥ 3		n	11
11.61	≥ 3	220	n, d	6, 11
11.701 ± 7	$1^-, 2^+; T = 2$	< 12		7
11.75 ± 40		< 50		5
(11.92)		390	n, d	6
(12.09)			n	11
12.39 ± 60		290	n, p, d	5, 6
12.57 ± 60		180	n, p, d	5, 6
12.88		155	n, p, d	6, 11
(12.97)		175	n, d	6
13.11 ± 60			n, (d)	5, 6, 11
13.83			n	11
14.36 ± 50	$(3)^+$	180	d	5, 6

[a] See also Table 16.4.

[b] See also Table 16.5.

3. (a) ^{9}Be(^{7}Li, t)^{13}C $Q_\text{m} = 8.180$ $E_\text{b} = 20.572$
   (b) ^{9}Be(^{7}Li, α)^{12}B $Q_\text{m} = 10.460$
   (c) ^{9}Be(^{7}Li, ^{8}Li)^{8}Be $Q_\text{m} = -17.611$

See (1982AJ01).

4. ^{10}B(^{7}Li, p)^{16}N $Q_\text{m} = 13.986$

See Table 16.4 and (1982AJ01).

5. ^{13}C(α, p)^{16}N $Q_\text{m} = -7.421$

Table 16.4: States of ^{16}N from ^{10}B(^{7}Li, p) [a]

E_x [b] (MeV)	J [c]	E_x [b] (MeV)	J [c]
0		5.142	[e]
0.124		5.230	[f]
0.296		5.318	0, 1
0.400		5.525	4, 3 [g]
3.352	[c]	5.734	[h]
3.524	[c]	6.002	1 [f]
3.964	[c]	6.172	[i]
4.321	[c]	6.374	[c]
4.392	[c]	6.504	[c]
4.785	[c]	6.608	4 [j]
5.054	1, 2 [d]		

[a] (1984FO07); angular distributions at $E(^{7}\text{Li}) = 16.0$ MeV. See also reaction 3 in (1982AJ01).

[b] ±3 keV.

[c] Based on the assumption that the angle-integrated cross section is proportional to $2J + 1$. States labelled [c] have J consistent with known values.

[d] If a doublet, $J = 1$ and 0.

[e] Doublet: The sum of the two $J = 7$, 8 or 6. (1984FO07) suggest $4^+(5^+, 3^+)$ for J^π of ^{16}N*(5.13) and $3^-(2^-)$ for the J^π of ^{16}N*(5.15) with the combination 3^+, 2^- extremely unlikely.

[f] Narrow state.

[g] If a doublet, and if one state is 3^+, the second member would have $J = 0$.

[h] If a doublet of which one member is 5^+, the other would have $J = 2$ (1, 3).

[i] (1984FO07) suggest an unresolved doublet: one of th states is a 4^- state, the other has $J = 2, 1$.

[j] $J = 4$, if a single state.

Table 16.5: States of ^{16}N from ^{13}C(α, p) [a]

E_x (MeV)	E_x (MeV)	E_x (MeV)	E_x (MeV)
0	5.14 ± 0.04 [b]	7.572 [f]	10.07 ± 0.04
0.120	5.522	7.637 [f]	10.37 ± 0.04
0.298	5.732	7.674 [f]	11.16 ± 0.04 [c]
0.397	6.171	7.877 [e]	11.75 ± 0.04 [c,g]
3.353	6.374	8.39 ± 0.03	12.39 ± 0.06
3.522	6.609 [c]	8.82 ± 0.03	12.57 ± 0.06
3.963	6.845 [c]	9.46 ± 0.03	13.11 ± 0.06
4.391	7.250 [d]	9.77 ± 0.03	14.30 ± 0.06
4.783			

[a] (1983HA32); $E_\alpha = 34.9$ MeV; DWBA analysis.

[b] Unresolved.

[c] Very sharp.

[d] $\Gamma = 17$ keV.

[e] $\Gamma = 100$ keV.

[f] Suggested $J^\pi = (4^+, 5^+)$, (4^-), (5^-) for ^{16}N*(7.57, 7.64, 7.67), respectively.

[g] $\Gamma < 50$ keV; not to be identified with the $T = 2$ state at 11.70 MeV.

At $E_\alpha = 34.9$ MeV the spectrum is dominated by a state at $E_x = 11.75 \pm 0.04$ MeV: see Table 16.5. Angular distributions have been analyzed with DWBA, whose predictions depend strongly on the choice of the α-particle optical potential (1983HA32). See also (1982AJ01).

6. (a) ^{14}C(d, γ)^{16}N $\quad Q_m = 10.474$
   (b) ^{14}C(d, n)^{15}N $\quad Q_m = 7.9829 \quad E_b = 10.474$
   (c) ^{14}C(d, p)^{15}C $\quad Q_m = -1.0065$
   (d) ^{14}C(d, d)^{14}C

For reaction (a) see (1971AJ02). Resonances observed in reactions (b, c, d) are displayed in Table 16.5 of (1982AJ01).

7. ^{14}C(^{3}He, p)^{16}N $\quad Q_m = 4.980$

Proton groups have been observed to ^{16}N states with $E_x < 12$ MeV and angular distributions [with $E(^3\text{He}) \leq 15$ MeV] lead to the J^π assignments shown in Table 16.6.

Table 16.6: Excited states in ^{16}N from ^{14}C(^{3}He, p) [a]

E_x (MeV $\pm$ keV)	Γ (keV)	$J^\pi; T$	E_x (MeV $\pm$ keV)	Γ (keV)	$J^\pi; T$
0.121 ± 6		0^-	5.724 ± 5		5^+
0.298 ± 6		3^-	6.168 ± 5		
0.396 ± 7			6.843 ± 5		
3.348 ± 7		1^+	7.113 ± 5		
3.517 ± 7		$2^+, (3)^+$	7.570 ± 5		
3.958 ± 7		$(2)^+, 3^+$	7.636 ± 5		
4.313 ± 9		1^+	7.673 ± 5		
4.386 ± 9			8.205 ± 5		
4.768 ± 11			9.760 ± 10	15 ± 8	$T = 1$
5.052 ± 9			9.813 ± 10		$T = 1$
5.137 ± 9			9.928 ± 7	< 12	$0^+; 2$
5.234 ± 9		$(1, 2, 3)^+$	11.701 ± 7	< 12	$1^-, 2^+; 2$
5.512 ± 5		$(1, 2, 3)^+$			

[a] For references see Table 16.5 in (1977AJ02).

8. ^{14}C(α, d)^{16}N $Q_m = -13.373$

At $E_\alpha = 46$ MeV the angular distributions of the groups to ^{16}N*(0.30, 3.96, 5.73, 7.60) have been determined: the most strongly populated state is the (5^+) state ^{16}N*(5.73): see (1971AJ02).

9. ^{14}N(t, p)^{16}N $Q_m = 4.842$

Observed proton groups are displayed in Table 16.7. See also (1981OS1H).

10. ^{15}N(n ,γ)^{16}N $Q_m = 2.491$

The thermal cross section is 24 ± 8 μb: see (1981MUZQ).

11. ^{15}N(n, n)^{15}N $E_b = 2.491$

Table 16.7: States in ^{16}N from ^{14}N(t, p) [a]

E_x (MeV ± keV)	Γ (keV)	L	J^π
0		3	2^- [f]
0.120 ± 10		1	0^- [f]
0.300 ± 10		3	3^- [f]
0.399 ± 10 [b]		1	1^- [f]
3.359 ± 10	15 ± 5	0	1^+ [f]
3.519 ± 10	$\leq 7 \pm 4$	[d]	
3.957 ± 10	$\leq 7 \pm 4$	2	3^+ [f]
4.318 ± 10	20 ± 5	0	1^+ [f]
4.391 ± 10	82 ± 20	1	1^- [f]
4.725 ± 10 [c]	290 ± 30	1	1^-
4.774 ± 10	59 ± 8	2	2^- [f]
5.053 ± 10	19 ± 6	$(1 + 3)$	2^-
5.130 ± 10	$\leq 7 \pm 4$	[d]	
5.150 ± 10	$\leq 7 \pm 4$		
5.226 ± 10	$\leq 7 \pm 4$	2	$(1, 2, 3)^+$
5.305 ± 10 [c]	260 ± 30	[d]	
5.520 ± 10	$\leq 7 \pm 4$	$(0, 1) + 2 + 4$ [e]	
5.730 ± 10	$\leq 7 \pm 4$	$(1, 3) + 4$ [e]	
6.009 ± 10	270 ± 30	1	1^-
6.167 ± 10	$\leq 7 \pm 4$	(3)	(4^-)
6.371 ± 10	30 ± 6	(3)	(3^-)
6.422 ± 10	300 ± 30	$0^+(2, 4)$ [e]	
6.512 ± 10	34 ± 6	$0^+(2, 3)$	1^+
6.613 ± 10	$\leq 7 \pm 4$	$(2 + 4)$ or 3	
6.854 ± 10	$\leq 7 \pm 4$	3 or $(2 + 4)$	
7.006 ± 10	22 ± 5	$0(+2)$	1^+
7.133 ± 10	$\leq 7 \pm 4$	(3, 2)	
7.250 ± 10	17 ± 5	$(2 + 4)$ or 3	
7.573 ± 10	$\leq 7 \pm 4$	3 or $(2 + 4)$	$3, 4^-$
7.640 ± 10	$\leq 7 \pm 4$	4	$(3, 4, 5)^+$

Table 16.7: States in ^{16}N from ^{14}N(t, p) [a] (continued)

E_x (MeV ± keV)	Γ (keV)	L	J^π
7.675 ± 10	$\leq 7 \pm 4$	$(1 + 4)$	
7.876 ± 10	100 ± 15	$1 + 4$ [e]	
8.043 ± 10	85 ± 15	$(2 + 4)$ or 3	
8.183 ± 10	28 ± 8	$2(+4)$	$(3, 2)^+$
8.280 ± 10	24 ± 8	(1)	$((0, 1, 2)^-)$
8.361 ± 10	18 ± 8	$(1 + 4)$ [e]	

[a] For references see Table 16.7 in (1982AJ01).

[b] $\tau_m = 5.1 \pm 0.3$ psec.

[c] The errors listed here for the E_x to these two broad peaks are probably underestimates: I am indebted to Dr. H. Fuchs for his comments.

[d] Results are ambiguous.

[e] May be a doublet.

[f] Identified with shell-model counterparts.

The scattering amplitude (bound) $a = 6.44 \pm 0.03$ fm, $\sigma_{\rm free} = 4.59 \pm 0.05$ b, $\sigma^{\rm spin}_{\rm inc}$(bound nucleus) < 1 mb (1979KO26). The total cross section has been measured for $E_n = 0.4$ to 32 MeV: see (1977AJ02, 1981MUZQ). Observed resonances are displayed in Table 16.8. See also (1985PA11, 1985RO1J; theor.).

12. ^{15}N(d, p)^{16}N $\qquad Q_m = 0.266$

Levels derived from observed proton groups and γ-rays are shown in Table 16.9. Gamma transitions are shown in the inset of Fig. 2. The very strong evidence for $J^\pi = 2^-, 0^-, 3^-$ and 1^-, respectively for ^{16}N*(0, 0.12, 0.30, 0.40) is reviewed in (1971AJ02). These states provide a probe of the residual interaction relating the 1p and 2s 1d shells: see (1984BI03) for a comparison of experiment and theory for M1 observables. See also (1983GA18) and (1985PA11; theor.).

13. ^{16}C$(\beta^-)^{16}$N $\qquad Q_m = 8.012$

See ^{16}C.

Table 16.8: Resonances in ^{15}N(n, n)^{15}N [a,b]

E_{n} (MeV ± keV)	Γ_{lab} (keV)	E_{x} (MeV)	J^{π}
0.921	14	3.354	1^{+} [c]
1.095	3	3.517	1
1.563	≤ 2	3.955	1
1.944	29	4.312	1^{+} [d]
2.038	56	4.400	1^{-} [d]
2.30 ± 70 [e]	410 ± 100 [e]	4.65	1^{-} [d]
2.399	107	4.738	2^{+} [d]
2.732	35	5.050	1^{-}
2.830	12	5.142	$3^{(-)}$
2.84 ± 70 [f]	710 ± 100 [f]	5.15	2^{-} [d]
2.915	4	5.222	≥ 2
2.93	260	5.24	1^{+}
3.225		5.512	
3.454	24	5.727	1^{+}
3.69	297	5.95	1^{-}
3.987	88	6.226	(1^{+})
4.126	78	6.356	(3^{-})
4.252	113	6.474	(2^{+})
4.64	> 150	6.84	≥ 2
4.80	37	6.99	≥ 1
5.055	25	7.227	≥ 2
5.43	30	7.58	≥ 3
5.56		7.70	
5.73	165	7.86	≥ 4
5.90		8.02	
6.28		8.37	≥ 1
6.42		8.51	≥ 1
6.65	45	8.72	≥ 1
6.76		8.82	
7.10	110	9.14	≥ 2

Table 16.8: Resonances in ^{15}N(n, n)^{15}N [a,b] (continued)

E_n (MeV ± keV)	Γ_{lab} (keV)	E_x (MeV)	J^π
7.31		9.34	
7.44	105	9.46	≥ 2
7.71	150	9.71	≥ 2
8.07	30	10.05	≥ 3
8.30	175	10.27	≥ 2
8.77	130	10.71	≥ 2
9.61		11.49	≥ 3
9.77		11.64	≥ 3
10.25		12.09	
10.64		12.46	
11.09		12.88	
11.41		13.12	
12.10		13.83	

[a] For references see Table 16.7 in (1977AJ02).

[b] Below $E_n = 4.5$ MeV, the multilevel R-matrix formalism was used to determine E_λ, Γ_λ and whenever possible J^π by a χ^2 fitting and minimization technique. Above this energy the $2J + 1$ dependence was used; the parity cannot be determined because no marked interference effects are observed between resonance and potential scattering. Above 5.65 MeV all J-values are lower limits because the inelastic channel is open. [A channel radius $a = 4.69$ fm was used.]

[c] Parity determined from angular distribution.

[d] J^π also obtained by phase-shift analysis.

[e] The phase-shift analysis indicates that the resonance is at $E_n = 2.42 \pm 0.08$ MeV with $\Gamma = 250 \pm 50$ keV. This is one of two ($\mathrm{d}_{3/2}\mathrm{p}_{1/2}^{-1}$) single-particle resonances.

[f] The phase-shift analysis finds $E_\lambda = 2.94 \pm 0.1$ MeV, $\Gamma = 320 \pm 80$ keV. This is the other $(\mathrm{d}_{3/2}\mathrm{p}_{1/2}^{-1})$ single-particle resonance.

Table 16.9: Levels of ^{16}N from ^{15}N(d, p) and ^{18}O(d, α) [a]

E_x [b] (MeV ± keV)	l_n [b]	E_x [c] (MeV ± keV)	J^π [a]
0		0	2^-
0.1201 ± 0.5 [d]		0.119 ± 15	0^-
0.2962 ± 1.0 [e]		0.301 ± 15	3^-
0.3973 ± 1.0 [e]		0.400 ± 15	1^-
3.365 ± 10		3.358 ± 15	1^-
3.523 ± 10	2 or $1 + 3$	3.524 ± 15	2^+
3.964 ± 10	3	3.964 ± 15	3^+ [h]
4.325 ± 10	1	4.324 ± 15	1^+
4.40	0	4.383 ± 15	$(0, 1)^-$
4.715 ± 10	1		$(1, 2, 3)^+$
4.780 ± 10		4.787 ± 15	
(4.90 ± 10)			
5.032 ± 10	2	5.065 ± 15	2^-
5.128 ± 10	≥ 2		≥ 2
		5.139 ± 15	
5.150 ± 10	2		$(2, 3)^-$
5.231 ± 10	3	5.240 ± 15	3^+
5.310 ± 10			
5.523 ± 10	3	5.528 ± 15	3^+
5.739 ± 10	2	5.740 ± 15	(1, 2) [i]
		6.01 ± 15	
6.170 ± 10	≥ 3	6.168 ± 15	4^- [h]
(6.28 ± 10)	1		$(0, 1, 2)^+$
6.376 ± 10	2	6.37 ± 15	$(1, 2, 3)^-$
6.431 ± 10			
6.514 ± 10	1	6.512 ± 15	$(0, 1, 2)^+$
6.609 ± 10		6.620 ± 15	
(6.79 ± 10)			
6.847 ± 10		6.852 ± 15	
7.034 ± 10		7.01 ± 15	
7.135 ± 10		7.141 ± 15	
7.250 ± 10		7.247 ± 15	

Table 16.9: Levels of ^{16}N from ^{15}N(d, p) and ^{18}O(d, α) [a] (continued)

E_x [b] (MeV $\pm$ keV)	l_n [b]	E_x [c] (MeV $\pm$ keV)	J^π [a]
7.577 ± 10		7.596 ± 15	
7.638 ± 10		7.64 ± 15	
7.676 ± 10		7.683 ± 15	
7.840 ± 10		7.88 ± 15	
		8.06 ± 15	
		8.18 ± 15	
		8.286 ± 15	
		8.374 ± 15	
		8.49 ± 30 [f]	
		8.819 ± 15 [g]	
		9.035 ± 15	
		(9.16 ± 30)	
		(9.34 ± 30)	
		9.459 ± 15	
		(9.66 ± 40)	
		9.794 ± 15 [g]	
		9.90 ± 30	
		10.055 ± 15 [g]	
		(10.17 ± 30)	
		(10.26 ± 30)	

[a] For the earlier references and additional information see Table 16.9 in (1982AJ01).

[b] ^{15}N(d, p)^{16}N.

[c] ^{18}O(d, α)^{16}N.

[d] $\tau_m = 7.58 \pm 0.09$ μsec.

[e] $\tau_m = 131.7 \pm 1.9$ and 5.63 ± 0.05 psec, respectively, for ^{16}N*(0.30, 0.40); $|g| = 0.532 \pm 0.020$ for ^{16}N*(0.30) (1984BI03).

[f] Γ for this level and the ones listed below $\leq 40 - 50$ keV.

[g] These levels appear to be correlated with thresholds for neutron emission to excited states of ^{15}N.

[h] (1982MA25): $E_d = 52$ MeV.

[i] A closely spaced doublet appears to be present. At least one of the states has unnatural parity.

14. ^{16}O$(\mu^-, \nu)^{16}$N $Q_{\rm m} = 95.240$

Partial μ^--capture rates to ^{16}N*(0.12, 0.40) $[J^\pi = 0^-, 1^-]$ are consistent with the assumption of a large mesonic exchange effect in the time part of the weak axial current (1979GU06). See also (1982FR08, 1983VA1E), ^{15}N in (1986AJ01) and the "General" section here.

15. ^{16}O$(\gamma, \pi^+)^{16}$N $Q_{\rm m} = -149.986$

The angular distribution of the π^+ to the four lowest states of ^{16}N (unresolved) has been measured at $E_{\rm e} = 200$ MeV (1983SH41), and for $E_{\pi^+} = 30$ MeV (1983JE08). See also (1982COZV, 1984BLZY).

16. ^{16}O(n, p)^{16}N $Q_{\rm m} = -9.637$

At $E_{\rm n} = 59.6$ MeV differential cross sections for the protons to the first four states of ^{16}N (unresolved) and to ^{16}N*(6.2, 7.8) have been analyzed by DWBA. Comparisons are made with results from the ^{16}O(γ, n) and ^{15}N(p, γ_0) reactions in the GDR region of ^{16}O (1982NE04, 1984BR03). See also (1983SCZR).

17. ^{16}O(t, ^{3}He)^{16}N $Q_{\rm m} = -10.401$

At $E_{\rm t} = 23.5$ MeV ^{16}N*(0, 0.30) $[J^\pi = 2^-, 3^-]$ are strongly populated relative to ^{16}N*(0.12, 0.40) $[J^\pi = 0^-, 1^-]$: see (1982AJ01).

18. ^{16}O(^{7}Li, ^{7}Be)^{16}N $Q_{\rm m} = -11.281$

Angular distributions are reported at $E(^7{\rm Li}) = 50$ MeV to ^{16}N*(0, 0.30, 6.17) [$J^\pi = 2^-$, 3^-, 4^-] and analyzed with microscopic DWBA calculations. ^{16}N*(0.12, 0.40, 3.35, 3.52, 3.96, 5.52, 5.73) are also populated (1984CO20). See also (1984GA1N) [$E(^7{\rm Li}) = 78$ MeV; angular distribution to ^{16}N*(6.2)], (1983PU01) and (1984BA53; theor.).

19. ^{17}O(d, ^{3}He)^{16}N $Q_{\rm m} = -8.287$

See Table 16.10 in (1982AJ01).

20. ^{18}O(p, ^{3}He)^{16}N $Q_{\rm m} = -14.107$

At $E_{\rm p} = 43$ MeV, the angular distribution of the ^{3}He nuclei corresponding to a state at $E_{\rm x} = 9.9$ MeV fixes $L = 0$ and therefore $J^{\pi} = 0^{+}$ for ^{16}N*(9.9): it is presumably the $T = 2$ analog of the ground state of ^{16}C: see (1982AJ01). See also (1985BLZY).

21. ^{18}O(d, α)^{16}N $Q_{\rm m} = 4.247$

Alpha particle groups observed in this reaction are displayed in Table 16.9. For polarization studies see (1982MA25) and ^{20}F in (1983AJ01, 1987AJ02). $\tau_{\rm m}$ for ^{16}N*$(0.40) = 6.5 \pm 0.5$ psec and $|{\rm g}| = 1.83 \pm 0.13$: see (1982AJ01).

22. ^{19}F(n, α)^{16}N $Q_{\rm m} = -1.523$

See (1982AJ01) and ^{20}F in (1983AJ01).

^{16}O

(Figs. 3 and 5)

GENERAL: (See also (1982AJ01).)

Shell model: (1978WI1B, 1981AN18, 1981BR16, 1981CO1X, 1981DE2G, 1981FO12, 1982AB05, 1982BR08, 1982HA19, 1982RA1N, 1982RE05, 1983DE37, 1983GL05, 1983GL1B, 1983MI26, 1983VA31, 1983WA17, 1983WA23, 1984BA04, 1984BO11, 1984CL10, 1984FA1F, 1984JA09, 1984MA11, 1984PRZY, 1984SA26, 1984VA06, 1984ZI04, 1984ZW1A, 1985AD04, 1985AN16, 1985CA26, 1985EL12, 1985GOZN, 1985KL04, 1985MI23, 1985PH01, 1985YE02, 1986DR04).

Collective, deformed and rotational models: (1981DE2G, 1982AB05, 1982BR08, 1982KU1K, 1982OS1C, 1982PA1E, 1982RA1N, 1983IK02, 1983MA29, 1983SC08, 1984BA04, 1984BU25, 1984CA1X, 1984DH03, 1984FL04, 1984SA37, 1984ZI04, 1985BA11, 1985EL12, 1985RO1G, 1986SU01).

Cluster and α-particle models: (1981AG1B, 1981FU1G, 1981KN12, 1981MA1G, 1982KI1C, 1982KU1F, 1982PA1E, 1982SMZM, 1982SU1B, 1982VA11, 1983CA12, 1983FU1D, 1983GI06, 1983GL05, 1983JA09, 1983KA39, 1983PI03, 1983SH38, 1983UE1B, 1984AU14, 1984BA04, 1984BA48, 1984DH03, 1984IK01, 1984OK04, 1985BA26, 1985EL12, 1985KW02, 1985VO1E, 1986SU01).

Special states: (1978WI1B, 1981DE2G, 1981ME1H, 1981SP1D, 1981SU09, 1981TO14, 1981TO16, 1982AB05, 1982BR08, 1982BR1M, 1982BU24, 1982HA19, 1982NA03, 1982OS1C, 1982PA1E, 1982RA1N, 1982RO01, 1982SMZM, 1982WE1J, 1982ZA1D, 1983AD1B, 1983AU1B, 1983BI1C, 1983DE1X, 1983IK02, 1983SP1B, 1983UE1B, 1983VA13, 1983VA31, 1983WA17, 1983WI15, 1984AD1E, 1984AU14, 1984BA04, 1984BA48, 1984BU25, 1984CA11, 1984CA07, 1984CL10, 1984CO02, 1984CZ01, 1984CZ02, 1984FL04, 1984HA14, 1984MO13, 1984NA26, 1984SA37, 1984ST1E, 1984VA06, 1984ZW1A, 1985BA11, 1985BA26, 1985BE2K, 1985BO18, 1985CA25, 1985CA08, 1985CH27, 1985CO01, 1985EL12, 1985FU05, 1985FUZZ, 1985GOZN, 1985HA18, 1985HA1J, 1985MI10, 1985PH01, 1985RO1G, 1985VO1E, 1986CZ01, 1986PI02, 1986SU01, 1986WA1T, 1986WI1P).

Electromagnetic transitions: (1981DWZZ, 1981SU09, 1982HA19, 1982LA26, 1983IK02, 1983VA08, 1983VA13, 1983WA17, 1984BA48, 1984CA11, 1984CA1W, 1984CZ01, 1984DE23, 1984HA14, 1984MO13, 1984NA26, 1984OR01, 1984SA26, 1984WE13, 1985AD04, 1985CA26, 1986DR04, 1986ER1A, 1986SU01, 1987RA01).

Giant resonances: (See also reactions 36 and 37.) (1981GA12, 1981KN12, 1981KO41, 1981SP1D, 1982CA1H, 1982DE51, 1982GO1T, 1982NA20, 1983BA65, 1983DA23, 1983DE37, 1983IS1F, 1983KA07, 1983KA28, 1983ME1K, 1983VA13, 1983WA1P, 1983WA1Q, 1983WA17, 1984AN10, 1984IS1B, 1984OR01, 1985CA06, 1985CA26, 1985CA08, 1985GI1G, 1986AD1B, 1986BLZZ, 1986ER1A, 1986ISZZ, 1986NA1H).

Astrophysical questions: (1981BE2K, 1981DE2C, 1981LA1L, 1981WA1Q, 1981WE1F, 1982BU1A, 1982CA1A, 1982HI1E, 1982WI1B, 1982WO1A, 1983AL23, 1983BO1F, 1983HA1P, 1983IB1A,

1983SI1B, 1983WE1A, 1984BL1J, 1984CO1H, 1984HA1R, 1984HA1Z, 1984LA1J, 1984NO1B, 1984TR1C, 1985AR1A, 1985BR1E, 1985DW1A, 1985HA1Z, 1985HA1R, 1985KO2A, 1986DO1L, 1986TH1E).

Applications: (1982BE64, 1983AM1A, 1983FA1F, 1983GO2D, 1983GR1L, 1983KI1D, 1983LI1T, 1984CA1D, 1985HA38, 1985WA1R, 1985YO1B, 1986DU1K, 1986SI1L).

