Energy Levels of Light Nuclei
$A = 16$

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Abstract: An evaluation of $A = 16$–17 was published in *Nuclear Physics A*375 (1982), 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 July 1, 1981)

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^{16}He

(Not illustrated)

This nucleus has not been observed. See also (1978NA07; 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 2.4 MeV (1974TH01). See also (1981SE06; 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 (1974BO05). Its mass excess is predicted to be 37.97 MeV: it would then be unstable with respect to decay into ^{15}B+n by 0.9 MeV [mass excess calculated using the transverse form of the mass equation] (1974TH01, 1975JE02). See also (1981SE06; theor.).

^{16}C

(Figs. 1 and 5)

GENERAL: See also (1977AJ02).

Experimental work: (1977AR06, 1981CH1U).

Theoretical work: (1979AL22).

Mass of ^{16}C: The atomic mass excess of ^{16}C based on the ^{14}C(t, p) Q_0 measurements of (1977FO09, 1978SE04) and on the (1977WA08) masses for ^{14}C, t and p is 13694 ± 4 keV.

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

The half-life of ^{16}C is 0.747 ± 0.008 sec: it decays to ^{16}N*(3.34, 4.32) [both $J^\pi = 1^+$] with branchings of 84% and 16% respectively [$\log ft = 3.55$, 3.83]; see Table 16.2 (1976AL02). See also (1978FO10).

Table 16.1: Energy levels of ^{16}C

E_x (MeV ± 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, 3
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 [a]

Decay to ^{16}N* (MeV)	J^π	Branch (%)	log ft
0.120	0^-	< 0.5 [b]	> 6.85
0.297	3^-	< 0.5 [b]	> 6.83
0.398	1^-	< 0.7 [b]	> 6.64
3.36	1^+	84.4 ± 1.7	3.551 ± 0.012
4.32	1^+	15.6 ± 1.7	3.83 ± 0.05

[a] (1976AL02).

[b] The combined branching to ^{16}N*(0.120, 0.297, 0.398) is $<$ 1.2% (1976AL02).

Table 16.3: States of ^{16}C from ^{14}C(t, p)

E_x (keV)		L [a]	J [b]
(1977FO09)	(1978SE04)		(1977BA59)
0	0	0	
1766 ± 10	1.77 [e]	2	2
3020 ± 15	3039 ± 20	(0) [c]	
3983 ± 10	3990 ± 10	(2) [c]	2 [f]
4083 ± 10	4094 ± 10	(3) [c]	3 [g]
4136 ± 10	4194 ± 10	4	4
6109 ± 15 [d]		2, 3, 4	

[a] From angular distribution measurements analyzed by DWBA $E_t = 18$ MeV (1977FO09) and 23 MeV (1978SE04).

[b] From $\gamma\gamma$ correlation measurements at $E_t = 12$ MeV (1977BA59).

[c] This state is weakly excited.

[d] $\Gamma \leq 25$ keV.

[e] State observed but E_x not determined.

[f] (1978SE04) suggest that the state is 2^- by comparison with the transition to ^{14}C*(7.38).

[g] The very low intensity of the proton group to ^{16}C*(4.14) suggests $J^\pi = 3^+$: see e.g. (1978SE04).

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

$Q_0 = -3015 \pm 8$ keV (1977FO09);

$Q_0 = -3013 \pm 4$ keV (1978SE04).

Observed proton groups are displayed in Table 16.3 (1977FO09, 1978SE04), together with the angular correlation results of (1977BA59). The similarities in the spectra of ^{14}C and ^{16}C are discussed by (1978FO06, 1978SE04). See also (1977FO1E, 1978FO10).

3. ^{14}C(^{18}O, ^{16}O)^{16}C $\qquad Q_m = 6.720$

See (1977AJ02).

^{16}N

(Figs. 2 and 5)

GENERAL: See also (1977AJ02).

Model calculations: (1979RO1J, 1980HA35).

Reactions involving muons: (1977BO23, 1977ER04, 1977NA1N, 1978GU07, 1978PA1F, 1978RO1P, 1979ER07, 1979GU06, 1979GU08, 1979HO07, 1979KI1G, 1979RH1A, 1979ST1Q, 1979WU10, 1980BR1A, 1980CH03, 1980GR05, 1981EI1A).

Reactions involving pions: (1977AL1W, 1977BA1Q, 1977BE2L, 1977ER04, 1977HO13, 1977SH1C, 1977SU1L, 1978FU09, 1978NA1N, 1978OH03, 1979BO21, 1979DE1W, 1979ER07, 1979KN1G, 1979NA1J, 1979PE1C, 1979SR1B, 1979TR1B, 1979WI1E, 1979WI1A, 1980BO1B, 1980BO24, 1980DE29, 1980GR05, 1980ST15, 1980WU01, 1981YA1A).

Other topics: (1976LE1F, 1977AR06, 1977BA22, 1977BR03, 1977HA1L, 1978BU1B, 1978FO10, 1978GA1C, 1978GE1C, 1978HE1C, 1978KO01, 1978LE15, 1979AB04, 1979AL22, 1981GR08).

1. ^{16}N(β^-)^{16}O $\qquad$ $Q_{\rm m} = 10.418$

The half-life of ^{16}N is 7.13 ± 0.02 sec: see Table 16.3 in (1971AJ02). See also (1975SA1D). 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 beta decay of ^{16}N*(0.12) [$J^\pi = 0^-$, $\tau_{1/2} = 5.26 \pm 0.06$ μsec] to ^{16}O$_{\rm g.s.}$ has been studied: the β-decay rate $\lambda_\beta = 0.43 \pm 0.10$ sec^{-1} (1975PA01). See also (1977AK1B; applications) and (1977BO23, 1978GU07, 1979GU08, 1979KO39, 1979MU1B, 1979RH1A, 1980CH03, 1981CH1B, 1981TO1J; theor.).

2. (a) ^{9}Be(^{7}Li, t)^{13}C $\qquad$ $Q_{\rm m} = 8.181$ $\qquad$ $E_{\rm b} = 20.575$
   (b) ^{9}Be(^{7}Li, α)^{12}B $\qquad$ $Q_{\rm m} = 10.462$
   (c) ^{9}Be(^{7}Li, ^{8}Li)^{8}Be $\qquad$ $Q_{\rm m} = -17.613$

The yields of t$_0$ and of α_0, α_1 and α_2 have been measured for $E(^7{\rm Li}) = 4$ to 14 MeV at 0°: several broad peaks are observed (1971WY01). The yields of α_0 and α_2 have also been studied for $E(^7{\rm Li}) = 3.3$ and 5.0 to 6.2 MeV (1969SN02). The cross section for reaction (c) rises monotonically for $E(^7{\rm Li}) = 1.1$ to 4 MeV (1957NO17, 1959NO40).

3. ^{10}B(^{7}Li, p)^{16}N $\qquad$ $Q_{\rm m} = 13.989$

Table 16.4: Energy levels of ^{16}N

E_x (MeV $\pm$ keV)	$J^\pi; T$	τ or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
0	$2^-; 1$	$\tau_{1/2} = 7.13 \pm 0.02$ sec	β^-	1, 3, 10, 12, 13, 14, 15, 18, 19, 24, 25, 26, 28, 29
0.1201 ± 0.5	0^-	$\tau_m = 7.58 \pm 0.09$ μsec	γ, β^-	10, 12, 13, 14, 18, 21, 24, 28, 29
0.2970 ± 0.7	3^-	[a]	γ	5, 10, 12, 13, 14, 18, 19, 24, 26, 28, 29
0.3975 ± 0.7	1^-	$\tau_m = 5.6 \pm 0.3$ psec	γ	5, 10, 11, 12, 13, 14, 18, 21,
		$\|g\| = -18.3 \pm 0.13$		24, 28, 29
3.355 ± 5	1^+	$\Gamma = 15 \pm 5$	n	3, 10, 12, 16, 18, 20, 28
3.519 ± 5	2^+	3	n	3, 10, 12, 16, 18, 28
3.960 ± 5	3^+	≤ 2	n	3, 7, 10, 11, 12, 16, 18, 28
4.319 ± 5	1^+	20 ± 5	n	3, 10, 12, 16, 18, 19, 28
4.387 ± 6	1^-	82 ± 20	n	3, 10, 12, 16, 18, 28
4.76 ± 50	1^-	250 ± 50	n	12, 16, 18
4.776 ± 10	2^+	59 ± 8	n	10, 12, 16, 18, 28
(4.90 ± 10)				18
5.050 ± 6	2^-	19 ± 6	n	10, 12, 16, 18, 28
5.130 ± 7	≥ 2	$\leq 7 \pm 4$	n	10, 12, 16, 18
5.150 ± 7	$(2, 3)^-$	$\leq 7 \pm 4$	n	12, 16, 18, 28
5.232 ± 5	3^+	≤ 4	n	10, 12, 16, 18, 28
5.24	1^+	260	n	16
5.25 ± 70	2^-	320 ± 80	n	12, 18
5.518 ± 6	3^+	$\leq 7 \pm 4$	n	10, 12, 16, 18, 28
5.730 ± 6	(5^+)	$\leq 7 \pm 4$	n	7, 10, 11, 12, 16, 18, 28
6.009 ± 10	1^-	270 ± 30	n	12, 16, 28
6.168 ± 4	(4^-)	$\leq 7 \pm 4$	n	10, 12, 18, 26, 28
6.373 ± 6	(3^-)	30 ± 6	n	12, 16, 18, 26, 28
6.426 ± 7		300 ± 30		12, 18
6.513 ± 6	1^+	34 ± 6	n	12, 16, 18, 28
6.613 ± 6		$\leq 7 \pm 4$		12, 13, 14, 18, 28
6.848 ± 6		$\leq 7 \pm 4$		10, 12, 18, 28
(6.84)	≥ 2	> 140	n	16
7.02 ± 20	1^+	22 ± 5	n	12, 16, 18, 28
7.134 ± 7		$\leq 7 \pm 4$		10, 12, 18, 28

Table 16.4: Energy levels of ^{16}N (continued)

E_x (MeV ± keV)	$J^\pi; T$	τ or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
7.250 ± 7	≥ 2	17 ± 5	n	12, 16, 18, 28
7.573 ± 6	≥ 3	$\leq 7 \pm 4$	n	10, 12, 16, 18, 28
7.637 ± 5	$(3, 4, 5)^+$	$\leq 7 \pm 4$		7, 10, 11, 12, 18, 28
7.675 ± 5		$\leq 7 \pm 4$	n	7, 12, 13, 16, 18, 28
7.877 ± 9	≥ 4	100 ± 15	n	12, 16, 18, 28
8.048 ± 9		85 ± 15	n	12, 16, 28
8.182 ± 9	$(3, 2)^+$	28 ± 8		10, 12, 17
8.282 ± 8		24 ± 8		12, 28
8.365 ± 8	≥ 1	18 ± 8	n	12, 16, 28
8.49 ± 30	≥ 1	≤ 50	n	16, 28
8.72	≥ 1	40	n	16
8.819 ± 15		≤ 50	n	16, 28
9.035 ± 15		≤ 50		28
9.16 ± 30	≥ 2	100	n	16, 28
9.34 ± 30		≤ 50	n	16, 28
9.459 ± 15	≥ 2	100	n	16, 28
9.760 ± 10	$T = 1$	15 ± 8		10
9.813 ± 10	$T = 1$			10
9.928 ± 7	$0^+; T = 2$	< 12		10, 27
10.055 ± 15	≥ 3	30	n	16
10.27	≥ 2	165	n	16
10.71	≥ 2	120	n	16
11.49	≥ 3		n	6, 16
11.62	≥ 3	220	n, d	9
11.701 ± 7	$1^-, 2^+; T = 2$	< 12		10
(11.92)		390	n, d	9
(12.09)			n	6, 16
12.26		290	n, p, d	9
(12.46)			n	16
12.61		180	n, p, d	9
12.88		155	n, p, d	9
(12.97)		175	n, d	9
13.12			n, (d)	9, 16

Table 16.4: Energy levels of ^{16}N (continued)

E_x (MeV $\pm$ keV)	$J^\pi; T$	τ or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
13.83			n	16
14.41 ± 50	$(3)^+$	180	d	9

[a] The previously reported τ_m needs, in the opinion of the reviewer, to be remeasured: see (1971AJ02) for the previously reported value.

Angular distributions have been obtained at $E(^7\text{Li}) = 16$ MeV to ^{16}N*(3.36, 3.52, 3.96, 4.32, 4.39). The σ_t for ^{16}N*(3.36, 3.96, 4.32, 4.39), whose J^π are known, follow the $2J_f + 1$ relation. From the σ_t for ^{16}N*(3.52) it follows then that $J = 2$ if it is a single state or $J = 0$ and 1 (with one of the two states having odd parity) if the group corresponds to two unresolved states (1975FO10). See also (1971AJ02).

4. ^{11}B(^{6}Li, p)^{16}N $\qquad Q_m = 9.785$

See (1966MC05).

5. ^{11}B(^{7}Li, d)^{16}N $\qquad Q_m = 4.759$

See (1966MC05) and (1969TH01: $E_x = 297.6 \pm 0.9$ and 397.8 ± 1.0 keV).

6. ^{13}C(α, p)^{16}N $\qquad Q_m = -7.421$

At $E_\alpha = 50$ MeV proton groups are reported to ^{16}N*(5.1, 5.6, 7.6, 11.4, 12.1) (1976BU21). See also (1977FO1E, 1981HA1J).

7. ^{13}C(^{6}Li, ^{3}He)^{16}N $\qquad Q_m = 3.401$

At $E(^6\text{Li}) = 44$ MeV angular distributions to ^{16}N*(3.96, 5.73, 7.65, 11.21, 11.81) are strongly forward peaked (1977MA1B; prelim.).

8. ^{14}C(d, γ)^{16}N $\qquad Q_m = 10.474$

Table 16.5: Resonances in ^{14}C + d

E_d (MeV)	Resonant for	$\Gamma_{c.m.}$(keV)	E_x (MeV)	Refs.
1.30	n_0	220	11.61	(1961CH14, 1963IM01)
1.65	n_0	390	11.92	(1961CH14)
2.04	n_0, p	290	12.26	(1961CH14, 1963IM01, 1956DO37)
2.44	n_0, p	180	12.61	(1961CH14, 1956DO37)
2.75	n_0, p	155	12.88	(1961CH14, 1963IM01, 1956DO37)
2.86	n_0	175	12.97	(1961CH14)
(3.10)	n_0	(175)	(13.18)	(1961CH14)
4.50 ± 0.05	d_0	180 [a]	14.41	(1973CO31)

[a] $\Gamma_d = 45$ keV; $l_d = 4$; $J^\pi = 3^+, (4^+, 5^+)$ (1973CO31: $E_d = 4$ to 10 MeV).

The cross section has been measured for $1.2 < E_d < 2.6$ MeV. It shows some evidence of structure (1964NE09). See also (1971AJ02).

9. (a) ^{14}C(d, n)^{15}N $\quad Q_m = 7.9828$ $\quad E_b = 10.474$
(b) ^{14}C(d, p)^{15}C $\quad Q_m = -1.0065$
(c) ^{14}C(d, d)^{14}C
(d) ^{14}C(d, t)^{13}C $\quad Q_m = -1.9192$
(e) ^{14}C(d, α)^{12}B $\quad Q_m = 0.361$

Observed resonances for n_0, p and d_0 are displayed in Table 16.5. For polarization measurements in reaction (a) see (1977AJ02). For reaction (b) see also (1977AJ02). See also ^{12}B in (1968AJ02) and ^{13}C, ^{14}C, ^{15}C and ^{15}N in (1981AJ01).

10. ^{14}C(^{3}He, p)^{16}N $\quad Q_m = 4.981$

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.

11. ^{14}C(α, d)^{16}N $\quad Q_m = -13.373$

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

E_x (MeV ± keV)		Γ (keV)	$J^\pi; T$
(1966GA08)	(1968HE03, 1972FR05)		
0.121 ± 6			0^-
0.298 ± 6			3^-
0.396 ± 7			
3.348 ± 7			1^+
3.517 ± 7			2^+, $(3)^+$
3.958 ± 7			$(2)^+$, 3^+
4.313 ± 9			1^+
4.386 ± 9			
4.768 ± 11			
5.052 ± 9			
5.137 ± 9			
5.234 ± 9			$(1, 2, 3)^+$
	5.512 ± 5		$(1, 2, 3)^+$
	5.724 ± 5		5^+
	6.168 ± 5		
	6.843 ± 5		
	7.113 ± 5		
	7.570 ± 5		
	7.636 ± 5		
	7.673 ± 5		
	8.205 ± 5		
	9.760 ± 10	15 ± 8	$T = 1$
	9.813 ± 10		$T = 1$
	9.928 ± 7	< 12	0^+; 2
	11.701 ± 7	< 12	1^-, 2^+; 2

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

(1966HE10)		L [a]	J^{π} [a]
E_x (MeV ± keV)	Γ (keV)		
0		3	2^- [b]
0.120 ± 10		1	0^- [b]
0.300 ± 10		3	3^- [b]
0.399 ± 10		1	1^- [b]
3.359 ± 10	15 ± 5	0	1^+ [b]
3.519 ± 10	≤ 7 ± 4	[c]	
3.957 ± 10	≤ 7 ± 4	2	3^+ [b]
4.318 ± 10	20 ± 5	0	1^+ [b]
4.391 ± 10	82 ± 20	1	1^- [b]
4.725 ± 10 [d]	290 ± 30	1	1^-
4.774 ± 10	59 ± 8	2	2^- [b]
5.053 ± 10	19 ± 6	(1 + 3)	2^-
5.130 ± 10	≤ 7 ± 4	[c]	
5.150 ± 10	≤ 7 ± 4		
5.226 ± 10	≤ 7 ± 4	2	$(1, 2, 3)^+$
5.305 ± 10 [d]	260 ± 30	[c]	
5.520 ± 10	≤ 7 ± 4	(0, 1) + 2 + 4 [e]	
5.730 ± 10	≤ 7 ± 4	(1, 3) + 4 [e]	
6.009 ± 10	270 ± 30	1	1^-
6.167 ± 10	≤ 7 ± 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	≤ 7 ± 4	(2 + 4) or 3	
6.854 ± 10	≤ 7 ± 4	3 or (2 + 4)	
7.006 ± 10	22 ± 5	0 (+ 2)	1^+
7.133 ± 10	≤ 7 ± 4	(3, 2)	
7.250 ± 10	17 ± 5	(2 + 4) or 3	
7.573 ± 10	≤ 7 ± 4	3 or (2 + 4)	$3, 4^-$
7.640 ± 10	≤ 7 ± 4	4	$(3, 4, 5)^+$

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

(1966HE10)		L [a]	J^{π} [a]
E_x (MeV ± keV)	Γ (keV)		
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] From reanalysis of data of (1966HE10): see (1975CR02, 1978FO04).

[b] Identified with shell-model counterparts (1975CR02).

[c] Results are ambiguous (1975CR02).

[d] 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.

[e] May be a doublet (1978FO04).

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) (1969LU07).

12. ^{14}N(t, p)^{16}N $\qquad Q_m = 4.843$

Observed proton groups are displayed in Table 16.7. Angular distributions have also been measured at $E_t = 15$ MeV to the first four states of ^{16}N: cross sections obtained by DWBA analysis using microscopic wave functions are in poor agreement with the data (1979FO01). These distributions have also been compared with those in the (^{3}He, p) reaction to analog states in ^{16}O: see reaction 38 in ^{16}O (1978FO27). τ_m for ^{16}N*(0.40) $= 5.1 \pm 0.3$ psec (1977HE1D, 1977HE12). See also (1977AJ02).

13. ^{14}N(α, 2p)^{16}N $\qquad Q_m = -14.971$

At $E_\alpha = 65$ MeV strong transitions are observed to the unresolved ground state quartet and to ^{16}N*(5.25, 6.61, 7.68) (1978JA10).

14. (a) ^{14}N(^{10}B, ^{8}B)^{16}N $\qquad Q_m = -13.688$

(b) ^{14}N(^{13}C, ^{11}C)^{16}N $\qquad Q_m = -10.343$

At $E(^{10}\text{B}) = 100$ MeV strong transitions are observed to the unresolved ground state quartet and to ^{16}N*(5.14, 6.59, 7.65) (1978HA10). For reaction (b) see (1980PR09).

15. ^{15}N(n ,γ)^{16}N $\qquad Q_{\text{m}} = 2.491$

The thermal cross section is 24 ± 8 μb (1973MU14).

16. ^{15}N(n, n)^{15}N $\qquad E_{\text{b}} = 2.491$

The scattering amplitude (bound) $a = 6.44 \pm 0.03$ fm, $\sigma_{\text{free}} = 4.59 \pm 0.05$ b, $\sigma^{\text{spin}}_{\text{inc}}$(bound nucleus) < 1 mb (1979KO26). The total cross section has been measured for $E_{\text{n}} = 0.4$ to 32 MeV: see (1971AJ02, 1976GAYV) and (1971ZE02). Observed resonances and parameters derived from R-matrix and phase-shift analyses of these data, angular distributions and polarization measurements are displayed in Table 16.8 (1971ZE02, 1971DO06). See also (1977AJ02) and (1976RO16, 1977RO09, 1978RO05, 1979AB17, 1979RO04, 1980HA35; theor.).

17. (a) ^{15}N(n, p)^{15}C $\qquad Q_{\text{m}} = 8.9893$ $\qquad E_{\text{b}} = 2.491$
(b) ^{15}N(n, d)^{14}C $\qquad Q_{\text{m}} = -7.9828$
(c) ^{15}N(n, t)^{13}C $\qquad Q_{\text{m}} = -9.9020$
(d) ^{15}N(n, α)^{12}B $\qquad Q_{\text{m}} = -7.621$

For reaction (b) see (1976AJ04, 1978BA1M). For reaction (c) see (1978BA1M). For reactions (a) and (d) see (1977AJ02).

18. ^{15}N(d, p)^{16}N $\qquad Q_{\text{m}} = 0.267$

Levels derived from observed proton groups and γ-rays are listed in Table 16.9. Gamma transitions are shown in the inset of Fig. 2: (1971PA28) report that the branchings of ^{16}N*(0.40) to ^{16}N*(0, 0.12, 0.30) are, respectively, 26.6 ± 0.6%, 73.4 ± 1.6% and ≤ 0.15%. The $0.30 \rightarrow 0.12$ transition is ≤ 1% (1971PA28).

The mean life of ^{16}N*(0.12) is 7.58 ± 0.09 μsec (1967BE14); together with the angular distribution analyses this leads to $J^{\pi} = 0^-$ for this state. The very strong evidence for $J^{\pi} = 2^-$, 3^- and 1^-, respectively, for ^{16}N*(0, 0.30, 0.40) is reviewed in (1971AJ02). See also (1977BA22, 1978PA05, 1979PA02; theor.).

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

E_n (MeV $\pm$ 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^- [g]
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
7.31		9.34	

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

$E_{\rm n}$ (MeV $\pm$ keV)	$\Gamma_{\rm lab}$ (keV)	$E_{\rm x}$ (MeV)	J^{π}
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] (1971ZE02, 1971DO06). See Table 16.7 in (1971AJ02) for the earlier work.

[b] Below $E_{\rm n} = 4.5$ 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.] (1971ZE02).

[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 $E_{\rm n} = 2.42 \pm 0.08$ MeV with $\Gamma = 250 \pm 50$ keV. This is one of two $({\rm d}_{3/2}{\rm p}^{-1}_{1/2})$ single-particle resonances (1971ZE02).

[f] The phase-shift analysis finds $E_{\lambda} = 2.94 \pm 0.1$ MeV, $\Gamma = 320 \pm 80$ keV. This is the other $({\rm d}_{3/2}{\rm p}^{-1}_{1/2})$ single-particle resonance (1971ZE02).

[g] See also (1979PA02).

Table 16.9: Levels of $^{15}N(d, p)^{16}N$ and $^{18}O(d, \alpha)^{16}N$

(1966HE10) [a] E_x (MeV ± keV)	l_n [a,b]	(1966HE10) [c]	(1970BO08) [c]	J^{π} [d]
0	[k]	0		2^- [l]
0.1201 ± 0.5 [e]	[k]	0.119 ± 15		0^-
0.2962 ± 1.0 [e]	[k]	0.301 ± 15		3^- [l]
0.3973 ± 1.0 [e]	[k]	0.400 ± 15		1^-
3.365 ± 10		3.358 ± 15		1^+ [l]
3.523 ± 10	2 or $1 + 3$	3.524 ± 15	[f]	2^+ [m]
3.964 ± 10	3	3.964 ± 15		3^+ [l,m]
4.325 ± 10	1	4.324 ± 15		1^+ [l]
4.40 [b]	0	4.383 ± 15		$(0, 1)^-$
4.715 ± 10	1			$(1, 2, 3)^+$
4.780 ± 10		4.787 ± 15	[f]	
(4.90 ± 10)				
5.032 ± 10	2	5.065 ± 15		2^- [m]
5.128 ± 10	≥ 2			≥ 2
		5.139 ± 15		
5.150 ± 10	2			$(2, 3)^-$
5.231 ± 10	3	5.240 ± 15		3^+ [m]
5.310 ± 10				
5.523 ± 10	3	5.528 ± 15	[f]	3^+ [m]
5.739 ± 10	2	5.740 ± 15	[f]	$(1, 2)^-$ [n]
			6.01 ± 15 [j]	
6.170 ± 10	≥ 3	6.168 ± 15	[g]	4^- [l]
(6.28 ± 10)	1			$(0, 1, 2)^+$
6.376 ± 10	2		6.37 ± 15 [j]	$(1, 2, 3)^-$
6.431 ± 10				
6.514 ± 10	1	6.512 ± 15	[g]	$(0, 1, 2)^+$
6.609 ± 10		6.620 ± 15	[g]	
(6.79 ± 10)				
6.847 ± 10		6.852 ± 15	[g]	
7.034 ± 10			7.01 ± 15 [j]	

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

(1966HE10) [a] E_x (MeV ± keV)	l_n [a,b]	(1966HE10) [c]	(1970BO08) [c]	J^π [d]
7.135 ± 10		7.141 ± 15	[g]	
7.250 ± 10		7.247 ± 15	[g]	
7.577 ± 10		7.596 ± 15	[g]	
7.638 ± 10			7.64 ± 15 [j]	
7.676 ± 10		7.683 ± 15		
7.840 ± 10			7.88 ± 15 [j]	
			8.06 ± 15 [j]	
			8.18 ± 15 [j]	
		8.286 ± 15	[g]	
		8.374 ± 15	[g]	
			8.49 ± 30 [h]	
			8.819 ± 15 [i]	
			9.035 ± 15	
			(9.16 ± 30)	
			(9.34 ± 30)	
			9.459 ± 15	
			(9.66 ± 40)	
			9.794 ± 15 [i]	
			9.90 ± 30	
			10.055 ± 15 [i]	
			(10.17 ± 30)	
			(10.26 ± 30)	

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

[b] (1972FU16, 1971FU14; $E_{\rm d} = 12$ MeV). I am very much indebted to Dr. H. Fuchs for his comments.

[c] ^{18}O(d, α)^{16}N.

[d] J^{π} assignment from angular distribution analyses and γ-decay; see (1977AJ02) for references.

[e] From γ-decay studies (1963GI11).

[f] Angular distribution reported in ^{18}O(d, α)^{16}N at $E_{\rm d} = 10.0 - 11.2$ MeV but L not determined (1970BO08).

[g] Alpha group seen but $E_{\rm x}$ not determined.

[h] Γ for this level and the ones listed below $\leq 40 - 50$ keV (1970BO08).

[i] These levels appear to be correlated with thresholds for neutron emission to excited states of ^{15}N (1970BO08, 1970BO09).

[j] T.I. Bonner, private communication.

[k] Absolute spectroscopic factors for ^{16}N*(0, 0.12, 0.30, 0.40) are 0.55, 0.46, 0.54, 0.52 (1973BO1G: average values in the range $E_{\rm d} = 5$ to 6 MeV).

[l] Polarization measurements at $E_{\vec{\rm d}} = 52$ MeV are consistent with $J^{\pi} = 2^-$, 3^-, 3^+ and 4^- for ^{16}N*(0, 0.30, 3.96, 6.17) and with 1^+ for ^{16}N*(3.36, 4.32) [admixture pof L $= 0 + 2$] (1981MA1W).

[m] Polarization measurements at $E_{\vec{\rm d}} = 8.5$ to 11.3 MeV are in agreement with the previously assigned J^{π} values for ^{16}N*(0, 0.12, 0.30, 0.40, 3.36, 4.32, 5.05) and lead to the unique J^{π} values for ^{16}N*(3.52, 3.96, 5.05, 5.23, 5.52) shown here (1978BA43).

[n] A closely spaced doublet appears to be present. At least one of the states has unnatural parity (1978BA43).

19. (a) ^{15}N(^{11}B, ^{10}B)^{16}N $\qquad Q_{\rm m} = -8.964$

(b) ^{15}N(^{13}C, ^{12}C)^{16}N $\qquad Q_{\rm m} = -2.455$

See (1980PR09).

20. ^{16}C$(\beta^-)^{16}$N $\qquad Q_{\rm m} = 8.012$

See ^{16}C.

21. ^{16}O(μ^-, ν)^{16}N $\qquad Q_{\rm m} = 95.241$

Partial μ^--capture rates leading 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 (1981GI1C), (1978GU07; theor.) and the “GENERAL” section here.

22. ^{16}O(π^-, γ)^{16}N $\qquad Q_{\rm m} = 129.148$

See (1979TR1B).

23. ^{16}O(n, p)^{16}N $\qquad Q_{\rm m} = -9.636$

See (1978NE1A, 1978NE1B; $E_{\rm n} = 60$ MeV). See also (1977AJ02).

24. ^{16}O(t, ^{3}He)^{16}N $\qquad Q_{\rm m} = -10.400$

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) [0^{-}, 1^{-}]. This suggests that the 2^{-} and 3^{-} states in ^{16}F are those that are strongly populated in the ^{16}O(^{3}He, t)^{16}F reaction [^{16}F*(0.42, 0.72)] and that the other two states in ^{16}F [^{16}F*(0, 0.20)] are 0^{-} and 1^{-} [the ordering within the 2^{-} and 3^{-}, and the 0^{-} and 1^{-} states, in ^{16}F is ambiguous] (1974FL06). See also ^{16}O(^{3}He, t) [reaction 4] in ^{16}F.

25. ^{16}O(^{11}B, ^{11}C)^{16}N $\qquad Q_{\rm m} = -12.401$

At $E(^{11}{\rm B}) = 115$ MeV unresolved groups near $E_{\rm x} = 0$ and 6 MeV are relatively strongly populated (1979RA10).

26. ^{17}O(d, ^{3}He)^{16}N $\qquad Q_{\rm m} = -8.287$

^{3}He groups observed in this reaction are displayed in Table 16.10 (1978MA16). Polarization data is consistent with 1p$_{1/2}$ for ^{16}N*(0, 0.30), with perhaps some small 1p$_{3/2}$ admixture for ^{16}N$_{\rm g.s.}$. There is no significant deviation for a pure 1p$_{3/2}$ VAP for the groups to ^{16}N*(6.17, 6.36) [$J^{\pi} = 4^{-}$, 3^{-}] (1981MA1E). Comparisons of the ^{16}N states with $T = 1$ states in ^{16}O are discussed by (1977WA11, 1978MA16): see reaction 81 in ^{16}O and Table 16.20. See also (1977AJ02).

27. ^{18}O(p, ^{3}He)^{16}N $\qquad Q_{\rm m} = -14.107$

At $E_{\rm p} = 43.7$ 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. Some lower-lying $T = 1$ states were also observed (1964CE05). See also (1978FO10).

Table 16.10: States of ^{16}N from ^{17}O(d, ^{3}He) [a]

E_x (MeV) [b]	l	C^2S	J^π
0	1	0.94	2^-
$\equiv$ 0.30	1	1.33	3^-
3.35	2	0.02	1^+
3.52	2	0.06	$(2)^+$
$\equiv$ 3.96	0	0.10	$(3)^+$
5.14 [c]	$1^+(2)$	$0.2 + 0.03$	$3^- + \geq 2$
5.53	0	0.08	$(2, 3)^+$
5.74	1	0.40	$(1, 2, 3, 4)^-$
6.17	1	1.20	$(4)^-$ [d]
6.36	1	0.80	3^-
7.66	1	0.30	$(2, 4)^-$ [d]
9.48	1	0.25	$(1, 2, 3, 4)^-$

[a] (1978MA16; $E_d = 52$ MeV.)
[b] Resolution of ^{3}He groups was 120 keV FWHM.
[c] Unresolved doublet; angular distribution dominated by $l = 1$ proton pickup.
[d] Based on analog relation with the $T = 1$ states in ^{16}O: see reaction 81 in ^{16}O and Table 16.20.

28. ^{18}O(d, α)^{16}N $\qquad\qquad Q_m = 4.246$

Alpha-particle groups observed in this reaction are displayed in Table 16.9. Polarization measurements are reported at $E_{\vec{d}} = 8.5$ to 11.3 MeV (1978BA43) and at 52 MeV (1981MA1W): see footnotes [j], [k] and [l] in Table 16.9. ^{16}N*(8.82, 9.8, 10.06) may be related to nearly bound virtual states of a $2s_{1/2}$ neutron with ^{15}N*(6.32, 7.30, 7.57) (1970BO08, 1970BO09). (1975AS02) find $\tau_m = 6.5 \pm 0.5$ psec for ^{16}N*(0.40) and $|g| = 1.83 \pm 0.13$; $|M|^2$ for the M1 transition to ^{16}N*(0.12) is 0.17 ± 0.02 W.u..

29. ^{19}F(n, α)^{16}N $\qquad\qquad Q_m = -1.522$

Angular distributions have been reported for $E_n = 4.7$ to 14.4 MeV [see (1971AJ02, 1977AJ02)] and at $E_n = 13.9$ and 15.6 MeV (1977RO06; $\alpha_{0+1+2+3}$). See also ^{20}F in (1983AJ01).

^{16}O

(Figs. 3 and 5)

GENERAL: See also (1977AJ02).

Shell model: (1976AP01, 1976BE1W, 1976NA1L, 1977AP01, 1977BR26, 1977CA02, 1977CA08, 1977CA1T, 1977GO20, 1977HE23, 1977HE13, 1977LI1M, 1977SA1Y, 1977WA1T, 1977ZH1A, 1978AP02, 1978BA52, 1978CH26, 1978DA15, 1978HE04, 1978HO07, 1979AY02, 1979HA59, 1979JO1F, 1979KA06, 1979PE03, 1979RO1J, 1979SA30, 1979ST20, 1979VA1F, 1980AN1L, 1980GI05, 1980HA35, 1980MC1D, 1980PE09, 1980WA1J, 1981KA09).

Collective, deformed and rotational models: (1975HO1H, 1977CA08, 1977VI03, 1978RA1B, 1979MA1J, 1979VL01, 1980BA1T, 1980BE38, 1980FU1H, 1980KU1E, 1980OK05, 1980PE09, 1981KA09).

Cluster and α-particle models: (1975FA1F, 1975HO1H, 1976AP1A, 1976AP01, 1976AP02, 1976FL1B, 1976HO1F, 1976SU08, 1977BA30, 1977BE49, 1977HE23, 1977HO1E, 1977HO1F, 1977SA19, 1977SA1C, 1977SU1J, 1978AP02, 1978CH26, 1978HE04, 1978IS04, 1978KH1C, 1979AD1A, 1979GO24, 1979GR1F, 1979IN06, 1979RO02, 1979WI1B, 1979ZA07, 1980AG08, 1980DU13, 1980FU1G, 1980FU1H, 1980GU1B, 1980IK1B, 1980SU07, 1981EL1C, 1981EM1A, 1981EM02, 1981MA1G, 1981WI01).

Special states: (1975FA1F, 1975BR1L, 1975SI1F, 1976AP1A, 1976AP01, 1976AP02, 1976BA40, 1976BO1T, 1976FA1E, 1976HE20, 1976LI22, 1976ST17, 1976SU08, 1977AP01, 1977BL06, 1977BU24, 1977CA08, 1977FA1C, 1977GO20, 1977GR24, 1977HE18, 1977KA2A, 1977KN03, 1977KR1B, 1977MO1Q, 1977PE1F, 1977SU1J, 1977SU03, 1977WA1T, 1978CA08, 1978AP02, 1978BA52, 1978BA31, 1978BE56, 1978CH1Y, 1978CO19, 1978DA15, 1978DE16, 1978EN1D, 1978HA49, 1978KA1W, 1978MC04, 1978RA1B, 1978SA1N, 1978SC18, 1978SH04, 1979AB04, 1979CH1X, 1979GM02, 1979IN07, 1979KA40, 1979KI10, 1979KU1D, 1979PE03, 1979PR1C, 1979RO1J, 1979RO1B, 1979RO02, 1979SH24, 1979VL01, 1980BE38, 1980BR21, 1980CA15, 1980FU1H, 1980GO1Q, 1980HA35, 1980HI1C, 1980KA28, 1980ME03, 1980OK05, 1980OV1A, 1980SH1N, 1980SP04, 1980SU07, 1980TA1L, 1980WA1E, 1980WA1J, 1981CH1B, 1981CU1J, 1981EM02, 1981KA09, 1981RO06, 1981SP1A, 1981WI01).

Electromagnetic transitions: (1976BA40, 1976HE20, 1976HO16, 1976ST17, 1976SU08, 1977AN1L, 1977BE49, 1977BI1D, 1977BL06, 1977BR03, 1977DE15, 1977DO06, 1977GO1J, 1977GR24, 1977HE1L, 1977KO1N, 1977KR1B, 1977PE1F, 1977WA1T, 1978AD02, 1978BA52, 1978SC18, 1978TR1F, 1979KA40, 1979KU1D, 1979MO1U, 1979MO1X, 1980AR12, 1980DU13, 1980MU01, 1980PE09, 1980TO11, 1981SP1A).

Giant resonances (See also reactions 54 and 58.): (1975GE1L, 1975KR1F, 1975KR1G, 1976AM02, 1976BE1P, 1976MU08, 1977AB08, 1977BR03, 1977DE15, 1977GM01, 1977GO1J, 1977HE23, 1977KN03, 1977KR1B, 1977LI1L, 1977SA1Q, 1978AD02, 1978HE04, 1978RO05, 1978ST1M, 1978YU1A, 1979BL03, 1979BO04, 1979DO17, 1979FA12, 1979GM02, 1979GO01, 1979HA1G, 1979IM03, 1979IZ01, 1979KI1M, 1979KN1D, 1979KO18, 1979KR1E, 1979SH24, 1979WA09,

1980AR12, 1980BA1T, 1980BO1M, 1980GO05, 1980MU01, 1980SH1N, 1980SP1E, 1981KH04, 1981LI03).

Astrophysical questions: (1976BO1M, 1976NO1C, 1976QU1A, 1976SI1D, 1976VA1D, 1977AR1H, 1977AU1B, 1977AU1E, 1977AU1F, 1977AU1J, 1977BU1J, 1977CA1N, 1977CA1K, 1977CL1C, 1977EN1B, 1977FR1K, 1977IB1A, 1977JO1D, 1977KI1M, 1977PA1J, 1977PR1E, 1977SI1F, 1977ST1J, 1977TO1J, 1977VO1A, 1977WA1P, 1978BU1H, 1978BU1B, 1978BY1A, 1978CL1F, 1978DI1D, 1978FE1E, 1978GL1E, 1978IB1B, 1978IB1C, 1978KA1R, 1978LA1K, 1978LE1W, 1978LU1C, 1978MC1G, 1978ME1D, 1978OR1A, 1978PE1H, 1978PO1B, 1978ST1C, 1978TO1C, 1978TR1D, 1978WO1E, 1979CH1T, 1979DE1X, 1979GL1J, 1979KA1T, 1979LA1P, 1979LA1H, 1979LE1F, 1979MA2D, 1979MC1C, 1979PE1E, 1979RA1C, 1979SA1M, 1979SW1B, 1979TI1B, 1979WE1F, 1979WI1D, 1980CA1M, 1980CL1B, 1980CO1R, 1980KA1Q, 1980MC1G, 1980ME1B, 1980MO1L, 1980RE1A, 1981DU1E, 1981GA1C, 1981GU1D, 1981WI1D, 1981WI1G).

Applications: (1976CH1N, 1976CH1P, 1976LE1Q, 1977EP1A, 1977GR1L, 1977LO1J, 1977MA1F, 1977MO1B, 1977TH1H, 1978EM1A, 1978HE1K, 1978TR1E, 1979GR1E, 1979JA1F, 1979LE1L, 1979SP1D, 1980HE1E, 1980LA1L, 1980MC1H).

Special reactions involving ^{16}O*:* (1976CH28, 1976DA1G, 1976HO1D, 1976JA1E, 1976LE1F, 1977AR06, 1977CE1B, 1977CH09, 1977CO14, 1977FE1B, 1977GA1L, 1977HA18, 1977HA1X, 1977HO27, 1977JA1K, 1977KA1P, 1977LI1J, 1977MA1U, 1977MA1W, 1977MO17, 1977NA03, 1977OB02, 1977PR05, 1977SH1H, 1977ST1J, 1977TO1G, 1977TR08, 1977VA02, 1978VO10, 1978BA1J, 1978BH03, 1978BI03, 1978CO05, 1978FR19, 1978GO1N, 1978GY1A, 1978HE11, 1978HE1J, 1978HE23, 1978JA1N, 1978KO01, 1978KU1F, 1978KU1G, 1978OB01, 1978VO1D, 1978VO1A, 1979BA2A, 1979BE1M, 1979BL1E, 1979DE1T, 1979DY01, 1979GA04, 1979GE1A, 1979GO11, 1979HE1D, 1979KO1M, 1979MC1D, 1979ME1H, 1979MO17, 1979PO08, 1979SA27, 1979SA26, 1979SC08, 1979ST1D, 1979ST1R, 1979VA12, 1980AK1C, 1980BA1G, 1980CE1B, 1980GR10, 1980KO10, 1980MI01, 1980OL1C, 1980OV1A, 1980SA1H, 1980SC1G, 1981BH02, 1981BO18, 1981CI03, 1981EG01, 1981MA1G, 1981SI01, 1981TA02, 1981TR03, 1981UC01).