Complex reactions involving ^{16}O: (1981EG02, 1981LA10, 1981MA1G, 1981NA07, 1981OL1C, 1982BJ01, 1982HI1G, 1982HO10, 1982MA1Z, 1982MO1K, 1982SI1C, 1982TA02, 1982VI01, 1982YU1A, 1983BE02, 1983BH09, 1983CH23, 1983DE26, 1983FR1G, 1983FR17, 1983FR1A, 1983IS1E, 1983JA05, 1983KW01, 1983LE1R, 1983LE1F, 1983OL1A, 1983PL1A, 1983SA06, 1983SI1A, 1983SO08, 1983VA23, 1983WE1C, 1983WI1A, 1984AI1B, 1984AN1G, 1984AS1D, 1984BA2F, 1984DE1Q, 1984FI17, 1984GR08, 1984HI1A, 1984HO23, 1984KA1J, 1984MA1P, 1984MU1G, 1984NA12, 1984PO03, 1984SI15, 1984SJ01, 1984ST1B, 1984TS03, 1984XI1B, 1985AG1A, 1985DA18, 1985GU08, 1985HO05, 1985KA1E, 1985KA1G, 1985KAZQ, 1985LI1B, 1985MC03, 1985MO08, 1985PO11, 1985RO10, 1985SA1W, 1985SH1G, 1985SI19, 1985ST20, 1985ST1B, 1985TO12, 1985UT01, 1985WA22, 1986MA19, 1986PA05, 1986RA1L, 1986SH2B, 1986UT01, 1986VA10, 1986WE1C).

Muon and neutrino capture and reactions: (1981GM02, 1981IS11, 1981OH06, 1981TO16, 1982DU04, 1982GA1A, 1982NA01, 1983EG03, 1983GM1A, 1983JA10, 1983VA1E, 1984GM1B, 1984JA06, 1984KI09, 1984NO03, 1984SR05, 1985BE2K, 1985CH04, 1985DO04, 1985GA1P, 1985NO10, 1986GM03, 1986MC02, 1986NO04, 1986RO06).

Pion capture and reactions (See also reactions 37 and 40.): (1979MI1A, 1980SH1R, 1981AN1H, 1981BE63, 1981BE2P, 1981CI04, 1981FE2A, 1981FR14, 1981FR17, 1981FR18, 1981GA1K, 1981GI1E, 1981GM03, 1981GO1K, 1981HO1G, 1981IS11, 1981LI1Q, 1981LI1T, 1981LI1W, 1981MA23, 1981OS1A, 1981RA16, 1981RO14, 1981SEZR, 1981ST19, 1981WE1G, 1982BE51, 1982BE1A, 1982BI08, 1982BL20, 1982CA03, 1982CH34, 1982DE1K, 1982DE24, 1982DO01, 1982ER04, 1982FR17, 1982GI12, 1982GO1B, 1982GOZX, 1982GR02, 1982GR1F, 1982IL02, 1982IN1A, 1982KA16, 1982KA14, 1982LI10, 1982LI1L, 1982MA22, 1982MO1G, 1982MO12, 1982MO1W, 1982OS01, 1982OS1C, 1982PI06, 1982RE15, 1982RI1A, 1982TH1C, 1982TH08, 1982WH1A, 1982ZA1E, 1983AM1C, 1983AS01, 1983BEYZ, 1983BI1N, 1983BL10, 1983CO08, 1983ER02, 1983ER04, 1983ER06, 1983GE12, 1983GI02, 1983GM1A, 1983GR07, 1983HO14, 1983KA08, 1983KI01, 1983KO2B, 1983MA16, 1983MA56, 1983MO1M, 1983PE14, 1983RI1C, 1983RIZW, 1983SE10, 1983SE11, 1983SH41, 1983SP1B, 1983TR1E, 1983TR1J, 1983YU1A, 1983ZA1D, 1984AL20, 1984AS05, 1984BE1Q, 1984BO1L, 1984BU11, 1984CA07, 1984CE1D, 1984CO02, 1984CO1U, 1984CZ01, 1984EF03, 1984GE1A, 1984GIZZ, 1984GI05, 1984GI1H, 1984GM01, 1984GR27, 1984KA36, 1984KA31, 1984KI17, 1984KY01, 1984LI25, 1984LI16, 1984MA1T, 1984MA33, 1984MA63, 1984SC09, 1984TR15, 1984WU05, 1985ALZX, 1985AN1G, 1985AR15, 1985BE1C, 1985BE1K, 1985BI01, 1985ER03, 1985FU05, 1985GI06, 1985KA30, 1985KO06, 1985LA20, 1985LE1E, 1985MA1X, 1985MA1K, 1985OH09, 1985RE1D, 1985RO17, 1985RO1M, 1985WH01, 1985WO1C, 1986AN40, 1986BO03, 1986CZ01, 1986ER1A, 1986FO03, 1986KA05, 1986RO03, 1986ZO1A).

K-mesons and other meson interactions: (1981BO09, 1981PO1F, 1981TO14, 1982BO1U, 1982PI02, 1982PO1C, 1983BA1Y, 1983BA71, 1983FE07, 1983GA17, 1983GE13, 1983GE1C, 1983MA1V, 1983PO1D, 1983TO21, 1984BO1H, 1984MA1F, 1984SIZZ, 1985BE31, 1985BE62, 1985CO1H, 1985GA1E, 1986BR1U, 1986DA1G, 1986HA1Y, 1986KI1K, 1986MI1N, 1986RO1X, 1986SH1K, 1986ZO1A).

Hypernuclei: (1981BO09, 1981PO1F, 1981RA18, 1982BA17, 1982BO1U, 1982BR1Q, 1982DA1Q, 1982DEZQ, 1982DO1L, 1982DO1M, 1982ER1E, 1982JO1C, 1982KA1D, 1982PO1C, 1983AU1A, 1983BA2P, 1983FE07, 1983JO1E, 1983MA1F, 1983PO1D, 1983SH38, 1983SH1E, 1983SI1E, 1983SI1H, 1984AS1D, 1984BA1N, 1984BO1H, 1984HA1D, 1984MA1F, 1984MI1E, 1984SIZZ, 1984ZH1B, 1985AH1A, 1985DEZY, 1985HA1X, 1985OS1C, 1985WA1N, 1985YA1B, 1985YA1C, 1985YA1K, 1985ZH1E, 1986BR1V, 1986DA1G, 1986DA1B, 1986HA1Y, 1986MA1W, 1986RO1X, 1986YA1Q, 1986YA1F, 1986ZO1A).

Antinucleon interactions: (1982BO24, 1982GR1J, 1982ZH1G, 1983GR11, 1983HE23, 1983NI07, 1983SU04, 1984DA23, 1984DA20, 1984MA17, 1984PO1A, 1984SU07, 1984WO01, 1985BA09, 1985BA51, 1985DA24, 1985DO1E, 1985DU05, 1985LE1B, 1985LI16, 1986SP01).

Other topics: (1978WI1B, 1981AN18, 1981BL1K, 1981BR16, 1981CA1H, 1981FO12, 1981GA1N, 1981GU10, 1981RA18, 1981SH1M, 1981ZH1G, 1982AB1J, 1982BA2G, 1982BO01, 1982BR08, 1982BR1M, 1982BR1U, 1982BU24, 1982CA12, 1982DE1N, 1982DR1E, 1982FA04, 1982HU12, 1982KU1F, 1982MO20, 1982NA03, 1982NE1E, 1982NG01, 1982PA22, 1982RE05, 1982SA31, 1982SH1H, 1982VE02, 1982ZA1D, 1983AD1B, 1983AR1J, 1983BA1U, 1983BI1C, 1983BIZU, 1983DA03, 1983DA23, 1983DE1W, 1983DO1D, 1983EI01, 1983FU1D, 1983GR26, 1983MA35, 1983ME1J, 1983ME1K, 1983MI1J, 1983MI26, 1983SH2D, 1983ST1K, 1983TR1K, 1983UE1B, 1983WA16, 1984BO53, 1984CA1X, 1984CL06, 1984CL10, 1984CZ01, 1984CZ02, 1984DH04, 1984DU04, 1984GO14, 1984GR18, 1984HO1N, 1984MA11, 1984PRZY, 1984SA26, 1984SH1X, 1984YA1F, 1985AD04, 1985AN28, 1985BA1A, 1985BO18, 1985BO30, 1985CA04, 1985CA25, 1985FU05, 1985GO1W, 1985KU1N, 1985MI10, 1985PH01, 1985PR02, 1985TR03, 1986DR04, 1986FO03, 1986PI02, 1986SA02, 1986YA1F, 1987RA01).

Ground state of ^{16}*O*: (1978WI1B, 1979MA1C, 1981AG1B, 1981BO39, 1981DE24, 1981DU16, 1981JA07, 1981VA1N, 1981ZA05, 1982AN1F, 1982BA2G, 1982BO01, 1982BR24, 1982BR1M, 1982CA12, 1982DE35, 1982FA04, 1982FR01, 1982KR1C, 1982LI07, 1982LO13, 1982MO20, 1982NE1E, 1982NG01, 1982SH1H, 1982TR1B, 1982ZA1D, 1982ZE1A, 1983ANZQ, 1983AR1J, 1983AU1B, 1983BI09, 1983BR1P, 1983DA03, 1983ES02, 1983GI06, 1983GO23, 1983GO16, 1983MA35, 1983MI26, 1983VA13, 1983VA31, 1983WA16, 1983WA23, 1984ANZW, 1984AU14, 1984BA41, 1984BA2F, 1984BA48, 1984BE27, 1984BO11, 1984BO53, 1984BR25, 1984DE23, 1984DH03, 1984FA1F, 1984FL04, 1984GE1A, 1984GO1G, 1984GO14, 1984HA14, 1984IK01, 1984JA09, 1984MA11, 1984ST1E, 1984WE04, 1984WU05, 1984ZI04, 1985AD04, 1985AN16, 1985AN28, 1985BE2K, 1985BO18, 1985BU03, 1985CA38, 1985CL1A, 1985GA1N, 1985GH01, 1985GOZN, 1985HA18, 1985HE15, 1985JA06, 1985KO02, 1985MI23, 1985WE09, 1986DR04, 1986PI02, 1986RR03, 1986RO03, 1986VI03, 1986WI04).

$\langle r^2\rangle^{1/2} = 2.710 \pm 0.015$ fm (1978KI01).

Abundance $= (99.762 \pm 0.015)$% (1984DE53).

$|\mathrm{g}| = +0.55 \pm 0.03$ for ^{16}O*(6.13) [see (1982AJ01)].

Table 16.10: Energy Levels of ^{16}O [a]

E_{x} (MeV ± keV)	$J^\pi; T$	K^π	$\Gamma_{\mathrm{c.m.}}$ or τ_{m} (keV)	Decay	Reactions
0	$0^+; 0$		stable		2, 3, 7, 8, 9, 10, 11, 12, 13, 14, 15, 18, 19, 20, 26, 28, 29, 30, 33, 34, 35, 36, 37, 38, 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, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74
6.0494 ± 1.0	$0^+; 0$	0^+	$\tau_{\mathrm{m}} = 96 \pm 7$ psec	π	2, 3, 7, 8, 9, 11, 13, 15, 17, 19, 26, 28, 29, 30, 34, 35, 39, 40, 43, 50, 51, 53, 61, 62, 65, 66, 68, 71, 73
6.129893 ± 0.04	$3^-; 0$		$\tau_{\mathrm{m}} = 26.6 \pm 0.7$ psec $\mathrm{g} = +0.556 \pm 0.004$	γ	2, 3, 7, 8, 9, 11, 13, 14, 15, 17, 26, 27, 28, 29, 30, 33, 34, 35, 39, 40, 41, 42, 43, 45, 46, 47, 49, 50, 61, 62, 63, 65, 66, 68, 71, 73
6.9171 ± 0.6	$2^+; 0$	0^+	$\tau_{\mathrm{m}} = 6.78 \pm 0.19$ fsec	γ	2, 3, 7, 8, 9, 11, 13, 15, 26, 27, 28, 29, 30, 33, 34, 38, 39, 40, 41, 42, 43, 45, 46, 49, 50, 51, 62, 63, 65, 66, 68, 71, 73
7.11685 ± 0.14	$1^-; 0$		$\tau_{\mathrm{m}} = 12.0 \pm 0.7$ fsec	γ	2, 3, 7, 8, 9, 13, 15, 26, 27, 28, 29, 30, 33, 34, 35, 38, 39, 40, 42, 43, 46, 61, 62, 63, 65, 66, 68, 73
8.8719 ± 0.5	$2^-; 0$		$\tau_{\mathrm{m}} = 180 \pm 16$ fsec	γ, α	2, 3, 7, 8, 12, 15, 26, 27, 29, 33, 34, 35, 39, 41, 42, 43, 45, 46, 62, 63, 68, 73
9.585 ± 11	$1^-; 0$	0^-	$\Gamma = 420 \pm 20$	γ, α	3, 5, 7, 8, 26, 34, 35, 41, 42, 43, 45, 46, 50, 51

Table 16.10: Energy Levels of ^{16}O [a] (continued)

(MeV ± keV)	$J^\pi; T$	K^π	$\Gamma_{\rm c.m.}$ or $\tau_{\rm m}$ (keV)	Decay	Reactions
9.8445 ± 0.5	$2^+; 0$		0.625 ± 0.100	γ, α	2, 3, 5, 7, 8, 15, 26, 27, 29, 33, 34, 35, 39, 42, 43, 45, 46, 50, 51, 61, 63, 65, 68, 71, 73
10.356 ± 3	$4^+; 0$	0^+	26 ± 3	γ, α	2, 3, 5, 7, 8, 9, 10, 12, 15, 17, 26, 27, 29, 34, 39, 42, 43, 45, 46, 50, 51, 57, 61, 63, 66, 68, 73
10.957 ± 1	$0^-; 0$		$\tau_{\rm m} = 8 \pm 5$ fsec		2, 26, 33, 34, 42, 43, 63, 68
11.080 ± 3	$3^+; 0$		$\Gamma < 12$	γ	2, 26, 33, 34, 63, 68
11.0967 ± 1.6	$4^+; 0$		0.28 ± 0.05	γ, α	2, 3, 5, 7, 9, 10, 12, 15, 26, 27, 39, 42, 43, 45, 46, 50, 51, 68
(11.26) [b]	(0^+; 0)		(2500)	(α)	5, 34
11.520 ± 4	$2^+; 0$		71 ± 3	γ, α	2, 3, 5, 15, 26, 39, 40, 42, 43, 45, 46, 50, 51, 57
11.60 ± 20	$3^-; 0$	0^-	800 ± 100	α	5, 10, 50, 51
12.049 ± 2	$0^+; 0$		1.5 ± 0.5	γ, α	5, 15, 19, 26, 39, 42, 43, 45, 46, 50, 51
12.440 ± 2	$1^-; 0$		91 ± 6	γ, p, α	3, 4, 5, 26, 30, 32, 33, 34, 39, 43, 46, 50, 51
12.530 ± 1	$2^-; 0$		$(97 \pm 10) \times 10^{-3}$	γ, p, α	2, 15, 26, 30, 32, 33, 34, 39, 42, 43, 46, 62
12.796 ± 4	$0^-; 1$		40 ± 4	p	26, 32, 33, 34, 42
12.9686 ± 0.4	$2^-; 1$		1.60 ± 0.14	γ, p, α	15, 26, 30, 32, 33, 34, 39, 61, 62, 63
13.020 ± 10	$2^+; 0$		150 ± 10	γ, p, α	3, 5, 39, 42, 43, 45, 46, 50, 51, 57
13.090 ± 8	$1^-; 1$		130 ± 5	γ, p, α	3, 4, 5, 7, 26, 33, 34, 39, 63
13.129 ± 10	$3^-; 0$		110 ± 30	γ, p, α	2, 3, 4, 5, 26, 33
13.259 ± 2	$3^-; 0$		21 ± 1	γ, p, α	3, 4, 5, 26, 32, 33, 34, 39, 42, 61, 62, 63, 65, 67
13.664 ± 3	$1^+; 0$		64 ± 3	γ, p, α	26, 30, 32, 43
13.869 ± 20	$4^+; 0$		89 ± 2	p, α	2, 5, 26, 32, 39, 42, 45, 46, 50, 51
13.980 ± 2	2^-		20 ± 2	p, α	2, 26, 27, 32

Table 16.10: Energy Levels of ^{16}O $^{\rm a}$ (continued)

(MeV $\pm$ keV)	$J^\pi; T$	K^π	$\Gamma_{\rm c.m.}$ or $\tau_{\rm m}$ (keV)	Decay	Reactions
14.032 ± 15	0^+		185 ± 35	γ, α	5, 39
14.1 ± 100	3^-		750 ± 200	α	5
14.302 ± 3	$4^{(-)}$		34 ± 12		15, 26, 27
14.399 ± 2	5^+		27 ± 5		2, 8, 15, 26, 27
14.620 ± 20	(4^+)		490 ± 15	α	5, 7
14.660 ± 20	5^-	0^-	670 ± 15	α	5, 7, 8, 9, 10, 50, 51
14.8153 ± 1.6	$6^+; 0$		70 ± 8	α	2, 5, 7, 15, 26, 27, 45, 46, 50, 51
14.926 ± 2	2^+		54 ± 5	p, α	2, 26, 32, 39
15.097 ± 5	0^+		166 ± 30	p, α	4, 5, 26, 32
15.196 ± 3	$2^-; 0$		63 ± 4	p, α	26, 27, 32, 39, 42, 45, 61, 62, 63
15.26 ± 50	2^+; (0)		300 ± 100	p, α	32, 39, 42, 45
15.408 ± 2	$3^-; 0$		132 ± 7	p, α	4, 5, 26, 27, 32, 39, 42, 46, 50, 51, 57, 61, 62, 63
15.785 ± 5	3^+		40 ± 10		15, 26, 27
15.828 ± 30	3^-		700 ± 120	α	5, 39
16.20 ± 90	$1^-; 0$		580 ± 60	γ, p, α	3, 26, 32
16.209 ± 2	$1^+; 1$		19 ± 3	γ, n, p	26, 27, 30, 31, 32, 37, 39
16.275 ± 7	6^+		420 ± 20	α	2, 5, 7, 8, 9, 10, 17, 27, 50, 51, 57
16.352 ± 8	2^+		61 ± 8	p, α	4, 5, 26, 32, 42, 45, 46, 65
16.4423 ± 1.6	$2^+; 1$		25 ± 2	γ, n, p, α	3, 4, 5, 26, 32, 39
16.817 ± 2	$(2^-; 0+1)$		28 ± 3	γ, p, α	15, 26, 30, 32
16.844 ± 21	4^+		570 ± 60	α	5
16.93 ± 50	2^+		≈ 280	α, ^{8}Be	5, 6
17.09 ± 40	$1^-; 1$		380 ± 40	γ, p	30, 32
17.129 ± 5	2^+		107 ± 14	n, p, α	4, 5
17.140 ± 10	$1^+; 1$		34 ± 3	γ, n, p, α	5, 30, 31, 32, 39
17.197 ± 17	2^+		160 ± 60	α, ^{8}Be	2, 5, 6, 27, 34, 42, 45, 46
17.282 ± 11	$1^-; 1$		78 ± 5	γ, n, p, α	4, 30, 31, 32, 37, 39
17.510 ± 26	1^-		180 ± 60	α	5
17.555 ± 21	(6^+)		180 ± 70	n, α	4, 5
17.609 ± 7	2^+; (1)		114 ± 14	p, α	4, 5, 32
17.72	$(0^+, 2^+)$		≈ 75	p, α, ^{8}Be	5, 6

Table 16.10: Energy Levels of ^{16}O $^{\rm a}$ (continued)

(MeV ± keV)	$J^\pi; T$	K^π	$\Gamma_{\rm c.m.}$ or $\tau_{\rm m}$ (keV)	Decay	Reactions
17.775 ± 11	$4^-; 0$		45 ± 7	p	15, 39, 40, 42, 45, 46, 62, 63
17.784 ± 15	4^+		400 ± 40	n, α, ^{8}Be	4, 5, 6, 39, 50, 51
17.877 ± 6	$(1, 2)^-; 1$		24 ± 3	γ, p, (α)	30, 32, 37
18.016 ± 1	$4^+; (0)$		14 ± 2	n, p, α, ^{8}Be	4, 5, 6, 15
18.029 ± 5	$3^{(-)}; 1$		26 ± 4	γ, n, p, α	15, 30, 31, 32, 39, 62
18.089 ± 25	(0^+)		288 ± 44	(γ), n, p, α	3, 4, 5, 31, 42, 46
18.202 ± 8	2^+		220 ± 50	γ, p	32, 39, 42, 46
18.29			≈ 380	γ, p, α	3, 4, 5
18.404 ± 12	5^-		550 ± 40	α	5
18.430 ± 15	$2^+; 0$		90 ± 40	p	32, 42, 45, 46
18.484 ± 6	1^-		35 ± 6	p	32
18.6	$(1^-, 5^-)$		≈ 150	α	5
18.6	(4^+)		≈ 300	α, ^{8}Be	5, 6
18.640 ± 15	(5^+)		22 ± 7	(n, p)	2, 15, 39
18.773 ± 22	1^-		215 ± 45	p, α	4, 5
18.785 ± 6	4^+		260 ± 20	n, p, α, ^{8}Be	4, 5, 6
18.79 ± 10	$1^+; 1$		120 ± 20	γ, p	30, 32, 39
18.977 ± 6	$4^-; 1$		8.2 ± 3.8	γ, p, α	15, 30, 32, 39, 40, 42, 45, 62, 63
19.001 ± 24	$2^-; 1$		420 ± 50	γ, p	30, 32, 39
19.08 ± 30	$2^+; (1)$		≈ 120	γ, (n), p, α	4, 5, 10, 30, 32
19.206 ± 12	$3^-; 1$		68 ± 10		39, 62, 63
19.253 ± 30	(5^-)		50 ± 45	n, α	4, 5
19.257 ± 9	$2^+; (1)$		155 ± 25	γ, p, α	4, 5, 30, 32
19.319 ± 14	(6^+)		65 ± 35	p, α, ^{8}Be	4, 5, 6
19.375 ± 2	4^+		23 ± 4	p, α	4, 5
19.47 ± 30	$1^-; 1$		200 ± 70	γ, p	30, 32, 39
19.539 ± 19	$2^+; 0$		255 ± 75	n, α	2, 4, 5, 42, 46
19.754 ± 16	2^+		290 ± 50	p, α	4, 5
19.808 ± 11	$4^-; 0$		32 ± 4		15, 40, 42, 62, 63
19.895 ± 7	$3; 1$		42 ± 9	γ, p, α	2, 30, 32
20.055 ± 13	$2^+; 0$		400 ± 32	γ, n, p, α	3, 4, 5, 45, 46
20.412 ± 17	$2^-; 1$		190 ± 20	γ, n, p	30, 31, 32, 39, 62, 63
20.541 ± 2	5^-		11 ± 2	p, α	2, 4, 5
20.560 ± 2	even π		< 5	p, α	4, 5
20.615 ± 3	even π		< 10	α	5

Table 16.10: Energy Levels of ^{16}O $^{\rm a}$ (continued)

(MeV ± keV)	$J^\pi; T$	K^π	$\Gamma_{\rm c.m.}$ or $\tau_{\rm m}$ (keV)	Decay	Reactions
(20.8)			(≈ 60)	n, p, α	4
20.857 ± 14	7^-	0^-	900 ± 60	α	5, 7, 8, 9, 10
20.945 ± 20	$1^-; 1$		300 ± 10	γ, n, p	30, 31, 32, 39
21.05 ± 50	$(2^+; 0)$		298 ± 43		42, 46
21.052 ± 6	6^+		205 ± 15	α	5
21.175 ± 15					2
21.50	$(1 \rightarrow 4)$		120	p	32
21.623 ± 11	7^-		60 ± 30	n, p, α	4, 5
21.648 ± 3	6^+		115 ± 8	n, α	4, 5, 7
21.776 ± 9	3^-		43 ± 20	n, p, α	2, 4, 5
22.04	0^+		60	n, d, α	4, 21
22.150 ± 10	$1^-; 1$		680 ± 10	γ, n, p, d, α	10, 20, 22, 25, 30, 31, 32, 36, 37, 38
22.35	2^+		175	n, d, α	21, 25
22.5 ± 100	3^-		400 ± 50	p, d, α	22, 25, 46
22.65 ± 30			60	n, α, ^{8}Be	2, 4, 6
22.721 ± 3	$0^+; 2$		12.5 ± 2.5	n, p, d, α	4, 5, 19, 22, 25, 65
22.89 ± 10	$1^-; 1$		300 ± 10	γ, p, d	20, 22, 30, 32
23.0 ± 100	6^+		$\lesssim 500$	(d), α, ^{8}Be	6, 7, 25
23.1			≈ 20	(n), d, α, ^{8}Be	5, 6, 21, 25
23.235 ± 62	$(1^-; 1)$		560 ± 150	n, p, d	21, 22, 23, 31, 42
23.51 ± 30	(5^-)		300	p, d, α	2, 5, 10, 22, 23, 25, 45, 46
23.879 ± 6	6^+		26 ± 4	p, α, ^{8}Be	4, 5, 6, 7
24.07 ± 30	$1^-; 1$		550 ± 40	γ, p, ^{3}He	13, 30, 32, 42
24.36 ± 70	$(2^+, 3^-); 0$		424 ± 45	n, p	31, 46
24.522 ± 11	$2^+; 2$		< 50		19, 65
24.76 ± 50	$(2,4)^+; 1$		340 ± 60	γ, n, p	30, 31, 32
25.12 ± 50	$1^-; 1$		3000 ± 300	γ, p, ^{3}He, α	13, 30, 32, 38, 45
25.50 ± 150	$1^-; 1$		1300 ± 300	γ	39, 42
25.6	$(3^-); 1$		450	^{3}He, α	5, 13
26.0 ± 100	$1^-; (1)$		$500 - 1000$	γ, ^{3}He, α	13
26.363 ± 62	$(2,4)^+; 1$		550 ± 70	γ, n, p, α	5, 30, 31, 32
27.35 ± 100	$(2,4)^+; 1$		830 ± 110	γ, p, ^{3}He, α, ^{8}Be	13, 30, 32
27.5	$(3^-; 0)$		≈ 2500	γ, ^{3}He	13
28.2	7^-		1000	α	5, 7
28.6 ± 200				γ, ^{3}He	13

Table 16.10: Energy Levels of ^{16}O [a] (continued)

(MeV ± keV)	$J^\pi; T$	K^π	$\Gamma_{\mathrm{c.m.}}$ or τ_{m} (keV)	Decay	Reactions
29.0	7^-		1000	p, α	5, 7
29.8 ± 100	$9^- + 8^+$		500 – 1000	^{3}He, α	10, 13
31.8 ± 600				γ, α	7, 38
34	$10^+(9^-)$		2300	α	5, 7
35				α	7

[a] See also Tables 16.11 and 16.22.

[b] I am indebted to Professor H.T. Richards concerning his comments on the existence of this level.

1. (a) ^{10}B(^{6}Li, γ)^{16}O $\quad Q_{\mathrm{m}} = 30.8734$
   (b) ^{10}B(^{6}Li, p)^{15}N $\quad Q_{\mathrm{m}} = 18.7459$ $\quad E_{\mathrm{b}} = 30.8734$
   (c) ^{10}B(^{6}Li, d)^{14}N $\quad Q_{\mathrm{m}} = 10.1371$
   (d) ^{10}B(^{6}Li, t)^{13}N $\quad Q_{\mathrm{m}} = 5.8410$
   (e) ^{10}B(^{6}Li, ^{3}He)^{13}C $\quad Q_{\mathrm{m}} = 8.0800$
   (f) ^{10}B(^{6}Li, α)^{12}C $\quad Q_{\mathrm{m}} = 23.7115$
   (g) ^{10}B(^{6}Li, ^{6}Li)^{10}B

At $E(^6\mathrm{Li}) = 4.9$ MeV, the cross sections for reactions (b) to (f) leading to low-lying states in the residual nuclei are proportional to $2J_{\mathrm{f}} + 1$: this is interpreted as indicating that the reactions proceed via a statistical compound nucleus mechanism. For highly excited states, the cross section is higher than would be predicted by a $2J_{\mathrm{f}} + 1$ dependence: see (1982AJ01). See also (1983KA1J).

2. ^{10}B(^{10}B, α)^{16}O $\quad Q_{\mathrm{m}} = 26.4137$

States of ^{16}O observed at $E(^{10}\mathrm{B}) = 20$ MeV are displayed in Table 16.10 of (1977AJ02). At the higher excitation energies, states are reported at $E_{\mathrm{x}} = 17.200 \pm 0.020$, 17.825 ± 0.025, 18.531 ± 0.025, 18.69 ± 0.03, 18.90 ± 0.035, 19.55 ± 0.035, 19.91 ± 0.02, 20.538 ± 0.015, 21.175 ± 0.015, 21.84 ± 0.025, 22.65 ± 0.03 and 23.51 ± 0.03 MeV. The reaction excites known $T = 0$ states: σ_{t} follows $2J_{\mathrm{f}} + 1$ for 11 of 12 groups leading to states of known J. The angular distributions show little structure: see (1977AJ02).

3. ^{12}C(α, γ)^{16}O $\quad Q_{\mathrm{m}} = 7.16195$

Table 16.11: Radiative decays in ^{16}O [a]

E_i (MeV)	$J^\pi_\mathrm{i}; T$	E_f (MeV)	$J^\pi_\mathrm{f}; T$	Branch (%)	Γ_rad (eV)
6.05	$0^+; 0$	0	$0^+; 0$	100	3.55 ± 0.21 [b]
6.13	$3^-; 0$	0	$0^+; 0$	100	$(2.60 \pm 0.13) \times 10^{-5}$
6.92	$2^+; 0$	0	$0^+; 0$	> 99	0.097 ± 0.003 [c]
		6.05	$0^+; 0$	$(2.7 \pm 0.3) \times 10^{-2}$	$(2.7 \pm 0.3) \times 10^{-5}$
		6.13	$3^-; 0$	$\leq 8 \times 10^{-3}$	
7.12	$1^-; 0$	0	$0^+; 0$	> 99	0.055 ± 0.003 [c]
		6.05	$0^+; 0$	$< 6 \times 10^{-4}$	
		6.13	$3^-; 0$	$(7.0 \pm 1.4) \times 10^{-2}$	
8.87	$2^-; 0$	0	$0^+; 0$	7.2 ± 0.8	$(2.6 \pm 0.4) \times 10^{-4}$
		6.05	$0^+; 0$	0.122 ± 0.033	$(3.1 \pm 1.0) \times 10^{-6}$
		6.13 [f]	$3^-; 0$	77.7 ± 1.6 [i]	$(2.8 \pm 0.3) \times 10^{-3}$ [d]
		6.92	$2^+; 0$	3.6 ± 0.5 [i]	$(1.5 \pm 0.3) \times 10^{-4}$
		7.12	$1^-; 0$	11.4 ± 0.5 [i]	$(4.2 \pm 0.8) \times 10^{-4}$ [e]
9.59	$1^-; 0$	0	$0^+; 0$	≈ 100	$(2.5 \pm 0.4) \times 10^{-2}$
		6.92	$2^+; 0$		$(2.9 \pm 1.0) \times 10^{-3}$
9.84	$2^+; 0$	0	$0^+; 0$	61 ± 4	$(5.7 \pm 0.6) \times 10^{-3}$
		6.05	$0^+; 0$	18 ± 4	$(1.9 \pm 0.4) \times 10^{-3}$
		6.92	$2^+; 0$	21 ± 4	$(2.2 \pm 0.4) \times 10^{-3}$
10.36	$4^+; 0$	0	$0^+; 0$		$(5.6 \pm 2.0) \times 10^{-8}$
		6.13	$3^-; 0$		$< 1.0 \times 10^{-3}$
		6.92	$2^+; 0$	≈ 100	$(6.2 \pm 0.6) \times 10^{-2}$
10.96	$0^-; 0$ [g]	7.12	$1^-; 0$	> 99	0.08 ± 0.05
11.10	$4^+; 0$	6.13	$3^-; 0$		$(3.1 \pm 1.3) \times 10^{-3}$
		6.92	$2^+; 0$		$(2.5 \pm 0.6) \times 10^{-3}$
11.52	$2^+; 0$	0	$0^+; 0$	91.7	0.61 ± 0.02
		6.05	$0^+; 0$	4.2 ± 0.7	$(3.0 \pm 0.5) \times 10^{-2}$
		6.92	$2^+; 0$	4.0 ± 1.0	$(2.9 \pm 0.7) \times 10^{-2}$
		7.12	$1^-; 0$	≤ 0.8	
12.05	$0^+; 0$	0	$0^+; 0$		4.03 ± 0.09 [b]
12.44	$1^-; 0$	0	$0^+; 0$	≈ 100	12 ± 2
		6.05	$0^+; 0$	1.2 ± 0.4	0.12 ± 0.04

Table 16.11: Radiative decays in ^{16}O [a] (continued)

$E_{\rm i}$ (MeV)	$J^\pi_{\rm i}; T$	$E_{\rm f}$ (MeV)	$J^\pi_{\rm f}; T$	Branch (%)	$\Gamma_{\rm rad}$ (eV)
12.53	$2^-; 0$	0	$0^+; 0$		$(2.1 \pm 0.6) \times 10^{-2}$
		6.13	$3^-; 0$	60 ± 6	2.1 ± 0.2
		6.92	$2^+; 0$	< 10	< 0.34
		7.12	$1^-; 0$	15 ± 3	0.5 ± 0.1
		8.87	$2^-; 0$	25 ± 3	0.9 ± 0.1
12.80	$0^-; 1$	7.12	$1^-; 0$	≈ 100	2.5 ± 0.2
12.97	$2^-; 1$	0	$0^+; 0$		$(7.1 \pm 0.2) \times 10^{-2}$
		6.13	$3^-; 0$	63 ± 6	2.3 ± 0.2
		7.12	$1^-; 0$	12 ± 3	0.44 ± 0.10
		8.87	$2^-; 0$	25 ± 3	0.90 ± 0.10
13.09 [h]	$1^-; 1$	0	$0^+; 0$	≈ 100	32 ± 5
		6.05	$0^+; 0$	0.58 ± 0.12	
		7.12	$1^-; 0$	3.1 ± 0.8	1.4 ± 0.4

[a] See Tables 16.12 in (1971AJ02), 16.15 in (1977AJ02) and 16.12 in (1982AJ01) for the earlier work and for references. See also Table 16.12 here.

[b] Monopole matrix element in fm^2.

[c] Weighted mean of earlier measurements and of a newer one reported in reaction 38 (1985MO10).

[d] $(3.0 \pm 0.4) \times 10^{-4}$ [M1], $(2.5 \pm 0.2) \times 10^{-3}$ [E2] (1982VE04).

[e] $(8 \pm 3) \times 10^{-5}$ [M1], $(3.4 \pm 0.5) \times 10^{-4}$ [E2] (1982VE04).

[f] $E_\gamma = 2471.5 \pm 0.5$ keV for $(8.87 \rightarrow 6.13)$ transition.

[g] Pairs due to this transition are not observed.

[h] For the radiative decay of higher states see Tables 16.12, 16.18, and 16.22.

[i] (1982VE04). See also for δ.

The yield of capture γ-rays has been studied for E_α up to 42 MeV [see Table 16.11 in (1977AJ02) and (1982AJ01)] and (1982KE10; $E_{\rm c.m.} = 1.34 \rightarrow 3.38$ MeV; ^{4}He(^{12}C, γ)) and (1985KO11; $E_\alpha = 3.55$ to 3.60 MeV). Observed resonances are displayed in Table 16.12 here.

This reaction plays an important role in astrophysical processes. The E2 S(300 keV) value is calculated to 0.09 MeV · b (1984DE42), 0.07 MeV · b (1985LA10), 0.10 MeV · b (1985FU04). The E1 S(300 keV) value is 0.16 MeV · b from fitting the early data [see (1977AJ02)] and 0.28 MeV · b from the (1982KE10) data (1985LA10) [0.30 MeV · b (1984DE42)]. (1983LA24) calculate that the (α, γ_3) S-factor is too small ($\lesssim$ 0.01 MeV · b at $E_{\rm c.m.} < 1.5$ MeV) to contribute significantly to the total S-factor (I am indebted to Prof. F.C. Barker for his comments.). The ratio $\sigma_{\rm E2}/\sigma_{\rm E1}$ has been measured for $E_\alpha = 2.28$ to 3.77 MeV: the data favor a non-negligible contribution of the E2 amplitude to the reaction rate at stellar energies (1985RE09). For other astrophysical studies see (1982AJ01) and (1981BA2F, 1982BA1D, 1982TO1D, 1983LA24, 1984FO1A, 1984RO1F, 1984TR1C, 1985AR1A, 1985BA1Q, 1985TR1E, 1986TH1E).

In an attempt to determine whether ^{16}O*(9.84) is a doublet (1985KO11) have studied the (α, γ_3) reaction [as well as the (α, α_0) scattering]: in the capture work they find $E_x = 9845.4 \pm 1$ keV (based on Q_m) and, together with the (α, α_0) results find no evidence for a doublet. $J^\pi = 2^+$ (1985KO11: see Table 16.12). At higher energies the E2 cross section shows resonances at $E_x = 13.2$, 15.9, 16.5, 18.3, 20.0, and 26.5 MeV [see Table 16.12]. Some E2 strength is also observed for $E_x = 14$ to 15.5 and 20.5 to 23 MeV. In the range $E_\alpha = 7$ to 27.5 MeV the $T = 0$ E2 strength is $\approx$ 17% of the sum rule. It appears from this and other experiments that the E2 centroid is at $E_x \approx 15$ MeV, with a 15 MeV spread. Structures are observed in the yield of γ-rays from the decay to ^{16}O*(14.8 ± 0.1) for $E_x = 34 - 39$ MeV. It is suggested that these correspond to a giant quadrupole excitation with $J^\pi = 8^+$ built on the 6^+_1 state at $E_x = 14.815$ MeV: see (1982AJ01). See also (1983KA1J, 1984NA1F) and (1982DU1A, 1982KN1B, 1985CH27, 1986AD1B; theor.).

4. (a) ^{12}C(α, n)^{15}O $Q_m = -8.5019$ $E_b = 7.16195$

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

For cross section measurements from threshold to $E_\alpha = 24.7$ MeV (reaction (a)) and to 33 MeV (reaction (b)) [see (1982AJ01)] and at $E_\alpha = 10.5$ to 20 MeV (1982AM02; p$_0$): see Table 16.12. See also (1981BE19; reaction (b); $E_\alpha = 18.5$, 21.7, 25.4 MeV), (1983KOZD; excitation function, reaction (a): $E_\alpha = 21.8$ to 27.2 MeV). The excitation curve for p$_3$ (to ^{15}N*(6.32)), measured for $E_\alpha = 24$ to 33 MeV, shows a large peak at $E_x \approx 29$ MeV, $\Gamma \approx 4$ MeV. It is suggested that it is related to the GQR in ^{16}O: see (1982AJ01). For the observed resonances see Table 16.12 here. See also (1984NA1F, 1984SH04), (1982WE16; applications) and (1985MA1L; theor.).

5. ^{12}C(α, α)^{12}C $E_b = 7.16195$

The yield of α-particles corresponding to ^{12}C*(0, 4.4, 7.7) and of 4.4, 12.7 and 15.1 MeV γ-rays has been studied at many energies in the range $E_\alpha = 2.5$ to 35.5 MeV [see (1982AJ01)], at $E_\alpha = 3.52$ to 3.62 MeV (1982FR10; α_0), 8 to 26 MeV (1985DY05; α_1 γ; see for astrophysical implications), 10.5 to 19.8 MeV (1982AM02; α_0, α_1; and α_2 from 14.6 MeV), 17.0 to 22.7 MeV (1982KA30; α_2), 27 to 42 MeV (1983AR12; α_0, α_1, α_2) and at $E(^{12}\text{C}) = 5.8$ to 13.5 MeV (1982KE10; α_0). See also (1981BE2D). Observed resonances are displayed in Table 16.12. Attempts have been made to observe narrow states near ^{16}O*(8.87, 9.85). No evidence has been found for a narrow (100 eV) 0^+ state in the vicinity of the 2^- state at 8.87 MeV [see (1982AJ01)] nor for a 3^- state near the 2^+ state at 9.84 MeV (1982FR10) [if such a 3^- state were to exist $\Gamma_{\text{lab}} \lesssim 150$ eV if its E_x is a few keV higher than that of the 2^+ state].

Total cross section measurements are reported by (1982DE20, 1984BU1L, 1984GO03, 1984SA28) and spallation measurements by (1981AN1K, 1982RA31, 1984GO03, 1984GO04, 1985AB02). For pion production see (1981AL1K, 1984AL1L). For two-proton correlations at 4.2 GeV/c see (1985BA2U). See also ^{12}C in (1985AJ01), (1981BE19, 1981WA1P, 1982WA23, 1984GU1E), (1982FI1C, 1982YA1A, 1983AD1C, 1983AD1D, 1984RE14), (1983OS1G; applications) and (1981FR1T, 1981MA42, 1981SH1A, 1983BA1V, 1983SM1B, 1984NA06, 1984SH22, 1985BA11, 1985BA63, 1986ALZZ; theor.).

6. ^{12}C(α, ^{8}Be)^{8}Be $Q_{\rm m} = -7.4585$ $E_{\rm b} = 7.16195$

The yield of ^{8}Be shows a number of resonances: see Table 16.12. There is no evidence below $E_{\rm x} \approx 24$ MeV for $J^{\pi} = 8^{+}$ states although the existence of such states below this energy cannot be ruled out since it is possible that the L of the entrance channel inhibits the formation of such states. Above 26 MeV $L = 8$ becomes dominant: see (1982AJ01).

7. ^{12}C(^{6}Li, d)^{16}O $Q_{\rm m} = 5.6868$

This reaction has been studied at many energies: see (1977AJ02) and Table 16.13 here. At the higher energies the spectra are dominated by states with $J \geq 4$ and natural parity. A study of d-α coincidences [involving ^{12}C*(0, 4.43, 7.66)] has been carried out at $E(^{6}\text{Li}) = 75$ and 90 MeV: the highest lying states obsrved in ^{16}O [and which have α-cluster properties and are built on $^{12}\text{C}_{\rm g.s.}$] are 7^{-} states at $E_{\rm x} = 27.7$ and 29.3 MeV (1982AR20). Two broad intense peaks corresponding to ^{16}O*(32, 35) are also observed [they decay by α_1] and a state at ≈ 34 MeV [$J^{\pi} = 10^{+}(9^{-})$] decays by α_2 [and weakly by α_0] (1982AR20, 1983AR12). No 8^{+} states are reported: see (1982AJ01, 1983AR12).

Cross sections for the population of ^{16}O*(8.87, 10.36, 11.08, 11.097) have been studied in the range $E(^{6}\text{Li}) = 20$ to 34 MeV: the large cross section to ^{16}O*(11.10) [$J^{\pi} = 4^{+}$] is the result of multistep processes (1981GL02).

For a study of inclusive deuteron spectra see (1982CU02). See also ^{18}F in (1983AJ01, 1987AJ02) and (1981AP02, 1981IN02, 1981MA26, 1983GO18, 1983GR1H, 1983OS03, 1984SE20, 1985EL12, 1985SE1H; theor.).

8. ^{12}C(^{7}Li, t)^{16}O $Q_{\rm m} = 4.695$

This reaction has been studied extensively: see (1977AJ02, 1982AJ01) and Table 16.13 here. See also ^{19}F in (1983AJ01, 1987AJ02), (1986JAZZ) and (1983PA06, 1985SH22; theor.).

Table 16.12: Resonances in ^{12}C + α

No.	E_α (MeV ± keV)	$\Gamma_{\mathrm{c.m.}}$ (keV)	Outgoing particles $^{\mathrm{a}}$ (x)	Γ_{x}	Γ_{α_0}/Γ	^{16}O* (MeV ± keV)	$J^\pi; T$	Refs. $^{\mathrm{b}}$
						8.87		
1	3.324	480 ± 20	γ_0	25 ± 4 meV		9.580 ± 12	1^-	(1982KE10)
			γ_3	2.9 ± 1.0 meV				
			α_0		≈ 1			
2	3.5770 ± 0.5	0.625 ± 0.100	γ_0	5.7 ± 0.6 meV		9.8440 ± 0.5 $^{\mathrm{c}}$	2^+	(1982KE10,
								1985KO11)
			γ_3	2.2 ± 0.4 meV				
			α_3					
3	4.259	27 ± 3	γ_0	$\leq$ 0.4 meV		10.356 ± 6	4^+	(1982KE10)
			γ_3	62 ± 6 meV				
			α_0		1			
4	5.245 ± 8	0.28 ± 0.05	γ_2	3.1 ± 1.3 meV		11.094	4^+	
			γ_3	2.5 ± 0.6 meV				
			α_0					
5	5.47	2500	α_0			(11.26)	(0^+)	
6	5.809 ± 18	73 ± 5	γ_0	0.65 ± 0.08 eV		11.52	2^+	
			γ_3	29 ± 7 meV				
			α_0		1			
7	5.92 ± 20	800 ± 100	α_0		1	11.60	3^-	
8	6.518 ± 10	1.5 ± 0.5	α_0			12.049	0^+	
9	7.043 ± 4	99 ± 7	γ_0	9.5 ± 1.7 eV $^{\mathrm{d}}$		12.442 ± 4	$1^-; 0$	
			γ_1	0.12 ± 0.06 eV $^{\mathrm{d}}$				
			p	1.1 keV				
			α_0	92 ± 8 keV	1.0			
			α_1	0.025 keV				
10	7.82 ± 10	150 ± 11	γ_0	$^{\mathrm{e}}$		13.02	2^+	
			α_0	150 ± 11 keV	≈ 1.0			
11	7.904 ± 11	130 ± 5	γ_0	44 ± 8 eV $^{\mathrm{f}}$		13.088 ± 11	$1^-; 1$	

Table 16.12: Resonances in ^{12}C + α (continued)

No.	E_α (MeV ± keV)	$\Gamma_{\mathrm{c.m.}}$ (keV)	Outgoing particles [a] (x)	Γ_{x}	Γ_{α_0}/Γ	^{16}O* (MeV ± keV)	$J^\pi; T$	Refs. [b]
			γ_4	1.35 ± 0.4 eV				
			p	100 keV				
			α_0	45 ± 18 keV	0.3			
			α_1	1 keV				
12	7.960 ± 10	110 ± 30	γ_0	> 0.01 eV		13.129	$3^-; 0$	
			p	1 keV				
			α_0	90 ± 14 keV	0.7			
			α_1	≈ 20 keV				
13	8.130 ± 15	26 ± 7	γ			13.257	$3^-; 1$	
			p	4.5 keV				
			α_0	9 ± 4 keV				
			α_1	7.5 keV				
			$\gamma_{4.4}$					
14	8.960 ± 10	75 ± 7	α_0	49 keV	0.65 ± 0.05	13.879 ± 8	4^+	
			α_1	23 keV				
15	9.1	4800	α_0			(14.0)	(0^+)	
16	9.164 ± 15	200 ± 50	α_0	≈ 200 keV	> 0.9	14.032	0^+	
17	9.3 ± 100	750 ± 200	α_0		0.2 ± 0.1	14.1	3^-	
			α_1					
18	9.948	487 ± 12	α_0		0.8 [h]	14.620 ± 11 [g]	(4^+)	(1982AM02)
			α_1					
19	10.002	672 ± 11	α_0		0.94	14.660 ± 11 [g]	5^-	(1982AM02)
			α_1					
20	10.195 ± 7	70 ± 8	α_0	22 keV	0.45 ± 0.05	14.805	6^+	
			α_1	48 keV				
21	10.544	166 ± 30	α_0, α_1, p_0		0.35	15.066 ± 11	0^+	(1982AM02)
22	10.999	133 ± 7	α_0, α_1, p_0		0.58	15.408 ± 2	3^-	(1982AM02)

Table 16.12: Resonances in $^{12}\mathrm{C} + \alpha$ (continued)

No.	E_α (MeV ± keV)	$\Gamma_{\mathrm{c.m.}}$ (keV)	Outgoing particles [a] (x)	Γ_x	Γ_{α_0}/Γ	^{16}O* (MeV ± keV)	$J^\pi; T$	Refs. [b]
23	11.560	703 ± 113	α_0, (α_1), $\gamma_{4.4}$		0.21	15.828 ± 30	3^-	(1982AM02)
24	11.6	≈ 600	γ_0	$\Gamma_\alpha\Gamma_\gamma/\Gamma \approx 0.4$ eV		15.9	2^+	
25	12.156	422 ± 14	α_0		0.93	16.275 ± 7	6^+	(1982AM02)
26	12.272	65 ± 45	α_0, (α_1, α_2), p_0		0.07	16.362 ± 20	(0^+, 1^-)	(1982AM02)
27	12.380	22 ± 3	γ_0, n, p_0, α_0, α_1, α_2,$\gamma_{4.4}$	$\Gamma_\alpha\Gamma_\gamma/\Gamma = 0.45$ eV	0.28	16.443 ± 2	2^+; (1)	(1982AM02)
28	12.5	730	p_0, α_0			(16.5)		
29	12.915	567 ± 60	α_0		0.28	16.844 ± 21	4^+	(1982AM02)
30	13.0	700	α_0			(16.9)	5^-	
31	13.05	≈ 280	α_2, ^{8}Be			16.94	2^+	(1982AM02)
32	13.296	107 ± 14	n, p_0, α_0, α_1, $\gamma_{4.4}$		0.37	17.129 ± 5	2^+	(1982AM02)
33	13.32	36 ± 5	α_0, α_1			17.15		(1982AM02)
34	13.35	160 ± 60	α_2, ^{8}Be			17.17	2^+	(1982AM02)
35	13.50	< 100	n			17.28		
36	13.805	182 ± 56	α_0, (α_1), α_2		0.16	17.510 ± 26	1^-	(1982AM02)
37	13.865	178 ± 66	n, (α_0, α_1)		0.07	17.555 ± 21	(6^+)	(1982AM02)
38	13.948	175 ± 55	p_0, α_0		0.32	17.618 ± 20	(0^+, 1^-)	(1982AM02)
39	14.08	(≈ 75)	(p_0), ^{8}Be			17.72	(0^+, 2^+)	(1982AM02)
40	14.170	396 ± 41	n, α_0, α_1, $\gamma_{4.4}$, ^{8}Be		0.34	17.784 ± 15	4^+	(1982AM02)
41	14.480	14 ± 2	(n), p_0, α_0, α_1, $\gamma_{4.4}$, ^{8}Be		0.36	18.016 ± 1	4^+; (0)	(1982AM02)
42	14.577	248 ± 90	(γ_0), n_0, p_0, α_0		0.31	18.089 ± 25	(0^+)	(1982AM02)
43	(14.62)	(≈ 45)	α_0			(18.12)	($\neq 4^+$)	(1982AM02)
44	14.85	≈ 380	γ_0, p_0, (α_1, $\gamma_{4.4}$)	$\Gamma_\alpha\Gamma_\gamma/\Gamma = 0.95$ eV		18.29		(1982AM02)
45	14.997	544 ± 39	α_0		0.40	18.404 ± 12	5^-	(1982AM02)
46	15.2	≈ 150	(α_0, α_1, α_2, $\gamma_{4.4}$)			18.6	(1^-, 5^-)	(1982AM02)
47	15.2	≈ 300	α_2, ^{8}Be			18.6	(4^+)	(1982AM02)
48	15.490	215 ± 45	p_0, α_0		0.26	18.773 ± 22	1^-	(1982AM02)
49	15.506	260 ± 16	n, p_0, α_0, (α_1), ^{8}Be		0.48	18.785 ± 6	4^+	(1982AM02)

Table 16.12: Resonances in ^{12}C + α (continued)

No.	E_α (MeV ± keV)	$\Gamma_{\rm c.m.}$ (keV)	Outgoing particles [a] (x)	$\Gamma_{\rm x}$	Γ_{α_0}/Γ	^{16}O* (MeV ± keV)	$J^\pi; T$	Refs. [b]
50	15.8	≈ 550	(α_0), α_1, $\gamma_{4.4}$			19.0	(5^-)	(1982AM02)
51	15.96	41	(n), α_0			(19.12)	$(2^+, 4^+)$	
52	16.130	50 ± 45	(n), (α_0)		0.04	19.253 ± 30	(5^-)	(1982AM02)
53	16.137	155 ± 23	p_0, α_0, (α_1)		0.34	19.257 ± 9	2^+	(1982AM02)
54	16.219	63 ± 33	p_0, (α_0), α_1, α_2, ^{8}Be		0.07	19.319 ± 14	(6^+)	(1982AM02)
55	16.293	23 ± 4	p_0, α_0, α_1, α_2		0.23	19.375 ± 2	4^+	(1982AM02)
56	16.496	255 ± 75	(n), α_0, (α_1, α_2)		0.20	19.527 ± 26	2^+	(1982AM02)
57	16.799	286 ± 44	p_0, α_0, α_1		0.29	19.754 ± 16	2^+	(1982AM02)
58	(16.92)	(≈ 175)	α_2			(19.85)		(1982AM02)
59	(17.05)	(≈ 30)	(α_0)			(19.94)	$(\neq 3^-)$	(1982AM02)
60	17.201	432 ± 40	γ_0, n, (p_0), α_0, (α_1)		0.43	20.055 ± 13	2^+	(1982AM02)
61	(17.27)	(≈ 45)	(α_0)			(20.11)	$(\neq 3^-)$	(1982AM02)
62	17.5	≈ 1500	p_0			(20.3)		
63	(17.66)	(≈ 150)	n, (p_0), α_0, α_2			(20.40)	(4^+)	(1982AM02)
64	(17.8)	(≈ 300)	(α_0), α_1			(20.5)		(1982AM02)
65	17.849	11 ± 2	p_0, α_0, α_1, α_2		0.14 ± 0.02	20.541 ± 2	5^-	(1982AM02)
66	17.875	< 5	α_0			20.560 ± 2	even	(1982AM02)
67	17.948	< 10	α_0			20.615 ± 3	even	(1982AM02)
68	(18.2)	(≈ 60)	n, (p_0)			(20.8)		(1982AM02)
69	18.271	904 ± 55	α_0		0.60	20.857 ± 14	7^-	(1982AM02)
70	(18.3)		α_0			(20.9)	2^+	(1982AM02)
71	(18.48)	(≈ 50)	n, p_0, (α_0)			(21.01)		(1982AM02)
72	18.50 ± 25	240 ± 80	γ_0, (α_0, α_1)		0.20	21.03	(1^-)	(1982AM02)
73	18.5	900	α_0		[i]	(21.0)	5^-	(1982KA30)
74	18.531	205 ± 14	α_0		0.50	21.052 ± 6	6^+	(1982AM02)
75	18.593	306 ± 46	(α_0)		0.20	(21.098)	4^+	(1982AM02)
76	19.294	61 ± 32	(n), p_0, α_0, α_2		< 0.05	21.623 ± 11	7^-	(1982AM02)

Table 16.12: Resonances in ^{12}C + α (continued)

No.	E_α (MeV ± keV)	$\Gamma_{\text{c.m.}}$ (keV)	Outgoing particles [a] (x)	Γ_x	Γ_{α_0}/Γ	^{16}O* (MeV ± keV)	$J^\pi; T$	Refs. [b]
77	19.327 [j]	115 ± 8	n, α_0, α_1, α_2		0.41	21.648 ± 3	6^+	(1982AM02)
78	19.498 [j]	43 ± 20	n, p_0, α_0, α_1, α_2		0.07	21.776 ± 9	3^-	(1982AM02)
79	19.85	60	n			22.04		
80	19.89	340	n			22.07		
81	19.95	< 150	n, ^{8}Be			22.11		
82	20.49	375	n			22.52		
83	20.71	60	n, ^{8}Be			22.68		
84	20.760 ± 5	12.5 ± 2.5	n_0, p_0, α_0, α_2			22.721	$0^+; T = 2$	
85	21.28	≈ 20	α_0, α_1, ^{8}Be			23.11		
86	21.3	≤ 500	^{8}Be			23.1	6^+	
87	21.67	< 40	n, α_0, α_2		≈ 0.31	23.40	(5^-)	(1982KA30)
88	21.85	300	α_0, α_1			23.54		
89	22.0	1500	$\gamma_{12.71}$			23.6		
90	22.14	120	n			23.75		
91	22.306 ± 6	26 ± 4	p_0, α_0, α_1, α_2, ^{8}Be	[k]	0.06 ± 0.02	23.879	6^+	
92	22.37	165	n			23.93		
93 [m]	22.75	≤ 500	^{8}Be			24.21		
94	23.2	750	$\gamma_{12.71}$, $\gamma_{15.11}$			24.5	$T = 1$	
95	24.1	450	$\gamma_{15.11}$			25.2	$T = 1$	
96	24.6	450	$\gamma_{15.11}$			25.6	$T = 1$	
97	25.5	450	$\gamma_{15.11}$			26.3	$T = 1$	
98	25.6	1200	α_0, $\gamma_{12.71}$	$\Gamma_\alpha \Gamma_\gamma / \Gamma = 1.2$ eV		26.3	2^+	
99	28.1	1000	α_0		0.35	28.2	7^-	(1983AR12)
100	29.1	1000	α_0, α_1, p_3		0.35	29.0	7^-	(1983AR12)
101	35.8 [n]	2.3 MeV	α_0, α_2		0.1 [l]	34.0	$10^+(9^-)$	(1983AR12)

[a] p_0 corresponds to ^{15}N(0). α_0, α_1 correspond to ^{12}C*(0, 4.4) and $\gamma_{4.4}$ corresponds to the γ-ray from the decay of ^{12}C*(4.4); γ_0, γ_1, γ_2, γ_3, γ_4 correspond to the transitions to ^{16}O*(0, 6.05, 6.13, 6.92, 7.12).