Muon and neutrino capture and reactions: (1974KO1H, 1976DA1H, 1977BA1P, 1977BO23, 1977ER04, 1977GR1C, 1977LA04, 1977MU1A, 1977WA1G, 1978BA57, 1978GU07, 1978GU05, 1978IT1A, 1978PA1F, 1978RO1P, 1979BU1H, 1979DO17, 1979ER07, 1979FR1N, 1979GM03, 1979GU06, 1979GU08, 1979HO07, 1979KI1G, 1979KO39, 1979ME1J, 1979MU1B, 1979RH1A, 1979ST1Q, 1979SU08, 1979VE1D, 1979WU10, 1980BA36, 1980BR1A, 1980CH03, 1980CH20, 1980CH25, 1980ER01, 1980GR05, 1980KO1Y, 1980SU03, 1981CH1B, 1981EI1A, 1981ER1C, 1981GI1C, 1981TO1J, 1981NG01, 1981VA1J).

Pion capture and reactions: (1976BU19, 1976DE40, 1976LI24, 1976LI26, 1976RO14, 1977AL1C, 1977AL1W, 1977BA24, 1977BA3J, 1977BA1Q, 1977BA2G, 1977BA3G, 1977BE69, 1977BE35, 1977BO05, 1977BO1E, 1977BR01, BU77C, 1977CH1N, 1977CO27, 1977DO06, 1977ER04, 1977GI16, 1977GI14, 1977HI10, 1977HO13, 1977HO1B, 1977KA1N, 1977KO25, 1977LE16, 1977MA1M, 1977MA35, 1977MA1F, 1977MC1E, 1977MI15, 1977MI19, 1977NA1N, 1977NA02, 1977NA1Q, 1977PR1G, 1977RO1R, 1977SA1Y, 1977SC1F, 1977SI01, 1977SM06, 1977SP1B, 1977ST1V, 1977SU1L, 1977VI1A, 1977WA1H, 1977WA1R, 1978AL03, 1978BA42, 1978BA55,

1978BE1N, 1978BE1X, 1978BE27, 1978BO01, 1978BO25, 1978BO26, 1978BR1J, 1978BR1K, 1978ER02, 1978ER04, 1978FU04, 1978FU09, 1978GA1D, 1978GI1E, 1978GI05, 1978GR1D, 1978IN04, 1978JA15, 1978JA1G, 1978JA13, 1978KO1V, 1978KW1A, 1978LI1E, 1978MA14, 1978ME1K, 1978MO01, 1978NA1Q, 1978NA1N, 1978OH03, 1978RO1J, 1978SC1G, 1978SH1M, 1978SH12, 1978SH16, 1978SP1C, 1978WE1H, 1978WE1C, 1978YO02, 1979AB1H, 1979AL1J, 1979AM1B, 1979AN1J, 1979AN1F, 1979AR1L, 1979BA2M, 1979BL07, 1979BO1U, 1979BO12, 1979BO2H, 1979BO21, 1979BR1E, 1979BU1K, 1979CH1P, 1979DE1W, 1979DI1A, 1979DO17, 1979DY02, 1979EP02, 1979ER07, 1979GI1C, 1979HI04, 1979HU02, 1979HU1D, 1979IN1A, 1979JA11, 1979JA16, 1979JO08, 1979KL06, 1979KL07, 1979KN1E, 1979KO17, 1979LI01, 1979LI11, 1979MA07, 1979MA2H, 1979NA1M, 1979NA1J, 1979OH1A, 1979OS1G, 1979OS07, 1979PI1C, 1979RE1A, 1979RO1L, 1979SC1E, 1979SH1P, 1979SH1E, 1979SR1B, 1979ST02, 1979TR1H, 1979TR1B, 1979UL1A, 1979WA1J, 1979WA1G, 1979WI1E, 1979WI1A, 1980AL1D, 1980AL24, 1980AR1E, 1980AS1A, 1980BA12, 1980BA31, 1980BE35, 1980BE24, 1980BE56, 1980BH1A, 1980BH1C, 1980BR08, 1980BU15, 1980CH25, 1980CO1A, 1980CR03, 1980DE24, 1980DE2A, 1980ER01, 1980FR1H, 1980GR05, 1980GR1M, 1980GR1N, 1980HO1L, 1980HO24, 1980JE1C, 1980KA1L, 1980LA1C, 1980LE02, 1980LI1H, 1980LI1J, 1980LI1L, 1980MI11, 1980NA1B, 1980NA10, 1980OB1B, 1980SC1B, 1980SC24, 1980SE11, 1980SI03, 1980SP1A, 1980ST15, 1980ST25, 1980TH01, 1980TH1C, 1980TR1H, 1980WU01, 1981AS1D, 1981BA1P, 1981BO06, 1981BU1E, 1981CU04, 1981DO01, 1981DO02, 1981FR1E, 1981FR1F, 1981GI1B, 1981GR1K, 1981IO01, 1981KI1D, 1981LE06, 1981LI04, 1981LI1M, 1981MA1H, 1981MO1D, 1981MO11, 1981OS04, 1981SA14, 1981TH1B, 1981TH1D, 1981WE1C, 1981WH01, 1981WH1D).

K-mesons and other meson interactions: (1976BO1R, 1976BR1G, 1976DA1E, 1977BA3G, 1977BO2C, 1977JU1C, 1977KI1F, 1977LA1D, 1977PO1A, 1977TH1D, 1978AT01, 1978CO17, 1978GR1D, 1978PO1A, 1978SC1G, 1978SO1A, 1979BA36, 1979BO12, 1979CH1H, 1979GA1D, 1979GA1E, 1979GI1E, 1979KI1C, 1979PO1D, 1979RA18, 1980BA1Y, 1980DO1G, 1980GA1C, 1980PO1A, 1981BE17, 1981BO09, 1981HU1B, 1981HU1C).

Antiproton interactions: (1977BA1W, 1977WE1E, 1978GR1D, 1978PO02, 1981AU01).

Other topics: (1975ER09, 1975GO1P, 1976BO1R, 1976BO1T, 1976DA1E, 1976FU1H, 1976GO27, 1976KN06, 1976LI22, 1976LO1D, 1976NA1L, 1976PR1B, 1976ST15, 1977AK1A, 1977AU1K, 1977BO2C, 1977BR1U, 1977BU24, 1977CA02, 1977CA1T, 1977DE16, 1977GO1J, 1977GO20, 1977HO1K, 1977HO22, 1977JE04, 1977KA2B, 1977KI1K, 1977KI1F, 1977KR1B, 1977LI1K, 1977LI1M, 1977MO1Q, 1977NE1C, 1977OS1E, 1977PO1A, 1977PR01, 1977SA1V, 1977SM1A, 1977SO12, 1977SU03, 1977TR01, 1977VA04, 1977WA1T, 1977ZA1C, 1978AN16, 1978AU12, 1978BA31, 1978BE57, 1978BI14, 1978BI1L, 1978BR27, 1978DA1A, 1978DE1K, 1978DE16, 1978EN1D, 1978FA1G, 1978GA1F, 1978HA1U, 1978HA49, 1978HO07, 1978KA04, 1978KA1W, 1978KH1B, 1978KO22, 1978KW1A, 1978LE06, 1978MC04, 1978MI1H, 1978MU1F, 1978ON01, 1978PO1A, 1978RO17, 1978SC18, 1978SH04, 1978SH1B, 1978SI08, 1978SI1G, 1978SO11, 1978SO1A, 1978ST1M, 1978UL02, 1979AB04, 1979AY02, 1979BE2L, 1979BI1C, 1979BO2F, 1979BO04, 1979BO2J, 1979BR30, 1979CH1H, 1979DE18, 1979DU03, 1979FL1H, 1979GA1D, 1979GA1E, 1979GO01, 1979GO24, 1979GO20, 1979GU16, 1979HA59, 1979HE1F, 1979JA09, 1979JA1U, 1979KA06, 1979KA13, 1979KA40, 1979KA43, 1979KI1C, 1979KI15, 1979KO1V,

1979KO27, 1979KO29, 1979LE1M, 1979MU12, 1979NO04, 1979PE03, 1979SA30, 1979ST20, 1979TA08, 1979TO19, 1979VA1F, 1979VA17, 1979ZA1B, 1979ZA07, 1980AN1L, 1980BO1G, 1980BO1N, 1980BR21, 1980CA15, 1980DA1C, 1980DE1F, 1980DW1A, 1980FA04, 1980FA01, 1980GI05, 1980GO1Q, 1980HE07, 1980HI1C, 1980HY03, 1980JA1D, 1980KA1M, 1980ME07, 1980MU01, 1980MU1F, 1980NG01, 1980PO1A, 1980QU1A, 1980SH1N, 1980TA1L, 1980TO11, 1980VA07, 1980ZO1A, 1981BL04, 1981BO20, 1981BR1F, 1981CU1J, 1981DA1C, 1981DU1D, 1981LI03, 1981RO06, 1981SH1H, 1981ZA1E).

Ground state of ^{16}*O:* (1976FU06, 1976GA24, 1976GI11, 1976SA1H, 1977AN12, 1977AN21, 1977BR03, 1977BU24, 1977DY1D, 1977GO1K, 1977GR08, 1977JE04, 1977MA35, 1977NO07, 1977PI10, 1977VA12, 1978CA08, 1978AL07, 1978AN07, 1978AN16, 1978BE57, 1978BE56, 1978BI14, 1978BI04, 1978BR1M, 1978CH28, 1978CH26, 1978FA1G, 1978HE1D, 1978KA04, 1978KO22, 1978MU1F, 1978NE03, 1978ON01, 1978RO17, 1978SH1B, 1978SI1G, 1978SM02, 1978SO11, 1978ST24, 1978UL02, 1978ZA05, 1978ZA1D, 1979AY02, 1979BE2M, 1979BI1C, 1979BR17, 1979BR30, 1979DU03, 1979FI01, 1979GO20, 1979GU08, 1979GU16, 1979HA59, 1979IN07, 1979JA09, 1979KA40, 1979KO29, 1979MA1C, 1979SA27, 1979SA30, 1979ST20, 1979VA17, 1980AN1M, 1980AR12, 1980BO1N, 1980BR13, 1980DE24, 1980FA04, 1980GI05, 1980GO05, 1980HI1C, 1980HO14, 1980HY03, 1980ME03, 1980MY01, 1980VA05, 1980WA1E, 1981AR1D, 1981AT1A, 1981BR1F, 1981DU1C, 1981SI1B, 1981ZA1E).

$\langle r^2\rangle^{1/2} = 2.710 \pm 0.015$ fm (1978KI01). See also (1980BA36).

$|\mathrm{g}| = +0.55 \pm 0.03$ for ^{16}O*(6.13) (1973BR31, 1973RA09, 1977KA02).

1. (a) ^{10}B(^{6}Li, p)^{15}N	$Q_\mathrm{m} = 18.748$	$E_\mathrm{b} = 30.876$
(b) ^{10}B(^{6}Li, d)^{14}N	$Q_\mathrm{m} = 10.140$	
(c) ^{10}B(^{6}Li, t)^{13}N	$Q_\mathrm{m} = 5.843$	
(d) ^{10}B(^{6}Li, ^{3}He)^{13}C	$Q_\mathrm{m} = 8.083$	
(e) ^{10}B(^{6}Li, α)^{12}C	$Q_\mathrm{m} = 23.714$	
(f) ^{10}B(^{6}Li, ^{6}Li)^{10}B		

At $E(^6\mathrm{Li}) = 4.9$ MeV, the cross sections for reactions (a) to (e) 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 (1966MC05). For reaction (f) see (1976PO02). See also (1977AJ02), and ^{12}C in (1980AJ01), ^{13}C, ^{13}N, ^{14}N and ^{15}N in (1981AJ01).

2. ^{10}B(^{10}B, α)^{16}O	$Q_\mathrm{m} = 26.4155$

Table 16.11: Energy levels of ^{16}O [a]

E_x (MeV $\pm$ keV)	$J^\pi; T$	K^π	$\Gamma_{c.m.}$ or τ_m (keV)	Decay	Reactions
0	$0^+; 0$		stable		2, 3, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 25, 26, 27, 28, 30, 31, 38, 40, 42, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98
6.0494 ± 1.0	$0^+; 0$	0^+	$\tau_m = 96 \pm 7$ psec	π	2, 3, 9, 10, 14, 38, 40, 49, 52, 57, 60, 61, 68, 80, 82, 84, 88
6.13043 ± 0.05	$3^-; 0$		$\tau_m = 26.6 \pm 0.7$ psec	γ	2, 3, 9, 10, 14, 18, 26, 38,
			$\lvert g \rvert = 0.55 \pm 0.03$		39, 40, 48, 49, 52, 57, 59, 60, 61, 63, 64, 68, 80, 81, 82, 84, 88, 89
6.9171 ± 0.6	$2^+; 0$	0^+	$\tau_m = 6.6 \pm 0.4$ fsec	γ	2, 3, 9, 10, 14, 38, 39, 40, 48, 49, 56, 57, 60, 61, 63, 64, 81, 82, 84, 85, 88, 89
7.11685 ± 0.14	$1^-; 0$		$\tau_m = 11.6 \pm 1.0$ fsec	γ	2, 3, 9, 10, 38, 39, 40, 48, 49, 52, 56, 57, 60, 61, 64, 80, 81, 82, 84, 85, 88, 89
8.8719 ± 0.5	$2^-; 0$		$\tau_m = 180 \pm 16$ fsec	γ, α	2, 3, 7, 9, 10, 11, 17, 26, 38, 39, 42, 48, 49, 52, 60, 61, 63, 64, 80, 81, 82, 84, 88, 89, 92, 96
9.632 ± 21	$1^-; 0$	0^-	$\Gamma_{c.m.} = 400 \pm 10$	γ, α	3, 7, 9, 10, 38, 49, 52, 64
9.847 ± 3	$2^+; 0$		0.625 ± 0.100	γ, α	2, 3, 7, 9, 10, 11, 26, 38, 39, 42, 48, 49, 52, 57, 60, 61, 63, 64, 82, 84, 88, 92, 96
10.355 ± 3	$4^+; 0$	0^+	25 ± 4	γ, α	2, 3, 7, 9, 10, 11, 13, 16, 17, 26, 27, 38, 39, 49, 57, 60, 61, 63, 64, 80, 82, 84, 85, 88, 92, 96

Table 16.11: Energy levels of ^{16}O [a] (continued)

E_x (MeV $\pm$ keV)	$J^\pi; T$	K^π	$\Gamma_{c.m.}$ or τ_m (keV)	Decay	Reactions
10.957 ± 1	$0^-; 0$		$\tau_m = 8 \pm 5$ fsec		2, 38, 48, 49, 60, 61, 82
11.080 ± 3	$3^+; 0$		$\Gamma < 12$	γ	2, 38, 48, 49, 82, 88
11.096 ± 2	$4^+; 0$		0.28 ± 0.05	γ, α	2, 3, 7, 9, 11, 13, 17, 26, 38, 39, 60, 61, 63, 64
(11.26) [b]	$(0^+; 0)$		(2500)	(α)	7, 49, 82, 84
11.520 ± 4	$2^+; 0$		74 ± 4	γ, α	2, 3, 7, 38, 57, 60, 61, 63, 64
11.60 ± 20	$3^-; 0$	0^-	800 ± 100	α	7, 10
12.049 ± 2	$0^+; 0$		1.5 ± 0.5	γ, α	7, 38, 57, 60, 61, 63, 64, 84
12.438 ± 3	$1^-; 0$		90 ± 10	γ, p, α	3, 5, 7, 38, 43, 44, 47, 48, 49, 60, 61, 64
12.530 ± 1	$2^-; 0$		0.8	γ, p, α	2, 38, 43, 44, 47, 48, 49, 57, 81
12.797 ± 4	$0^-; 1$		38 ± 4	γ, p	38, 44, 48, 49
12.9685 ± 0.4	$2^-; 1$		1.9 ± 0.2	γ, p, α	38, 43, 44, 47, 48, 49, 57, 80, 81, 82
13.02 ± 10	$2^+; 0$		150 ± 10	γ, p, α	3, 7, 44, 47, 57, 60, 61, 63, 64
13.090 ± 5	$1^-; 1$		130 ± 5	γ, p, α	3, 5, 7, 9, 38, 43, 44, 47, 48, 57, 82
13.120 ± 10	$3^-; 0$		130 ± 30	γ, p, α	2, 3, 5, 7, 38, 48
13.258 ± 2	$3^-; 1$		21 ± 1	γ, p, α	3, 5, 7, 38, 44, 47, 48, 49, 60, 80, 81, 82, 85
13.664 ± 3	$1^+; 0$		63 ± 3	γ, p, α	38, 43, 44, 47, 61
13.869 ± 2	$4^+; 0$		84 ± 2	p, α	2, 7, 38, 44, 47, 60, 63
13.980 ± 2	2^-		20 ± 2	p, α	2, 38, 39, 44, 47
14.032 ± 15	0^+		200 ± 50	α	7
14.1 ± 100	3^-		750 ± 200	α	7
14.302 ± 3			34 ± 12		26, 38, 39
14.399 ± 2	≥ 5		27 ± 5		2, 10, 26, 38, 39
14.620 ± 11	(4^+)		490 ± 20	α	7, 9
14.660 ± 11	5^-	0^-	650 ± 50	α	7, 9, 10, 11, 13
14.816 ± 2	$6^+; 0$		70 ± 8	α	2, 3, 7, 9, 26, 38, 39, 64
14.922 ± 6	2^+		65 ± 5	p, α	2, 37, 38, 44, 47
15.100 ± 3	0^+		166 ± 30	p, α	5, 7, 38

Table 16.11: Energy levels of ^{16}O [a] (continued)

E_x (MeV ± keV)	$J^\pi; T$	K^π	$\Gamma_{c.m.}$ or τ_m (keV)	Decay	Reactions
15.196 ± 3	2^-		58 ± 10	p, α	38, 39, 44, 47, 81
15.26 ± 20	2^+; (0)		300 ± 100	p, α	44, 47, 60, 63
15.408 ± 2	3^-; 0		133 ± 7	p, α	5, 7, 37, 38, 39, 44, 47, 60, 64, 80, 81
15.785 ± 5	(3^+)		40 ± 10		38, 39
15.828 ± 30	3^-		700 ± 120	α	7
(15.9)	(2^+)		≈ 600	γ, α	3
16.209 ± 2	(4^+)		40 ± 10		38, 39
16.22 ± 20	1^+; 1		18 ± 3	γ, n, p	37, 44, 45, 57
16.275 ± 7	6^+; 0	0^+	420 ± 20	α	2, 7, 9, 10, 11, 13, 27, 39
16.350 ± 13	$(0^+, 1^-)$		65 ± 45	p, α	5, 7, 38, 84
16.442 ± 2	2^+; (1)		22 ± 3	γ, n, p, α	3, 4, 5, 7, 38, 44, 47, 57, 60, 63, 64
16.817 ± 2	3^+		70 ± 10	γ, p, α	38, 44, 47, 57
16.844 ± 21	4^+		570 ± 60	α	7
16.93 ± 50	2^+		≈ 280	α	7, 8, 60
17.0	1^-; 1		≈ 1500	γ, p	43
17.129 ± 5	2^+		107 ± 14	n, p, α	4, 5, 7
17.14 ± 20	1^-; 1		36 ± 5	γ, n, p, α	7, 39, 43, 44, 45, 49, 57
17.20 ± 20	2^+		160 ± 60	α	2, 7, 8, 49, 60, 63, 64
17.27 ± 20	1^-; 1		90 ± 10	γ, n, p, α	4, 43, 44, 45
17.510 ± 26	1^-		180 ± 60	α	7
17.555 ± 21	(6^+)		180 ± 70	n, α	4, 7
17.618 ± 20	$(0^+, 1^-)$		175 ± 60	p, α	5, 7
17.72	$(0^+, 2^+)$		≈ 75	(p), α	5, 8
17.784 ± 15	4^+		400 ± 40	n, α	4, 7, 8
17.788 ± 16	4^-; 0		150 ± 60		57, 58, 60, 63, 64, 81, 82
18.016 ± 1	4^+; (0)		14 ± 2	(n), p, α	4, 5, 7, 8
18.033 ± 10	3^+; 1		26 ± 5	γ, n, p	43, 44, 45, 81, 82
18.11 ± 30	$(0, 2)^+$; 0		300 ± 50	(γ), n, p, α	3, 5, 7, 45, 60, 64
18.29			≈ 300	γ, p, α	3, 5, 7
18.404 ± 12	5^-		550 ± 40	α	7
18.46 ± 25	2^+; 0		60 ± 10	n, p	45, 57, 60, 63, 64
18.6	$(1^-, 5^-)$		≈ 150	α	7
18.6	(4^+)		≈ 300	α	7, 8

Table 16.11: Energy levels of ^{16}O [a] (continued)

E_x (MeV ± keV)	$J^\pi; T$	K^π	$\Gamma_{c.m.}$ or τ_m (keV)	Decay	Reactions
18.69 ± 30			260 ± 30	n, p	2, 45, 60, 64
18.773 ± 22	1^-		215 ± 45	p, α	5, 7
18.785 ± 6	4^+		260 ± 20	n, p, α	4, 5, 7, 8
18.975 ± 10	$4^-; 1$		≤ 40	p	44, 57, 58, 60, 63, 81, 82
18.99 ± 30	1^+		≈ 250	γ, p	43
19.0	(5^-)		≈ 550	α	7
19.08 ± 30	2^+; (1)		≈ 120	γ, p	43, 44
19.206 ± 12	$3^-; 1$		68 ± 10		81, 82
19.25 ± 20	(2^-; 1)		90 ± 10	n, p, (α)	7, 45
19.257 ± 9	2^+		155 ± 25	γ, p, α	5, 7, 43
19.319 ± 14	6^+		65 ± 35	n, α	5, 7, 8
19.375 ± 2	4^+		23 ± 4	p, α	5, 7
19.48 ± 25	$1^-; 1$		250 ± 50	γ, n, p	43, 44, 45, 57
19.53 ± 30	$2^+; 0$		255 ± 75	n, p, α	2, 4, 7, 45, 60, 64
19.754 ± 16	2^+		290 ± 50	p, α	5, 7
19.802 ± 16	$4^-; 0$		36 ± 5		57, 58, 81, 82
19.90 ± 20	3; 0		100 ± 30	γ, n, p, α	2, 7, 43, 44, 45, 58, 60
20.055 ± 13	$2^+; 0$		350 ± 50	γ, n, (p), α	3, 4, 5, 7, 64
20.43 ± 30	$2^-; 1$		190 ± 40	γ, n, p	43, 44, 45, 57, 81
(20.5)			(≈ 300)	α	7
20.541 ± 2	5^-		11 ± 2	p, α	2, 5, 7
20.560 ± 2			< 5	α	7
20.615 ± 3			< 10	α	7, 27
(20.8)			(≈ 60)	n, (p), α	4, 5
20.857 ± 14	7^-	0^-	900 ± 100	α	7, 9, 10, 11, 13
20.945 ± 20	$1^-; 1$		300 ± 10	γ, n, p	3, 43, 44, 45, 57
21.05 ± 50	(2^+; 0)		320 ± 50		60, 64
21.052 ± 6	6^+		205 ± 20	α	7
21.175 ± 15					2
21.50	($1 \rightarrow 4$)		120	p	44
21.52	7^-		61 ± 32	(n), α	4, 7
21.648 ± 3	6^+		115 ± 8	n, α	4, 7, 9
21.776 ± 9	3^-		43 ± 20	n, p, α	2, 4, 5, 7
22.04			60	n, d, α	4, 32
22.150 ± 10	$1^-; 1$		730 ± 10	γ, n, p, d	31, 36, 43, 44, 45
22.44 ± 100	(1^-; 1)		300 ± 100	n, p, d, α	32, 36, 45, 60

Table 16.11: Energy levels of ^{16}O [a] (continued)

E_x (MeV ± keV)	$J^\pi; T$	K^π	$\Gamma_{c.m.}$ or τ_m (keV)	Decay	Reactions
22.5 ± 500	(8^+)	(0^+)			13
22.65 ± 30				n, α	2, 4, 8
22.720 ± 5	$0^+; T = 2$		12.5 ± 2.5	n, p, d, α	4, 5, 7, 29, 33, 36, 84
22.89 ± 10	$1^-; 0$		300 ± 10	γ, p, d	31, 43, 44
23.0 ± 100	6^+		≤ 500	α	8, 9
23.11			≈ 20	α	7, 8
23.2 ± 80	$(1^-; 1)$		550 ± 150	n, p	45, 60
23.51 ± 30			300	p, d, α	2, 7, 33, 34, 36
23.879 ± 6	6^+		26 ± 4	p, α	5, 7, 8, 9
24.07 ± 30	$1^-; 1$		550 ± 50	γ, (n), p, ^{3}He	18, 19, 43, 44, 60
24.35 ± 70	$(2^+, 3^-); 0$		400 ± 50	n, p	45, 64
24.522 ± 11	$2^+; 2$		< 50		29, 84
24.76 ± 60	$(2, 4)^+; 1$		340 ± 60	γ, n, p, ^{3}He, α	23, 43, 44, 45
25.12 ± 50	$1^-; 1$		3000 ± 300	γ, p, ^{3}He	18, 43, 44, 47, 63
25.5 ± 150	$1^-; 1$		1300 ± 300		60
25.6	$(3^-); 1$		450	α	7
26.0 ± 100	$1^-; (1)$		$500 - 1000$	γ, ^{3}He, α	18, 23
26.3	2^+		1200	α	7
26.4 ± 100	$(2, 4)^+; 1$		550 ± 100	γ, n, p, ^{3}He, α	18, 20, 43, 44, 45, 47
27.0 ± 100	$(T = 1)$		broad	^{3}He, α	23
27.3 ± 70	$(2, 4)^+; 1$		830 ± 110	γ, p, ^{3}He, α	18, 23, 24, 43, 44, 47
27.5	$(3^-; 0)$		≈ 2500	γ, ^{3}He	18
28.6 ± 200				γ, ^{3}He	18
29.7 ± 100	$(T = 1)$		470 ± 150	n, p, d, ^{3}He, α	23, 34, 45
31.8 ± 600				γ	56

[a] See also Table 16.12.
[b] I am indebted to Professor H.T. Richards for his remarks concerning the existence of this level.

States of ^{16}O observed at $E(^{10}\text{B}) = 20$ MeV are displayed in Table 16.10 of (1977AJ02). At the higher excitation energies, states are reported at $E_x = 17.200 \pm 0.020$, 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 $2J_f + 1$ for 11 of 12 groups leading to states of known J. The angular distributions show little structure (1976AJ02). See also (1978MA07) and ^{20}Ne.

3. $^{12}\text{C}(\alpha, \gamma)^{16}\text{O}$ $\qquad Q_m = 7.1620$

Table 16.12: Radiative decays in ^{16}O [a]

E_i (MeV)	$J^\pi_i; T$	E_f (MeV)	$J^\pi_f; T$	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	0.100 ± 0.004 [e]
		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	0.057 ± 0.006 [f]
		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 [h]	$3^-; 0$	76.0 ± 3.0	$(2.8 \pm 0.3) \times 10^{-3}$ [g]
		6.92	$2^+; 0$	4.2 ± 0.8	$(1.5 \pm 0.3) \times 10^{-4}$
		7.12	$1^-; 0$	12.6 ± 2.0	$(4.6 \pm 0.8) \times 10^{-4}$ [g]
9.63	$1^-; 0$	0	$0^+; 0$	≈ 100	$(23 \pm 3) \times 10^{-3}$
9.85	$2^+; 0$	0	$0^+; 0$	61 ± 4	$(6.0 \pm 0.4) \times 10^{-3}$
		6.05	$0^+; 0$	18 ± 4	$(1.9 \pm 0.4) \times 10^{-3}$
		6.92	$2^+; 0$	21 ± 4	$(2.2 \pm 0.4) \times 10^{-3}$
10.35	$4^+; 0$	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	$(5.8 \pm 0.7) \times 10^{-2}$
10.96	$0^-; 0$ [c]	7.12	$1^-; 0$	> 99	(0.08 ± 0.05)
11.10	$4^+; 0$	6.13	$3^-; 0$	[a]	$(3.1 \pm 1.3) \times 10^{-3}$
		6.92	$2^+; 0$	[a]	$(2.5 \pm 0.6) \times 10^{-3}$
11.52	$2^+; 0$	0	$0^+; 0$	91.7	0.61 ± 0.02 [a]
		6.05	$0^+; 0$	4.2 ± 0.7	$(2.8 \pm 0.6) \times 10^{-2}$
		6.92	$2^+; 0$	4.0 ± 1.0	$(29 \pm 7) \times 10^{-3}$
		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 [a]	0.12 ± 0.04
12.53	$2^-; 0$	0	$0^+; 0$		$(108 \pm 15) \times 10^{-3}$ [a]

Table 16.12: Radiative decays in ^{16}O [a] (continued)

E_i (MeV)	J^π_i; T	E_f (MeV)	J^π_f; T	Branch (%)	Γ_{rad} (eV)
		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		$(71 \pm 2) \times 10^{-3}$
		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	1^-; 1	0	0^+; 0	≈ 100	32 ± 5 [a]
		6.05	0^+; 0	0.58 ± 0.12	
		7.12	1^-; 0	3.1 ± 0.8	1.4 ± 0.04
13.26 [d]	3^-; 1	6.13	3^-; 0	> 85	9.2 ± 1.5

[a] See Tables 16.12 in (1971AJ02) and 16.15 in (1977AJ02) for the earlier work. See the latter table for the references for the values displayed here.

[b] Monopole matrix element in fm^2.

[c] Pairs due to this transition are not observed (1978AL19).

[d] Fot the radiative decay of higher states see Tables 16.13, 16.18 and 16.22.

[e] See also (1977LA15: 94 ± 10 meV).

[f] "Best" value based on (1977LA15: 60 ± 10 meV) and earlier values displayed in (1977AJ02).

[g] $(3.0 \pm 0.5) \times 10^{-4}$ (M1), $(2.5 \pm 0.3) \times 10^{-3}$ (E2); and $< 6.4 \times 10^{-5}$ (M1), $> 4 \times 10^{-4}$ (E2) for the transitions to ^{16}O*(6.13, 7.12), respectively.

[h] $E_\gamma = 2471.5 \pm 0.5$ keV for ($8.87 \rightarrow 6.13$) transition (1970GA09).

The yield of capture γ-rays has been studied for $E_\alpha < 42$ MeV; see Table 16.11 of (1977AJ02) and (1981SA07). Observed resonances are displayed in Table 16.13 here.

This reaction plays an important role in astrophysical processes. (1974DY02) has determined σ_{E1} for $E_\alpha = 1.88$ to 3.92 MeV. From these data $S(E_\alpha(\text{lab}) = 400 \text{ keV}) = 0.08^{+0.05}_{-0.04}$ MeV · b (1974KO06) [used a hybrid R-matrix-optical-model analysis of (α, γ) and (α, α)], $0.08^{+0.14}_{-0.07}$ MeV · b (1976HU10) [used a two channel, two level approximation of a modified K-matrix]. (1974DY02) state that S depends quite strongly on $\theta^2_\alpha(6.92)/\theta^2_\alpha(7.12)$: S may have to be increased to allow for the tail of ^{16}O*(6.92). For astrophysical considerations see the "GENERAL" section here, (1971AJ02, 1977AJ02) and (1976FO1F, 1977BA3Y, 1977SA1W, 1978RO1D, 1978RO1L, 1978TA1U, 1980BA2R, 1981KH1B).

Table 16.13: Resonances in $^{12}C + \alpha$

No.	E_α (MeV $\pm$ keV)	$\Gamma_{c.m.}$ (keV)	Outgoing particles [a] (x)	Γ_x	Γ_α/Γ	$^{16}O^*$ (MeV)	$J^\pi; T$	Refs. [b]
						8.87		(1977MC08) [k]
1	3.322 ± 30	400	γ_0	23 ± 3 meV		9.65 [h]	1^-	(1977MC08)
			α_0		≈ 1			
2	3.575 ± 10	0.625 ± 0.100	γ_0	5.9 ± 0.6 meV		9.842	2^+	
			γ_3	2.2 ± 0.4 meV				
			α_0					
3	4.256 ± 11	27 ± 4	γ_0			10.353	4^+	
			γ_3	58 ± 7 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	7.045 ± 5 [c]	99 ± 7	γ_0	9.5 ± 1.7 eV [e]		12.444	$1^-; 0$	(1976OP02)
			γ_1	0.12 ± 0.06 eV [e]				
			p	1.1 keV				
			α_0	92 ± 8 keV	1.0			
			α_1	0.025 keV				
10	7.82 ± 10	150 ± 11	γ_0	[f]		13.02	2^+	
			α_0	150 ± 11 keV	0.8			
11	7.915 ± 10 [d]	130 ± 5	γ_0	44 ± 8 eV [g]		13.085 [i]	$1^-; 1$	(1976OP02)
			γ_4	1.35 ± 0.4 eV				
			p	100 keV				

Table 16.13: Resonances in ^{12}C + α (continued)

No.	E_α (MeV ± keV)	$\Gamma_{\text{c.m.}}$ (keV)	Outgoing particles [a] (x)	Γ_{x}	Γ_α/Γ	^{16}O* (MeV)	$J^\pi; T$	Refs. [b]
			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 ± 0.1	14.620 ± 11	(4^+)	(1979AMZU)
			α_1					
19	10.002	672 ± 11	α_0		≈ 0.95	14.660 ± 11	5^-	(1979AMZU)
			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^+	(1979AMZU)
22	10.999	133 ± 7	α_0, α_1, p_0		0.58	15.408 ± 2	3^-	(1979AMZU)
23	11.560	703 ± 113	$\alpha_0, (\alpha_1), \gamma_{4.4}$		0.21	15.828 ± 30	3^-	(1979AMZU)
24	11.6	≈ 600	γ_0	$\Gamma_\alpha\Gamma_\gamma/\Gamma \approx 0.4$ eV		15.9	2^+	

Table 16.13: Resonances in ^{12}C + α (continued)

No.	E_α (MeV $\pm$ keV)	$\Gamma_{\rm c.m.}$ (keV)	Outgoing particles [a] (x)	$\Gamma_{\rm x}$	Γ_α/Γ	^{16}O* (MeV)	$J^\pi; T$	Refs. [b]
25	12.156	422 ± 14	α_0		0.93	16.275 ± 7	6^+	(1979AMZU)
26	12.272	65 ± 45	α_0, α_1, α_2, p_0		0.07	16.362 ± 20	$(0^+, 1^-)$	(1979AMZU)
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 [i]	2^+; (1)	(1979AMZU)
28	12.5	730	p_0, α_0			(16.5)		
29	12.915	567 ± 60	α_0		0.28	16.844 ± 21	4^+	(1979AMZU)
30	13.0	700	α_0			(16.9)	5^-	
31	13.05	≈ 280	α_2, ^{8}Be			16.94	2^+	(1979AMZU)
32	13.296	107 ± 14	n, p_0, α_0, α_1, $\gamma_{4.4}$		0.37	17.129 ± 5	2^+	(1979AMZU)
33	13.32	36 ± 5	α_0, α_1			17.15		(1979AMZU)
34	13.35	160 ± 60	α_2, ^{8}Be			17.17	2^+	(1979AMZU)
35	13.50	< 100	n			17.28		
36	13.805	182 ± 56	α_0, (α_1), α_2		0.16	17.510 ± 26	1^-	(1979AMZU)
37	13.865	178 ± 66	n, (α_0, α_1)		0.07	17.555 ± 21	(6^+)	(1979AMZU)
38	13.948	175 ± 55	p_0, α_0		0.32	17.618 ± 20	$0^+, 1^-$	(1979AMZU)
39	14.08	(≈ 75)	(p_0), ^{8}Be			17.72	$(0^+, 2^+)$	(1979AMZU)
40	14.170	396 ± 41	n, α_0, α_1, $\gamma_{4.4}$, ^{8}Be		0.34	17.784 ± 15	4^+	(1979AMZU)
41	14.480	14 ± 2	(n), p_0, α_0, α_1, $\gamma_{4.4}$, ^{8}Be		0.36	18.016 ± 1	4^+; (0)	(1979AMZU)
42	14.577	248 ± 90	(γ_0), n_0, p_0, α_0		0.31	18.089 ± 25	(0^+)	(1979AMZU, 1979MO03)
43	(14.62)	(≈ 45)				(18.12)	$(\neq 4^+)$	(1979AMZU)
44	14.85	≈ 300	γ_0, p_0, $(\alpha_1, \gamma_{4.4})$	$\Gamma_\alpha\Gamma_\gamma/\Gamma = 0.95$ eV		18.29		(1979AMZU)
45	14.997	544 ± 39	α_0		0.40	18.404 ± 12	5^-	(1979AMZU)
46	15.2	≈ 150	α_0, $(\alpha_1, \alpha_2, \gamma_{4.4})$			18.6	$(1^-, 5^-)$	(1979AMZU)
47	15.2	≈ 300	α_2, ^{8}Be			18.6	(4^+)	(1979AMZU)
48	15.490	215 ± 45	p_0, α_0		0.26	18.773 ± 22	1^-	(1979AMZU)
49	15.506	260 ± 16	n, p_0, α_0, (α_1), ^{8}Be		0.48	18.785 ± 6	4^+	(1979AMZU)
50	15.8	≈ 550	(α_0), α_1, $\gamma_{4.4}$			19.0	(5^-)	(1979AMZU)
51	15.96	41	(n), α_0			(19.12)	$(2^+, 4^+)$	

Table 16.13: Resonances in ^{12}C + α (continued)

No.	E_α (MeV ± keV)	$\Gamma_{\rm c.m.}$ (keV)	Outgoing particles [a] (x)	Γ_x	Γ_α/Γ	^{16}O* (MeV)	$J^\pi; T$	Refs. [b]
52	16.130	50 ± 45	(n), (α_0)		0.04	19.253 ± 30	(5^-)	(1979AMZU)
53	16.137	155 ± 23	p_0, α_0, (α_1)		0.34	19.257 ± 9	2^+	(1979AMZU)
54	16.219	63 ± 33	p_0, (α_0), α_1, α_2, ^{8}Be		0.07	19.319 ± 14	(6^+)	(1979AMZU)
55	16.293	23 ± 4	p_0, α_0, α_1, α_2		0.23	19.375 ± 2	4^+	(1979AMZU)
56	16.496	255 ± 75	(n), α_0, (α_1, α_2)		0.20	19.527 ± 26	2^+	(1979AMZU)
57	16.799	286 ± 44	p_0, α_0, α_1		0.29	19.754 ± 16	2^+	(1979AMZU)
58	(16.92)	(≈ 175)	α_2			(19.85)		(1979AMZU)
59	(17.05)	(≈ 30)	(α_0)			(19.94)	$(\neq 3^-)$	(1979AMZU)
60	17.201	432 ± 40	γ_0, n, (p_0), α_0, (α_1)		0.43	20.055 ± 13	2^+	(1979AMZU)
61	(17.27)	(≈ 45)	(α_0)			(20.11)	$(\neq 3^-)$	(1979AMZU)
62	17.5	≈ 1500	p_0			(20.3)		
63	(17.66)	(≈ 150)	n, (p_0), α_2			(20.40)	(4^+)	(1979AMZU)
64	(17.8)	(≈ 300)	(α_0), α_1			(20.5)		(1979AMZU)
65	17.849	11 ± 2	p_0, α_0, α_1, α_2		0.14 ± 0.02	20.541 ± 2	5^-	(1979AMZU)
66	17.875	< 5	α_0			20.560 ± 2	even	(1979AMZU)
67	17.948	< 10	α_0			20.615 ± 3	even	(1979AMZU)
68	(18.2)	(≈ 60)	n, (p_0)			(20.8)		(1979AMZU)
69	18.271	904 ± 55	α_0		0.60	20.857 ± 14	7^-	(1979AMZU)
70	(18.3)		α_0			(20.9)	(2^+)	(1979AMZU)
71	(18.48)	(≈ 50)	n, p_0, (α_0)			(21.01)		(1979AMZU)
72	18.50 ± 25	240 ± 80	γ_0, (α_0, α_1)		0.20	21.03	(1^-)	(1979AMZU)
73	18.5	900	α_0			(21.0)	(5^-)	
74	18.531	205 ± 14	α_0		0.50	21.052 ± 6	6^+	(1979AMZU)
75	18.593	306 ± 46	(α_0)		0.21	(21.098)	4^+	(1979AMZU)
76	19.14	61 ± 32	(n), α_0, α_2			21.52	7^-	(1979AMZU, 1981FR11)
77	19.327	115 ± 8	n, α_0, α_1, α_2		0.41	21.648 ± 3	6^+	(1979AMZU)
78	19.498	43 ± 20	n, p_0, α_0, α_1, α_2		0.07	21.776 ± 9	3^-	(1979AMZU)

Table 16.13: Resonances in ^{12}C + α (continued)

No.	E_α (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Outgoing particles [a] (x)	Γ_x	Γ_α/Γ	^{16}O* (MeV)	$J^\pi; T$	Refs. [b]
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			23.40		
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	[j]	0.06 ± 0.02	23.879	6^+	
92	22.37	165	n			23.93		
93	22.75	$\lesssim 500$	^{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	29 [l]	4 MeV	α_0, α_1, p_3			29		(1978BU27)

[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) and 16.12 (1977AJ02). Please note that (1979AMZU) is an unpublished thesis. (1981AM1C) has been submitted for publication.
[c] 7040 ± 5 keV (1976OP02).
[d] 7880 ± 15 keV (1976OP02).
[e] Branching ratios to ^{16}O*(0, 6.05) $= 98.8$% and 1.2%.
[f] $\Gamma_{\gamma_0} = 0.7 \pm 0.2$ eV (1971KE09), based on $\Gamma_{\alpha_0}/\Gamma = 1.0$ (1968MO08) and $\Gamma_{\rm c.m.} = 190 \pm 40$ keV (1971KE09).
[g] $\Gamma_{\alpha_0}\Gamma_{\gamma_0}/\Gamma^2 = (1.49 \pm 0.17) \times 10^{-4}$ (1971KE09).
[h] $\theta^2_\alpha(7.12)/\theta^2_\alpha(9.63) = 0.19^{+0.16}_{-0.11}$ (1974KO06). See also reactions 9 and 12.
[i] See column 2 and footnote [d].
[j] $\Gamma_{^8{\rm Be}}$, Γ_{α_0} and $\Gamma_{\alpha_2} \approx 3.5$, 1.5 ± 0.5 and ≈ 6 keV, respectively (1976BR07).
[k] An attempt is reported by (1977MC08) to observe a 0^+ state in the vicinity of the known 2^- state at 8.87 MeV. No such state is seen: $\theta^2_\alpha \leq 2 \times 10^{-4}$.
[l] See (1981SA07) for $(\alpha,\gamma_{14.8})$ measurements which indicate an 8^+ GQR built on the 6^+_1 state ^{16}O*(14.82).