[b] Previous references are listed in Tables 16.11 (1971AJ02), 16.12 (1977AJ02) and 16.13 (1982AJ01).

[c] (1982KE10) report $E_{\rm x} = 9848 \pm 2$ keV.

[d] Branching ratios to ^{16}O*(0, 6.05) $= 98.8$% and 1.2%.

[e] $\Gamma_{\gamma_0} = 0.7 \pm 0.2$ eV, based on $\Gamma_{\alpha_0}/\Gamma = 1.0$ and $\Gamma_{\rm c.m.} = 190 \pm 40$ keV.

[f] $\Gamma_{\alpha_0}\Gamma_{\gamma_0}/\Gamma^2 = (1.49 \pm 0.17) \times 10^{-4}$.

[g] Uncertainties in $E_{\rm x}$ may be larger.

[h] For this and the states below Γ_α/Γ is ± 0.10 for isolated narrow levels.

[i] $\Gamma_{\alpha_2}/\Gamma \approx 0.16$ (1982KA30).

[j] A resonance is reported at $E_\alpha = 19.4$ MeV: 4^+ is dominant, $\Gamma_\alpha/\Gamma \ll 1$, $\Gamma_{\alpha_2}/\Gamma \geq 0.48$ (1982KA30).

[k] $\Gamma_{^8{\rm Be}}$ and Γ_{α_0} and $\Gamma_{\alpha_2} \approx 3.5$, 1.5 ± 0.5 and ≈ 6 keV, respectively.

[l] $\Gamma_{\alpha_2}/\Gamma = 0.2$ (1983AR12).

[m] Broad maxima are reported in the activation cross section at $E_\alpha = 22.8$, 24.3, 25.3 and 26.9 MeV (1983KOZD; prelim.).

[n] See (1981SA07) for $(\alpha,\gamma_{14.8})$ measurements which indicate an 8^+ GQR built on the 6^+_1 state ^{16}O*(14.82).

Table 16.13: States of ^{16}O from ^{12}C(^{6}Li, d) and ^{12}C(^{7}Li, t)

E_x [a] (MeV ± keV)	$\Gamma_{\mathrm{c.m.}}$ [b] (keV)	$\theta^2_\alpha/\theta^2_\alpha(2^+)$ [c]	Γ_{α_0}/Γ	J^π; K^π
0		0.93, 0.18		0^+
6.05		0.38, 1.10		$0^+; 0^+$
6.13		0.23, 0.22		3^-
6.92		$\equiv 1.0$		$2^+; 0^+$
7.12		0.53, 0.39		1^-
8.87	< 20			2^-
9.63 ± 30 [d]	400 ± 10	0.30, 0.60		$1^-; 0^-$
9.84	< 20	$\leq 0.05, \leq 0.01$		2^+
10.346 ± 6 [e]	35 ± 5	0.25, 0.47	0.86 ± 0.09	$4^+; 0^+$
10.96				0^-
11.10 [e]	< 30	$\leq 0.06, \leq 0.03$	0.31 ± 0.03 $(J = 4^+)$	$3^+ + 4^+$
11.59 ± 20	700 ± 100	≈ 0.4		$3^-; 0^-$
13.09	≈ 230			1^-
14.363 ± 15	< 120			> 5, $\pi =$ nat.
14.66 ± 20	500 ± 50		1.03 ± 0.1	$5^-; 0^-$
14.82	45 ± 10			(6^+)
16.30 ± 20	300 ± 50		1.07 ± 0.11	$6^+; 0^+$
17.65 ± 50	100 ± 50			
17.85 ± 50	≈ 200			
(18.6) [f]				(5^-)
19.30 ± 50	≈ 200			
20.8 ± 100 [e]	500 ± 100		1.16 ± 0.23	$7^-; 0^-$
21.6 ± 100	≤ 100		0.67 ± 0.14	6^+
23.0 ± 100	≈ 200			(6^+)
23.8 ± 100	1980 ± 250			(6^+)
26.9 ± 100	1700 ± 250			(7^-)
27.7 [f]				(7^-)
(29.3) [f]				(7^-)
32 [g]	broad			

Table 16.13: States of ^{16}O from ^{12}C(^{6}Li, d) and ^{12}C(^{7}Li, t) (continued)

$E_{\rm x}$ [a] (MeV ± keV)	$\Gamma_{\rm c.m.}$ [b] (keV)	$\theta^2_\alpha/\theta^2_\alpha(2^+)$ [c]	$\Gamma_{\alpha 0}/\Gamma$	J^π; K^π
34 [h]				$10^+(9^-)$
35 [g]	broad			

[a] $E_{\rm x}$ quoted without errors are from Table 16.10. For the earlier references see Table 16.14 in (1982AJ01). Angular distributions are reported in both reactions for the first nine states.

[b] Line widths, not corrected for α-penetrabilities.

[c] Ratio of dimensionless reduced α-width calculated at a channel radius of 5.4 fm, relative to that for ^{16}O*(6.92). (N, L) here are taken to be (2, 0) and (4, 1) respectively, for ^{16}O*(0, 7.12). The first number listed is the value reported at E(^{6}Li)$= 42$ MeV, the second at E(^{6}Li)$= 90.2$ MeV.

[d] On the basis of studies of the ^{12}C(^{6}Li, d), ^{12}C(^{7}Li, t), ^{12}C(^{10}B, ^{6}Li) and ^{19}F(p, α) reactions, the energy of ^{16}O*(9.6) is 9619 ± 15 keV with $\Gamma = 400 \pm 10$ keV (line width). $\Gamma_{\rm R} = 430 \pm 10$ keV as inferred from the best fit B-W line shape. This value is corrected for penetrability ((1981OV02) and F. Becchetti, private communication).

[e] Angular distributions are reported at E(^{6}Li) $= 35.5 - 35.6$ MeV to ^{16}O*(10.36) and to the unresolved 3^+ and 4^+ states at 11.1 MeV. It appears that the 4^+ state is dominantly populated, and that two-step processes may be important in this reaction.

[f] (1982AR20); decay primarily by α_0.

[g] (1982AR20); decay primarily by α_1.

[h] (1982AR20, 1983AR12); decays primarily by α_2.

9. ^{12}C(^{10}B, ^{6}Li)^{16}O $\qquad Q_{\rm m} = 2.7022$

At E(^{10}B) $= 18$ and 45 MeV angular distributions have been studied involving ^{16}O*(0, 6.1, 7.1, 8.9, 9.9, 10.4). At E(^{10}B) $= 68$ MeV angular distributions to ^{16}O*(0, 6.1, 6.9, 10.4, 11.1, 14.7, 16.2, 20.9) are forward peaked and fairly structureless. ^{16}O*(0, 6.9, 11.1) are weakly excited: see (1982AJ01).

10. ^{12}C(^{12}C, ^{8}Be)^{16}O $\qquad Q_{\rm m} = -0.2047$

Angular distributions have been reported at E(^{12}C) to 63 MeV [see (1977AJ02)] and at 4.9 to 10.5 MeV (1984HU1E) and at 11.2 to 12.6 MeV (1982TA21; g.s.). Angular correlations at E(^{12}C) $= 78$ MeV confirm $J^\pi = 4^+$, 5^-, 6^+ and 7^- for ^{16}O*(10.36, 14.59, 16.3, 20.9). $\Gamma_{\alpha_0}/\Gamma = 0.90 \pm 0.10$, 0.75 ± 0.15 and 0.90 ± 0.10, respectively, for the first three of these states. In addition a state is reported at $E_{\rm x} = 22.5 \pm 0.5$ MeV which may be the 8^+ member of the $K^\pi = 0^+$, 4p-4h rotational band (1979SA29). For further work at $E(^{12}{\rm C}) = 90$, 110 and 140 MeV see (1986SH10). At $E_\alpha = 120$ MeV α_0 decays of ^{16}O*(16.3, 20.9) [$J^\pi = 6^+, 7^-$] and α_1 decays of ^{16}O*(19.1, 22.1, 23.5) are observed as is a broad structure in both channels corresponding to ^{16}O*(30.0) with $J^\pi = 9^- + 8^+$. There is no evidence for localized $L = 8$ α_0 strength below 29 MeV (1985RA12). See also (1983SH1Z, 1985KA1J). For the decay of ^{20}Ne states see (1985LAZZ) and (1983AJ01, 1987AJ02). For excitation functions see (1982SA27 [yield of 6.1 MeV γ-ray from threshold to 40 MeV], 1982TA21) and (1982AJ01). See also (1984SP1C), (1979GO1C, 1984CU1B), (1986SZ02; applied), (1984HU1E; astrophys.) and (1982SU1B, 1982SU06, 1983DEZW, 1984DA1B; theor.).

11. (a) ^{12}C(^{14}N, ^{10}B)^{16}O $\quad Q_{\rm m} = -4.4503$
(b) ^{12}C(^{17}O, ^{13}C)^{16}O $\quad Q_{\rm m} = 0.8027$

Angular distributions are reported at $E(^{14}{\rm N}) = 53$ MeV involving ^{16}O*(0, 6.05, 6.13, 6.92) and various states of ^{10}B, and at 78.8 MeV involving $^{16}{\rm O}_{\rm g.s.}$: see (1982AJ01). Angular distributions have been measured for the g.s. in reaction (b) for $E(^{17}{\rm O}) = 40$ to 70 MeV (1986FR04).

12. ^{12}C(^{20}Ne, ^{16}O)^{16}O $\quad Q_{\rm m} = 2.428$

Angular distributions have been measured to $E(^{20}{\rm Ne}) = 147$ MeV: see (1977AJ02). For yield measurements see (1983RI13). See also (1982AJ01).

13. (a) ^{13}C(^{3}He, γ)^{16}O $\quad Q_{\rm m} = 22.79338$
(b) ^{13}C(^{3}He, n)^{15}O $\quad Q_{\rm m} = 7.1295$ $\quad E_{\rm b} = 22.79338$
(c) ^{13}C(^{3}He, p)^{15}N $\quad Q_{\rm m} = 10.6658$
(d) ^{13}C(^{3}He, d)^{14}N $\quad Q_{\rm m} = 2.5071$
(e) ^{13}C(^{3}He, ^{3}He)^{13}C
(f) ^{13}C(^{3}He, α)^{12}C $\quad Q_{\rm m} = 15.6314$
(g) ^{13}C(^{3}He, ^{8}Be)^{8}Be $\quad Q_{\rm m} = 8.1729$

The yield of capture γ-rays (reaction (a)) has been studied for $E(^3{\rm He})$ up to 16 MeV [see (1977AJ02)], as have angular distributions. Observed resonances are displayed in Table 16.14. It is suggested that the structures at $E_{\rm x} \approx 26 - 29$ MeV are part of giant resonances built on the first few excited states of ^{16}O (1979VE02). See also (1985CH27, 1986AD1B; theor.).

The excitation functions (reaction (b)) to $E(^3{\rm He}) = 11$ MeV are marked at low energies by complex structures and possibly by two resonances at $E(^3{\rm He}) = 1.55$ and 2.0 MeV: see Table

Table 16.14: Resonances in ^{13}C + ^{3}He [a]

E(^{3}He) (MeV ± keV)	$\Gamma_{\rm c.m.}$ (keV)	Outgoing particles	^{16}O* (MeV)	$J^\pi; T$
1.55	≈ 80	n_0, n_3	24.05	
1.55 ± 100	450	γ_0	24.1	
2.0	≈ 250	n_0	24.4	
2.6 ± 100		$\alpha\gamma_{15.1}$	24.9	$(T = 1)$
2.87 ± 50	600	γ_0	25.12	1^-
≈ 3.1		α_0, α_2	≈ 25.3	
≈ 3.5	≈ 300	α_0	≈ 25.6	(3^-)
≈ 4	≈ 300	α_0, α_1, α_2	≈ 26	(3^-)
4.0 ± 100	[b]	γ_0, γ_{1+2}, $\alpha\gamma_{15.1}$	26.0	1^-; (1)
4.6 ± 100 [c]	720 ± 160	γ_2, p_0	26.5	2^+, 4^+
5.2 ± 100	[b]	$\alpha\gamma_{15.1}$	27.0	$(T = 1)$
5.6 ± 100	≈ 600	γ_0, γ_{1+2}, $\alpha\gamma_{15.1}$, ^{8}Be	27.3	(1^-)
≈ 5.8	≈ 2500	γ_{3+4}	27.5	
6.0 ± 100	≈ 500	p_0, p_{1+2}, ^{3}He, α_1, α_2	27.7	$(3^-; 0)$
≈ 6		γ_0	28	
6.5 ± 100	[b]	$\alpha\gamma_{15.1}$	28.1	$(T = 1)$
6.8 ± 100		α_0, α_1, α_2	28.3	$(T = 0)$
7.1 ± 200		γ_{1+2}	28.6	
7.5 ± 100	[b]	$\alpha\gamma_{15.1}$	28.9	$(T = 1)$
8.6 ± 100	[b]	$\alpha\gamma_{15.1}$	29.8	$(T = 1)$
9.4 ± 100	[b]	$\alpha\gamma_{15.1}$	30.4	$(T = 1)$
10.1 ± 100	[b]	$\alpha\gamma_{15.1}$	31.0	$(T = 1)$

[a] For references see Tables 16.15 in (1971AJ02), 16.13 in (1977AJ02) and 16.15 in (1982AJ01).

[b] Lab widths $0.5 - 1$ MeV.

[c] Based on $\Gamma_{\rm c.m.} = 530 \pm 80$ keV [from ^{15}N(p, γ), see Table 16.17], $\Gamma_{p_0} = 150 \pm 45$ keV [$J^\pi = 2^+$], 110 ± 35 keV [4^+]; $\Gamma_{p_0}/\Gamma = 0.29 \pm 0.10$ [2^+], 0.21 ± 0.07 [4^+], $\Gamma_{\gamma_2} = 740 \pm 240$ eV [2^+], 410 ± 140 eV [4^+].

16.14. See also (1977AJ02) for polarization measurements. Excitation functions (reaction (c)) for $E(^3\text{He}) = 3.6$ to 6.6 MeV have been measured for p_0, p_{1+2}, p_3: a resonance is reported at $E(^3\text{He}) = 4.6$ MeV. A resonance at 6 MeV has also been observed: see Table 16.14. A comparison of polarization measured in this reaction and of analyzing power measured in ^{15}N(p, ^{3}He) is presented by (1986PO1M). See also (1986SI1K). Analyzing powers have been measured at $E(^3\overrightarrow{\text{He}}) = 33$ MeV for the elastic scattering (reaction (d)) and the deuteron groups to ^{14}N*(0, 2.31, 3.95, 9.51) (1986DR03).

Yields of α_0, α_1, α_2, and γ-rays from the decay of ^{12}C*(12.71, 15.11) (reaction (f)) have been studied up to $E(^3\text{He}) = 12$ MeV. Observed resonances are displayed in Table 16.14. Those seen in the yield of $\gamma_{15.1}$ are assumed to correspond to ^{16}O states which have primarily a $T = 1$ character. Analyzing power measurements are reported at $E(^3\overrightarrow{\text{He}}) = 33$ MeV to ^{12}C*(4.4) (1981KA1K). Excitation functions for α_0 and α_1 are also reported for $E(^3\text{He}) = 16$ to 23 MeV (1982GU12). The excitation function for ^{8}Be(g.s.) (reaction (g)) has been studied for $E(^3\text{He}) = 2$ to 6 MeV. It shows a strong resonance at $E(^3\text{He}) = 5.6$ MeV corresponding to a state in ^{16}O at $E_\text{x} = 27.3$ MeV. J^π appears to be 2^+ from angular distribution measurements. See also (1982AJ01) and (1985AB1K; search for anomalous deuterons at 10.8 GeV/c).

14. ^{13}C(α, n)^{16}O $\qquad Q_\text{m} = 2.2156$

Angular distributions for the n_0 group have been measured for $E_\alpha = 12.8$ to 22.5 MeV: see (1971AJ02). The energy of the γ-ray from the decay of ^{16}O*(6.13) is 6129.266 ± 0.054 keV (1982AL19) [based on the ^{198}Au standard $E_\gamma = 411804.4 \pm 1.1$ eV]. See also (1982AJ01), (1982CRZY), (1982SA1M, 1985MA65; applications) and (1981CH1K, 1982IB1A, 1983CO1K, 1983IB1A, 1985AR1A, 1985MA1A, 1986DO1L; astrophys.).

15. ^{13}C(^{6}Li, t)^{16}O $\qquad Q_\text{m} = 6.9977$

See Table 16.15. See also (1982AJ01) and ^{19}F in (1983AJ01).

16. ^{13}C(^{9}Be, ^{6}He)^{16}O $\qquad Q_\text{m} = 1.617$

See (1981BR1H; theor.).

17. ^{13}C(^{12}C, ^{9}Be)^{16}O $\qquad Q_\text{m} = -3.4856$

At $E(^{13}\text{C}) = 105$ MeV, ^{16}O*(6.05, 6.13, 10.35, 16.3, 20.7) are strongly populated: see (1982AJ01). See also (1977AJ02) and (1985OS06; theor.).

Table 16.15: States of ^{16}O from ^{13}C(^{6}Li, t)^{16}O

E_x [a] (MeV ± keV)	$\Gamma_{\rm c.m.}$ (keV) [c]	Comments [d]
0 [b]		
6.13 [b]		
7.0 [u,b]		
8.87 [b,c]		c.n.
9.84 [b,c]		c.n.
10.36 [b,c]		c.n.
11.10 [u,b,c]		4^+ probably dominates; m.s.
11.52 [c]		
12.05 [c]		consistent with $L = 1 \rightarrow 0^+$
12.53 [c]		consistent with $L = 2 \rightarrow 2^-$
12.97 [c]		consistent with $L = 2 \rightarrow 2^-$
13.10 [u,c]		$L = 2$, but which state is involved?
14.3 [c]		$L = 4 \rightarrow 4^{(-)}$
14.40 [c]		anomalous shape
14.82 [c]		$L = 5$; probably $J^\pi = 6^+$
15.79 [c]		consistent with $L = 3 \rightarrow 3^+$
16.812 ± 15 [c]	28 ± 7	consistent with $L = 3 \rightarrow 3^+$
17.764 ± 15 [c,e]	45 ± 7	$L = 4$ or $L = 5$
18.032 ± 15 [u,c,f]	40 ± 7	$L = 3$; both states are probably populated
18.640 ± 15 [c]	22 ± 7	$L = 4$ or 5; probably 5^+
18.976 ± 15 [c]	25 ± 7	probably 4^-
19.814 ± 15 [c]	23 ± 7	
20.5 [u]		very strongly excited

u = unresolved.

c.n. = formation appears to be by a compound nuclear process.

m.s. = multistep process.

[a] E_x without uncertainties are from Table 16.10.

[b] Angular distributions have been reported at $E(^6\text{Li}) = 25$ MeV to the first seven groups shown here (1982AB02) and at 28 MeV (1980CU03): see also (1982AJ01).

[c] Angular distribution at $E(^6\text{Li}) = 34$ MeV (1983KE06).

[d] For abbreviations see above. When an L is shown, stripping patterns are evident (1983KE06).

[e] There is some evidence for a state at $E_x = 17.90$ MeV (1983KE06).

[f] There is some evidence for a state at $E_x = 18.46$ MeV with $\Gamma \approx 60$ keV (1983KE06).

18. ^{13}C(^{17}O, ^{14}C)^{16}O $Q_{\rm m} = 4.0328$

See (1982AJ01) and (1984AB1A; theor.).

19. ^{14}C(^{3}He, n)^{16}O $Q_{\rm m} = 14.6169$

At $E(^{3}{\rm He}) = 11$ to 16 MeV, neutron groups are observed to $T = 2$ states at $E_{\rm x} = 22.717 \pm 0.008$ and 24.522 ± 0.011 MeV ($\Gamma < 30$ keV and < 50 keV, respectively). These two states are presumably the first two $T = 2$ states in ^{16}O, the analog states to ^{16}C*(0, 1.75). J^{π} for ^{16}O*(24.52) is found to be 2^{+} from angular distribution measurements (1970AD01). At $E(^{3}{\rm He}) = 25.4$ MeV forward angle differential cross sections have been determined to the 0^{+} states ^{16}O*(0, 6.05, 12.05) (1981CE05).

20. ^{14}N(d, γ)^{16}O $Q_{\rm m} = 20.7363$

The γ_0 yield has been studied for $E_{\rm d} = 0.5$ to 5.5 MeV. Observed resonances are displayed in Table 16.16. (1982GOZY, 1983GOZU; prelim.) have measured the radiative capture in the region of the GDR [$E_{\vec{\rm d}} = 1.5$ to 4.8 MeV]. See also (1983KA1J) and (1985CH27, 1986AD1B; theor.).

21. ^{14}N(d, n)^{15}O $Q_{\rm m} = 5.0724$ $E_{\rm b} = 20.7363$

For $E_{\rm d} = 0.66$ to 5.62 MeV, there is a great deal of resonance structure in the excitation curves with the anomalies appearing at different energies at different angles: the more prominent structures in the yield curves are displayed in Table 16.16. For polarization measurements see (1977AJ02) and (1981LI23) in ^{15}O (1986AJ01).

22. ^{14}N(d, p)^{15}N $Q_{\rm m} = 8.6087$ $E_{\rm b} = 20.7363$

The yield of various proton groups for $E_{\rm d} < 5.0$ MeV shows some fluctuations and two resonances: see Table 16.16 and (1982AJ01). For polarization measurements see (1982AJ01) and (1981US02). See also (1983DA31; applications) and (1984CH1Q; theor.).

23. ^{14}N(d, d)^{14}N $E_{\rm b} = 20.7363$

Table 16.16: Structure in $^{14}\mathrm{N} + \mathrm{d}$ [a]

E_{d} (MeV)	Resonant channel	$\Gamma_{\mathrm{c.m.}}$ (keV)	$J^\pi; T$	E_{x} (MeV)
1.4	n_0, α_0	300 [e]	0^+ [e]	22.0
1.7 ± 0.1	γ_0, p_0, p_1, $\alpha_0 \rightarrow \alpha_3$	400 [e,f]	1^- [e,f]	22.2
1.85	n_0, α_0	175	2^+ [e]	22.35
2.0 ± 0.1	p_0, p_1, α_0, α_3	350 [e,f]	3^- [e,f]	22.5
2.272 ± 0.005 [b]	p_0, p_{1+2}, (p_3), p_4, p_5, α_0, α_2	12 ± 3	$0^+; 2$	22.722
2.40 ± 0.05 [c]	γ_0 [d], p_0, p_1	500 [e,f]	$1^-; 1$	22.83
2.5	α_0			22.9
2.6	(n_0), α_0, α_1	200 [e]	4^+ [e]	23.0
2.8	(n_0), p_0, p_1, d_0	350 [e,f]	2^+ [e]	23.2
3.24	p_0, p_{1+2}, p_4, p_5, p_6, d_0, α_3			23.57
4.2	γ_0, (p_0), d_0, $\gamma_{15.1}$			24.4
4.58	(p_0), d_0, $\gamma_{15.1}$			24.74
4.9	n_0, p_0			25.0
5.95	d_1, $\gamma_{15.1}$			25.9
7.1	$\gamma_{15.1}$			26.9
7.4	d_2			27.2
7.7	d_1			27.5
(8.5)	$(\gamma_{15.1})$			(28.2)
10.2	d_2			29.7

[a] For earlier references see Table 16.14 in (1977AJ02) and 16.16 in (1982AJ01).

[b] $(\Gamma_{\mathrm{d}_0}\Gamma_{\mathrm{i}}/\Gamma^2) \times 10^{-3}$ are greater than 1.6 ± 0.4, 0.27 ± 0.13, 0.41 ± 0.15 and 0.07 ± 0.05 for the α_2, p_0, p_{1+2}, and p_3 groups.

[c] If this resonance is fitted with a single-level Breit-Wigner shape, penetrability effects could lower the resonance energy by as much as 50 keV, assuming $l = 1$.

[d] The angular distribution of γ_0 is consistent with E1.

[e] (1983US01).

[f] See also (1981US02).

The yield of elastically scattered deuterons has been studied for $E_{\mathrm{d}} = 0.65$ to 5.5 MeV and for 14.0 to 15.5 MeV: see (1971AJ02, 1977AJ02). There is indication of broad structure at $E_{\mathrm{d}} = 5.9$ MeV and of sharp structure at $E_{\mathrm{d}} = 7.7$ MeV in the total cross section of the d_1 group to the $T = 1$ (isospin-forbidden), $J^\pi = 0^+$ state at $E_{\mathrm{x}} = 2.31$ MeV in ^{14}N. The yield of deuterons (d_2) to ^{14}N*(3.95) [$J^\pi = 1^+$, $T = 0$] shows gross structures at $E_{\mathrm{d}} = 7.4$ and 10.2 MeV (1970DU04): see Table 16.16. The yield of d_1 has also been studied for $E_{\mathrm{d}} = 10.0$ to 17.9 MeV: see (1982AJ01). For polarization measurements see (1982AJ01). See also (1986AO1A; theor.).