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 16.13]. 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 (1974SN02). Structures are observed in the yield of γ-rays from the decay of ^{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 $E_x = 14.816$ MeV (1981SA07). See also (1975HA1R, 1980WE1D).

4. ^{12}C(α, n)^{15}O $\quad Q_m = -8.5019 \quad E_b = 7.1620$

For cross-section measurements from threshold to $E_\alpha = 24.7$ MeV see (1971AJ02) and Table 16.11 in (1977AJ02). Observed resonances are displayed in Table 16.13 here. The production of neutrons at $E_\alpha = 710$ MeV has been studied by (1980CE01). See also (1977AJ02, 1977GR18, 1977LI19) and (1978WE1L; applications).

5. ^{12}C(α, p)^{15}N $\quad Q_m = -4.9656 \quad E_b = 7.1620$

The yield of p_0 has been studied for $E_\alpha = 7.7$ to 23 MeV: see (1977AJ02), (1979AMZU, 1981AM1C; $15 \leq E_x \leq 22$ MeV) and (1979MO03; $17.5 \leq E_x \leq 18.7$ 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 (1978BU27). For other resonances see Table 16.13. See also ^{15}N in (1981AJ01).

6. (a) ^{12}C(α, d)^{14}N $\quad Q_m = -13.57434 \quad E_b = 7.1620$
(b) ^{12}C(α, t)^{13}N $\quad Q_m = -17.8706$
(c) ^{12}C(α, ^{3}He)^{13}C $\quad Q_m = -15.6314$

See (1981AJ01).

7. ^{12}C(α, α)^{12}C $\quad E_b = 7.1620$

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 Table 16.11 in (1977AJ02), (1978AM1B, 1979AM1E, 1979AMZU, 1981AM1C; $E_\alpha = 15$ to 20 MeV), and (1979AR05; 17 to 23 MeV) and (1981FR11; 17.4 to 20.5 MeV; α_2). Observed resonances are displayed in Table 16.13. No evidence is observed for a narrow (100 eV) 0^+ state in the vicinity of ^{16}O*(8.87); thus the α-decay reported in ^{16}N(β^-) [reaction 52] appears to be due to ^{16}O*(8.87) ($J^\pi = 2^-$) and is thus parity forbidden (1977MC08). No evidence is found by (1981FR11) for 8^+ strength.

Total reaction cross-section measurements are reported at 1.55 and 2.89 GeV/c per nucleon (1978JA16). See also (1979DE1P, 1979DE31, 1980DE1H, 1980DE28, 1981BA1Q, 1981PE01). For π^0 measurements see (1976WA10). For spallation measurements see (1977FO04, 1978DU1B, 1979GL1K, 1979VI05, 1980AB1B, 1981GO1E) and (1977AJ02).

See also (1978FR1L, 1979WA1L), (1976SI1E, 1980DE1Z), (1976CU07, 1977BA12, 1977BA1N, 1977BA30, 1976BR1L, 1977DA20, 1977FR12, 1977HU09, 1977IK1A, 1977SA2B, 1977ZE01, 1978FR1F, 1978SU1H, 1978SU1G, 1979VE1C, 1980BA2K, 1980DM1A, 1980FU05, 1980FU1F, 1980LI09, 1980ST1K, 1981SU05, 1981WI01; theor.) and ^{12}C in (1980AJ01).

8. (a) ^{12}C(α, ^{8}Be)^{8}Be	$Q_{\rm m} = -7.4586$	$E_{\rm b} = 7.1620$
(b) ^{12}C(α, 2α)^{8}Be	$Q_{\rm m} = -7.3667$	
(c) ^{12}C(α, 4α)	$Q_{\rm m} = -7.2748$	

The yield of ^{8}Be (reaction (a)) shows a number of resonances: see Table 16.13. 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 (1976BR07). For reactions (b) and (c) see (1977AJ02).

9. ^{12}C(^{6}Li, d)^{16}O $\qquad Q_{\rm m} = 5.6885$

This reaction has been studied at many energies: see the references in (1977AJ02) and Table 16.14. At the higher energies the spectra are dominated by states with $J \geq 4$ (and natural parity). An attempt to locate an 8^+ state with $E_{\rm x}$ = 17 to 24 MeV by (d, α) angular correlations has been unsuccessful: see (1976AR10; E(^{6}Li) = 29.0 and 34.7 MeV). The ratio R [$\equiv \theta^2_\alpha$(7.1 MeV)/θ^2_α(9.6 MeV)] is of astrophysical interest: an FRDW analysis by (1980BE33) leads to $R = 0.7 \pm 0.2$ for $s = 5.4$ fm. See also (1978BE43).

For analyzing power measurements see ^{18}F in (1983AJ01): (1978MA13; E(^{6}Li) $= 20$ MeV; to ^{16}O states with $E_{\rm x} < 11.1$ MeV). See also (1979BEZU, 1980FU1D, 1980MA1N), (1977FO1E, 1978BE1H, 1978FI1E, 1979MA1T) and (1976ST22, 1977BA56, 1978AP02, 1978CU07, 1978ME1J, 1979SU1F, 1979ZE1B, 1980AP02; theor.).

10. ^{12}C(^{7}Li, t)^{16}O $\qquad Q_{\rm m} = 4.695$

This reaction has been studied extensively: see (1977AJ02) for the earlier references. Observed states are displayed in Table 16.14. Angular distributions have been reported recently at $E(^7\text{Li}) = 34$ MeV (1978BE42; first nine states) and at 68 MeV (1979BE1H; to ^{16}O*(6.92, 10.35, 16.3)). The value of R [see reaction 9] derived by (1978BE42) is 0.35 ± 0.13. See also ^{19}F in (1983AJ01), (1976SA1K, 1978CL08, 1979RO1M, 1980DE2K, 1981DE15) and (1977BI1F; theor.).

Table 16.14: States of ^{16}O from ^{12}C(^{6}Li, d) and ^{12}C(^{7}Li, t)

E_x [a] (MeV ± keV)	$\Gamma_{c.m.}$ [b] (keV)	$\theta^2_\alpha/\theta^2_\alpha(2^+)$ [c]	Γ_{α_0}/Γ [d]	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 [i]	400 ± 10 [i]	0.30, 0.60		1^-; 0^-
9.85	< 20	$\lesssim 0.05$, $\lesssim 0.01$		2^+
10.346 ± 6 [e,j]	35 ± 5	0.25, 0.47	0.86 ± 0.09	4^+; 0^+
10.95				0^-
11.09 [j]	< 30	$\lesssim 0.06$, $\lesssim 0.03$	0.31 ± 0.03 ($J = 4^+$)	$3^+ + 4^+$
11.59 ± 20	700 ± 100	≈ 0.4		3^-; 0^-
13.09	≈ 230			1^-
14.363 ± 15 [h]	< 120			> 5, π = nat.
14.66 ± 20	500 ± 50		1.03 ± 0.1	5^-; 0^-
14.82	45 ± 10			(6^+)
16.30 ± 20 [e,k]	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	$\lesssim 100$		0.67 ± 0.14	6^+ [g]
23.0 ± 100	≈ 200			(6^+)
23.8 ± 100	1980 ± 250			(6^+) [g]
26.9 ± 100	1700 ± 250			(7^-) [g]

Table 16.14: States of ^{16}O from ^{12}C(^{6}Li, d) and ^{12}C(^{7}Li, t) (continued)

E_x [a] (MeV ± keV)	$\Gamma_{c.m.}$ [b] (keV)	$\theta^2_\alpha/\theta^2_\alpha(2^+)$ [c]	$\Gamma_{\alpha 0}/\Gamma$ [d]	J^π; K^π
(29.3) [g]				(7^-) [g]

[a] E_x quoted without errors are from Table 16.11. The others are from (1978BE43: $E(^6$Li$) = 42.1$ MeV) and (1980BE33: $E(^6$Li$) = 90.2$ MeV). The states with $E_x < 11.1$ MeV have also been studied by (1978BE42: $E(^7$Li$) = 34$ MeV). Angular distributions are reported in both reactions for the first nine states. See also (1978CU03).

[b] See (1978BE42, 1978BE43, 1980BE33): 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 (1978BE43), the second at $E(^6$Li$) = 90.2$ MeV (1980BE33).

[d] (1980CU08); d-α angular correlations. See also (1977CU1B, 1978CU03, 1978AR01).

[e] (1971BA31).

[f] (1979AR05); d-α angular correlations.

[g] (1976AR04, 1976AR10); d-α angular correlations.

[h] Observed at $E(^7$Li$) = 38$ MeV (1976CO23) and M.E. Cobern, private communication.

[i] 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, $\Gamma = 400 \pm 10$ keV (line width). $\Gamma_R = 430 \pm 10$ keV as inferred from the best fit BW line shape. This value is corrected for penetrability (1981OV02 and F. Becchetti, private communication).

[j] Angular distributions are reported at $E(^6$Li$) = 35.5 - 35.6$ MeV to ^{16}O*(10.35) 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 (1978CL08, 1980KE10). See also (1978CU03).

[k] Angular distributions at $E(^6$Li$) = 35.5$ MeV (1978CL08) and 28 and 34 MeV (1978CU03).

11. ^{12}C(^{10}B, ^{6}Li)^{16}O $\qquad Q_m = 2.7014$

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) (1970HI08). 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 (1981BI07). See also footnote [i] in Table 16.14 and (1978BE2F).

12. ^{12}C(^{11}B, ^{7}Li)^{16}O $\qquad Q_m = -1.503$

See (1978BE2F). See also (1977AJ02).

13. ^{12}C(^{12}C, ^{8}Be)^{16}O $Q_{\rm m} = -0.2047$

Angular distributions have been reported at $E(^{12}{\rm C})$ to 63 MeV: see (1977AJ02). Angular correlations at $E(^{12}{\rm C}) = 78$ MeV confirm $J^\pi = 4^+, 5^-, 6^+$ and 7^- for ^{16}O*(10.35, 14.59, 16.3, 20.9). $\Gamma_{\alpha_0}/\Gamma = 0.90 \pm 0.10, 0.75 \pm 0.15$ 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 (1977SA2A, 1979SA29). For the decay of ^{20}Ne states see (1979YO04) and (1983AJ01). For excitation function and fusion measurements see (1977HI04, 1977WA04, 1978CO05, 1978JA08, 1979HE1E, 1980KO02, 1980WA16, 1980WI1E). See also (1977AB1E, 1978TO12; theor.).

14. ^{12}C(^{14}N, ^{10}B)^{16}O $Q_{\rm m} = -4.4512$

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 (1976ZE04) and at $E(^{14}{\rm N}) = 78.8$ MeV (1977MO1A, 1979MO14) involving $^{16}{\rm O}_{\rm g.s.}$.

15. (a) ^{12}C(^{17}O, ^{13}C)^{16}O $Q_{\rm m} = 0.8021$

(b) ^{12}C(^{18}O, ^{14}C)^{16}O $Q_{\rm m} = 0.9341$

Angular distributions are reported at $E(^{17}{\rm O}) = 30.5$ and 33.8 MeV (1978CH16). For reaction (b) see (1977AJ02) and (1978TA09; theor.).

16. ^{12}C(^{19}F, ^{15}N)^{16}O $Q_{\rm m} = 3.1481$

Angular distributions have been measured at $E(^{19}{\rm F}) = 40$, 60 and 68.8 MeV involving different states in ^{15}N and ^{16}O*(0, 6.1, 7.0, 10.4) (1972SC17).

17. ^{12}C(^{20}Ne, ^{16}O)^{16}O $Q_{\rm m} = 2.4310$

Angular distributions have been measured to $E(^{20}{\rm Ne}) = 147$ MeV: see (1977AJ02). Excitation functions are reported at $E(^{20}{\rm Ne}) = 45.3$ to 93.3 MeV (1978DO01) and 150 to 250 MeV (1979OR01: $E_{\rm x} = 10 - 15$ MeV and $20 - 25$ MeV). For an experiment studying $^{16}{\rm O} + \alpha$ coincidences see (1981OS07). See also (1975PI05).

18. ^{13}C(^{3}He, γ)^{16}O $\qquad Q_{\rm m} = 22.7934$

The yield of capture γ-rays has been studied for $E(^{3}{\rm He})$ to 16 MeV [see (1977AJ02)], as have angular distributions. Observed resonances are displayed in Table 16.15. 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).

19. ^{13}C(^{3}He, n)^{15}O $\qquad Q_{\rm m} = 7.1295$ $\qquad E_{\rm b} = 22.7934$

The excitation functions 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 16.15. See also (1977AJ02) for polarization measurements.

20. ^{13}C(^{3}He, p)^{15}N $\qquad Q_{\rm m} = 10.6658$ $\qquad E_{\rm b} = 22.7934$

Excitation functions for $E(^{3}{\rm He}) = 3.6$ to 6.6 MeV have been measured for p_0, p_{1+2}, p_3: a resonance is reported at $E(^{3}{\rm He}) = 4.6$ MeV (1978CH19). A resonance at 6 MeV has also been observed: see Table 16.15. See also ^{15}N in (1981AJ01).

21. ^{13}C(^{3}He, d)^{14}N $\qquad Q_{\rm m} = 2.0571$ $\qquad E_{\rm b} = 22.7934$

See ^{14}N in (1981AJ01).

22. (a) ^{13}C(^{3}He, t)^{13}N $\qquad Q_{\rm m} = -2.2392$ $\qquad E_{\rm b} = 22.7934$
(b) ^{13}C(^{3}He, ^{3}He)^{13}C

The excitation function for formation of $^{13}{\rm N}_{\rm g.s.}$ has been studied for $E(^{3}{\rm He}) = 11$ to 17 MeV: see (1977AJ02). Polarization measurements are reported by (1981BA1G) at $E(^{3}\vec{\rm He}) = 33$ MeV (t_0, t_{2+3}). For reaction (b) see Table 16.15.

23. ^{13}C(^{3}He, α)^{12}C $\qquad Q_{\rm m} = 15.6314$ $\qquad E_{\rm b} = 22.7934$

Table 16.15: Resonances in $^{13}C + ^{3}He$

$E(^{3}He)$ (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Outgoing particles	$^{16}O^*$ (MeV)	$J^\pi; T$	Refs. [a]
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^-	(1979VE02)
≈ 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)	(1979VE02)
4.6 ± 100 [c]	720 ± 160	γ_2, p_0	26.5	2^+, 4^+	(1977CH16, 1978CH19, 1979VE02)
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^-)	(1979VE02)
≈ 5.8	≈ 2500	γ_{3+4}	27.5		(1979VE02)
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		(1979VE02)
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 earlier references see Tables 16.15 in (1971AJ02) and 16.13 in (1977AJ02).

[b] Lab widths $0.5 - 1$ MeV (1969TA09).

[c] Based on $\Gamma_{c.m.} = 530 \pm 80$ keV [from $^{15}N(p, \gamma)$, see Table 16.18], $\Gamma_{p_0} = 150 \pm 45$ 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 $[4^+]$ (1977CH16, 1978CH19).

Yields of α_0, α_1, α_2 and γ-rays from the decay of ^{12}C*(12.71, 15.11) have been studied up to $E(^3\text{He}) = 12$ MeV. Observed resonances are displayed in Table 16.15. 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 $E(^3\vec{\text{He}}) = 33$ MeV to ^{12}C*(4.4) (1981KA1K). See (1971AJ02, 1977AJ02) for the earlier references and ^{12}C in (1980AJ01).

24. ^{13}C(^{3}He, ^{8}Be)^{8}Be $Q_\text{m} = 8.1728$ $E_\text{b} = 22.7934$

The excitation function for ^{8}Be$_{\text{g.s.}}$ 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 (1968JA07).

25. ^{13}C(α, n)^{16}O $Q_\text{m} = 2.2156$

Angular distributions for the n_0 group have been measured for $E_\alpha = 12.8$ to 22.5 MeV: see (1971AJ02). See also (1977AJ02), (1981HA1J), (1977SC1L, 1980CO1P, 1980TR1K; astrophys.) and (1978GE16, 1980BA1Q; applications).

26. ^{13}C(^{6}Li, t)^{16}O $Q_\text{m} = 6.9994$

Angular distributions have been studied at $E(^6\text{Li}) = 20$ and 28 MeV to ^{16}O*(0 [at 28 MeV], 6.13, 7.0, 8.87, 9.85, 10.35, 11.09). At these energies the spectra are dominated by the triton groups to ^{16}O*(11.09, 14.30, 14.39, 14.82). At $E(^6\text{Li}) = 25$ MeV the excitation of ^{16}O*(14.52, 14.66) is also reported: see (1977AJ02) and (1980CU03). See also (1977MA2G) and ^{19}F in (1983AJ01).

27. ^{13}C(^{12}C, ^{9}Be)^{16}O $Q_\text{m} = -3.4859$

Angular distributions have been measured at $E(^{12}\text{C}) = 87$ MeV and at $E(^{13}\text{C}) = 36$ MeV: see (1977AJ02). At $E(^{13}\text{C}) = 105$ MeV, ^{16}O*($6.05 + 6.13$, 10.35, 16.3, 20.7) are strongly populated (1979BR04).

28. ^{13}C(^{17}O, ^{14}C)^{16}O $Q_\text{m} = 4.0322$

Angular distributions have been measured at $E(^{17}\text{O}) = 29.8$ and 32.3 MeV (1977CH22, 1978CH16).

29. ^{14}C(^{3}He, n)^{16}O $\qquad Q_m = 14.6168$

At $E(^3\text{He}) = 11$ to 16 MeV, neutron groups are observed to $T = 2$ states at $E_x = 22.717 \pm 0.008$ 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). See also (1971AJ02).

30. ^{14}C(^{18}O, ^{16}C)^{16}O $\qquad Q_m = -6.720$

See ^{16}C.

31. ^{14}N(d, γ)^{16}O $\qquad Q_m = 20.7363$

The γ_0 yield has been studied for $E_d = 0.5$ to 5.5 MeV. Three resonances are reported: see Table 16.16. See (1977AJ02) for references.

32. ^{14}N(d, n)^{15}O $\qquad Q_m = 5.0725 \qquad E_b = 20.7363$

For $E_d = 0.66$ 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). See also ^{15}O in (1981AJ01), (1981NO1B) and (1977YO1F; applications).

33. ^{14}N(d, p)^{15}N $\qquad Q_m = 8.6087 \qquad E_b = 20.7363$

The yield of various proton groups for $E_d < 5.0$ MeV shows some fluctuations and two resonances: see Table 16.16 and (1971AJ02, 1977AJ02) for the earlier references. Recent work includes that of (1976VA20; 0.309 to 0.638 MeV; p_0, p_{1+2}, p_3, p_4, p_5), (1980NI04; 0.32 to 1.45 MeV; p_5), (1979US01; $E_{\vec{d}} = 1.50$ to 3.00 MeV; p_5) and (1977KO33; $E_d = 0.5$ to 5.0 MeV; p_0, p_{1+2}, $p_3 \rightarrow p_8$, p_{10}). Polarization measurements are also reported by (1980KR01; $E_{\vec{d}} = 10$ MeV; p_0, p_{1+2}, p_3, p_7, p_8; 9.5 to 10.75 MeV; p_4, p_5, p_6). See also (1977AJ02) and ^{15}N in (1981AJ01).

34. ^{14}N(d, d)^{14}N $\qquad E_b = 20.7363$

Table 16.16: Structure in ^{14}N + d

$E_{\rm d}$ (MeV)	Resonant channel	$\Gamma_{\rm c.m.}$ (keV)	$J^\pi; T$	$E_{\rm x}$ (MeV)	Refs. [a]
1.4	n_0			22.0	
1.7 ± 0.1	γ_0, $\alpha_0 \rightarrow \alpha_3$			22.2	
1.85	n_0, α_0			22.35	
2.0 ± 0.1	α_0, α_3			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	(1977KO33)
2.40 ± 0.05 [c]	γ_0 [d]	600	$1^-; 1$	22.83	
2.5	α_0			22.9	
2.6	(n_0), α_1			23.0	
2.8	(n_0), d_0			23.2	
3.24	p_0, p_{1+2}, p_4, p_5, p_6, d_0, α_3			23.57	(1977KO33)
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).

[b] $(\Gamma_{\rm d_0}\Gamma_{\rm i}/\Gamma^2) \times 10^{-3}$ 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 $l = 1$ (1972WE04).

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

The yield of elastically scattered deuterons has been studied for $E_d = 0.65$ to 5.5 MeV and for 14.0 to 15.5 MeV: see (1971AJ02, 1977AJ02). There is indication of broad structure at $E_d = 5.9$ MeV and of sharp structure at $E_d = 7.7$ MeV in the total cross section of the d_1 group to the $T = 1$ (isospin-forbidden), $J^\pi = 0^+$ state at $E_x = 2.31$ MeV in ^{14}N. The yield of deuterons (d_2) to ^{14}N*(3.95) [$J^\pi = 1^+, T = 0$] shows gross structures at $E_d = 7.4$ and 10.2 MeV (1970DU04): see Table 16.16. The yield of d_1 has also been studied for $E_d = 10.0$ to 17.9 MeV by (1979AO01). For polarization measurements, see (1977AJ02) and (1980KR01: $E_d = 10$ MeV; d_0). See also ^{14}N in (1981AJ01) and (1977IZ01, 1977IZ1B, 1979SE04; theor.).

35. (a) ^{14}N(d, t)^{13}N $\quad Q_m = -4.2963 \quad E_b = 20.7363$

(b) ^{14}N(d, ^{3}He)^{13}C $\quad Q_m = -2.0571$

For polarization measurements see (1977AJ02) and (1981MA14). See also ^{13}C, ^{13}N in (1981AJ01).

36. ^{14}N(d, α)^{12}C $\quad Q_m = 13.5743 \quad E_b = 20.7363$

There is a great deal of structure in the yields of various α-particle groups for $E_d = 0.5$ to 12 MeV: see Table 16.16 in (1971AJ02) for the earlier work, and (1977KO33: 0.5 to 5.0 MeV; $\alpha_0 \rightarrow \alpha_3$, $\alpha_5 \rightarrow \alpha_7$). The latter group reports broad oscillations ($\Gamma \approx 0.5$ MeV) in the α_0 and α_1 yields for $E_d = 2.0$ 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 $E_d = 2.8$ to 12 MeV. Pronounced resonances are observed at $E_d = 4.2$, 4.58 and 5.95 MeV and broader peaks occur at $E_d = 7.1$ and, possibly, at 8.5 MeV. See also ^{12}C in (1980AJ01).

For polarization measurements, see (1979DE45: $E_{\vec{d}} = 1.5$ to 3.0 MeV; α_0, α_1), (1980KR1G, 1981KR1A: $E_{\vec{d}} = 10$ MeV; $\alpha_0 \rightarrow \alpha_5$) and (1977AJ02). See also (1979SE04; theor.).

37. ^{14}N(t, n)^{16}O $\quad Q_m = 14.4790$

See (1977AJ02).

38. (a) ^{14}N(^{3}He, p)^{16}O $\quad Q_m = 15.2428$

(b) ^{14}N(^{3}He, pα)^{12}C $\quad Q_m = 8.0808$

Observed proton groups are displayed in Table 16.17. Angular distributions have been measured at $E(^3\text{He}) = 2.5$ to 24.7 MeV: see (1977AJ02) for the earlier work and (1979SL02: 9.8 MeV; p_0), (1978BI10, 1978FO27: 15 MeV; most states in Table 16.17) and (1977MA2L: 24.7 MeV; p to ^{16}O*(0, 6.13, 16.21, 17.14). Branching ratios and τ_m measurements are shown in Tables 16.11 and 16.12.

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

E_x (MeV ± keV) [a.b]	$\Gamma_{c.m.}$ [a,b] (keV)	L [c]	J^{π} [c]
0		$0+2$ [d]	
6.052 ± 5		(0) [e]	
6.131 ± 4		$1+3$ [d]	
6.916 ± 3		(0)	
7.115 ± 3		$1+3$ [d]	
8.870 ± 3	< 20	$3+1$	
9.614 ± 30	510 ± 60		
9.847 ± 3	< 20	$0(+2)$	
10.356 ± 3	25 ± 5	[e]	
10.957 ± 1	< 12	1 [d]	
11.080 ± 3	< 12	$2+4$ [f]	
11.098 ± 2	< 12		
11.520 ± 4	64 ± 5	[e]	
12.049 ± 2	< 12	0	
12.438 ± 3	70 ± 10	1	
12.530 ± 2	< 12	$1+3$ [d]	
12.797 ± 4	40 ± 10	1	$0^-; T=1$ [g]
12.970 ± 1	< 12	$1+3$	$2^-; T=1$ [g]
13.105 ± 15	160 ± 30	$0+3$ [f]	
13.257 ± 2	20 ± 5	$(1+3)$	$3^-; T=1$ [g]
13.663 ± 4	63 ± 7	0	
13.869 ± 2	85 ± 20	(4) [e]	
13.979 ± 2	14 ± 5	$1(+3)$	
14.302 ± 3	< 20	[e]	
14.399 ± 2	27 ± 5	(4)	
14.818 ± 3		2	$(0 \rightarrow 4)^+$
14.927 ± 2	60 ± 10	$0(+2)$	$(0, 1, 2)^+$ [h]
15.103 ± 5			
15.196 ± 3		$(0+2)$	
15.409 ± 6		[e]	
15.785 ± 5	40 ± 10	$2(+4)$	$(2, 3, 4)^+$ [h]

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

E_x (MeV ± keV) [a.b]	$\Gamma_{c.m.}$ [a,b] (keV)	L [c]	J^{π} [c]
16.114 ± 4 [j]			
16.209 ± 2	40 ± 10	$0 + 2$	
16.350 ± 13			
16.440 ± 3	≈ 30	$0 + 2$	
16.817 ± 2	70 ± 10		

[a] (1964BR08): $E(^{3}\text{He}) = 3.74$ and 3.97 MeV.
[b] (1978BI10): $E(^{3}\text{He}) = 15$ MeV.
[c] (1978BI10, 1978FO19, 1978FO27).
[d] See also (1971WE16).
[e] Mostly compound nucleus.
[f] Unresolved.
[g] (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.
[h] (1978FO19) suggest that these two states [^{16}O*(14.93, 15.79)] are 1^+ and 3^+ 2p-2h states with $T_p = T_h = 0$.
[i] Very weak proton group. I am indebted to Prof. H.T. Richards for his comments.

At $E(^{3}\text{He}) = 8$ MeV a study of the protons in coincidence with 4.4 MeV γ-rays (reaction (b)) indicates that the reaction proceeds via ^{16}O*(12.51, 13.97, 14.39, 14.92, 15.82, 16.23, 17.82, 18.04) [±40 keV] (1969HO13). In a kinematically complete experiment at $E(^{3}\text{He}) = 13$ MeV, ^{16}O*(14.94, 18.04) are strongly populated (1980FR1J; prelim.). See also (1979HA1M).

39. (a) ^{14}N(α, d)^{16}O $\qquad Q_m = -3.1104$

(b) ^{14}N(α, dα)^{12}C $\qquad Q_m = -10.2724$

Angular distributions to states of ^{16}O have been reported at many energies to $E_\alpha = 48$ MeV: see (1971AJ02, 1977AJ02). Among the states reported by (1972LO08) [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 of (1972LO08) 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]. (1979CL10) report $\Gamma_{c.m.} = 34\pm12$, 27 ± 5 and 70 ± 8 keV, respectively for ^{16}O*(14.31 ± 10, 14.40 ± 10, 14.81). For reaction (b) see (1977AJ02).

40. ^{14}N(^{6}Li, α)^{16}O $\qquad Q_m = 19.2628$

Angular distributions have been measured at $E(^{6}\text{Li}) = 5.3$ to 6.0 MeV and $E(^{14}\text{N}) = 27.6$ MeV: see (1977AJ02).

41. ^{14}N(^{10}B, ^{8}Be)^{16}O $\qquad Q_m = 14.7104$

See (1978WU1C). See also (1977HI01).

42. (a) ^{14}N(^{11}B, ^{9}Be)^{16}O $\qquad Q_m = 4.9204$
(b) ^{14}N(^{13}C, ^{11}B)^{16}O $\qquad Q_m = 2.0576$

At $E(^{14}\text{N}) = 50$ MeV angular distributions are reported to ^{16}O*(0, 6.1 [u], 7.0 [u], 8.87, 9.85, 10.3 [u], 11.0 [u]) [u $=$ unresolved] (1977RE08). For both reactions see (1980PR09). See also (1977AJ02).

43. ^{15}N(p, γ)^{16}O $\qquad Q_m = 12.1276$

The yield of ground state radiation (γ_0) has been measured for $E_p = 0.15$ to 27.4 MeV: see Table 16.18 in (1977AJ02) and (1979SN01: $E_{\bar{p}} = 4$ to 9 MeV), (1977CH19: 6 to 22 MeV; also γ_2), (1977CA21: $E_{\bar{p}} = 8.6$ to 11 MeV) and (1978OC01: 8.6 to 18 MeV; also $\gamma_{1+2+3+4}$ for $12.7 \rightarrow 18$ MeV). Table 16.18 displays the parameters of the observed resonances. The cross section shows a great deal of structure up to $E_p = 17$ MeV. Above that energy the γ_0 yield decreases monotonically. Besides the GDR which peaks at ^{16}O*(22.15) (1978OC01), the giant M2 resonance, based on ^{16}O*(6.13), is identified to be ^{16}O*(20.43) (1977CH19), and there is evidence for the emergence of a giant structure (E2) with $E_x = 24 - 29$ MeV in the $\gamma_{1+2+3+4}$ yield (1978OC01). (1979SN01) report that the total M1 transition strength, built on the 2p-2h ground state correlations, B(M1)$\downarrow$ ≥ 0.24 nm^2 for ^{16}O*(16.22, 17.14, 18.8).

A study of the M1 decays of ^{16}O*(16.22, 17.14) [both $J^\pi = 1^+$; $T = 1$] to ^{16}O*(6.05) finds $B(\text{M1}, 1^+ \rightarrow 0^+_2)/B(\text{M1}, 1^+ \rightarrow 0^+_1) \approx 0.7$ for both transitions. The M1 (E2) γ-decay of ^{16}O*(18.03, 18.98) [$J^\pi = 3^-$; $T = 1$ and $J^\pi = 4^-$; $T = 1$, respectively] to ^{16}O*(6.13) [$J^\pi = 3^-$] are also reported by (1980IK1A). See also (1981SN1A).

Below $E_p = 0.4$ MeV capture to the ground state is dominant: $S(0) = 64 \pm 6$ keV $\cdot$ b, a value which makes the oxygen side cycle in CNO burning more important than previously thought. Study of the direct radiative capture process leads to a single-particle spectroscopic factor $C^2S = 1.8 \pm 0.4$ for ^{16}O$_{\text{g.s.}}$ (1974RO37).

Table 16.18: Levels of ^{16}O from ^{15}N(p, γ) ^{16}O, ^{15}N(p, p)^{15}N and ^{15}N(p, α)^{12}C

No.	E_p (keV)	Γ_{γ_0} [a] (eV)	Γ_{γ_1} [a] (eV)	Γ_p [a] (keV)	$\Gamma_p\Gamma_\gamma/\Gamma$ (eV)	Γ_{α_0} [a] (keV)	Γ_{α_1} [a] (keV)	Γ_{lab} (keV)	$J^\pi; T$	E_x (MeV ± keV)	Refs. [b]
1	338	12 ± 2	0.12 ± 0.04	1.2		95	0.025	96	$1^-; 0$	12.444	
2	429 ± 1	$(21 \pm 6) \times 10^{-3}$	2.1 ± 2	0.02		nr	0.90	0.9	$2^-; 0$	12.530	
3	710 ± 7			40		nr		40 ± 4	$0^-; 1$	12.793	
4	897.37 ± 0.29	$(78 \pm 16) \times 10^{-3}$		1.2		nr	0.69 ± 0.07	2.0 ± 0.2	$2^-; 1$	12.9685	(1977BR32)
5	1028 ± 10	32 ± 5		100		40	r	140 ± 10	$1^-; 1$	13.091	(1977BR32)
6	1050 ± 150					$\Gamma_p\Gamma_{\alpha_0} = 500$ keV^2			2^+	13.1	(1977BR32)
7	1210 ± 3			4.1		r	8.2 ± 1.1	22.5 ± 1	$3^-; 1$	13.261	(1977BR32)
8	1640 ± 3	≈ 8.5		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	2977 ± 10			33		1.5	30	69 ± 10	2^+	14.917 ± 5 [c]	(1977JA11, 1978FR04)
12	3170 [j]			12 [d]		152	163	327 ± 100	0^+	15.10 ± 50	(1978FR04)
13	3260 [j]			48		nr	7	62 ± 10	2^-	15.188 ± 30 [c]	(1978FR04)
14	3340 [j]			15 [d]		12	182	315 ± 100	2^+; (0)	15.26 ± 20 [c]	(1978FR04)
15	3520 ± 40			23		103	1	167 ± 20	3^-	15.43 [c]	(1977JA11, 1978FR04)
16	4380 ± 20	3.6	r	16	2.65 ± 0.22			19 ± 3	$1^+; 1$	16.23	(1979SN01, 1980IK1A)
17	4620 ± 20			r		(r)	r			16.46	(1977JA11)
18	5010 ± 20			r		nr	r	75 ± 10	3^+	16.82	(1977JA11)
19	5200	r						≈ 1500	$1^-; 1$	17.0	
20	5350 ± 20	6.5	r	26	3.75 ± 0.50			38 ± 5	$1^+;1$	17.14	(1979SN01, 1980IK1A)
21	5490 ± 20	67	o	45				≈ 110	$1^-; 1$	17.27	
22	6290 ± 20	nr	5 ± 2 [4 ± 2 [e]]	≤ 15 [f]				≤ 40	$3^-; 1$	18.02	(1977CH19, 1980IK1A)
23	7310 ± 20		≤ 2 [e,o]	≤ 40 [f]				≤ 40	$4^-; 1$	18.98	(1977CH19, 1980IK1A)
24	7330 ± 30	38		≤ 130	$\geq 1.8 \pm 0.3$			≈ 260	1^+	18.99	(1979SN01)
25	7420	r		≈ 30				≈ 130	2^+; (1)	19.08	
26	7600 ± 30	nr	1.5 [h]					100	(2, 3; 1)	19.25	
27	7840 ± 30	59		(r)				350	$1^-; 1$	19.47	
28	8290 ± 20	nr	17 ± 6 [e]	25 ± 10 [f]				80 ± 30	3	19.89	(1977CH19)
29	8860 ± 30	nr	120 ± 45 [e]	86 [f]				200 ± 40	$2^-; 1$	20.43 [g]	(1977CH19)
30	8990			i				160		20.55	
31	9410 [j]	170		i	21 ± 1			320 ± 10	$1^-; 1$	20.945 ± 20	(1978OC01, 1977CA21)
32	10000 [j]			k				130	$1 \rightarrow 4$	21.50	
33	10180 [j]			l		r		< 45	$T = 0$	21.66	
34	10700 [j,m]	r		k	488 ± 20			730 ± 10	$1^-; 1$	22.150 ± 10	(1978OC01)
35	11490 [j]	120	27 [h]	k	69 ± 5			320 ± 10	$1^-; 1$	22.89 ± 10	(1978OC01)
36	12740 [j]	r			130 ± 13			590 ± 40	$1^-; 1$	24.07 ± 30	(1978OC01)
37	13490 ± 60		230 ± 90, or 130 ± 50 [e]	85 [f]				360 ± 60	$(2, 4)^+; 1$	24.76	(1977CH19)
38	13870 [j]	r			651 ± 117		p	3150 ± 320	$1^-; 1$	25.12 ± 60	(1978OC01)
39	15250 ± 80		740 ± 240, or 410 ± 140 [e]	122 [f]			p	565 ± 85 [n]	$(2, 4)^+; 1$	26.41	(1977CH19)
40	16250 ± 100		1070 ± 380, or 590 ± 10 [e]	206 [f]			p	880 ± 125	$(2, 4)^+; 1$	27.35	(1977CH19)

[a] nr = non-resonant; r = resonant.

[b] For earlier references see Tables 16.21 in (1971AJ02) and 16.19 in (1977AJ02).

[c] The values for Γ_{x}, Γ, J^{π} and E_{x} are from a multilevel R-matrix analysis of p_0, α_0 and α_1 excitation curves (1978FR04): in addition to these states, others at $E_{\mathrm{x}} = 14.0$ [0^+] (fixed), 14.6 [1^-] and 16.2 MeV [1^+], $\Gamma = 0.44$, 0.68 and 1.23 MeV were included in the analysis.

[d] Not observed in p_0 channel.

[e] Γ_{γ_2} (eV) (1977CH19).

[f] Γ_{p_0} based on $\Gamma_{\mathrm{c.m.}}$ and values of Γ_{p_0}/Γ assumed by (1977CH19).

[g] This state is attributed to the giant M2 resonance based on ^{16}O*(6.13) [$J^{\pi} = 3^-$] (1977CH19).

[h] $\gamma_1 + \gamma_2$.

[i] Resonant in p_2 (1971DR06).

[j] Nominal E_{p} calculated from E_{x}.

[k] Resonant in p_1 (1971DR06).

[l] Resonant in p_0, p_1, p_6 (1971DR06).

[m] $\sigma = 12.9$ mb at peak of GDR (1978OC01).

[n] Average of values obtained in this experiment and in ^{12}C(α, γ_2) (1977CH19).

[o] Resonant in γ_2.

[p] Apparent resonance in yield of (p, $\alpha\gamma_{15.1}$) (1978OC01).

For branching ratios and Γ_γ values for the low-energy resonances see Table 16.12. See also (1978WI1J, 1979WIZW), (1975HA1Q, 1975PA1J, 1976HA1Q, 1979GL1H, 1979HA1G, 1979SN1A, 1980WE1D, 1981WI1E), (1975ZI1A, 1976BO1M, 1977RO1H, 1978RO1D, 1980BA2R; astrophys.) and (1977BA4A, 1977HO32, 1978BA52, 1978GA13; theor.).

44. ^{15}N(p, p)^{15}N $E_b = 12.1276$

Elastic scattering studies are reported for $E_p = 0.6$ to 15 MeV: see Table 16.20 in (1971AJ02), 16.18 in (1977AJ02), (1977JA11; 2.50 to 5.14 MeV) and (1978FR04; 2.88 to 3.64 MeV). See also (1976LA1G). Observed anomalies are displayed in Table 16.18. For inelastic groups see (1971DR06). See also (1980FA06) and (1980DO01, 1980HA35; theor.).

45. ^{15}N(p, n)^{15}O $Q_m = -3.5363$ $E_b = 12.1276$

Excitation functions and cross sections have been measured for $E_p = 3.8$ to 19.0 MeV: see (1977AJ02) and (1978CH09; $8.5 \rightarrow 19.0$ MeV; n_0). For a listing of observed resonances see Table 16.19. Angular distributions of n_0 have been studied for $E_p = 5.52$ to 9.26 MeV (1981MU01) and 9.05 to 15.62 MeV (1981BY01). Polarization measurements are reported for the n_0 group at $E_{\vec{p}} = 7$ to 17 MeV: see (1981MU1D, 1981WA1F). See also (1977BY1A, 1980BY1A, 1981BY1B), (1976WA1C, 1979BY1B, 1980WA1K, 1981CO1C, 1981WA1G) and (1977BA02, 1977HO32, 1979AB17, 1980DO01, 1980HA35, 1981PH1B; theor.).

46. (a) ^{15}N(p, t)^{13}N $Q_m = -12.9050$ $E_b = 12.1276$
(b) ^{15}N(p, ^{3}He)^{13}C $Q_m = -10.6658$

The yields of the first three triton and ^{3}He groups have been measured for $E_p = 24.0$ to 43.5 MeV (1974PI05, 1975MI01). Polarized protons with $E_p = 43.8$ MeV have been used to study the transitions to ^{13}C*(0, 3.68, 7.55, 15.11) and ^{13}N*(0, 3.51, 7.38, 15.07) (1974MA12). See also ^{13}C, ^{13}N in (1981AJ01).

47. ^{15}N(p, α)^{12}C $Q_m = 4.9656$ $E_b = 12.1276$

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 $E_p = 93$ keV to 45 MeV: see Tables 16.20 in (1971AJ02), 16.18 in (1977AJ02) and (1979ZY02: 93 to 418 keV; α_0), (1977BR32: 0.9 to 1.25 MeV; α_0, α_1), (1977JA11: 2.5 to 5.14 MeV; α_0, α_1) and (1978FR04: 2.88 to 3.64 MeV; α_0, α_1). The yield of 15.11 MeV γ-rays has been measured for $E_p = 12.5$ to 17.7 MeV (1978OC01). Observed resonances are displayed in Table 16.18.

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,e]	200 ± 50	2	20.45
9.08 ± 40 [e]	130 ± 50		20.63
9.42 ± 100 [e]	235 ± 45		20.95
10.73 ± 100 [e]	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] First fourteen resonances are from (1968BA42); the higher energy resonances are from (1978CH09: n_0).

[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: see (1968BA42).

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

[e] See also (1968BA42).

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	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	0.26
9.63	$1^-; 0$		0	[d]				
9.85	$2^+; 0$	1	not direct	[d]			2	0.025
10.35	$4^+; 0$		3	[d]			2	0.025
10.95	$0^-; 0$	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	$2^-; 0$ [j]	2	2	0.72	1	0.07		
12.80	$0^-; 1$	0	0	0.44				
12.97	$2^-; 1$ [j]	2	2	0.40	1	0.69	1	0.38
13.10	$1^-; 1$	(0)		0.58			1	0.10
			$2(+0)$					
13.13 [g]	$3^-; 0$	(2)		0.32				
13.25	$3^-; 1$	2	2	0.46	1	0.70	1	0.34
15.22	$2^-; 0$ [e]				1	0.12		
15.42	$3^-; 0$ [e]				1	0.37		
17.14			obs.					
17.20	2^+		obs.					
17.788 ± 16 [i]	$4^-; 0$					0.17		
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]	S [f]	Γ [j] (keV)		
18.48	$T=1$	(1)	0.25					
18.975 ± 10 [i]	$4^-; 1$	1	0.73					
19.206 ± 12 [i]	$3^-; 1$ [h]	1	0.50			68 ± 10		
19.802 ± 16 [i]	$4^-; 0$	1	0.52			36 ± 5		
20.45	$(2, 4)^-; 1$	1	0.21					

[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 as discussed by (1973BO1G) [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 (1978MA16). See also (1981MA1E; $E_{\bar{\rm d}} = 52$ MeV).
[f] ^{17}O(^{3}He, α); $E(^3$He)$= 11$ MeV (1971BO02).
[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. See also (1981MA1E).
[i] (1980BR1H): ^{17}O(^{3}He, α). $\Gamma < 50$ keV for ^{16}O*(17.79).
[j] See text (1977WA11).