24. (a) ^{14}N(d, t)^{13}N $\qquad Q_{\mathrm{m}} = -4.2962 \qquad E_{\mathrm{b}} = 20.7363$
    (b) ^{14}N(d, ^{3}He)^{13}C $\qquad Q_{\mathrm{m}} = -2.0571$

See (1982AJ01) and (1981NE1B; theor.).

25. ^{14}N(d, α)^{12}C $\qquad Q_{\mathrm{m}} = 13.5743 \qquad E_{\mathrm{b}} = 20.7363$

There is a great deal of structure in the yields of various α-particle groups for $E_{\mathrm{d}} = 0.5$ to 12 MeV. Broad oscillations ($\Gamma \approx 0.5$ MeV) are reported in the α_0 and α_1 yields for $E_{\mathrm{d}} = 2.0$ to 5.0 MeV. In addition, ^{16}O*(23.54) is reflected in the α_3 yield: see Table 16.16. The yield of 15.11 MeV γ-rays [from the decay of ^{12}C*(15.11), $J^\pi = 1^+$, $T = 1$] which is isospin-forbidden has been studied for $E_{\mathrm{d}} = 2.8$ to 12 MeV. Pronounced resonances are observed at $E_{\mathrm{d}} = 4.2$, 4.58 and 5.95 MeV and broader peaks occur at $E_{\mathrm{d}} = 7.1$ and, possibly, at 8.5 MeV: see (1982AJ01).

For polarization measurements see (1983US01) and (1982AJ01). See also (1983DA31; applications).

26. (a) ^{14}N(^{3}He, p)^{16}O $\qquad Q_{\mathrm{m}} = 15.24276$
    (b) ^{14}N(^{3}He, pα)^{12}C $\qquad Q_{\mathrm{m}} = 8.08081$

Observed proton groups are displayed in Table 16.17. Angular distributions have been measured at $E(^3\mathrm{He}) = 2.5$ to 24.7 MeV: see (1982AJ01). Branching ratios and τ_{m} measurements are shown in Tables 16.10 and 16.11.

27. ^{14}N(α, d)^{16}O $\qquad Q_{\mathrm{m}} = -3.1104$

Angular distributions to states of ^{16}O have been reported at many energies to $E_\alpha = 48$ MeV: see (1971AJ02, 1977AJ02). Among the states which have been reported [see Table 16.7 in (1977AJ02)] are ^{16}O*(11.094 ± 3, 14.400 ± 3, 14.815 ± 2, 17.18 ± 50) [MeV ± keV]: the results are consistent with $J^\pi = 5^+, 6^+, 4^+$ for ^{16}O*(14.40, 14.82, 16.29) [2p-2h] and with 6^+ for ^{16}O*(16.30) [4p-4h]. $\Gamma_{\mathrm{c.m.}} = 34 \pm 12$, 27 ± 5 and 70 ± 8 keV, respectively for ^{16}O*(14.31 ± 10, 14.40 ± 10, 14.81).

Table 16.17: ^{16}O states from ^{14}N(^{3}He, p)^{16}O [a]

E_x (MeV ± keV)	$\Gamma_{\text{c.m.}}$ (keV)	L	J^π
0		$0+2$	
6.052 ± 5		(0) [b]	
6.131 ± 4		$1+3$	
6.916 ± 3		(0)	
7.115 ± 3		$1+3$	
8.870 ± 3	< 20	$3+1$	
9.614 ± 30	510 ± 60		
9.847 ± 3	< 20	$0(+2)$	
10.356 ± 3	25 ± 5	[b]	
10.957 ± 1	< 12	1	
11.080 ± 3	< 12	$2+4$ [c]	
11.098 ± 2	< 12		
11.520 ± 4	64 ± 5	[b]	
12.049 ± 2	< 12	0	
12.438 ± 3	70 ± 10	1	
12.530 ± 2 [d]	< 12	$1+3$	
12.797 ± 4	40 ± 10	1	$0^-; T=1$ [f]
12.970 ± 1	< 12	$1+3$	$2^-; T=1$ [f]
13.105 ± 15	160 ± 30	$0+3$ [c]	
13.257 ± 2	20 ± 5	$(1+3)$	$3^-; T=1$ [f]
13.663 ± 4	63 ± 7	0	
13.869 ± 2	85 ± 20	(4) [b]	
13.979 ± 2 [d]	14 ± 5	$1(+3)$	
14.302 ± 3	< 20	[b]	
14.399 ± 2 [d]	27 ± 5	(4)	
14.818 ± 3		2	$(0 \rightarrow 4)^+$
14.927 ± 2 [d]	60 ± 10	$0(+2)$	$(0,1,2)^+$ [g]
15.103 ± 5			
15.196 ± 3		$(0+2)$	
15.409 ± 6		[b]	

Table 16.17: ^{16}O states from ^{14}N(^{3}He, p)^{16}O [a] (continued)

E_x (MeV $\pm$ keV)	$\Gamma_{\rm c.m.}$ (keV)	L	J^π
15.785 ± 5 [d]	40 ± 10	$2(+4)$	$(2, 3, 4)^+$ [g]
16.114 ± 4 [e]			
16.209 ± 2 [d]	40 ± 10	$0 + 2$	
16.350 ± 13			
16.440 ± 3	~ 30	$0 + 2$	
16.817 ± 2	70 ± 10		
[h]			

[a] For references see Table 16.17 in (1982AJ01).

[b] Mostly compound nucleus.

[c] Unresolved.

[d] Also reported in p$\gamma_{4.4}$ coincidences.

[e] Very weak proton group. I am indebted in Prof. H.T. Richards for his comments.

[f] (1978FO27) have compared the cross section ratios of these three $T = 1$ states with their analogs in ^{16}N populated in the (t, p) reaction: only the 2^- states have the expected cross section ratio of 0.5 for (^{3}He, p)/(t, p). The populations of the 0^- and 3^- states in ^{16}O are lower by a factor of two.

[g] (1978FO19) suggest that these two states [^{16}O*(14.93, 15.79)] are 1^+ and 3^+ 2p-2h states with $T_p = T_h = 0$.

[h] States at 17.82 and 18.04 (± 0.04) MeV are also reported in p$\gamma_{4.4}$ coincidences.

28. ^{14}N(^{6}Li, α)^{16}O $\qquad Q_m = 19.2611$

See (1977AJ02).

29. (a) ^{14}N(^{11}B, ^{9}Be)^{16}O $\qquad Q_m = 4.9208$
(b) ^{14}N(^{12}C, ^{10}B)^{16}O $\qquad Q_m = -4.4503$
(c) ^{14}N(^{13}C, ^{11}B)^{16}O $\qquad Q_m = 2.0575$
(d) ^{14}N(^{14}N, ^{12}C)^{16}O $\qquad Q_m = 10.46390$

For reactions (a) and (c) see (1982AJ01). For reactions (b) see (1985AR1P). For reaction cross sections (reaction (d)) see (1982DE39). See also (1983KL1A).

Table 16.18: Levels of ^{16}O from ^{15}N(p, γ), ^{15}N(p, p) and ^{15}N(p, α)

No.	E_p (keV)	Γ_{γ_0} (eV)	Γ_{γ_1} (eV)	Γ_p (keV)	$\Gamma_p\Gamma_\gamma/\Gamma$ (eV)	Γ_{α_0} (keV)	Γ_{α_1} (keV)	Γ_{lab} (keV)	$J^\pi; T$	E_x (MeV ± keV)
1	335 ± 4 [a]	12 ± 2	0.12 ± 0.04	0.9 ± 0.1		102 ± 4	0.025	110 ± 4	$1^-; 0$	12.442
2	429 ± 1	$(21 \pm 6) \times 10^{-3}$	2.1 ± 0.2	0.025 ± 0.003 [b]		nr	0.072 ± 0.010 [b]	0.103 ± 0.011 [b]	$2^-; 0$	12.530
3	710 ± 7			40		nr		40 ± 4	$0^-; 1$	12.793
4	897.37 ± 0.29	$(78 \pm 16) \times 10^{-3}$		0.99 ± 0.12 [b]		nr	0.60 ± 0.08 [b]	1.70 ± 0.15 [b]	$2^-; 1$	12.9686
5	1028 ± 10	32 ± 5		100		40	r	140 ± 10	$1^-; 1$	13.091
6	1050 ± 150					$\Gamma_p\Gamma_{\alpha_0} = 500$ keV^2			2^+	13.1
7	1210 ± 3			4.1		r	8.2 ± 1.1	22.5 ± 1	$3^-; 1$	13.262
8	1640 ± 3	< 1 [c]		10		nr	59 ± 6	68 ± 3	$1^+; 0$	13.664
9	1890 ± 20			0.5		r	(r)	90 ± 2		13.90
10	1979 ± 3			r		nr	r	23 ± 2	2^-	13.982
11	2982 ± 6 [d]			20 ± 3 [e]		1.5	30 [f]	55 ± 5 [d]	2^+	14.921 [k]
12	3170 [g]			12 [h]		152	163	330 ± 100	0^+	15.10 [k]
13	3264 ± 11 [d]			[i]		nr	7 [j]	67 ± 4 [d]	2^-	15.186 [k]
14	3340 [g,l]			15 [h]		12	182	315 ± 100	2^+; (0)	15.26 [k]
15	3499 ± 8 [d,l]			15 ± 5 [e]		103	1	131 ± 18 [d]	3^-	15.406 [k]
16	4350 ± 90 [e]			210 ± 38 [e]				620 ± 60 [e]	$1^-; 0$	16.20
17	4357 ± 5 [d]	3.7 ± 0.5 [m]	0.44 ± 0.06 [m]	7 ± 3 [e]	2.70 ± 0.25 [c]			20 ± 3 [d]	$1^+; 1$	16.210
18	4505 ± 12 [e]			53 ± 12 [e]				65 ± 8 [e]	$0^+; 0$	16.349
19	4612 ± 9 [c]			r	1.11 ± 0.24 [n]	r	r	26 ± 8 [c]	$1 - 4; 1$ [c]	16.449
20	5001 ± 5 [d,l]			7 ± 2 [e]	[o]	nr	r	28 ± 4 [d]	$3^+; 0 + 1$ [c]	16.813
21	5300 ± 40 [e]	r		[p]				405 ± 43 [d]	$1^-;1$	17.09
22	5329 ± 5 [d]	6.7 ± 1.0	1.00 ± 0.17 [m]	22 [c]	3.90 ± 0.50 [c]			33 ± 4 [d]	$1^+;1$	17.120
23	5487 ± 9 [d]	67		45	[q]			80 ± 8 [d]	$1^-; 1$	17.268
24	5848 ± 8 [e]			37 ± 8 [e]				117 ± 15 [e]	2^+; (1)	17.607
25	6100 ± 100 [e]			500 ± 100 [e]				875 ± 110 [e]	2^-	17.84
26	6137 ± 6 [d]			6 [c]	(r)		r	26 ± 3 [d]	$1^-, 2^-; 1$	17.877
27	6297 ± 6 [d]	nr	4.8 ± 1.9 [s]	13 ± 3 [e,t]			8.9 ± 3.2 [c]	28 ± 6	$3^-; 1$ [x]	18.027
28	6490 ± 15 [e]			33 ± 12 [e]				150 ± 26	2^+	18.208
29	6727 ± 15 [e]			11 ± 6				97 ± 41	2^+	18.430
30	6785 ± 6 [e]			17 ± 3				37 ± 6	1^-	18.484
31	7100 ± 100 [c]	≥ 3.6 [m]		[u]					$1^+; 1$	18.78
32	7313 ± 9 [c]		7.1 ± 3.1 [v]	[w]	[w]		0.57 ± 0.49 [c]	8.7 ± 4.1 [c]	$4^-; 1$ [x]	18.979
33	7330 ± 30	38		≤ 130	$\geq 1.8 \pm 0.3$			≈ 260	1^+	18.99
34	7420	r		≈ 30				≈ 130	2^+; (1)	19.08
35	7600 ± 30 [y]	nr	1.5 [z]					100	(2, 3; 1)	19.25
36	7840 ± 30 [y]			(r)				350	$1^-; 1$	19.47

Table 16.18: Levels of ^{16}O from ^{15}N(p, γ), ^{15}N(p, p) and ^{15}N(p, α) (continued)

No.	E_p (keV)	Γ_{γ_0} (eV)	Γ_{γ_1} (eV)	Γ_p (keV)	$\Gamma_\mathrm{p}\Gamma_\gamma/\Gamma$ (eV)	Γ_{α_0} (keV)	Γ_{α_1} (keV)	Γ_lab (keV)	$J^\pi; T$	E_x (MeV ± keV)
37	8289 ± 7 [c]	nr	17 ± 6 [aa]	25 ± 10 [bb]	[cc]		r	45 ± 10	3; 1 [c]	19.893
38	8843 ± 17 [c]	nr	38 [dd]	[dd]	[dd]			200 ± 20	$1 - 4; 1$	20.412
39	8990			[ee]				160		20.55
40	9410 [g]	170		[ee]	21 ± 1			320 ± 10	$1^-; 1$	20.945 ± 20
41	10000 [g]			[gg]				130	$1 \rightarrow 4$	21.50
42	10180 [g]			[hh]		r		< 45	$T = 0$	21.66
43	10700 [g,ff]	r		[gg]	488 ± 20			730 ± 10	$1^-; 1$	22.150 ± 10
44	11490 [g]	120	27 [z]	[gg]	69 ± 5			320 ± 10	$1^-; 1$	22.89 ± 10
45	12740 [g]	r			130 ± 13			590 ± 40	$1^-; 1$	24.07 ± 30
46	13490 ± 60		230 ± 90, or 130 ± 50 [ii]	85 [bb]				360 ± 60	$(2, 4)^+; 1$	24.76
47	13870 [g]	r			651 ± 117		[jj]	3150 ± 320	$1^-; 1$	25.12 ± 60
48	15250 ± 80		740 ± 240, or 410 ± 140 [ii]	122 [bb]			[jj]	565 ± 85 [kk]	$(2, 4)^+; 1$	26.41
49	16250 ± 100		1070 ± 380, or 590 ± 10 [ii]	206 [bb]			[jj]	880 ± 125	$(2, 4)^+; 1$	27.35

nr = non-resonant
r = resonant
For earlier references see Tables 16.21 in (1971AJ02), 16.19 in (1977AJ02) and 16.18 in (1982AJ01).
[a] (1982RE06).
[b] (1983LE25).
[c] See (1983SN03).
[d] Weighted mean of values obtained by (1983SN03, 1984DA18) and in earlier work [see (1982AJ01)].
[e] (1984DA18). See also for calculated Γ_{n}.
[f] $\Gamma_{\mathrm{p}}\Gamma_{\alpha_1}/\Gamma = 16.4$ keV (1983SN03).
[g] Nominal E_{p} calculated from E_{x}.
[h] Not observed in p_0 channel.
[i] 35 ± 3 keV ($s = 1$), 15 ± 2 keV ($s = 0$); $\Gamma_{\mathrm{p}}/\Gamma = 0.78$ (1984DA18).
[j] $\Gamma_{\mathrm{p}}\Gamma_{\alpha_1}/\Gamma = 10.9$ keV (1983SN03).
[k] See also footnote [c] in Table 16.18 (1982AJ01).
[l] Broad structures have also been observed at $E_{\mathrm{p}} \approx 3.5$ MeV in $(\alpha_1\gamma)$ and at 5.7 MeV in $(\alpha_1\gamma)$ and (γ_{1+2}) (1983SN03).
[m] Γ_γ uncertainties neglect the error in $\Gamma_{\mathrm{p}}/\Gamma$ (1983SN03).
[n] $\Gamma_{\mathrm{p}}\Gamma_{\gamma_2}/\Gamma$; also $\Gamma_{\gamma_2} \approx 11$ eV (1983SN03).
[o] $\Gamma_{\mathrm{p}}\Gamma_{\gamma_2}/\Gamma = 0.48 \pm 0.09$ eV, $\Gamma_{\mathrm{p}}\Gamma_{\gamma_{3+4}}/\Gamma = 0.62 \pm 0.13$ eV, $\Gamma_{\mathrm{p}}\Gamma_{\alpha_1}/\Gamma = 6.8$ eV; $\Gamma_{\gamma_2} = 1.0$ eV, $\Gamma_{\gamma_3} = 1.2$ eV, $\Gamma_{\mathrm{p}}/\Gamma = 0.5$ [see, however, values shown for Γ_{p} and Γ] (1983SN03).
[p] $\Gamma_{\mathrm{p}} = 24 \pm 6$ ($l = 0$), 246 ± 24 keV ($l = 2$) (1984DA18).
[q] $\Gamma_{\gamma_3} = 8$ eV, $\Gamma_{\mathrm{p}}\Gamma_{\gamma_3}/\Gamma = 3.27 \pm 0.41$ eV (1983SN03).
[r] $\Gamma_{\gamma_4} = 2$ eV, $\Gamma_{\mathrm{p}}\Gamma_{\gamma_4}/\Gamma = 0.69 \pm 0.10$ eV, $\Gamma_{\mathrm{p}}\Gamma_{\alpha_1}/\Gamma = 1.48$ keV (1983SN03).
[s] Γ_{γ_2}; $\Gamma_{\gamma_3} = 0.76 \pm 0.39$ eV: see (1983SN03).
[t] $\Gamma_{\mathrm{p}_0} = 7.8 \pm 2.8$ keV, $\Gamma_{\mathrm{p}_{1+2}} = 2.7 \pm 1.2$ keV; $\Gamma_{\mathrm{p}}\Gamma_{\gamma_2}/\Gamma = 1.96 \pm 0.27$ eV, $\Gamma_{\mathrm{p}}\Gamma_{\gamma_{3+4}}/\Gamma = 0.31 \pm 0.11$ eV, $\Gamma_{\mathrm{p}}\Gamma_{\mathrm{p}_{1+2}}/\Gamma = 1.11 \pm 0.26$ keV, $\Gamma_{\mathrm{p}}\Gamma_{\alpha_1}/\Gamma = 4.25 \pm 1.00$ keV: see (1983SN03).
[u] $\Gamma_{\mathrm{p}}/\Gamma \leq 0.5$, $\Gamma_{\mathrm{p}}\Gamma_{\gamma_0}/\Gamma \geq 1.8 \pm 0.3$ eV (1983SN03).
[v] Γ_{γ_2}; $\Gamma_{\gamma_3} < 0.3$ eV: see (1983SN03).
[w] $\Gamma_{\mathrm{p}_0} = 0.98 \pm 0.19$ keV, $\Gamma_{\mathrm{p}_{1+2}} = 5.2 \pm 2.3$ keV; $\Gamma_{\mathrm{p}}\Gamma_{\gamma_2}/\Gamma = 0.85 \pm 0.01$ eV, $\Gamma_{\mathrm{p}}\Gamma_{\gamma_{3+4}}/\Gamma < 0.03$ eV, $\Gamma_{\mathrm{p}}\Gamma_{\mathrm{p}_{1+2}}/\Gamma = 0.62 \pm 0.09$, $\Gamma_{\mathrm{p}}\Gamma_{\alpha_0}/\Gamma < 0.09$ keV: see (1983SN03).
[x] See also Table IV in (1983SN03).
[y] See also (1983SN03).
[z] $\gamma_1 + \gamma_2$.
[aa] Γ_{γ_2} (1977CH19). See also (1983SN03).
[bb] Γ_{p_0} based on $\Gamma_{\mathrm{c.m.}}$ and values of $\Gamma_{\mathrm{p}_0}/\Gamma$ assumed by (1977CH19).
[cc] $\Gamma_{\mathrm{p}}\Gamma_{\gamma_2}/\Gamma = 3.9 \pm 0.56$ eV, $\Gamma_{\mathrm{p}}\Gamma_{\mathrm{p}_{1+2}}/\Gamma = 4.48$ keV, $\Gamma_{\mathrm{p}}\Gamma_{\mathrm{p}_3}/\Gamma = 0.52$ keV, $\Gamma_{\mathrm{p}}\Gamma_{\alpha_1}/\Gamma = 1.07$ keV (1983SN03).
[dd] $\Gamma_{\gamma_2} = 38$ eV; $\Gamma_{\mathrm{p}}\Gamma_{\gamma_2}/\Gamma = 18.8 \pm 3.9$ eV, $\Gamma_{\mathrm{p}}\Gamma_{\mathrm{p}_{1+2}}/\Gamma = 15.8$ keV, $\Gamma_{\mathrm{p}}\Gamma_{\mathrm{p}_3}/\Gamma = 5.8$ keV, $\Gamma_{\mathrm{p}}\Gamma_{\mathrm{n}_0}/\Gamma = 22$ keV; the state is probably 4^+; $T = 1$: see (1983SN03).
[ee] Resonant in p_2.
[ff] $\sigma = 12.9$ mb at peak of GDR (1978OC01).
[gg] Resonant in p_1.
[hh] Resonant in p_0, p_1, p_6.
[ii] Γ_{γ_2} (eV).
[jj] Apparent resonance in yield of $(\alpha\gamma_{15.1})$ (1978OC01).
[kk] Average of values obtained in this experiment and in $^{12}\mathrm{C}(\alpha, \gamma_2)$.

30. ^{15}N(p, γ)^{16}O $\qquad Q_{\rm m} = 12.12776$

The yield of γ-rays has been measured for $E_{\rm p} = 0.15$ to 27.4 MeV [see (1982AJ01)] and for $E_{\rm p} = 2.5$ to 9.5 MeV (1983SN03; γ_0, γ_{1+2}, γ_{3+4}; also with polarized protons): observed resonances are displayed in Table 16.18. The γ_0 cross section shows a great deal of structure up to $E_{\rm p} = 17$ MeV. Above that energy the γ_0 yield decreases monotonically. Besides the GDR which peaks at ^{16}O*(22.15) there is evidence for the emergence of a giant structure (E2) with $E_{\rm x} = 24 - 29$ MeV in the $\gamma_{1+2+3+4}$ yield (1978OC01). A study at $E_{\bar{\rm p}} = 6.25$ to 13.75 MeV (angular distributions and asymmetry measurements) shows an E2 strength of 4 ± 1.5% of the isoscalar EWSR in excess of that due to direct capture alone. This excess lies entirely above $E_{\rm x} = 23$ MeV (1983MAZH; prelim.) Differential cross sections for γ_0 and several other (unresolved) γ-rays at $E_{\rm p} \approx 28$ to 48 MeV generally show a broad bump at $E_{\rm x} \approx 34$ [±2 MeV (extimate by reviewer)]: the angular distributions show a dominant E1 character (1983AN12, 1983AN16). See also (1986BRZZ; prelim.).

A study of the M1 decays of ^{16}O*(16.21, 17.14) [both J^π; $T = 1^+$; 1] to ^{16}O*(6.05) finds $B({\rm M1}, 1^+ \rightarrow 0^+_2)/B({\rm M1}, 1^+ \rightarrow 0^+_1) = 0.48 \pm 0.03$ and 0.55 ± 0.04, respectively. ^{16}O*(18.03) is due to a 3^-; 1 state with a strength $\Gamma_{\rm p}\Gamma_{\gamma_2}/\Gamma = 1.96 \pm 0.27$ eV and ^{16}O*(18.98) is due to the 4^-; 1 stretched particle-hole state with a strength of (0.85 ± 0.10) eV (1983SN03). See also (1983SN03) for the identification of analog states in ^{16}N and in ^{16}O, and for a discussion of Gamow-Teller matrix elements in $A = 14 - 18$ nuclei.

For astrophysical considerations see (1982AJ01) and (1981BA2F, 1982BA80, 1982RO1A). See also Table 16.11 here, (1983RA1G, 1984JEZY), (1981GA1M, 1983GOZU, 1985BL1B, 1986WE1D) and (1984CA18, 1984CA19, 1984SE16, 1985CH27, 1986AD1B; theor.).

31. ^{15}N(p, n)^{15}O $\qquad Q_{\rm m} = -3.5363 \qquad E_{\rm b} = 12.12776$

Excitation functions and cross sections have been measured for $E_{\rm p} = 3.8$ to 19.0 MeV: see (1982AJ01). For a listing of observed resonances see Table 16.19. (1983BY03) have measured the polarization and analyzing power for the $\rm n_0$ group for $E_{\bar{\rm p}} = 4.5$ to 11.3 MeV and have deduced integrated cross sections. See also (1982BY1A) and (1981NE1B; theor.).

32. (a) ^{15}N(p, p)^{15}N $\qquad E_{\rm b} = 12.12776$

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

(c) ^{15}N(p, ^{3}He)^{13}C $\qquad Q_{\rm m} = -10.6658$

Elastic scattering studies have been reported for $E_{\rm p} = 0.6$ to 15 MeV [see (1982AJ01)] and $E_{\bar{\rm p}} = 2.7$ to 7.0 MeV (1984DA18). In the range $E_{\rm p} = 2.5$ to 9.5 MeV (1983SN03; also incident polarized protons) have studied angular distributions and excitation functions for the ($\rm p_{1+2}\gamma$) and

Table 16.19: Resonances in ^{15}N(p, n)^{15}O [a]

E_p (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	$J^\pi; T$ [b]	E_x (MeV)
4.37 ± 15	19 ± 6	$1^{(+)}; 1$	16.22
4.45 ± 30	240 ± 30	$0^{(-)}$	16.30
5.35 ± 15	33 ± 5	$1^{(-)}; 1$	17.14
5.52 ± 15	90 ± 10	$1^-; 1$	17.30
5.88 ± 15	59 ± 10	$\geq 1; 1$	17.64
6.12 ± 15	101 ± 10	$\geq 1; 1$	17.86
6.23 ± 15 [c]	≤ 50	$T = 1$	17.96
6.33 ± 15	26 ± 5	$\geq 1; 1$	18.06
6.43 ± 30	≈ 300		18.15
6.76 ± 25	≈ 160		18.46
7.03 ± 30	260 ± 30		18.71
7.59 ± 25	90 ± 10	$2^-; 1$	19.24
7.86 ± 30	300 ± 80		19.49
8.30 ± 25	120 ± 40		19.90
8.88 ± 40 [d]	200 ± 50	2	20.45
9.08 ± 40	130 ± 50		20.63
9.42 ± 100	235 ± 45		20.95
10.73 ± 100	800 ± 95	1	22.18
11.01 ± 100	300 ± 100		22.44
11.92 ± 100	520 ± 200		23.29
13.03 ± 100	520 ± 100		24.33
13.63 ± 100	≈ 280	2, 4	24.89
15.12 ± 100	610 ± 140	2, 4	26.29
18.4 ± 200	470 ± 150		29.4

[a] For references see Table 16.19 in (1982AJ01).

[b] Assignments are from (p, n) and (p, γ) results. The T-assignments are made on the basis of energy and width comparisons with states of ^{16}N.

[c] Probably a doublet.

[d] Values of $(2J + 1)\Gamma_{p_0}\Gamma_{n_0}/\Gamma^2$ are derived for this resonance and the ones below: see (1978CH09).