A study of the α_0 cross section for $E_{\rm p} = 93$ to 418 keV leads to $S(0) = 78 \pm 6$ MeV $\cdot$ b (1979ZY02). For the $\alpha_1\gamma$-channel $S(0) \approx 0.1$ keV $\cdot$ b (1974RO37). See also (1977AJ02), (1979CL10), (1977RO1H, 1980BA2R; astrophys.), (1978TH1F; applications) and (1977GA1H; theor.).

48. ^{15}N(d, n)^{16}O $\qquad Q_{\rm m} = 9.9029$

Observed neutron groups, l-values and spectroscopic factors are displayed in Table 16.20. Angular distributions are reported for $E_{\rm d}$ to 6 MeV: see (1977AJ02).

49. ^{15}N(^{3}He, d)^{16}O $\qquad Q_{\rm m} = 6.6340$

Angular distributions have been measured at $E(^3$He$) = 11$, 16.0 and 24.9 MeV [see (1977AJ02)]: l- and S-values are shown in Table 16.20.

50. ^{15}N(α, t)^{16}O $\qquad Q_{\rm m} = -7.6865$

At $E_\alpha = 65$ MeV, the population of many ^{16}O states with $E_{\rm x} < 22$ MeV is reported by (1980YA1B).

51. (a) ^{15}N(^{11}B, ^{10}Be)^{16}O $\qquad Q_{\rm m} = 0.8988$
(b) ^{15}N(^{13}C, ^{12}B)^{16}O $\qquad Q_{\rm m} = -5.406$

Angular distributions are reported at $E(^{11}\text{B}) = 115$ MeV to ^{16}O*(6.13) and at $E(^{13}\text{C}) = 105$ MeV to ^{16}O*(6.13, 8.87) (1979RA10, 1980PR09).

52. ^{16}N(β^-)^{16}O $\qquad Q_\text{m} = 10.418$

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.

The α-decay of ^{16}O*(8.87, 9.63, 9.85) 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] (1974NE10).

Transition energies derived from γ-ray measurements are: $E_\text{x} = 6130.43 \pm 0.05$ keV [$E_\gamma = 6129.170 \pm 0.043$ keV (1975SH18)] and 7116.85 ± 0.14 keV [$E_\gamma = 7115.15 \pm 0.14$ keV (1976AL16)].

53. (a) ^{16}O(γ, n)^{15}O $\qquad Q_\text{m} = -15.6639$
(b) ^{16}O(γ, 2n)^{14}O $\qquad Q_\text{m} = -28.8882$
(c) ^{16}O(γ, pn)^{14}N $\qquad Q_\text{m} = -22.9609$

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 $E_\text{x} = 17.3$ [u], 19.3 [u] and 21.0 MeV [u = unresolved], followed by the giant resonance whose principal structures are at ≈ 22.2 and 24.1 MeV, with additional structures at 23 and 25 MeV: see (1976BE1H, 1977AJ02). The cross section for (γ, n_0) decreases monotonically for $E_\text{x} = 25.5$ to 43.8 MeV. There is a significant E2 cross section in that region: it exhausts $\approx 68\%$ of the isovector E2 energy-weighted sum rule (1979PH07). The differential (γ, n_0) cross sections have been measured for $E_\gamma = 60$ to 160 MeV (1980GO13).

The absorption cross section has been measured from $E_\text{bs} = 10$ MeV to above the meson threshold (1975AH06). The yield of reaction (b) has been studied from threshold to $E_\gamma = 120$ MeV [see (1977AJ02)] and for $E_\text{bs} = 100$ to 800 MeV (1977JO02). The (γ, Tn) cross section has recently been reported for $E_\gamma = 15.9$ to 39.7 MeV (1980JU01). See also (1976BE1H). The polarization of n_0 has been studied for $E_\gamma = 21.6$ to 25.7 MeV (1979NA1R). See also (1977AJ02). For the decay of ^{16}O* to ^{15}O states, see ^{15}O in (1981AJ01). See also (1975KN10), (1976BE1H, 1976KI1F, 1977DA1B, 1979HA1G, 1980CA1P, 1980SC1E, 1981SC1G) and (1976BA48, 1976KA34, 1977GR08, 1977MA2H, 1978CO14, 1978EL05, 1978KA1Q, 1978SC11, 1979MA2L, 1979RO04, 1979RO1B, 1980BO1P, 1980DU21, 1980OS1A, 1980TA1D, 1981BA04, 1981BO1P, 1981CA1F, 1981KO1G, 1981RO1N, 1981WE1C; theor.).

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

Final state		Branch (%)	log ft [b]
^{16}O* (MeV)	J^π		
0	0^+	26 ± 2 [c]	9.10 ± 0.04 [g]
6.05	0^+	$(1.2 \pm 0.4) \times 10^{-2}$ [d]	9.96 ± 0.15 [g]
6.13	3^-	68 ± 2 [c]	4.47 [h]
7.12	1^-	4.9 ± 0.4 [c]	5.09 [h]
8.87	2^-	1.0 ± 0.2 [c]	4.37 [h]
9.63	1^-	$(1.20 \pm 0.05) \times 10^{-3}$ [e]	6.21 [h]
9.85	2^+	$(6.5 \pm 2.0) \times 10^{-7}$ [f]	9.07 ± 0.13 [i]

[a] See also reaction 1 in ^{16}N.
[b] $\tau_{1/2} = 7.13 \pm 0.02$ sec: see Table 16.3 in (1971AJ02).
[c] (1956WI1A, 1958AL13, 1959AL06).
[d] (1968WA18).
[e] (1961KA06).
[f] (1969HA42).
[g] (1971TO08): log f_1t.
[h] B. Zimmerman, private communication: log f_0t.
[i] E.K. Warburton, private communication: log f_1t.

54. (a) ^{16}O(γ, p)^{15}N $\qquad Q_{\rm m} = -12.1276$
(b) ^{16}O(γ, π^+)^{16}N $\qquad Q_{\rm m} = -149.986$

The (γ, p_0) cross section derived from the inverse capture reaction (reaction 43) confirms the giant resonance structure indicated above, in reaction 53, as do also the direct (γ, p_0) measurements. The total (γ, p) cross section is given by (1968DE07). Recent measurements of the (γ, p_0) cross section are reported by (1977FI03: $E_{\rm bs} = 40$ to 105 MeV), (1980SC27: $E_\gamma = 80$ MeV; forward angles) and (1977MA01: $E_{\rm bs} = 100$ to 280 MeV). See also (1977AJ02) and (1980KH1C, 1980KI1E). The momentum distribution for $p_{1/2}$ shell protons in ^{16}O up to 930 MeV/c has been derived by (1978FI05). See also (1979MA1G). Branching ratios for the decays of ^{16}O states in the giant resonance region to various excited states in ^{15}N are discussed in ^{15}N (1981AJ01).

The cross section for reaction (b) for $E_{\rm bs} = 175$ MeV is reported by (1979BO21). See also (1977BE2L, 1981YA1A). For other π-emitting photonuclear reactions see (1979EP02, 1980BO24) and "*Special reactions involving* ^{16}*O*" section here. See also (1976HA1Q, 1980WE1D, 1981HA1T) and (1976BA48, 1976KA34, 1977NE2A, 1978FI10, 1978RO05, 1978SC11, 1979KO17, 1979LE1N, 1979LO03, 1979WA1G, 1980MO1M, 1981BO14, 1981BO1P, 1981CA1F, 1981CO1K; theor.).

55. (a) $^{16}O(\gamma, d)^{14}N$ $Q_m = -20.7363$

(b) $^{16}O(\gamma, t)^{13}N$ $Q_m = -25.033$

(c) $^{16}O(\gamma, \alpha)^{12}C$ $Q_m = -7.1620$

For the earlier work on these reactions see (1971AJ02, 1977AJ02). For reaction (a) see also (1979WIZW). A study of the $^{16}O(\gamma, \alpha_0)$ 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 spallation see (1978DI1A). See also (1981CH28).

56. $^{16}O(\gamma, \gamma)^{16}O$

(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 60 NZ/A MeV · mb by a factor 1.4. See also (1980IS1C). The integrated cross section to 31 MeV for elastic scattering is 0.62 ± 0.07 MeV · mb; the inelastic is $\leq 5\%$ of the elastic cross section (1980IS1G). For widths of excited states of ^{16}O see Table 16.22. The separation between the $^{16}O^*(7.12, 6.92)$ γ-lines is 199.8 ± 0.5 keV (1970SW03). Based on 7116.85 ± 0.14 keV (Table 16.11), E_x for the lower state is 6917.11 ± 0.6 keV.

57. (a) $^{16}O(e, e)^{16}O$

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

(c) $^{16}O(e, e\pi^+)^{16}N$ $Q_m = -149.986$

(d) $^{16}O(e, e\pi^-)^{16}F$ $Q_m = -154.996$

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 studies: see (1977AJ02) and (1979MI09: $q = 0.5$ to 2.6 fm^{-1}; elastic). Table 16.22 lists the excited states observed from (e, e′). The isospin-forbidden (E1) excitation of $^{16}O^*(7.12)$ has been reported by (1975MI08, 1975MI13): the isovector contribution interferes destructively with the isoscalar part and has a strength $\approx 1\%$ of the $T = 0$ amplitude (1975MI08). The 0^+ states of $^{16}O^*(6.05, 12.05, 14.00)$ saturate $\approx 19\%$ of an isoscalar monopole sum rule (1973BE50). As for the E2 strength it is distributed over a wide energy region: see Table 16.22. The effective mass of an intranuclear nucleon has been derived by (1978DE32) from studies on this and on other light nuclei. See also (1980DE2G).

Reaction (b) has been studied at $E_e = 500$ MeV: two peaks at $E = 11.5$ and 18 MeV carry most of the strength of the $1p_{1/2}$ and $1p_{3/2}$ hole states, respectively (1977TU1C). See also (1977BE1Q, 1980BA1W). The virtual photon shape and intensity for (e, e′π) has been deduced at $E_e = 180.4$ MeV ($E_\pi = 28$ MeV, $\theta_\pi = 90°$) (1980ST15). The ratio π^-/π^+ for $E_e = 280$ MeV ($E_\pi = 10$ MeV, $\theta_\pi = 90°$) is reported by (1979JE04). See also (1976BU1H, 1979SC1E, 1980BU1C, 1981BU1C),

(1976TU1C, 1979LI06, 1979MO1G, 1980CA1J, 1980MO1C, 1981MO1H) and (1976AN1D, 1976BH1B, 1976FR1G, 1976GA24, 1976HE20, 1976RA34, 1977DE16, 1977HE13, 1977WA1G, 1978CA08, 1978FU04, 1978HA36, 1978HA43, 1978KA04, 1978KR04, 1978RI1C, 1979BU1A, 1979DO17, 1979IN06, 1979KN1E, 1979KO29, 1979LI15, 1979WA1G, 1979RO02, 1980DE30, 1980ER01, 1980GR05, 1980SA1E, 1980SH1N, 1980VA07, 1981AG02, 1981BA10, 1981BO1M, 1981BU04, 1981DE1T, 1981KA12, 1981OR1B, 1981PE1C; theor.).

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

E_x (MeV ± keV)	$J^\pi; T$	Mult.	Γ (keV)	Γ_{γ_0} (eV)
6.05	0^+	E0		3.55 ± 0.21 [b]
6.13	3^-	E3		$(2.60 \pm 0.13) \times 10^{-5}$
6.92	2^+	E2		0.130 ± 0.009
				0.100 ± 0.004
7.12 [c]	1^-	E1		$(4.6 \pm 2.3) \times 10^{-2}$
9.85	2^+	E2		$(8.8 \pm 1.7) \times 10^{-3}$
10.35	4^+	E4		$(5.6 \pm 2.0) \times 10^{-8}$
11.52	2^+	E2		0.61 ± 0.02
12.05	0^+	E0		4.03 ± 0.09 [b]
12.53	2^-	M2		0.021 ± 0.006
				0.108 ± 0.015
12.97	2^-	M2		0.071 ± 0.002
13.0	2^+	E2		0.89
13.10 ± 250	$1^-; 1$	E1		$\leq 49 \pm 13$
14.00 ± 50	0^+	E0	170 ± 50	3.3 ± 0.7 [b]
15.15 ± 150	2^+	E2	500 ± 200	1.0 ± 0.5
16.21 ± 30	1^+	M1	18 ± 3	5.1 ± 0.8
16.46 ± 70	2^+	E2	35 ± 5	0.5 ± 0.2
16.80 ± 100	(3^+)		≤ 100	$(1.7 \pm 1.9) \times 10^{-3}$
17.14	$1^-; 1$	E1	40 ± 6	62 ± 12
17.60 ± 100	(2^-)		≤ 100	0.07 ± 0.04
[d]				
18.50 ± 100	2^+	E2	60 ± 9	
19.00 ± 100	$1^-; 1$	E1	300 ± 100	41 ± 20
19.04 ± 50	$2^-; 1$	M2	400 ± 50, 850 ± 150	1.5 ± 0.3
19.50 ± 100	$1^-; 1$	E1	200 ± 70	40 ± 20

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

E_x (MeV ± keV)	$J^\pi; T$	Mult.	Γ (keV)	Γ_{γ_0} (eV)
20.36 ± 70	2^-	M2	500 ± 100	2.9 ± 1.0
20.95 ± 50	$1^-; 1$	E1	270 ± 70	180 ± 50
21.34 ± 250	(2^-)	(M2)		
22.3				
23.0				
23.7 ± 250	$(2^-; 1)$			
24.2				
25.5 ± 250	$1^-; 1$	E1		
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).
[b] Monopole matrix element in fm^2.
[c] See also text and (1975MI13).
[d] Measurements are also reported to ^{16}O*(17.79, 18.6, 18.98, 19.8) with $J^\pi = 4^-$ (1981HY1A; prelim.).

58. (a) ^{16}O(π^+, π^+)^{16}O
(b) ^{16}O(π^-, π^-)^{16}O

Angular distributions of elastically scattered pions have been studied at $E_{\pi^+} = 20$ MeV (1981OB1B), $E_{\pi^-} = 20$, 30, 40 and 50 MeV (1981KA1N), 29.2 MeV (1979JO08), $E_{\pi^+} = 30.0$ and 49.7 MeV (1981PR03), 40 and 49.7 MeV (1978MA14, 1979BL07), 46.8 MeV (1979DY02), 79, 114, 163, 240 and 343 MeV (1978AL03, 1978IN04, 1978JA13 ($\pi^\pm$), 1980AL24), at $E_{\pi^-} = 114$, 163 and 240 MeV (1978IN04) and at $E_{\pi^\pm} = 165$ and $E_{\pi^+} = 315$ MeV (1980NA10). At $E_{\pi^-} = 1$ GeV/c angular distributions of ^{16}O*(0, 6.1) are reported. See also (1978BU09) and (1977AJ02) for the earlier work. At $E_{\pi^+} = E_{\pi^-} = 164$ 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 81]. See also (1977MI19, 1980MI05, 1981BA1N, 1981BA12, 1981OB1A), (1980DE24, 1981CU04, 1981TA08; theor.) and the "*Pion capture and reactions*" section here.

Table 16.23: Recent [a] ^{16}O(p, p), (d, d), (^{3}He, ^{3}He), (α, α), (^{6}Li, ^{6}Li), (^{7}Li, ^{7}Li), (^{9}Be, ^{9}Be), (^{10}B, ^{10}B), (^{11}B, ^{11}B), (^{12}C, ^{12}C), (^{13}C, ^{13}C), (^{14}C, ^{14}C), (^{14}N, ^{14}N), (^{16}O, ^{16}O) measurements

E_p (MeV)	Angular distribution of group	Refs. [b]
5.82	p_0	(1977SA1B)
6.9	p_0	(1979PR04)
27.2	p_1	(1977CE01)
30.1	p_0	(1979VO08)
35.2	p_0, p_3	(1980FA07)
42.5, 44.0, 49.3	p_5	(1977PE09)
65 [c]	p_0	(1979SA38, 1981SA1F)
135	p_0, p_2, p_4	(1980KE14)
135	p to ^{16}O*(17.79, 18.98, 19.80)	(1979HE09)
800 [c]	p_0, p_2, p_3, p_4, p_5	(1979AD03)
E_d (MeV)	Angular distribution of group	Refs. [d]
12.00	d_0	(1979AN15)
20.5 [c]	d_0, d_2	(1980CL1C)
52.0 [c]	d_0	(1980MA10)
56.0 [c]	d_0	(1980HA14)
$E(^3He)$ (MeV)	Angular distribution of ^{3}He group to	Refs. [e]
32.0 [c]	g.s.	(1980LU02)
41.0	g.s.	(1980TR02)
44.04	g.s.	(1979GO07)
130.0	see Table 16.24	(1977BU03)
132	g.s.	(1981CH1C)
E_α (MeV)	Angular distribution of group	Refs.
$6.9 \rightarrow 10.2$	α_0	(1978ST08)
$13.05 \rightarrow 14.12$	α_0	(1975CE01)
$14.6 \rightarrow 20.4$	α_0, α_{1+2}, α_3, α_4, α_5	(1979BI10)
$20.1 \rightarrow 23.2$	α_0	(1977EN01)
23.7	α_0, α_{1+2}, α_{3+4}, α_5, α_{6+7}	(1976FE12)
65	α* [f]	(1976JA17)
75	α_4, α to ^{16}O*(12.44)	see (1980HA07)

Table 16.23: Recent [a] ^{16}O(p, p), (d, d), (^{3}He, ^{3}He), (α, α), (^{6}Li, ^{6}Li), (^{7}Li, ^{7}Li), (^{9}Be, ^{9}Be), (^{10}B, ^{10}B), (^{11}B, ^{11}B), (^{12}C, ^{12}C), (^{13}C, ^{13}C), (^{14}C, ^{14}C), (^{14}N, ^{14}N), (^{16}O, ^{16}O) measurements (continued)

$E(^{6}\text{Li})$ (MeV)	Angular distribution of group to	Refs.
32	g.s.	(1980AN16)
50.6	g.s.	(1976CH27)
$E(^{7}\text{Li})$ (MeV)	Angular distribution of group to	Refs.
68	g.s.	(1979BR03)
$E(^{9}\text{Be})$ (MeV) (reaction 66)	Angular distribution of group to	Refs.
20, 26	g.s.	(1979UN01)
27.4	g.s.	(1978GR22)
$E(^{16}\text{O}) = 15 \rightarrow 25$	g.s.	(1970BA49)
$25.7 \rightarrow 29.5$	g.s.	(1975FU05)
$E(^{10}\text{B})$ (MeV)	Angular distribution of group to	Refs.
33.7, 41.6, 49.5	g.s.	(1980PA01)
65.8	g.s.	(1977MO1A, 1979MO14)
100	^{16}O*(0, 6.1, 6.9)	(1975NA15, 1977TO02)
$E(^{11}\text{B})$ (MeV) (reaction 67) [g]	Angular distribution of group to	Refs.
41.6, 49.5	g.s.	(1980PA01)
115	g.s.	(1979BR03, 1979RA10)
$E(^{12}\text{C})$ or $E(^{16}\text{O})$ (MeV) (reaction 68)	Angular distribution of group to	Refs. [h]
$E(^{12}\text{C}) = 65$	g.s.	(1978BO11)
77	g.s.	(1977MO1A, 1979MO14)
115	g.s.	(1979RA10)
$E(^{16}\text{O}) = 30.8$, 31.9, 33.9	g.s.	(1978SC06)
31.7, 46.0, 51.3, 52.7	g.s.	(1978MA32)
46.0, 47.8, 49.7, 51.3, 52.7	^{16}O*(6.1, 7.0)	(1978MA32)
$33.2 \rightarrow 35.2$	g.s.	(1980FR05)
52	^{16}O*(6.05, 6.13)	(1977SH16)
55.3, 56.7, 65.8	^{16}O*(6.05, 6.13)	(1978KA13)

Table 16.23: Recent [a] ^{16}O(p, p), (d, d), (^{3}He, ^{3}He), (α, α), (^{6}Li, ^{6}Li), (^{7}Li, ^{7}Li), (^{9}Be, ^{9}Be), (^{10}B, ^{10}B), (^{11}B, ^{11}B), (^{12}C, ^{12}C), (^{13}C, ^{13}C), (^{14}C, ^{14}C), (^{14}N, ^{14}N), (^{16}O, ^{16}O) measurements (continued)

$80 \rightarrow 122$	g.s.	(1977CO20)
140, 218, 315	g.s.	(1981BR05)
E(^{13}C) (MeV) (reaction 69)	Angular distribution of group to	Refs.
36	g.s.	(1976WE21)
105	g.s.	(1979BR03, 1979RA10)
E(^{16}O) (MeV) (reaction 69)	Angular distribution of group to	Refs. [h]
14, 17, 20	g.s.	(1970BA49)
20, 25, 30	g.s.	(1975SC35)
E(^{14}N) (MeV) (reaction 70)	Angular distribution of group to	Refs.
76.2	g.s.	(1977MO1A, 1979MO14)
79	g.s.	(1976MO03)
155	^{16}O*(0, 6.1, 6.9)	(1975NA15, 1977TO02)
E(^{16}O) (MeV) (reaction 71)	Angular distribution of group to	Refs.
$35 \rightarrow 80$	g.s.	(1978FE04)
95.2	g.s.	(1977MO1A, 1979MO14)

[a] See also Tables 16.27 in (1971AJ02) and 16.25 in (1977AJ02).
[b] See also (1976DA1L, 1977SE1F, 1979MA48, 1979GL1C).
[c] Polarized.
[d] See also (1978RO1M).
[e] See also (1978CH1P).
[f] ^{4}He*(20.1) [$J^\pi = 0^+$].
[g] See also reaction 71 in (1977AJ02).
[h] See also (1978MA1R, 1979DO01, 1980WI1P).
[i] See also for population of ^{12}C states.