($p_3\gamma$) transitions. Excitation functions for α_0 and α_1 particles [corresponding to ^{12}C*(0, 4.43)] and of 4.43 MeV γ-rays have been measured for $E_{\rm p} = 93$ keV to 45 MeV [see (1982AJ01)] and at $E_{\rm p} = 77.6$ to 810 keV (1982RE06; α_0) and 2.5 to 9.5 MeV (1983SN03; also incident polarized protons; $\alpha_1\gamma$). The yield of 15.1 MeV γ-rays has been measured for $E_{\rm p} = 12.5$ to 17.7 MeV (1978OC01). Observed anomalies and resonances are displayed in Table 16.18.

A phase shift analysis of angular distributions of cross section and analyzing power for elastic scattering has yielded information on many ^{16}O states in the range $E_{\rm x} = 14.8$ to 18.6 MeV. In particular a broad $J^\pi = 2^-$, $T = 1$ state at 17.8 MeV appears to be the analog of the 1p1h ($d_{3/2}$, $p_{1/2}^{-1}$) ^{16}N state at $E_{\rm x} \approx 5.0$ MeV. The isospin mixing of the 2^- states ^{16}O*(12.53, 12.97) has been studied by (1983LE25): the charge dependent matrix element responsible for the mixing is deduced to be 181 ± 10 keV.

The α_0 yield and angular distribution study by (1982RE06) leads to a zero-energy intercept of the astrophysical $S(E)$ factor, $S(0) = 65 \pm 4$ MeV $\cdot$ b. See (1982AJ01) for the earlier work and (1983MA83), (1981BA2F, 1982BA80; astrophysics), (1982MA1R, 1983AM1D, 1983DA1L, 1983FR1M, 1986AM1B, 1986FR1L, 1986SA41; applied) and (1983KL1B, 1985KL04; theor.). For reaction (c) see (1986PO1M).

Table 16.20: States in ^{16}O from ^{15}N(d, n), ^{15}N(^{3}He, d), ^{17}O(d, t) and ^{17}O(^{3}He, α)

^{16}O* (MeV)	$J^\pi; T$	l [a]	l [b]	S [c]	l [e]	C^2S [e]	l [f]	S [f]	
0	$0^+; 0$	1	1	3.1	2	0.74	2	0.88	
6.05	$0^+; 0$		1	[d]			2	0.009	
6.13	$3^-; 0$	2	2		1	0.46	1 [j]	0.37	
6.92	$2^+; 0$	not direct	$1+3$	[d]	obs.		$(2+0)$	0.022	
7.12	$1^-; 0$	0	$0+2$		1	0.04	$(3+1)$	0.007	
8.87	$2^-; 0$	2	2	0.72	1	0.33	1 [j]	0.26	
9.59	$1^-; 0$		0	[d]					
9.84	$2^+; 0$	1	not direct	[d]			2	0.025	
10.36	$4^+; 0$		3	[d]			2	0.025	
10.96	$0^-; 0$	0	0	0.76			$(3+1)$	0.008	
11.08	$3^+; 0$	3	3	0.18			2	0.044 or 0.086	
11.26	$0^+; 0$		broad						
12.44	$1^-; 0$	0	0	0.40					
12.53	$2^-; 0$	2	2	0.72	1	0.07			
12.80	$0^-; 1$	0	0	0.44					
12.97	$2^-; 1$	2	2	0.40	1	0.69	1 [j]	0.38	
13.09	$1^-; 1$	(0)		0.58			1	0.10	
			$2(+0)$						
13.13 [g]	$3^-; 0$	(2)		0.32					
13.26	$3^-; 1$	2	2	0.46	1	0.70	1 [j]	0.34	
^{16}O* (MeV)	$J^\pi; T$	l [a]	l [b]	S [c]	l [e]	C^2S [e]	l [f]	S [f]	Γ (keV)

Table 16.20: States in ^{16}O from ^{15}N(d, n), ^{15}N(^{3}He, d), ^{17}O(d, t) and ^{17}O(^{3}He, α) (continued)

^{16}O* (MeV)	$J^\pi; T$	l [a]	l [b]	S [c]	l [e]	C^2S [e]	l [f]	S [f]	
15.20	2^-; 0 [e]				1	0.12	[j]		
15.41	3^-; 0 [e]				1	0.37	[j]		
17.14			obs.						
17.20	2^+		obs.						
17.788 ± 16 [i]	4^-; 0					0.17	[j]		< 50
18.033 ± 10 [i]	3^+; 1 [h]				(1)	0.12			

^{16}O* (MeV $\pm$ keV)	$J^\pi; T$	l [e]	C^2S [e]	l [f]	Γ (keV)
18.48	$T = 1$	(1)	0.25	[j]	
18.975 ± 10 [i]	4^-; 1	1	0.73	[j]	
19.206 ± 12 [i]	3^-; 1 [h]	1	0.50	[j]	68 ± 10
19.802 ± 16 [i]	4^-; 0	1	0.52	[j]	36 ± 5
20.41	$(2, 4)^-$; 1	1	0.21	[j]	

[a] ^{15}N(d, n); $E_{\rm d} = 4.8$ to 6 MeV; see (1977AJ02) for references.

[b] ^{15}N(^{3}He, d); E(^{3}He)= 11, 16.0 and 24.0 MeV; see (1977AJ02).

[c] "Best" values from (d, n) and (^{3}He, d) data. See Table 16.22 in (1977AJ02) for a more complete display.

[d] Very small value of S: see (1977AJ02).

[e] ^{17}O(d, t); $E_{\rm d} = 52$ MeV.

[f] ^{17}O(^{3}He, α); E(^{3}He)= 11 MeV.

[g] $\Gamma = 128$ keV.

[h] I am indebted to Prof. H.T. Richards for an illuminating discussion of the evidence for the parameters of this state.

[i] ^{17}O(^{3}He, α).

[j] (1982KA12); $E(^3\overline{\rm He}) = 33$ MeV.

33. ^{15}N(d, n)^{16}O $\qquad Q_{\rm m} = 9.9030$

Observed neutron groups, l-values and spectroscopic factors are displayed in Table 16.20. See also (1984HE20).

34. ^{15}N(^{3}He, d)^{16}O $\qquad Q_{\rm m} = 6.6340$

See Table 16.20.

35. ^{16}N(β^-)^{16}O $\qquad Q_{\rm m} = 10.419$

Table 16.21: Beta decay of the ground state of ^{16}N [a]

Final state		Branch	log ft
^{16}O* (MeV)	J^π	(%)	
0	0^+	27.9 ± 0.5 [a] 28.1 ± 0.64 [b]	9.069 ± 0.005 [e]
6.05	0^+	$(1.2 \pm 0.4) \times 10^{-2}$	9.96 ± 0.15 [e]
6.13	3^-	66.2 ± 0.6 [c]	4.48 ± 0.04
7.12	1^-	4.8 ± 0.4	5.11 ± 0.04
8.87	2^-	1.06 ± 0.07 [d]	4.41 ± 0.03 [d]
9.59	1^-	$(1.20 \pm 0.05) \times 10^{-3}$	6.12 ± 0.05
9.84	2^+	$(6.5 \pm 2.0) \times 10^{-7}$	9.07 ± 0.13 [e]

[a] (1984WA07).

[b] (1985HE08). "Best" value is (28.0 ± 0.4)%.

[c] Recalculated so that the sum of the branches $= 100$%.

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

[e] $\log f_1 t$.

The ground state of ^{16}N decays to seven states of ^{16}O: reported branching ratios are listed in Table 16.21. The ground state transition has the unique first-forbidden shape corresponding to $\Delta J = 2$, yes, fixing J^π of ^{16}N as 2^-: see (1959AJ76). For the β-decay of ^{16}N*(0.12) see reaction 1 in ^{16}N. For an analysis of shape of the ^{16}N beta spectrum see (1984WA07).

The α-decay of ^{16}O*(8.87, 9.59, 9.84) has been observed: see (1971AJ02). The parity-forbidden α-decay from the 2^- state ^{16}O*(8.87) has been reported: $\Gamma_\alpha = (1.03 \pm 0.28) \times 10^{-10}$ eV [$E_\alpha = 1282 \pm 5$ keV]: see (1977AJ02).

Transition energies derived from γ-ray measurements are: $E_x = 6130.40 \pm 0.04$ keV [$E_\gamma = 6129.142 \pm 0.032$ keV (1982SH23)] and 7116.85 ± 0.14 keV [$E_\gamma = 7115.15 \pm 0.14$ keV]: see (1977AJ02). See also p. 16 in (1982OL01).

36. (a) ^{16}O(γ, n)^{15}O $\quad Q_m = -15.6639$
    (b) ^{16}O(γ, 2n)^{14}O $\quad Q_m = -28.8863$
    (c) ^{16}O(γ, pn)^{14}N $\quad Q_m = -22.9609$
    (d) ^{16}O(γ, 2d)^{12}C $\quad Q_m = -31.0087$

The absorption cross section and the (γ, n) cross section are marked by a number of resonances. On the basis of monoenergetic photon data, excited states of ^{16}O are observed at $E_x = 17.3$[u], 19.3[u] and 21.0 MeV [u $=$ unresolved], followed by the giant resonance whose principal structures are at 22.1 and 24.1 MeV, with additional structures at 23 and 25 MeV: see (1977AJ02, 1983BE01). The integrated nuclear absorption cross section for $E_\gamma = 10$ to 30 MeV is 182 ± 16 MeV · mb (1983SH35). See also reaction 38. The (γ, 1n) cross section has been measured for $E_\gamma = 17$ to 33 MeV: in that energy interval the (γ, 2n) cross section is negligible. The cross section for formation of the GDR at 22.1 MeV is 10.0 ± 0.4 mb and the integrated cross section to 30 MeV is 54.8 ± 5 MeV · mb. There is apparently significant single particle hole excitation of ^{16}O near 28 MeV and significant collectivity of the GDR. A sharp rise is observed in the average $E_{\rm n}$ above 26 MeV (1983BE01). See also (1982BE28). The cross section for (γ, $\rm n_0$) decreases monotonically for $E_{\rm x} = 25.5$ to 43.8 MeV. In the range $30 - 35$ MeV the E2 cross section exhausts about 4% of the isovector E2 EWSR (1984KU21). Over the range 25.5 to 43.8 MeV it exhausts $\approx 68\%$ of the isovector E2 EWSR (1979PH07).

The absorption cross section has been measured from $E_{\rm bs} = 10$ MeV to above the meson threshold: see (1982AJ01). The (γ, 1n), (γ, 2n) and (γ, Tn) cross sections have been studied with monoenergetic photons for $E_\gamma = 24$ to 133 MeV. Above 60 MeV, the main reaction mechanisms appear to be absorption of the photons by a correlated n-p pair in the nucleus: the integrated cross section from threshold to 140 MeV is 161 ± 16 MeV · mb (1982CA05). For differential cross sections involving the $\rm n_0$ and $\rm n_3$ groups see (1982GO09, 1982SC02) in ^{15}O (1986AJ01). For reaction (b) and pion production see (1982COZV). For the hadron production cross section over the range 0.25 to 2.7 GeV see (1983AR24).

See also (1982AJ01) and (1982RO1J), (1982VI07; applied), (1981SP1D, 1982DE1H, 1982JU03, 1982LO1B, BL83, 1983BL12, 1985AH06, 1985FU1C, 1985HO27, 1985NA1D, 1985PY01, 1985SH1P) and (1981DE18, 1981GA1M, 1981OS1A, 1981WE1G, 1982CA01, 1982ME08, 1983BE1U, 1983BE45, 1983BO1G, 1983BO1B, 1983CA22, 1983HE18, 1983KA28, 1984CA18, 1984CA19, 1984CH1R, 1984GL11, 1984KO33, 1984MO13, 1984RO05, 1985CO01, 1985EM02, 1985GI1G; theor.).

37. (a) ^{16}O(γ, p)^{15}N	$Q_{\rm m} = -12.12776$
(b) ^{16}O(γ, d)^{14}N	$Q_{\rm m} = -20.7363$
(c) ^{16}O(γ, α)^{12}C	$Q_{\rm m} = -7.16195$
(d) ^{16}O(γ, π^+)^{16}N	$Q_{\rm m} = -149.986$
(e) ^{16}O(γ, π^-)^{16}F	$Q_{\rm m} = -154.984$

The (γ, $\rm p_0$) cross section derived from the inverse capture reaction (reaction 30) confirms the giant resonance structure indicated above in reaction 36, as do also the direct (γ, $\rm p_0$) measurements. For the earlier work see (1982AJ01). (1981WI09) have used linearly polarized bremsstrahlung photons with $E_{\rm bs} = 22$ and 30 MeV. This work confirms 1^+ for ^{16}O*(16.2), a broad E1 state nearby, and 1^- for ^{16}O*(17.3) [not resolved from ^{16}O*(17.1)] (1981WI09). These results are in agreement with the results from ^{15}N(p, γ): see Table 16.18. Proton spectra have been measured at $E_\gamma \approx 360$ MeV by (1984HO24). Differential cross sections have been determined for the $\rm p_0$, $\rm p_{1+2}$ and $\rm p_3$

groups for $E_\gamma = 101.5$ to 382 MeV (1985LE07) and for the p_0 group at 196 MeV (1985TU02). The latter data are in disagreement with calculations which incorporate meson exchange and Δ amplitudes (1985TU02). See also ^{15}N in (1986AJ01) and (1981WI09, 1985ADZW).

For reaction (b) see (1982AJ01). A study of the ^{16}O(γ, α_0) reaction at $\theta = 45°$ and $90°$ shows a 2^+ resonance at $E_x = 18.2$ MeV with an E2 strength which is spread out over a wide energy interval. A strong resonance corresponding to an isospin-forbidden 1^- state at $E_x \approx 21.1$ MeV is also observed (1975SK06). For pion production (reactions (d)) see ^{16}N. See also (1983JE08, 1984HO24). See also (1982SA1A; astrophysics), (1981GA1M, 1981SP1D, 1985FU1C, 1985HO27, 1985MA1G) and (1981BO38, 1982CA01, 1982DE2C, 1982DU1A, 1983BO1B, 1983BO1H, 1983CA22, 1983CI13, 1983HE18, 1983PE1E, 1984BE1Z, 1984CA18, 1984CA19, 1984CH1R, 1985CH27, 1985GI1G, 1986CH05, 1986HO11; theor.).

38. ^{16}O(γ, γ)^{16}O

(1970AH02) report resonances at $E_\gamma = 22.5 \pm 0.3$, 25.2 ± 0.3, 31.8 ± 0.6 and 50 ± 3 MeV: the dipole sum up to 80 MeV exceeds the classical value by a factor 1.4. (1983DO05) have measured the elastic photon scattering cross section for $E_\gamma = 25$ to 39 MeV. The E2 strength is $1.25^{+1.3}_{-0.9}$ of the total EWSR over that interval. The widths of ^{16}O*(6.92, 7.12) are, respectively, 94 ± 4 and 54 ± 4 meV (1985MO10): see also Table 16.11.

See also (1984NA18), (1985NA1D) and (1983CA1P, 1984MA1W; theor.).

39. (a) ^{16}O(e, e)^{16}O
(b) ^{16}O(e, ep)^{15}N $\qquad Q_m = -12.12776$

The ^{16}O charge radius $= 2.710 \pm 0.015$ fm (1978KI01). Form factors for transitions to the ground and to excited states of ^{16}O have been reported in many earlier studies [see (1982AJ01)], by (1982NO04; ^{16}O*(6.92)), by (1986BU02; ^{16}O*(6.05, 6.13, 6.92, 7.12, 9.84, 10.36, 11.10, 11.52, 12.05)) and by (1985HY1A; see Table 16.22). The form factor for ^{16}O*(9.84) indicates a transition density peaked in the interior (1986BU02). Table 16.22 lists the excited states observed from (e, e′). (1983KU14; $E_e = 30.2$ to 59.3 MeV) find that the energy-weighted M2 strength is nearly exhausted by the M2 states which have been observed. The isospin-forbidden (E1) excitation of ^{16}O*(7.12) is reported: the isovector contribution interferes destructively with the isoscalar part and has a strength $\approx$ 1% of the $T = 0$ amplitude. The 0^+ states of ^{16}O*(6.05, 12.05, 14.00) saturate $\approx$ 19% of an isoscalar monopole sum rule. As for the E2 strength it is distributed over a wide energy region: see Table 16.22, and (1982AJ01) for references.

Table 16.22: Excited states observed in ^{16}O(e, e′)^{16}O [a]

E_x (MeV ± keV)	$J^\pi; T$	Mult.	$\Gamma_{\rm c.m.}$ (keV)	Γ_{γ_0} (eV)
6.05	0^+	C0		3.55 ± 0.21 [c]
6.13	3^-	C3		$(2.60 \pm 0.13) \times 10^{-5}$
6.92	2^+	C2		0.105 ± 0.007
7.12	1^-	C1		$(4.6 \pm 2.3) \times 10^{-2}$
8.87 [b]	2^-	M2		
9.84	2^+	C2		$(8.8 \pm 1.7) \times 10^{-3}$
10.36	4^+	C4		$(5.6 \pm 2.0) \times 10^{-8}$
11.52	2^+	C2		0.61 ± 0.02
12.05	0^+	C0		4.03 ± 0.09 [c]
12.44 [b]	1^-	C1		
12.53 [b]	2^-	M2		0.021 ± 0.006
12.97 [b]	2^-	M2		0.071 ± 0.002
13.02	2^+	C2		0.89
13.10 ± 250	$1^-; 1$	C1		$\leq 49 \pm 13$
13.26 [b]	3^-	C3		
13.87 [b]	4^+	C4		
14.00 ± 50 [b]	0^+	C0	170 ± 50	3.3 ± 0.7 [c]
≈ 14.7 [b]			≈ 600	
14.93 [b]	2^+	C2		
15.15 ± 150	2^+	C2	500 ± 200	1.0 ± 0.5
15.20 [b]	2^-	M2		
15.41 [b]	3^-	C3		
≈ 15.85 [b]			≈ 600	
16.22 ± 10 [b,d]	$1^+; 1$	M1	18 ± 3	3.2 ± 0.3
16.45 ± 10 [b,d]	2^+	C2	32 ± 4	0.18 ± 0.01
16.82 ± 10 [b,d]	2^-	M2	30 ± 5	0.05 ± 0.01
17.14 ± 10 [b,d]	$1^+; 1$	M1	< 25	6.1 ± 0.5
17.30 ± 10 [b,d]	1^-	C1	70 ± 10	3.4 ± 2.3
17.774 ± 17 [b]	$4^-; 0$	M4		
17.78 ± 10 [d,e]	2^-	M2		0.07 ± 0.01

Table 16.22: Excited states observed in ^{16}O(e, e$'$)^{16}O [a] (continued)

E_x (MeV ± keV)	$J^\pi; T$	Mult.	$\Gamma_{\rm c.m.}$ (keV)	Γ_{γ_0} (eV)
17.880 ± 15 [b]	4^+	C4		
18.021 ± 23 [b]	$3^-; 1$			
18.20 ± 10 [d]	2^+	C2	280 ± 20	1.68 ± 0.22
18.50 ± 10 [b,d]	2^-	M2	70 ± 5	0.38 ± 0.07
18.635 ± 20 [b]	(4^-)		35 ± 30	
18.79 ± 10 [d]	$1^+; 1$	M1	120 ± 20	5.3 ± 0.3
18.968 ± 17 [b,f]	$4^-; 1$	M4		
19.02 ± 40 [d,g]	$2^-; 1$	M2	420 ± 50	2.52 ± 0.38
19.206 ± 12 [b]	$3^-; 1$	C3		
19.43 ± 20 [b]	$1^-; 1$	C1	150 ± 15	40 ± 20
20.19 ± 40 [b]		M2	450 ± 70	2.9 ± 1.0
20.34 ± 25 [b]			≈ 200	
20.51 ± 25 [b]	(4^-)		50 ± 30	
20.88 [b]			≈ 90	
20.95 ± 50	$1^-; 1$	C1	270 ± 70	180 ± 50
≈ 21.46 [b]			≈ 300	
22.60 ± 20 [b]			90 ± 40	
23.0				
23.7 ± 250	$(2^-; 1)$			
24.2				
25.5 ± 250	$1^-; 1$	C1		
26.7 ± 250	1^+	M1		
44.5	$(1^-; 1)$		$2000 - 3000$	5300
49	$(1^-; 1)$		$2000 - 3000$	19000

[a] See also Table 16.26 in (1971AJ02). For references see Table 16.24 in (1977AJ02). See also the text.

[b] (1985HY1A: momentum transfer range 0.8 to 2.5 fm^{-1}). I am indebted to Drs. C.E. Hyde-Wright and B.L. Berman for communicating these results to me.

[c] Monopole matrix element in fm^2.

[d] (1983KU14).

[e] An unresolved complex of M1 strength has a centroid at $E_x \approx 17.7$ MeV: the total Γ_{γ_0} is 7.4 ± 1.9 eV (1983KU14).

[f] See also (1986MA48).

[g] The total cross section ($E_x = 18.7 - 19.4$ MeV) is 12% M1 and 88% M2, leading to $B(\mathrm{M1})\uparrow = 0.13 \pm 0.03\ \mu_N^2$ and $B(\mathrm{M2})\uparrow = 341 \pm 51\ \mu_N^2 \cdot \mathrm{fm}^2$, A. Richter (private communication). I am greatly indebted to Professor Richter for his comments.

A study of reaction (b) at 500 MeV shows separation energies of 12.2 and 18.5 MeV, corresponding to ^{15}N*(0, 6.32) (1982BE02; studied the momentum distribution of the recoiling nucleus). At $E_e = 112 - 130$ MeV in (e, e′) the excitation of ^{16}O*(11.52, 12.05, 22.3) and some other state is reported. The (e, ep) and (e, eα) processes lead to the excitation of ^{15}N*(0, 6.32) and of ^{12}C*(0, 4.44) (1982VO05, 1983VO1F, 1984VO1G, 1984VOZW). The inelastic cross section for 730 MeV electrons has been measured by (1984OC01): the quasi-free peak occurs at an energy loss of 120 ± 5 MeV and the Δ-peak at 375 ± 10 MeV. The peak cross sections per nucleon are in agreement with those measured for other light nuclei (1984OC01).

See also (1983KEZZ), (1981RI1A, 1982BE1J, 1982BE1A, 1982DE1K, 1982RI1B, 1983BE36, 1983CO18, 1983KE1B, 1983SI1K, 1983TR1J, 1985BE1K, 1985KO44) and (1981AG1B, 1981DU16, 1981DU19, 1981IS11, 1981KO41, 1981LI1X, 1981ME1H, 1981TO1N, 1981VA1N, 1982AV08, 1982BO28, 1982ER05, 1982FA04, 1983BE29, 1983BR1P, 1983CA1M, 1983CO15, 1983RI07, 1984BA52, 1984CO1U, 1984DE02, 1984LA28, 1984MO13, 1984NE1G, 1984WA1J, 1985BA26, 1985BO13, 1985CA17, 1985CA38, 1985CA37, 1985CO01, 1985DE16, 1985FUZZ, 1985KE1A, 1985KO06, 1985NI02, 1985PE14, 1985PI10, 1985TR03, 1986FR02, 1986WA1T; theor.).

40. ^{16}O($\pi^\pm$, $\pi^\pm$)^{16}O

Angular distributions of elastically scattered pions have been studied at $E_{\pi^-} = 20$ to 240 MeV and at 1 GeV/c as well as at $E_{\pi^+} = 20$ to 315 MeV [see (1982AJ01)] and recently at $E_{\pi^+} = 20$ MeV (1983OB02) and 48.3 and 62.8 MeV (1985BA27), at $E_{\pi^\pm} = 114$ MeV (1985DH01), at $E_{\pi^-} = 115$, 163 and 244 MeV (1982BA72; back angles). See also (1984BU1V). At $E_{\pi^\pm} = 164$ MeV ^{16}O*(0, 6.1, $6.9 + 7.1$, 11.5, 17.8, 19.0, 19.8) are relatively strongly populated. The π^+ and π^- cross sections to ^{16}O*(17.8, 19.8) [$J^\pi = 4^-$; $T = 0$] are substantially different while those to ^{16}O*(19.0) [4^-; 1] are equal. Isospin mixing is suggested with off-diagonal charge-dependent mixing matrix elements of -147 ± 25 and -99 ± 17 keV (1980HO13). [See also reaction 62]. Differential cross sections for ^{16}O*(6.1) are reported at $E_\pi = 164$ MeV by (1984BL17). For a study of the angular distribution of 6.13 MeV γ-rays at 2.0 GeV/c see (1984KI22). At $E_{\pi^+} = 240$ MeV the inelastic pion scattering is dominated by a single quasi-free pion-nucleon interaction mechanism (1983IN02): this is not the case at energies below the Δ-resonance (114 and 163 MeV). See also (1985BLZZ).

For a study of ($\pi^{\pm}$, $\pi^{\pm}$p) and (π^{-}, π^{-}n) at $E_{\pi^{\pm}} = 165$ MeV see (1982PI06). See also the "General" section here, (1984BA1B, 1984BUZZ, 1986DHZZ) and (1982FR17, 1982OS01, 1982RE15, 1983CA05; theor.).

41. ^{16}O(n, n$'$)^{16}O

Angular distributions have been measured at $E_{\rm n}$ to 24 MeV [see (1982AJ01)] and recently at $E_{\rm n} = 9.2$ to 15 MeV (1983DA22; n_0) and 18 to 26 MeV (1985PE10; n_0) [see also (1983ISZW, 1984FI1M, 1984ISZZ, 1985FIZW; prelim.: n to ^{16}O*(6.13, 6.92, 8.87, 9.63))] and at $E_{\rm n} = 23$ MeV (1985LA13; n_0). See also (1985PE1C, 1986ISZZ), (1982AO03, 1982BO24, 1982LI13, 1985DI1B, 1985GO1Y, 1985LI1P, 1986DE10; theor.) and ^{17}O.

42. (a) ^{16}O(p, p$'$)^{16}O
(b) ^{16}O(p, 2p)^{15}O $Q_{\rm m} = -12.12776$
(c) ^{16}O(p, pd)^{14}N $Q_{\rm m} = -20.7363$
(d) ^{16}O(p, pt)^{13}N $Q_{\rm m} = -25.0325$
(e) ^{16}O(p, pα)^{12}C $Q_{\rm m} = -7.16195$
(f) ^{16}O($\bar{\rm p}$, $\bar{\rm p}$)^{16}O

Angular distributions of elastically and inelastically scattered protons have been measured at many energies up to $E_{\rm p} = 1000$ MeV [see (1982AJ01)] and recently at $E_{\bar{\rm p}} \approx 6.5$ MeV (1982SE01; p_0), 35 MeV (1986OH1C; p to ^{16}O*(10.96, 12.80); both 0^-), 65 MeV (1982SA19; p_0), 65 MeV (1984HO17; p to ^{16}O*(10.96, 12.80)), 135 MeV (1986KE05; p_1), 200 MeV (1985GL01; p_0), 318 and 498 MeV (1986LO1D; p to ^{16}O*(10.36, 11.52) and others), and 1 GeV (1985AL16; p_0), as well as at $E_{\rm p} = 135$ MeV (1984AM04; p to many states [see Table 16.23]; see for deformation parameters and electromagnetic transition rates). Parameters of the observed groups are displayed in Table 16.23. For polarization transfer coefficients to the 4^- states ^{16}O*(17.8, 19.0, 19.8) see (1985WIZW; $E_{\bar{\rm p}} = 200$ MeV). See also (1986LO1D). For a study of the spin rotation parameter at $E_{\bar{\rm p}} = 800$ MeV see (1986FE01).

For reaction (b) see (1985BE30; 1 GeV). For reactions (c) and (d) see (1982SA24; 101.3 MeV). See also (1982REZZ). For the (p, pn) reaction see (1983WA1C, 1984WA21, 1985BE30). For reaction (e) see (1984CA09; $E_{\rm p} = 101.5$ MeV). See also (1984VDZZ, 1985VDZX) and ^{12}C in (1990AJ01). See also (1981NA14, 1982BE1E, 1983BEYW, 1983FIZW, 1983HYZZ, 1983KEZZ, 1983LOZW), (1982BE1A, 1982DE1K, 1983BE1A, 1983KE1B, 1983SC1G, 1984GE1A, 1984LI25, 1985PE10, 1986GL1G, 1986ISZZ), (1981IL1A, 1981KO1J, 1981ME1H, 1981PI11, 1981VA1L, 1982CH1P, 1982HA05, 1982KA14, 1982KO23, 1982NA13, 1982SA37, 1982ST1G, 1982WA1H,

1983DI09, 1983EL10, 1983GO1V, 1983GO10, 1983IK1B, 1983KA1A, 1983KO1B, 1983LY07, 1983LI1P, 1983SH05, 1983SM04, 1983TU1B, 1984BA52, 1984GO04, 1984HY01, 1984KO1X, 1984PH02, 1984PI05, 1984PI17, 1984WO12, 1985AU1C, 1985CH10, 1985CH31, 1985GA1N, 1985GO1Y, 1985HE1D, 1985HY01, 1985KE1A, 1985KO37, 1985NA1E, 1985PE14, 1985VD03, 1986DE1G, 1986DE10, 1986KU1D, 1986LO1A; theor.) and ^{17}F. The elastic scattering of 178.4 MeV antiprotons has been studied by (1986BR04). See also the “General” section here.

Table 16.23: Excited states of ^{16}O from ^{16}O(p, p′), (d, d′), (^{3}He, ^{3}He′) and (α, α') [a]

No.	E_x [b] (MeV ± keV)	L [b]	E_x [c] (MeV)	E_x [d] (MeV ± keV)	E_x [e] (MeV ± keV)	L [e]	Γ [b] (keV)	$J^\pi; T$ [b]
1			6.05					
2	6.13 [f]	3	6.13	6.13 [h]	6.13	3		$3^-; 0$
3	6.92 [f]	2	6.92	6.92 [d]	6.92	2		$2^+; 0$ [d,f]
4	7.12 [f]	1	7.12		7.12	1		$1^-; 0$
5	8.87		8.87	8.87 ± 30 [d]	8.87	3 [a]		
6	9.84 [f]	2	9.85	9.84 ± 30	9.85	2		$2^+; 0$ [d,f]
7	10.35 ± 20 [f]	4	10.34	10.35 ± 30	10.35 ± 30	4		$4^+; 0$
8	10.95 ± 30 [g]	1	10.95					$0^-; 0$
9	11.10 ± 20 [f]	4	11.1 [h]	11.09 ± 30 [h]	11.10 ± 30	4		$4^+; 0$
10	11.52 ± 20 [f]	2	11.52	11.52 ± 30 [d]	11.52 ± 30	2	74 ± 4	$2^+; 0$
11	12.05 ± 20 [f]		12.05	12.04 ± 30	12.05 ± 30	(0)		$0^+; 0$
12			12.44		12.44	1		$1^-; 0$
13	12.53 ± 20	1	12.53		12.51 ± 30			
14	12.80 [g]							$0^-; 1$
15	13.02 ± 20	2	13.1 [h]	13.11 ± 30	13.07 ± 20 [h]	2		$2^+; 0$
16	13.26 ± 30	3						$3^-; 1$
17			13.66					
18	13.95 ± 50	(0 + 4)		13.97 ± 30	13.95 ± 50 [h]	4		$4^+; 0$
19				14.94 ± 30	14.87 ± 100	6		6^+
20	15.26 ± 50	(3)		15.4				
21	15.50 ± 30 [f]	3			15.50 ± 50	3	200 ± 60	$3^-; 0$
22	16.52 ± 50	2		16.46 ± 30	16.40 ± 100		< 100	2^+
23	16.93 ± 50	(3)						
24	17.25 ± 50 [f]			17.19 ± 30	17.25 ± 80	(2)	160 ± 60	$1^+; 0$ [f]
25	17.79 ± 40	(3)		17.8	17.83 ± 100		150 ± 60	$4^-; 0$
26	18.15 ± 50	(2)			18.0 ± 100	2	300 ± 50	$(2^+); 0$
27	18.40 ± 100	2		18.52 ± 30	18.5 ± 100	2	250 ± 50	$2^+; 0$
28	18.60 ± 100				18.70 ± 100	(3)	280 ± 80 [h]	
29	18.98 ± 40	(3)		19.09 ± 30			< 100	$4^-; 1$
30	19.35 ± 80	(1)						
31	19.56 ± 50 [f]				19.50 ± 100	(2, 3)	300 ± 50	$3^-; 0$

Table 16.23: Excited states of ^{16}O from ^{16}O(p, p′), (d, d′), (^{3}He, ^{3}He′) and (α, α') [a] (continued)

No.	$E_{\rm x}$ [b] (MeV ± keV)	L [b]	$E_{\rm x}$ [c] (MeV)	$E_{\rm x}$ [d] (MeV ± keV)	$E_{\rm x}$ [e] (MeV ± keV)	L [e]	Γ [b] (keV)	$J^\pi; T$ [b]
32	19.80 ± 40	3					< 100	$4^-; 0$
33				20.2 ± 200 [h]	20.15 ± 100	2	350 ± 50	$2^+; 0$
34	20.56 ± 80	(1, 2)					370 ± 100	
35	21.05 ± 50	1			21.0 ± 100	2	320 ± 50	$(2^+; 0)$
36				21.6 ± 200			1000 ± 300	2^+
37	21.80 ± 80	1			21.85 ± 100	2	400 ± 50	$(2^+; 0)$
38	22.40 ± 80	(1, 2)					420 ± 100	$1^-; 1$
39					22.5 ± 100		400 ± 50	$(2^+, 3^-); 0$
40	23.20 ± 80	1					600 ± 200	$1^-; 1$
41				23.50 ± 150	23.25 ± 100	2	400 ± 50	$2^+; 0$
42					23.85 ± 100	(0)	400 ± 50	$(2^+, 0^+); 0$
43	24.00 ± 100	(1, 2)					1200 ± 300	$1^-; 1$
44					24.4 ± 100		400 ± 50	$(2^+, 3^-); 0$
45				25.15 ± 300			2800 ± 600	2^+
46	25.50 ± 150	(1)					1300 ± 300	$1^-; 1$

[a] For references see Table 16.24 in (1982AJ01).

[b] (p, p′).

[c] (d, d′). Energies are nominal (±100 to ±260 keV); angular distributions reported to all but last state.

[d] (^{3}He, ^{3}He′).

[e] (α, α').

[f] (1984AM04): $E_{\rm p} = 135$ MeV.

[g] (1984HO17); $E_{\bar{\rm p}} = 65$ MeV.

[h] Unresolved states.

43. ^{16}O(d, d′)^{16}O

Angular distribution studies have been carried out for $E_{\rm d}$ up to 81.6 MeV [see (1982AJ01)] and recently at $E_{\rm d} = 20.5$ MeV (1984FR14; d_0) and 200, 400 and 700 MeV (1986VA1N). Observed deuteron groups are displayed in Table 16.23. For a polarization study at $E_{\vec{\rm d}} = 56$ MeV see (1986MA2M). See also ^{18}F in (1987AJ02) and (1981RO1T, 1982AO03, 1982CO10, 1982GA1E, 1982NI1B, 1982TH02, 1982TH09, 1983IC01, 1985HO19; theor.).

44. ^{16}O(t, t)^{16}O

Angular distributions are reported for $E_{\rm t}$ to 20.01 MeV: see (1977AJ02). See also ^{19}F in (1983AJ01) and (1982AO03, 1982KU04, 1982NI1B, 1985HO19, 1986WA1P, 1986WA1U; theor.).

45. ^{16}O(^{3}He, ^{3}He)^{16}O

Angular distributions have been measured to $E(^3\text{He}) = 132$ MeV [see (1982AJ01)] and, recently, at 14 MeV (1982AB04), 25 MeV (1982VE13) and 40.9 MeV (1982AL14) for the elastic group. The matter radius $\langle r^2 \rangle^{1/2} = 2.46 \pm 0.12$ fm (1982VE13). Inelastic groups are shown in Table 16.23. See also (1982TA05) and (1981CO15, 1982NI1B, 1985HA11, 1985HO19, 1986WA1P, 1986WA1U; theor.)

46. (a) ^{16}O(α, α')^{16}O

(b) ^{16}O(α, 2α)^{12}C $\qquad Q_{\rm m} = -7.16195$

Angular distributions of α-particles have been measured up to $E_\alpha = 146$ MeV [see (1982AJ01)] and recently at $E_\alpha = 3.5$ to 4.9 MeV (1981BU27; α_0), 9.52 to 9.80 MeV (1981GA35) and 39.3 to 69.5 MeV (1983MI22; α_0). Differential cross sections have also been measured at $E_\alpha = 9.2$ to 13.5 MeV (α_0) and 12.4 to 13.45 MeV (α_1, α_2) (1985CA09) and at 14.70 to 20.4 MeV (α_0) and 18.0 to 20.4 MeV (α_1) (1984RI06): see ^{20}Ne in (1983AJ01, 1987AJ02). Observed excited states are displayed in Table 16.23.

Angular correlations (reaction (b)) have been studied to ^{12}C$_{\rm g.s.}$ at $E_\alpha = 23.0$ to 27.5 MeV to try to determine if a 3$^-$ state exists near the 2$^+$ state ^{16}O*(9.84): the evidence is strong that this is not the case (1983FR14). The isoscalar (E2, $T = 0$) giant resonance decays predominantly via the α_1 channel which contains $\approx$ 40% of the E2 EWSR, rather than via the α_0 and p$_0$ channels (1978KN02; $E_\alpha = 155$ MeV). For the (α, αd), (α, αt) and (α, α^3He) reactions at $E_\alpha = 139.2$ MeV, see (1982SA24).

See also (1983SA07, 1984SA28, 1985ISZU), (1981SP1D, 1981VA1M, 1983CH1B) and (1981BA20, 1981FI1B, 1981GY01, 1981LA13, 1981SP1C, 1982AO1B, 1982AO03, 1982AO1F, 1982BU1D, 1982DI1D, 1982FL1A, 1982JA07, 1982LA04, 1982LE23, 1982WA13, 1982YI01, 1983BR1V, 1983BU15, 1983CH53, 1983CI04, 1983OK06, 1983SA1L, 1983SM1B, 1983WI12, 1984CH41, 1984GO04, 1984HO08, 1984JA03, 1984KR10, 1984LA01, 1984LI28, 1984LO1C, 1984PR09, 1984SA1T, 1985HO19, 1985MI11, 1985SA09, 1986HO1U, 1985MAZZ; theor.).

47. (a) ^{16}O(^{6}Li, ^{6}Li)^{16}O

(b) ^{16}O(^{7}Li, ^{7}Li)^{16}O

Elastic angular distributions for reaction (a) have been measured at $E(^6\text{Li}) = 4.5$ to 50.6 MeV and $E(^{16}\text{O}) = 36$ to 51 MeV [see Tables 16.25 in (1977AJ02) and 16.23 in (1982AJ01)] and recently at $E(^6\text{Li}) = 36$ MeV (1982WO09), 48 MeV (1984CO05) and 75.4 MeV (1981TA23), as well as at $E(^6\text{Li}) = 25.7$ MeV and $E(^{16}\text{O}) = 68.6$ MeV (1984VI01, 1985CO21, 1985VI03; also to ^{16}O*(6.13) and partially to ^{6}Li*(2.19)) and at $E(^6\text{Li}) = 35.3$ MeV and $E(^{16}\text{O}) = 94.2$ MeV (1984VI02). See also ^{6}Li in (1988AJ01). For studies of d-α angular correlations see ^{20}Ne in (1983AJ01, 1987AJ02). For a fusion cross section study see (1986MA19).

Elastic distributions for reaction (b) have been studied at $E(^7\text{Li}) = 9.0$ to 20 and at 68 MeV [see Tables 16.25 in (1977AJ02) and 16.23 in (1982AJ01)] as well as at $E(^7\text{Li}) = 50$ MeV (1984CO20). For fusion cross section studies see (1984MA28, 1986MA19). See also (1986MO1E, 1986SA2P) and (1982AL02, 1982GU21, 1982RA22, 1983BU15, 1983JO1A, 1983KH1A, 1984WI08, 1985SA13; theor.).

48. $^{16}\text{O}(^9\text{Be}, ^9\text{Be})^{16}\text{O}$

Elastic angular distributions have been reported at $E(^9\text{Be}) = 20$ to 27.4 MeV and $E(^{16}\text{O}) = 15$ to 29.5 MeV [see Table 16.23 in (1982AJ01)] and recently at $E(^9\text{Be}) = 43$ MeV (1985WI18), 140 MeV (1984FUZZ) and 157.7 MeV (1983SA20, 1984FU10). For fusion cross sections see (1982AJ01, 1982BE54). See also (1981ST1P, 1983BI13, 1983DA10) and (1981GR17, 1982GU21, 1983GR18, 1984HA43; theor.).

49. (a) $^{16}\text{O}(^{10}\text{B}, ^{10}\text{B})^{16}\text{O}$
(b) $^{16}\text{O}(^{11}\text{B}, ^{11}\text{B})^{16}\text{O}$

Angular distributions have been reported at $E(^{10}\text{B}) = 33.7$ to 100 MeV and at $E(^{11}\text{B}) = 41.6$, 49.5 and 115 MeV: see Table 16.23 in (1982AJ01). For fusion cross section measurements (reaction (a)) see (1982AJ01) and (1984GO05). See also (1981ST1P, 1983BI13, 1984FR1A, 1984HA53) and (1983CI08, 1983GO13, 1985HU04; theor.).

50. (a) $^{16}\text{O}(^{12}\text{C}, ^{12}\text{C})^{16}\text{O}$
(b) $^{16}\text{O}(^{12}\text{C}, \alpha^{12}\text{C})^{12}\text{C}$ $\qquad Q_\text{m} = -7.16195$

Angular distributions have been reported at many energies to $E(^{16}\text{O}) = 315$ MeV [see (1982AJ01)] and recently at $E(^{16}\text{O}) = 15.8$ to 26.3 MeV (1983FR02; elastic), 34.1 to 36.8 MeV (1982WI04; elastic), 62, 80, 100, 125 and 150 MeV (1985BE40; elastic) and 1503 MeV (1985RO08; elastic). See also (1986BRZY). Most of the studies of this reaction have involved yield and cross section measurements, as they apply to compound structures in ^{28}Si, fusion cross sections and evaporation residues: see (1982AJ01) and (1980CO08, 1981RA20, 1981TA24, 1982BR1P, 1982CO22,

1982FR04, 1982WI04, 1983CHZX, 1983FR02, 1983GO11, 1983KA01 [alignment of ^{16}O*(6.13)], 1983KA10, 1983LA07, 1983ME04, 1983ME10, 1983SC29, 1983VO1A, 1984BE22, 1984HU02, 1984MU04, 1985BE40, 1985CA01, 1985KA03, 1985MU18). See also (1982HUZV, 1983DE1Y, 1983KL1A, 1984RU1A).

At $E(^{16}\text{O}) = 100$ MeV members of the $K^\pi = 0^+$ [^{16}O*(6.05, 6.92, 10.35, 16.3)] and $K^\pi = 0^-$ bands [^{16}O*(9.63, 11.60, 14.67)] are reported to be preferentially populated (1984PO01). In reaction (b), as well as in the scattering of 140 MeV ^{16}O on ^{13}C and ^{28}Si, ^{16}O*(9.83, 10.33, 11.04, 11.47, 11.98, 12.38, 12.98, 13.81, 14.75, 15.33, 17.76) with $J^\pi = 2^+, 4^+, 4^+, 2^+, 0^+, 1^-, 2^+, 4^+, 6^+, 3^-$, respectively, for the first ten states, are populated: the state at 11.5 MeV is preferentially populated (1984RA10). For the earlier work see (1982AJ01). See also (1982ST11, 1983SH26, 1984MU04, 1985KA1J). For pion emission see (1983NO1E).

See also (1981CO1W, 1982PR1A, 1983AZ1A, 1983CA1N, 1984TS07, 1985BE02), (1979GO1C, 1981BR1P, 1981ST1P, 1982BA1D, 1982BR1T, 1982CI1C, 1982EV1B, 1982KO1C, 1982LE1N, 1982MA2B, 1983BI13, 1983BR1R, 1983DU13, 1983HE1B, 1984FR1A, 1984GE1D, 1984HA53, 1984SN01, 1984TR1E, 1985BA1T, 1985BE1A, 1985CU1A, 1985GA1J, 1985SN1A) and (1981CA09, 1981DY02, 1981HU07, 1982AB1F, 1982BA22, 1982FL1B, 1982GE1B, 1982GU21, 1982HA42, 1982HA56, 1982HU1G, 1982KA35, 1982LO13, 1982ME12, 1983AD1E, 1983AU04, 1983BU15, 1983CI08, 1983CI09, 1983DE1U, 1983DE21, 1983DE2G, 1983FR23, 1983HU1C, 1983KA30, 1983LI1L, 1983MA29, 1983SM1B, 1983TA07, 1984BA26, 1984DE2B, 1984HA43, 1984IN03, 1984KA1H, 1984LA1L, 1984MAZT, 1984SA31, 1985AI1A, 1985BA63, 1985DEZV, 1985HU04, 1985HU1C, 1985KA1X, 1985KA28, 1985KO1J, 1985ME14, 1985NO1E, 1985SA1D, 1985TR1D, 1985VI09; theor.).

51. (a) ^{16}O(^{13}C, ^{13}C)^{16}O
(b) ^{16}O(^{14}C, ^{14}C)^{16}O

For elastic scattering studies see Table 16.23 in (1982AJ01). For yield and fusion measurements see (1982HE07, 1983DA02, 1985BE37). For the excitation of a number of states in ^{16}O in reaction (a) see (1984RA10) in reaction 50. See also (1983VO1B, 1985GA1M, 1985KA1J, 1986STZY), (1982LE1N, 1983DU13, 1985CU1A, 1985RE1C) and (1983FR23, 1984HA43, 1984IN03, 1986CI01; theor.).

52. (a) ^{16}O(^{14}N, ^{14}N)^{16}O
(b) ^{16}O(^{15}N, ^{15}N)^{16}O

For elastic scattering studies see Table 16.23 in (1982AJ01) and (1977AJ02) and (1983SR01; $E(^{16}\text{O}) = 35.1$ and 42.6 MeV; on ^{15}N; elastic). For yield and total fusion cross-section measurements see (1982AJ01) and (1982FI1G, 1983SR01, 1985NO1C). See also (1981ST1P, 1983BI13,

1983DA10, 1983DU13, 1984FR1A, 1985BE1A, 1985CU1A) and (1982HA42, 1982LO13, 1982OH05, 1982OK02, 1983CI08, 1984HA43, 1984IN03, 1985HU04, 1985KO1J; theor.).

53. ^{16}O(^{16}O, ^{16}O)^{16}O

The angular distributions for elastic scattering have been measured with $E(^{16}\text{O})$ up to 140.4 MeV [see (1982AJ01)] and, recently, at 14 to 26 MeV (1984WU04), 17 to 25 MeV (1983BI1H; prelim.), 31 to 32.6 MeV (1982STZR; prelim.) and 31 to 36 MeV (1983TI01, 1985TI05). At $E(^{16}\text{O}) = 53.6$ to 68.4 MeV angular distributions are reported involving ^{16}O*(6.05) [$J^\pi = 0^+$] (1982WEZR; prelim.). Coupled channels effects are important at energies a few times the Coulomb barrier (1985BA60). See also (1982BI1F) and (1977AJ02). For yield and fusion cross sections see (1982AJ01) and (1981GA33, 1982BI1F, 1982DE48, 1982WE07 [6.13 MeV γ], 1983BI1H, 1983TI01, 1984WU04, 1985BA60, 1985GA05, 1985NO1C, 1985TH03, 1985TI05, 1986TH01). See also (1982GA1G, 1982STZR, 1982WAZN, 1983DE1Y, 1984PO15, 1984TI1C, 1985LI04).

At $E(^{16}\text{O}) = 62.2$ MeV (1981BA55) observe ^{16}O*(0, 6.5) and see no evidence for a low-l window leading to deep inelastic scattering. For a study of the angular correlation of α-particles see (1982PE08). See also (1985GA1M), (1981RO1W, 1982BA1D, 1982SA1A, 1984FO1A, 1985BA1T; astrophysics), (1979GO1C, 1981BR1M, 1981BR1P, 1981ST1P, 1982CI1C, 1982KO1C, 1982PA1H, 1983BI13, 1983BR1R, 1983DU13, 1984BR1L, 1984FR1A, 1984HA53, 1984TR1E, 1985BE1A, 1985CU1A, 1986BE2H) and (1981CA09, 1981FR1N, 1981GI10, 1981HU07, 1981IS1B, 1981KH03, 1981LA1G, 1981LE20, 1981PA09, 1981PI1D, 1981PR07, 1981SA33, 1981SH1L, 1981TA20, 1981UR01, 1982BA22, 1982HA29, 1982HA42, 1982HA56, 1982HE1G, 1982IS1C, 1982LO13, 1982MO1V, 1982NE1E, 1982PR04, 1982SA1C, 1982SA14, 1982SA20, 1982SC24, 1982SM1D, 1982SO1C, 1983BU15, 1983CI08, 1983DI15, 1983DR01, 1983DR02, 1983FA08, 1983FR23, 1983HO1F, 1983KA40, 1983LA14, 1983LA19, 1983LA20, 1983MA29, 1983NA1J, 1983OK06, 1983RO16, 1983SA14, 1983SA36, 1983TA1G, 1983TO1Q, 1984BA65, 1984BR1P, 1984CA28, 1984FA05, 1984FO21, 1984HA43, 1984IN03, 1984JO06, 1984LA1L, 1984MI1P, 1984NA15, 1984OS06, 1984RE09, 1984RE08, 1984SA08, 1984SU02, 1984WO02, 1985BO1Y, 1985BR1K, 1985CH34, 1985CU01, 1985CU1E, 1985GA1R, 1985HO1K, 1985HU04, 1985CH18, 1985KO1J, 1985LA14, 1985LE25, 1985MA09, 1985MA21, 1985NE1H, 1985PA14, 1985TA06, 1985TO07, 1985TO06, 1985TO17, 1985WO08, 1985WU03, 1986HO1U, 1986NG1A, 1986ST1N; theor.).

54. (a) ^{16}O(^{17}O, ^{17}O)^{16}O
(b) ^{16}O(^{18}O, ^{18}O)^{16}O

Angular distributions of elastically scattered ions have been studied at $E(^{16}\text{O}) = 24$, 28 and 32 MeV and $E(^{17}\text{O}) = 53.0$ to 66 MeV (reaction (a)) and at $E(^{16}\text{O}) = 24$ to 54.8 MeV and $E(^{18}\text{O}) = 35$ to 89.3 MeV (reaction (b)) [see (1982AJ01)] and, recently, at $E(^{17}\text{O}) = 22$ MeV (1983BU08). Yields and fusion cross sections are reported in (1982AJ01) and (1985TH03, 1986TH01). See also

(1985GA1M), (1982HO1E, 1983DU13, 1983FR1B, 1984HA53) and (1981CA09, 1981LA16, 1983SH04, 1985MA1T, 1985WU03; theor.).

55. (a) ^{16}O(^{19}F, ^{19}F)^{16}O
(b) ^{16}O(^{20}Ne, ^{20}Ne)^{16}O

Elastic scattering angular distributions have been studied at $E(^{16}\mathrm{O}) = 21.4$ and 25.8 MeV and at $E(^{19}\mathrm{F}) = 33$ and 36 MeV: see (1977AJ02). See also (1983DU13). Angular distributions in reaction (b) have been measured at $E(^{16}\mathrm{O}) = 40.7$ to 94.8 MeV and at $E(^{20}\mathrm{Ne}) = 50$ MeV [see (1982AJ01)] and at $E(^{16}\mathrm{O}) = 25.6$ to 44.5 MeV (1984GA22) and 44.1 to 63.9 MeV [see (1983KO31)]. For yield and fusion cross section measurements see (1982SC13, 1982SH1N, 1982XA01, 1983SH25, 1984GA22). See also (1981BR1P, 1983BR1R, 1983DU13, 1986ST1J) and (1982SM1D, 1983KO31, 1983MA29, 1984NI1D, 1985GU1J, 1985IC01, 1985KO43, 1985KO38; theor.).

56. (a) ^{16}O(^{23}Na, ^{23}Na)^{16}O
(b) ^{16}O(^{24}Mg, ^{24}Mg)^{16}O
(c) ^{16}O(^{25}Mg, ^{25}Mg)^{16}O
(d) ^{16}O(^{26}Mg, ^{26}Mg)^{16}O

Elastic angular distributions are reported at $E(^{16}\mathrm{O}) = 35$ to 60.7 MeV (reaction (b)) and 27.4 to 50 MeV (reaction (d)) [see (1982AJ01)] and at $E(^{16}\mathrm{O}) = 150$ MeV (1982HUZV; reaction (b); elastic). Yield, evaporation residue and fusion measurements have been made by (1982HUZV, 1982RA25, 1983FU03, 1983KOZZ, 1983ROZZ, 1985SAZZ) and see (1982AJ01). See also (1985RA06), (1981SC1N, 1982BR1T, 1982CI1C, 1982MA2B, 1983BI13, 1983DU13, 1983HE1B, 1984FR1A) and (1981HU07, 1981KR13, 1982BRZE, 1982FL1B, 1982HA56, 1982LO13, 1982NE1E, 1982PA09, 1982SM1D, 1983CI08, 1983MA29, 1983PA1C, 1983PA1F, 1984DE08, 1984GU13, 1984MU1H, 1985AN16, 1985CH11, 1985HA11, 1985HU04, 1985NI1C, 1985XI01, 1986NG1A; theor.).

57. ^{16}O(^{27}Al, ^{27}Al)^{16}O

An elastic angular distribution has been measured at $E(^{16}\mathrm{O}) = 46.5$ MeV: see (1982AJ01). For yield, fusion and evaporation residue studies see (1982AJ01) and (1983CH04, 1983ST1L, 1985IK02, 1985PA08). See also (1984PE11). For fragmentation studies see (1981TA16, 1985DEZZ, 1985SH1Q); for work on deeply inelastic collisions see (1982YO01). For pion production see (1985OB1B, 1986YO02). Angular correlations have been studied at $E(^{16}\mathrm{O}) = 65 - 65.6$ MeV

(1977HA18, 1981TS01, 1986PA05), 77 MeV (1985PA08) and 87.4 MeV (1983SA07). The sequential decay of ^{16}O*(10, 11.6, 13.2, 15.2, 16.2, 21) is reported via α_0 by (1983SA07). See also (1981LYZY, 1984TR06, 1985BE02), (1983BI13, 1983DU13, 1984FR1A, 1984GE1D, 1984HA53, 1984NG1A, 1985SH1T, 1985ST1B) and (1981AFZZ, 1982BL12, 1982FL1B, 1982GI1C, 1982HA56, 1982HU1G, 1982ME12, 1982TO04, 1982WO1C, 1983CI08, 1983GO13, 1983VI1D, 1984FO21, 1984NI05, 1985FO1F, 1985HU04, 1986NG1A, 1986PR01; theor.).

58. (a) ^{16}O(^{28}Si, ^{28}Si)^{16}O
    (b) ^{16}O(^{29}Si, ^{29}Si)^{16}O
    (c) ^{16}O(^{30}Si, ^{30}Si)^{16}O
    (d) ^{16}O(^{31}P, ^{31}P)^{16}O

Angular distributions for reaction (a) have been reported at $E(^{16}\text{O}) = 32$ to 215.2 MeV [see (1982AJ01)] and, recently, at $E(^{16}\text{O}) = 29.3$ to 35 MeV and $E(^{28}\text{Si}) = 51.3$ to 61.3 MeV (1984ME01; also ^{28}Si*), at $E(^{16}\text{O}) = 30.6$ and $E(^{28}\text{Si}) = 53.6$ MeV (1983KA20), at $E(^{16}\text{O}) = 33.2$ to 54.7 MeV (1981BR13; also ^{28}Si*), at $E(^{16}\text{O}) = 45$ to 63 MeV (1983SH18) and 75 MeV (1986SA2Q). Elastic angular distributions for reactions (b) and (c) are reported at $E(^{16}\text{O}) = 60$ MeV (1983SH18). For yield, fusion cross section and evaporation residue measurements see (1982AJ01) and (1981BR13, 1983KA20, 1983SH18, 1984ME01). See also (1983ROZZ). For the excitation of a number of states in ^{16}O see (1984RA10) in reaction 50. For pion production see (1983AGZX).

See also (1981SC1N, 1982BR1T, 1982KO1C, 1982LE1N, 1982MA2B, 1983BR1R, 1983DU13, 1984FR1A, 1984HA53) and (1981FR1L, 1981LA12, 1981SH24, 1982AL02, 1982BRZE, 1982DO05, 1982FR09, 1982HA29, 1982LO13, 1983BR1M, 1983BR18, 1983BR1U, 1983CA11, 1983CI08, 1983DI05, 1983HO18, 1983HU1C, 1983KA30, 1983KO06, 1983MA29, 1983PO08, 1983QU01, 1983SA1D, 1983SH08, 1983SH17, 1983SI07, 1983ST1F, 1983WI1H, 1984BR1N, 1984BR28, 1984GU09, 1984HU05, 1984HU06, 1984HU1N, 1984KO15, 1984KO30, 1984PO12, 1984PO1M, 1984QU03, 1985AN16, 1985BA12, 1985BA42, 1985BR02, 1985BR1J, 1985BR25, 1985BR26, 1985DE23, 1985HO24, 1985HU04, 1985QU02, 1985SH1R, 1985VI09, 1985XI01, 1986HN01, 1986NG1A; theor.).

59. (a) ^{16}O(^{40}Ca, ^{40}Ca)^{16}O
    (b) ^{16}O(^{42}Ca, ^{42}Ca)^{16}O
    (c) ^{16}O(^{44}Ca, ^{44}Ca)^{16}O
    (d) ^{16}O(^{48}Ca, ^{48}Ca)^{16}O
    (e) ^{16}O(^{48}Ti, ^{48}Ti)^{16}O

Elastic angular distributions are reported on ^{40}Ca at $E(^{16}\text{O}) = 50$ to 214.1 MeV [see (1982AJ01)] and at $E(^{16}\text{O}) = 60$ MeV (1982RE03; also on ^{42,44}Ca; also inelastic distributions involving

Ca*) and at 150 MeV (1983STZW). Elastic angular distributions have been measured on ^{48}Ca at $E(^{16}\mathrm{O}) = 60$ MeV [see (1982AJ01)] and at 56 MeV (1982RE03; also ^{48}Ca*) and 158.2 MeV (1982HU10; also ^{48}Ca*). Yield, fusion cross section and evaporation residue measurements are reported in (1982AJ01) and by (1981KU10, 1983CH04, 1983IKZZ, 1983ROZZ, 1983ST1L, 1985BU16, 1986NA01). See also (1984SAZX). For a measurement of the total non-fusion reaction cross section at $E(^{16}\mathrm{O}) = 158.2$ MeV (reaction (d)) see (1982HU10). For a study of deep inelastic collisions at 142 MeV (reaction (d)) see (1982WA03). For reaction (e) see (1985RI01).

See also (1981TAZU, 1981TEZZ), (1981SC1N, 1982BR1T, 1983BI13, 1984FR1A, 1984MA2E, 1986BE2H) and (1981BO31, 1981HU07, 1981IS1B, 1981KR14, 1981KU09, 1981KU03, 1982AL02, 1982BE58, 1982BL12, 1982BRZE, 1982DA02, 1982HA56, 1982KO25, 1982NE1E, 1982NG1B, 1982SA07, 1982ST08, 1982WO1D, 1983BR1U, 1983CI08, 1983GO09, 1983GO13, 1983HU1C, 1983OK06, 1983PO08, 1983TO03, 1983TO1K, 1983TO1Q, 1983VI1D, 1983WI1H, 1983WO08, 1984GO13, 1984GU09, 1984HU1Q, 1984MA2K, 1984YA08, 1985AN16, 1985BL01, 1985GO01, 1985HU04, 1985ME14, 1985PA27, 1985QU02, 1985SA03, 1985ST20, 1985ST25, 1985UD02, 1985YA1H, 1986GA01, 1986MA04, 1986WA08; theor.).

60. $^{17}\mathrm{O}(\gamma, \mathrm{n})^{16}\mathrm{O}$ $\qquad Q_\mathrm{m} = -4.1436$

See (1981HO1H, 1985JU02) and ^{17}O.

61. $^{17}\mathrm{O}(\mathrm{p, d})^{16}\mathrm{O}$ $\qquad Q_\mathrm{m} = -1.9191$

Angular distributions for the ground state deuteron group have been studied at $E_\mathrm{p} = 8.62$ to 11.44 MeV. At $E_\mathrm{p} = 31$ MeV, angular distributions are reported for the deuterons corresponding to ^{16}O*(0, $6.05 + 6.13$, 7.12, 8.87, 10.36, 12.97, 13.26). States at $E_\mathrm{x} = 15.22$ and 15.42 MeV were also observed. Spectroscopic factors were obtained from a DWBA analysis: see (1977AJ02).

62. $^{17}\mathrm{O}(\mathrm{d, t})^{16}\mathrm{O}$ $\qquad Q_\mathrm{m} = 2.1136$

Information obtained from this reaction at $E_\mathrm{d} = 52$ MeV is displayed in Table 16.20. Comparison of the (d, t) and (d, ^{3}He) reactions leads to assignments of analog states in ^{16}N and in ^{16}O [see Table 16.10 in (1982AJ01)]. A study of this reaction, the (d, ^{3}He) reaction, and reaction 63 below, suggests that there is more than 17% isospin mixing of the 2^- states ^{16}O*(12.97, 12.53): the corresponding mixing matrix element is $\geq 155 \pm 30$ keV. An isospin mixing matrix element of 110 ± 10 keV for the 4^- states of ^{16}O*(17.79, 18.98, 19.80) is compatible with the results from this reaction and with pion scattering. [See also reaction 40.]

63. ^{17}O(^{3}He, α)^{16}O $Q_{\rm m} = 16.4341$

Angular distributions have been reported at $E(^{3}{\rm He}) = 11$ MeV [see (1977AJ02)], at $E(^{3}{\rm He}) = 14$ MeV (1985PO17; α_0) and at $E(^{3}\overrightarrow{\rm He}) = 33$ MeV (1982KA12; to many states of ^{16}O). Table 16.20 displays some of the information derived from this reaction. For polarization measurements see (1982KA12) and ^{20}Ne in (1983AJ01, 1987AJ02). See also (1982AJ01).

64. ^{18}O(π^{+}, d)^{16}O $Q_{\rm m} = 130.3863$

See (1982DO01).

65. ^{18}O(p, t)^{16}O $Q_{\rm m} = -3.7061$

Angular distributions of tritons have been measured for $E_{\rm p} = 43.7$ MeV [see (1982AJ01)] and at $E_{\rm p} = 90$ MeV (1985VOZZ: to ^{16}O*(6.1, 6.92, 7.12, 9.84, 13.26, 16.35). The latter does no have $J^{\pi} = 0^{+}$ (1985VOZZ; prelim.). See, however, (1985BLZY; prelim.). The population of ^{16}O*(22.7, 24.5) is consistent with $L = 0$ and 2, respectively, and with assignments of $T = 2$, $J^{\pi} = 0^{+}$ and 2^{+}. The decay of ^{16}O*(22.7), J^{π}; $T = 0^{+}$; 2, is via α_0, α_1 and α_2 [^{12}C*(0, 4.4, 7.7)] with (1.6 ± 0.7), (1.9 ± 0.7) and (14 ± 2)% branches and $\Gamma_{\rm i}({\rm eV}) = 190 \pm 100$, 230 ± 110 and 1680 ± 550 eV, respectively; via $\rm p_0$, $\rm p_{1+2}$, $\rm p_3$ with (7 ± 2), (11 ± 2) and (5 ± 2)% branches and $\Gamma_{\rm i}({\rm eV}) = 840 \pm 343$, 1320 ± 454 and 600 ± 300 eV; and via $\rm n_{1+2}$ with a (23 ± 15)% branch [$\Gamma_{\rm n} = 2760 \pm 1970$ eV] (the $\rm n_0$ branch is < 15%) [$\Gamma_{\rm i}$ are based on a total width of 12 ± 3.5 keV]. See also (1982AJ01), ^{19}F in (1987AJ02) and (1982GO10, 1982NA1H, 1985BA1A; theor.).

66. ^{18}O(α, ^{6}He)^{16}O $Q_{\rm m} = -11.213$

Angular distributions have been measured at $E_{\alpha} = 58$ MeV to ^{16}O*(0, 6.1, 6.92, 7.12). Groups at $E_{\rm x} = 10.4$, 13.3 ± 0.1 and 16.3 ± 0.1 MeV were also observed: see (1977AJ02).

67. ^{18}O(^{18}O, ^{20}O)^{16}O $Q_{\rm m} = -0.624$

Angular distributions involving $^{16}{\rm O}_{\rm g.s.}$ and ^{20}O states are reported at $E(^{18}{\rm O}) = 24$ to 36 MeV and at 52 MeV: see (1982AJ01).

68. ^{19}F(p, α)^{16}O $Q_{\rm m} = 8.1137$

Angular distributions have been measured at many energies up to $E_\mathrm{p} = 44.5$ MeV [see (1982AJ01)] and at $E_\mathrm{p} = 1.55$ to 2.03 MeV (1978DE1D; α_0, α_1), 1.66 to 1.86 MeV (1985OU01; α_0), 10.0 to 11.4 MeV (1984IN04; ^{16}O*(0, 6.05, 6.13, 6.92, 7.13, 8.87, 9.84, 10.36, 10.96, $11.08 + 11.10$)). See also Table 16.31 in (1971AJ02).

The internal conversion to pair production ratio of the E0 transition ^{16}O*$(6.05 \rightarrow \mathrm{g.s.})$ $[0^+ \rightarrow 0^+]$ is $(4.00 \pm 0.46) \times 10^{-5}$. The ratio of double γ-emission to pair production $\Gamma_{\mathrm{E1E1}}/\Gamma_{\mathrm{E0}(\pi)} = (2.5 \pm 1.1) \times 10^{-4}$. τ_m for ^{16}O*(6.05, 6.13) are 96 ± 7 psec and 26.6 ± 0.7 psec, respectively. See (1982AJ01) for references. $|g|$ for ^{16}O*$(6.13) = 0.556 \pm 0.004$ (1984AS03). For γ-ray branching ratios and mixing ratios see Table 16.11 and (1982VE04).

See also ^{20}Ne in (1983AJ01, 1987AJ02), (1981KE1E, 1982MA1V, 1983GA18, 1983KN01, 1984KN1A, 1985ISZU, 1985LO1C), (1981DO1G, 1983TO1F, 1984DU1H, 1985TO1J; applied) and (1983IN1B).

69. ^{19}F(^{3}He, ^{6}Li)^{16}O $\qquad Q_\mathrm{m} = 4.0954$

See (1977AJ02).

70. (a) ^{20}Ne(γ, α)^{16}O $\qquad Q_\mathrm{m} = -4.734$

(b) ^{20}Ne(p, pα)^{16}O $\qquad Q_\mathrm{m} = -4.734$

See (1984CA09; reaction (b)) and (1982RA1M, 1982SA1A; astrophysics). See also (1982AJ01) and ^{20}Ne in (1983AJ01, 1987AJ02).

71. ^{20}Ne(d, ^{6}Li)^{16}O $\qquad Q_\mathrm{m} = -3.2589$

Angular distributions have been studied at E_d to 80 MeV: see (1982AJ01). At $E_\mathrm{d} = 55$ MeV ^{16}O*(0, 6.05, 6.13, 6.92, 9.8, 11.10) are strongly populated (1981JAZV; prelim.). See also (1984CO08; theor.).

72. ^{23}Na(d, ^{9}Be)^{16}O $\qquad Q_\mathrm{m} = -3.006$

The angular distribution to $^{16}\mathrm{O}_{\mathrm{g.s.}}$ has been measured at $E_\mathrm{d} = 13.6$ MeV (1981RU09).

73. ^{24}Mg(α, ^{12}C)^{16}O $\qquad Q_\mathrm{m} = -6.7712$

Angular distributions have been reported at $E_\alpha = 22.8$ to 25.4 MeV and at 90.3 MeV, the latter to ^{16}O*(0, 6.1, 7.0, 8.8, 9.8, 10.3) [see (1982AJ01)] and at $E_\alpha = 25.1$ to 27.8 MeV (1986SK01).

74. ^{24}Mg(^{12}C, ^{20}Ne)^{16}O $\qquad Q_{\rm m} = -2.150$

At $E(^{12}\text{C}) = 40$ MeV the ground state angular distribution has been studied by (1982LI16).

^{16}F

(Fig. 4 and 5)

GENERAL: (See also (1982AJ01).)

For reactions involving pions see (1983AS01, 1984AS05) and reaction 2. See also (1982BR08, 1983ANZQ, 1983AN25, 1983CO15, 1983KO2B, 1986YA1Q, 1986YA1F).

For a comparison of analog states in ^{16}O and ^{16}F see (1982FA06, 1983KE06, 1984ST10). See also (1985AN28, 1985HA01).

1. (a) ^{14}N(^{3}He, n)^{16}F $\quad Q_{\rm m} = -0.957$
   (b) ^{14}N(^{3}He, np)^{15}O $\quad Q_{\rm m} = -0.421$

Observed neutron groups from reaction (a) and results from reaction (b) are displayed in Table 16.25.

2. ^{16}O(γ, π^-)^{16}F $\quad Q_{\rm m} = -154.984$

See (1983JE08).

3. ^{16}O(p, n)^{16}F $\quad Q_{\rm m} = -16.199$

Observed neutron groups are displayed in Table 16.25. Angular distributions have recently been studied at $E_{\rm p} = 35$ MeV (1982OR04; n_0, n_1) and (1982OH03; to ^{16}F*(6.37)), at $E_{\rm p} = 99.1$ and 135.2 MeV (1982FA06; see Table 16.25) and at $E_{\bar{\rm p}} = 135.2$ MeV (1982MA11; to ^{16}F*(6.37)). See also (1983MAZG, 1985FLZZ). (1982AN08) have compared (p, n) cross sections with B(M1). See also ^{17}F, (1984BA1R, 1985OR1G), (1984LI25, 1985OR1H) and (1984BO1N, 1984GAZP, 1984OR01, 1985GA1N, 1985GA11, 1985YA10; theor.).

4. ^{16}O(^{3}He, t)^{16}F $\quad Q_{\rm m} = -15.436$

Observed triton groups are shown in Table 16.25. Angular distributions at $E(^{3}{\rm He}) = 81$ MeV, analyzed by DWBA, and angular correlation measurements [mainly involving protons to ^{15}O*(0, 6.18)], together with information from reactions 1 and 3, lead to the J^{π} values shown in the table (1984ST10). The analog of the giant dipole resonance [$E_{\rm x} \approx 9.5$ MeV] is strongly excited. The magnetic quadrupole strength has two strong components in ^{16}F*(0.42, 7.5) (1984ST10). The 4^- state at 6.4 MeV and the GDR have also been observed by (1982TA05; $E(^{3}{\rm He}) = 170$ MeV). See also (1984VA17) and (1982AJ01).

Table 16.24: Energy levels of ^{16}F

E_x (MeV ± keV)	$J^\pi; T$	$\Gamma_{\rm c.m.}$ (keV)	Decay	Reactions
0	$0^-; 1$	40 ± 20 [a]	p	1, 2, 3, 4, 5, 6
0.193 ± 6	1^-	< 40 [a]	p	1, 3, 4, 6
0.424 ± 5	2^-	40 ± 30	p	1, 3, 4, 6
0.721 ± 4	3^-	< 15	p	1, 3, 4, 6
3.758 ± 6	1^+	< 40	p	1, 3, 4, 6
3.870 ± 6	2^+	< 20	p	1, 4, 6
4.372 ± 6	3^+	50 ± 20	p	1, 3, 4, 6
4.654 ± 6	1^+	60 ± 20	p	1, 3, 4, 6
(4.71 ± 20)				6
4.977 ± 8	(2^+)	60 ± 40	p	1, 4, 6
5.272 ± 8	(1^-)		p	1, 3, 4
5.404 ± 10	4		p	1, 4, 6
5.449 ± 14			p	1
5.524 ± 9	$\pi = +$		p	1, 4, 6
(5.57 ± 20)			p	1
5.856 ± 10	2^-		p	1, 3, 4
(6.05 ± 20)				6
6.224 ± 14				1, 3
6.372 ± 9	4^-			1, 3, 4
6.559 ± 10	$(3^- + 1^-)$		p	4
6.679 ± 8		≤ 45		1, 4, 6
(6.93 ± 20)				6
7.110 ± 20				1
7.50 ± 30	2^-	950 ± 100	p	3, 4
7.90 ± 15		< 100		1, 3, 4
9.50 ± 30	$1^-(+2^-)$	1050 ± 100	p	3, 4
9.60 ± 20		250 ± 50		4
11.50 ± 50	$1^-(+2^-)$	1900 ± 500	p	3, 4

[a] (1984ST10) report $\Gamma_{\rm c.m.} \approx 25$ and ≈ 100 keV for ^{16}F*(0, 0.19).

Table 16.25: ^{16}F levels from ^{14}N(^{3}He, n),^{16}O(p, n), ^{16}O(^{3}He, t) and ^{19}F(^{3}He, ^{6}He) [a]

^{16}F* [b] (MeV ± keV)	L [b]	^{16}F* [c] (MeV ± keV)	J^{π} [d]	^{16}F* [e] (MeV ± keV)	Δl [f]	^{16}F* [g] (MeV ± keV)	^{16}F* [h] (MeV ± keV)	$\Gamma_{\mathrm{c.m.}}$ [i] (keV)	J^{π} [j]
0	1	0	(1^-)	0		0	0	40 ± 20	0^-
0.192 ± 15	1	0.190 ± 20	(0^-)	0.197 ± 12		0.19 ± 20	0.192 ± 10	< 40	1^-
0.425 ± 15	3	0.425 ± 10	(≥ 2)	0.424 ± 5	1	0.425 ± 20	0.424	40 ± 30	2^-
0.722 ± 10	(3)	0.725 ± 10	(≥ 2)	0.720 ± 6	3	0.72 ± 20	0.722 ± 10	< 15	3^-
3.751 ± 10	0	3.775 ± 10 [k]	(1)	3.76	0	3.75 ± 20	3.740 ± 15 [n]	< 40	1^+
3.861 ± 10	2	3.880 ± 10 [k]	≥ 1			3.86 ± 20	3.873 ± 15 [n]	< 20	2^+
4.370 ± 10		4.375 ± 10 [k]	(≥ 2)	4.37	2	4.37 ± 20	4.372 [n]	50 ± 20	3^+
4.646 ± 10	0	4.661 ± 10 [k]	≥ 1	4.65	0	4.66 ± 20	4.652 ± 10 [n]	60 ± 20	1^+
						4.71 ± 20 [m]			
4.973 ± 10	2	4.97 ± 20 [l]	≥ 2			4.97 ± 20	5.007 ± 20	60 ± 40	(2^+)
5.264 ± 20		5.27 ± 20 [l]		5.27	1		5.274 ± 10 [n]		(1^-)
5.390 ± 20	2	5.40 ± 20 [l]				5.39 ± 20	5.414 ± 15		4
5.448 ± 20		5.45 ± 20 [l]							
5.528 ± 20	2	5.52 ± 20 [l]				5.53 ± 20	5.521 ± 15		$\pi = +$
		(5.57 ± 20) [l]							
5.840 ± 40				5.86	3		5.858 ± 10 [n]		2^-
						6.05 ± 20 [m]			
6.230 ± 50				6.22	0		6.224 ± 15		
6.371 ± 20				6.37	3		6.372 ± 10		4^-
							6.559 ± 10 [n]		
6.678 ± 10		6.68 ± 20 [l]	≥ 1			6.68 ± 20		≤ 45	$(3^- + 1^-)$
						6.93 ± 20 [m]			
7.110 ± 20									
				≈ 7.5	1		7.50 ± 30 [n,o]	950 ± 100	2^-
7.730 ± 40							7.90 ± 15	< 100	
				≈ 9.5	1		9.50 ± 30 [n,o]	1050 ± 100	$1^-(+2^-)$
							9.60 ± 20	250 ± 50	

Table 16.25: ^{16}F levels from ^{14}N(^{3}He, n),^{16}O(p, n), ^{16}O(^{3}He, t) and ^{19}F(^{3}He, ^{6}He) [a] (continued)

^{16}F* [b] (MeV ± keV)	L [b]	^{16}F* [c] (MeV ± keV)	J^{π} [d]	^{16}F* [e] (MeV ± keV)	Δl [f]	^{16}F* [g] (MeV ± keV)	^{16}F* [h] (MeV ± keV)	$\Gamma_{\rm c.m.}$ [i] (keV)	J^{π} [j]
				≈ 11.5	1		11.50 ± 50 [n,o]	1900 ± 500	$1^{-}(+2^{-})$

[a] See also Tables 16.33 in (1971AJ02) and 16.26 in (1982AJ01) for the earlier work and for references.

[b] ^{14}N(^{3}He, n)^{16}F.

[c] ^{14}N(^{3}He, np)^{15}O.

[d] From angular correlation studies.

[e] ^{16}O(p, n)^{16}F. $E_{\rm x}$ shown without uncertainties are from Table 16.24.

[f] (1982FA06; $E_{\rm p} = 99.1$ and 135.2 MeV).

[g] ^{16}O(^{3}He, t) and ^{19}F(^{3}He, ^{6}He)^{16}F.

[h] ^{16}O(^{3}He, t): (1984ST10; $E(^{3}{\rm He}) = 81$ MeV) and Dr. M. Harakeh (private communication).

[i] From (a) and (1984ST10, 1985HA01).

[j] From (a) and (1984ST10).

[k] See also (1985HA01).

[l] (1985HA01).

[m] Observed only in ^{19}F(^{3}He, ^{6}He).

[n] Decays to ^{15}O$_{\rm g.s.}$ by proton emission (1984ST10).

[o] Decays to ^{15}O*(6.18) (1984ST10).

5. (a) ^{16}O(^{6}Li, ^{6}He)^{16}F $\qquad Q_{\rm m} = -18.924$
(b) ^{16}O(^{7}Li, ^{7}He)^{16}F $\qquad Q_{\rm m} = -26.62$

See (1984GL06; $E(^{6}{\rm Li}) = 93$ MeV, $E(^{7}{\rm Li}) = 78$ MeV).

6. ^{19}F(^{3}He, ^{6}He)^{16}F $\qquad Q_{\rm m} = -14.828$

See Table 16.25 and (1982AJ01).

^{16}Ne

(Fig. 5)

GENERAL: (See also (1982AJ01).)

See (1981SEZR, 1983ANZQ, 1985AN28, 1985MA1X).

Mass of ^{16}*Ne*: The Q-values of the ^{20}Ne(α, ^{8}He) and ^{16}O(π^{+}, π^{-}) reactions lead to atomic mass excesses of 23.93 ± 0.08 MeV (1978KE06), 23.978 ± 0.024 MeV (1983WO01) and 24.048 ± 0.045 MeV (1980BU15) [recalculated using the (1985WA02) masses for ^{8}He, ^{16}O and ^{20}Ne]. The weighted mean is 23.989 ± 0.020 MeV which is also the (1985WA02) value. ^{16}Ne is then bound with respect to decay into ^{15}F + p by 0.07 MeV and unbound with respect to ^{14}O + 2p by 1.40 MeV.

1. ^{16}O(π^{+}, π^{-})^{16}Ne $\qquad Q_{\rm m} = -24.77$

Angular distributions to ^{16}Ne$_{\rm g.s.}$ have been studied at $E_{\pi^{+}} = 120$ and 200 MeV (1984GI05) and at 164 MeV (1983GR07). For the ground state cross section for $E_{\pi^{+}} = 80$ to 292 MeV see (1982GR02, 1982GR1F) and the analysis in (1982BL20, 1984GI05, 1985GI06). See also (1982AJ01, 1982IN1A, 1982MO12, 1984BA1B, 1985WO1C).

2. ^{20}Ne(α, ^{8}He)^{16}Ne $\qquad Q_{\rm m} = -60.21$

At $E_{\alpha} \approx 117.5$ MeV, ^{16}Ne*(0, 1.69 ± 0.07) are populated, the former with a differential cross section of 5 ± 3 nb/sr at 8° (lab). The $\Gamma_{\rm c.m.}$ for the ground state group is 200 ± 100 keV; applying penetrability corrections leads to a total decay width of $5 - 100$ keV. The di-proton branching ratio is $10 - 90$%, with the most probable value being 20%. The cubic term, b, in the IMME is 8 ± 5

Table 16.26: Energy levels of ^{16}Ne

$E_{\rm x}$ (MeV $\pm$ keV)	$J^\pi; T$	$\Gamma_{\rm c.m.}$ (keV)	Decay	Reactions
0	0^+; 2	122 ± 37	p	1, 2
1.69 ± 0.07	(2^+); 2		(p)	2

keV, $15 \pm d$ keV based, respectively, on the masses of ^{16}Ne*(0, 1.69). The first $T = 2$ states in ^{16}F[0^+, 2^+] are predicted to lie at $E_{\rm x} = 10.08 \pm 0.02$ and 11.87 ± 0.03 MeV (1978KE06). At $E_\alpha = 129$ MeV (1983WO01) find $\Gamma_{\rm c.m.}$ for ^{16}Ne$_{\rm g.s.}$ $= 110 \pm 40$ keV and the d and e coefficients in the IMME are both 4 ± 3 keV.

^{16}Na, ^{16}Mg, ^{16}Al, ^{16}Si

(Not observed)

See (1983ANZQ; theor.).

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