59. ^{16}O(n, n)^{16}O

Angular distributions have been measured at energies to $E_n = 24$ MeV: see Tables 16.27 in (1971AJ02) and 16.25 in (1977AJ02) and (1975BE1Y: 5.04, 6.25, 9.29 MeV), (1978NO04: 8.85 MeV; 6.13 MeV γ-ray), (1977GL1B: 9.25 to 15 MeV; n_0) and (1980GR15: 24 MeV; n_0, n_2, n_3) [$\beta_3 = 0.60$, $\beta_2 = 0.36$]. The energy of ^{16}O*(6.13) is $E_x = 6129.1 \pm 1.2$ keV [$E_\gamma = 6127.8 \pm 1.2$ keV] (1966BE1A). See also (1978BE2B), (1977AJ02), (1977NO07, 1977PH01, 1978TA1A, 1978TH1A; theor.) and ^{17}O.

60. (a) ^{16}O(p, p)^{16}O

(b) ^{16}O(p, 2p)^{15}O	$Q_m = -12.1276$
(c) ^{16}O(p, pd)^{14}N	$Q_m = -20.7363$
(d) ^{16}O(p, pt)^{13}N	$Q_m = -25.033$
(e) ^{16}O(p, p^{3}He)^{13}C	$Q_m = -22.7934$
(f) ^{16}O(p, pα)^{12}C	$Q_m = -7.1620$

Angular distributions of elastically and inelastically scattered protons have been measured at many energies up to $E_p = 1000$ MeV: see Tables 16.27 in (1971AJ02), 16.25 in (1977AJ02) and 16.23 here. Parameters of the observed groups are displayed in Table 16.24. At $E_p = 135$ MeV, ^{16}O*(17.79, 18.98, 19.80) [± 0.04 MeV] are strongly populated: the angular distributions of the proton groups lead to an assignment of 4^- for ^{16}O*(17.79) (1979HE09). Angular distributions of the protons to ^{16}O*(8.88) [$J^\pi = 2^-$] at $E_{\bar{p}} = 42.5$, 44.0 and 49.3 MeV lead to strength distributions which suggest the existence of an octupole (E3) giant resonance at $E_x \approx 40$ MeV (1977PE09). At $E_{\bar{p}} = 40$ MeV the spin-flip cross section to ^{16}O*(8.88) is interpreted as showing dominance of multistep processes in the reaction (1978MO14, 1981CO08). See also (1977KI1N; 3 GeV; intensity of 6.13 MeV γ-ray).

For reaction (b) see (1976KI10, 1980KI06; $E_{\bar{p}} = 200$ MeV). See also (1977NA29, 1978NA18, 1980SA1J), ^{14}N in (1981AJ01) and ^{17}F. For reactions (c), (d) and (e) see (1977GR04; $E_p = 75$ MeV). For reaction (f) see (1981CA02; $E_p = 101.5$ MeV; to ^{12}C$_{\text{g.s.}}$) and ^{12}C in (1980AJ01). For the cross section for production of pions at $E_p = 585$ MeV see (1979CR1E). For antiproton scattering see (1981AU01; theor.).

See also (1976NO02, 1977BA85, 1981KR1B), (1976HA1Q, 1977BA2G, 1977BR1E, 1978AL1G, 1979DE1P, 1979LI06, 1980DE1V, 1980WH1A, 1981MO1L, 1981RA1B), (1976AN1E, 1976GO04, 1977AL06, 1977DY1D, 1977GA22, 1977KO2G, 1977LE05, 1977MA15, 1977MA2J, 1977MO1T, 1977PH02, 1977VA12, 1977VI03, 1978AL07, 1978AU12, 1978BI1L, 1978BR06, 1978BR28, 1978CH28, 1978CU04, 1978GO1L, 1978HA18, 1978HA35, 1978HE03, 1978IO1B, 1978LE06, 1978MA25, 1978PH01, 1978PI01, 1978WR01, 1979AB13, 1979BI1C, 1979HE04, 1979JA1P, 1979KI10, 1979KO01, 1979KO1C, 1979KO2D, 1979KU07, 1979MA20, 1979MA1M, 1979MI1K, 1979PH05, 1979WA09, 1979WA1G, 1980AM1D, 1980AY01, 1980DE1Y, 1980KO1V, 1980MA06, 1980MC1C, 1980WU02, 1981BA12, 1981MI1B, 1981PE1C, 1981RO08, 1981TH1B, 1981TU1A; theor.) and ^{17}F.

Table 16.24: 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 [d] (MeV)	E_x [f] (MeV ± keV)	E_x [h] (MeV ± keV)	L [h,i]	Γ [b] (keV)	$J^\pi; T$ [b,i]
1			6.05					
2	6.13 [a]		6.13	6.13 [e,f]	6.13 [i]	3		3^-; 0
3	6.92 [a]		6.92	6.92 [f,g]	6.92 [i]	2		2^+; 0 [f,g]
4	7.12 [a]		7.12		7.12 [i]	1		1^-; 0
5	8.87 [a]		8.87	8.87 ± 30 [f,g]	8.87 [a]	3 [a]		
6	9.85 [a]		9.85	9.84 ± 30	9.85 [i]	2		2^+; 0 [f]
7	10.35 ± 20	4	10.34	10.35 ± 30	10.35 ± 30	4		4^+; 0
8	10.95 ± 30	1	10.95					$T = 0$
9	11.10 ± 20	4	11.1 [e]	11.09 ± 30 [e]	11.10 ± 30	4		4^+; 0
10	11.52 ± 20	2	11.52	11.52 ± 30 [f,g]	11.52 ± 30	2	74 ± 4 [i]	2^+; 0
11	12.05 ± 20		12.05	12.04 ± 30	12.05 ± 30	(0)		0^+; 0
12			12.44		12.44 [i]	1		1^-; 0
13	12.53 ± 20	1	12.53		12.51 ± 30			
14	13.02 ± 20	2	13.1 [e]	13.11 ± 30 [g]	13.07 ± 20 [e]	2		2^+; 0 [g]
15	13.26 ± 30	3						3^-; 1
16			13.66					
17	13.95 ± 50	$(0+4)$		13.97 ± 30	13.95 ± 50 [e]	4		4^+; 0
18				14.94 ± 30	14.87 ± 100	6		6^+
19	15.26 ± 50	(3)		15.4				
20	15.50 ± 30	3			15.50 ± 50	3	200 ± 60	3^-; 0
21	16.52 ± 50	2		16.46 ± 30	16.40 ± 100		< 100	2^+ [f]
22	16.93 ± 50	(3)						
23	17.25 ± 50			17.19 ± 30 [g]	17.25 ± 80	(2)	160 ± 60	2^+ [f,g]
24	17.79 ± 40 [c]	(3)		17.8	17.83 ± 100		150 ± 60	4^-; 0 [c,j]
25	18.15 ± 50	(2)			18.0 ± 100 [i]	2	300 ± 50	(2^+); 0
26	18.40 ± 100	2		18.52 ± 30 [g]	18.5 ± 100 [i]	2	250 ± 50 [i]	2^+; 0 [g]
27	18.60 ± 100				18.70 ± 100	(3)	280 ± 80 [e]	
28	18.98 ± 40 [c]	(3)		19.09 ± 30			< 100	4^-; 1 [c,j]
29	19.35 ± 80	(1)						
30	19.56 ± 50				19.50 ± 100	(2, 3)	300 ± 50 [i]	$(2^+, 3^-)$; 0
31	19.80 ± 40 [c]	3					< 100	4^-; 0 [j]
32				20.2 ± 200 [e,g]	20.15 ± 100 [i]	2	350 ± 50 [i]	2^+; 0 [g]
33	20.56 ± 80	(1, 2)					370 ± 100	
34	21.05 ± 50	1			21.0 ± 100	2	320 ± 50	$(2^+; 0)$
35				21.6 ± 200 [g]			1000 ± 300 [g]	2^+ [g]
36	21.80 ± 80	1			21.85 ± 100 [i]	2	400 ± 50 [i]	$(2^+; 0)$
37	22.40 ± 80	(1, 2)					420 ± 100	1^-; 1

Table 16.24: Excited states of ^{16}O from ^{16}O(p, p′), (d, d′), (^{3}He, ^{3}He′) and (α, α') [a] (continued)

No.	E_x [b] (MeV ± keV)	L [b]	E_x [d] (MeV)	E_x [f] (MeV ± keV)	E_x [h] (MeV ± keV)	L [h,i]	Γ [b] (keV)	$J^\pi; T$ [b,i]
38					22.5 ± 100 [i]		400 ± 50	$(2^+, 3^-); 0$
39	23.20 ± 80	1					600 ± 200	$1^-; 1$
40				23.50 ± 150 [g]	23.25 ± 100 [i]	2	400 ± 50 [i]	$2^+; 0$ [g]
41					23.85 ± 100 [i]	(0)	400 ± 50	$(2^+, 0^+); 0$
42	24.00 ± 100	(1, 2)					1200 ± 300	$1^-; 1$
43					24.4 ± 100 [i]		400 ± 50 [i]	$(2^+, 3^-); 0$
44				25.15 ± 300 [g]			2800 ± 600 [g]	2^+ [g]
45	25.50 ± 150	(1)					1300 ± 300	$1^-; 1$

[a] See also Tables 16.28 and 16.29 in (1971AJ02) and 16.26 in (1977AJ02).
[b] (p, p′): (1975BU1F, 1976BU15; $E_p = 45$ MeV).
[c] (p, p′): (1979HE09; $E_p = 135$ MeV).
[d] (d, d′): (1974DU06; $E_d = 81.6$ MeV). Energies are nominal (±100 to ±260 keV); angular distributions reported to all but last state.
[e] Unresolved states.
[f] (^{3}He, ^{3}He′): (1974MO26; $E(^3\text{He}) = 71$ MeV). Angular distributions are reported to states labelled by [f].
[g] (^{3}He, ^{3}He′): (1977BU03; $E(^3\text{He}) = 130$ MeV); measured angular distributions.
[h] (α, α'): (1976BU15; $E_\alpha = 60$ MeV).
[i] (α, α'): (1976HA19, 1976HA27; $E_\alpha = 104$ MeV).
[j] See also (1981BA12; theor.).

61. ^{16}O(d, d)^{16}O

Angular distribution studies have been carried out for E_d up to 81.6 MeV: see Tables 16.27 in (1971AJ02), 16.25 in (1977AJ02) and 16.23 here. Observed deuteron groups are displayed in Table 16.24. See also ^{18}F in (1983AJ01), (1977TE1A) and (1976CO29, 1976LE26, 1977DM1A, 1978LE13, 1978TA1A, 1978TH1A, 1979GR11, 1980AY01, 1980NI11; theor.).

62. ^{16}O(t, t)^{16}O

Angular distributions are reported for E_t to 20.01 MeV: see Tables 16.27 in (1971AJ02) and 16.25 in (1977AJ02). See also (1978LE13, 1980KH09; theor.). See also ^{19}F in (1978AJ03).

63. ^{16}O(^{3}He, ^{3}He)^{16}O

Angular distributions have been measured to $E(^3\text{He}) = 132$ MeV: see Tables 16.27 in (1971AJ02), 16.25 in (1977AJ02) and 16.23 here. Inelastic groups are shown in Table 16.24. The total E2 strength exhausted to $E_x = 30$ MeV is $\approx 37\%$ of the quadrupole EWSR (1977BU03; see also for $\beta_2 R$). See also (1977SE1F), (1975AU01; S_α), (1976HA1Q, 1979KA1G, 1980TR1L) and (1977LE05, 1978LE13, 1978TA1A, 1978TH1A, 1979BE1Q, 1979LE18; theor.).

64. (a) ^{16}O(α, α)^{16}O
(b) ^{16}O(α, 2α)^{12}C $Q_m = -7.1620$

Angular distributions of α-particles have been measured up to $E_\alpha = 146$ MeV: see Tables 16.27 in (1971AJ02), 16.25 in (1977AJ02) and 16.23 here. Observed excited states are displayed in Table 16.24.

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). See also (1976HA27, 1980HA07, 1981HA14). Reaction (b) has also been studied by (1980WA07; $E_\alpha = 140$ MeV) and (1979DO04; $E_\alpha = 700$ MeV): values of S_α and N_{eff} are derived. See also (1976WO11, 1977AJ02). For the (α, αp) reaction see (1980SA1D).

See also ^{20}Ne in (1983AJ01), (1975DE1J, 1978SH1H, 1980SH1A), (1978PO1D; applied), (1980RE1A; astrophys.), (1976BE1P, 1976HA1Q, 1977MA2E, 1978CH1C, 1979BE2K, 1979KN1F, 1979MA1V, 1980SP1E, 1980WE1D, 1981CA1D) and (1975CO1H, 1976AM02, 1976BA52, 1976CU07, 1976HE19, 1976LO1F, 1976MI17, 1976PA20, 1977AB03, 1977BA12, 1977BR06, 1977BU01, 1977CL1D, 1977DM1A, 1977IK1C, 1977HO1H, 1977LE05, 1977OH01, 1977SA19, 1977TR1A, 1977WE1M, 1978CH1Y, 1978LE13, 1978MA1G, 1978TA1A, 1978TH1A, 1978ZE03, 1979CO1P, 1979GR11, 1979IZ01, 1979JA01, 1979JA15, 1979LA08, 1979LE1B, 1979LE11, 1979VE09, 1980DM1A, 1980KH09, 1980LE26, 1980TO1E, 1981DY02; theor.).

65. (a) ^{16}O(^{6}Li, ^{6}Li)^{16}O
(b) ^{16}O(^{7}Li, ^{7}Li)^{16}O

For studies of the elastic scattering see Table 16.25 in (1977AJ02) and 16.23 here. For studies of (d-α) angular correlations see ^{20}Ne in (1983AJ01). See also (1977SA1X, 1979KN1A), (1976OG1A, 1978FI1E) and (1978ME14, 1978PE1C, 1979SU1F, 1980KH09, 1981ME1E, 1981DY02, 1981GU1B; theor.).

66. ^{16}O(^{9}Be, ^{9}Be)^{16}O

For angular distributions see Table 16.23. For fusion cross sections see (1977SW05, 1978CH02). See also (1978PA1B, 1979HU1B, 1979MA30, 1979PA1B, 1981GU1B; theor.).

67. (a) ^{16}O(^{10}B, ^{10}B)^{16}O
(b) ^{16}O(^{11}B, ^{11}B)^{16}O

Angular distributions are displayed in Table 16.23. For fusion cross-section measurements (reaction (a)) see (1979GO09, 1980WI09, 1981TH1A). See also (1979GO1R) and (1980VA03, 1981VA1E; theor.).

68. (a) ^{16}O(^{12}C, ^{12}C)^{16}O
(b) ^{16}O(^{12}C, α^{12}C)^{12}C $\qquad Q_{\rm m} = -7.1620$

Angular distributions have been reported at many energies to $E(^{16}{\rm O}) = 315$ MeV: see reaction 64 (1971AJ02) and Tables 16.25 (1977AJ02) and 16.23 here. Most of the studies of this reaction have involved yield and cross-section measurements, as they apply to compound structures in ^{28}Si, as well as fusion cross sections: see (1977AJ02) and to compound structures in ^{28}Si, as well as fusion cross sections: see (1977AJ02) and (1977BR38, 1977CO20, 1977NA23, 1977TA03, 1978CH15, 1978FE04, 1978JA04, 1978KA13, 1978MA22, 1978MA32, 1978SC06, 1979CH07, 1979FU02, 1979JA25, 1979KO03, 1979KO20, 1980BE02, 1980FR10, 1980FR05, 1980JA06, 1981FU05). See also (1976FR20, 1978CI06, 1978MA1R, 1978SH01, 1979FR1L, 1979LU1B, 1979UZ1A, 1980FR1N, 1980WI1P, 1981SC1C, 1981WI1L).

At $E(^{16}{\rm O}) = 77$ MeV reaction (b) mainly proceeds via ^{16}O*(10.3 ± 0.4, 14.8 ± 0.4) [which are associated with the $J^\pi = 4^+$, 6^+ states ^{16}O*(10.35, 14.82)] (1979FU02). At $E(^{16}{\rm O}) = 140$ MeV the breakup is interpreted as proceeding via ^{16}O*(11.6, 13.1, 15.8) (1980RA12). See also (1979SC10). For the excitation of the GQR in ^{12}C see (1979DO01: $E(^{16}{\rm O}) = 315$ MeV).

See also (1978LA1J, 1979GA1H, 1979SA1L, 1980TA1B), (1977GA1B, 1978GA1B, 1978HO1C, 1978LE1T, 1978MA1F, 1978TA1B, 1978TS04, 1979GA1F, 1980ER1D, 1980GA1E), (1978RO1D; astrophys.) and (1976BA52, 1976CH1M, 1977BA28, 1977BA3E, 1977CH11, 1977CL1D, 1977FR12, 1977JA1E, 1977PA1G, 1977RO1N, 1978AB1C, 1978AV1A, 1978BA53, 1978BH1B, 1978BI1G, 1978FR1N, 1978GO07, 1978MA28, 1978MA50, 1978MA1G, 1978TA16, 1978TA11, 1978VA1A, 1979GO24, 1979KR07, 1979NA03, 1979ST1L, 1979TA07, 1979TA1K, 1979TA12, 1979TE1A, 1979VE1C, 1980AB1D, 1980DE2A, 1980DR08, 1980FU1F, 1980GA1J, 1980HU02, 1980KO27, 1980LA16, 1980LA1N, 1980TA1E, 1980TA1G, 1980VA03, 1980VO1D, 1981GA1D, 1981GU1B, 1981HA18, 1981HU1D, 1981SC05, 1981TA01, 1981TO1F, 1981UB01, 1981WI01; theor.).

69. (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. For reaction (a) see also (1979CH07; fusion), (1980RA12; α-breakup) and (1976DU04, 1979GA1H). For reaction (b) see (1978BE2C, 1981KO07). For theoretical papers see (1978PA1B, 1978SC1E, 1979HE02, 1979PA1B, 1981HA18).

70. (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 and (1977AJ02). For total fusion cross-section measurements (reaction (a)) see (1977SW02, 1977VO08, 1981VO01). See also (1978AV1A, 1978VA1A; theor.).

71. ^{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 reaction 66 in (1971AJ02), Table 16.25 in (1977AJ02) and 16.23 here. The angular distributions corresponding to the excitation of the first four excited states of ^{16}O have been studied at 51.5 and 140.4 MeV: see (1977AJ02). For yield and total fusion cross sections see (1977KO16, 1978FE04, 1978TS04, 1979CH19, 1979KO15, 1979KO20, 1980FR10, 1980HU12, 1981LA08). See also (1980CH1E, 1980WE1B, 1981VO1B).

See also (1977CO1Q, 1978HA1F, 1979GA1H, 1979LA1R, 1979SA26, 1979SA1L, 1980CO08, 1981DE20), (1978HO1C), (1978RO1D; astrophys.) and (1976AL1E, 1976AR14, 1976BA52, 1976CH1M, 1976CU07, 1976LO1F, 1976MI17, 1976MO31, 1977BA07, 1977BR06, 1977CA07, 1977CH11, 1977CL1D, 1977FL02, 1977FR12, 1977FR1N, 1977FR18, 1977FU1K, 1977GA1K, 1977HA27, 1977HO1N, 1977IK1A, 1977KO03, 1977LA1D, 1977OS02, 1977PL02, 1977SA1P, 1977SA09, 1977SA10, 1977SA1C, 1977TO08, 1977WE1M, 1977ZI01, 1978AN1J, 1978AN24, 1978AR1H, 1978AV1A, 1978BA2C, 1978BE2E, 1978BO10, 1978BR1M, 1978CH10, 1978CU1E, 1978CU06, 1978DA18, 1978FL04, 1978FR1H, 1978GU06, 1978KO22, 1978KR13, 1978LE16, 1978LE17, 1978PA1G, 1978SC1K, 1978SC23, 1978SC1E, 1978SI08, 1978SU1C, 1978VA1G, 1978VA1A, 1978VO06, 1978VO13, 1979AN11, 1979BE32, 1979CH19, 1979DH01, 1979FR11, 1979JA08, 1979MU1D, 1979PH01, 1979SI05, 1979SI06, 1979TA1K, 1979VE1C, 1980AB1D, 1980AN30, 1980BA48, 1980BE25, 1980FA1D, 1980FL02, 1980GA1E, 1980KO08, 1980KO21, 1980KO24, 1980KO27, 1980LA1M, 1980OH05, 1980PR1C, 1980SI09, 1980SI1J, 1980TA03, 1980TA1E, 1980TA14, 1980TO1D, 1980VA03, 1980VI1B, 1980WO01, 1981AB1A, 1981BA02, 1981DE13, 1981DY02, 1981HA18, 1981HE01, 1981MA1G, 1981SA12, 1981SA1K, 1981SI1E, 1981TA14, 1981UB01, 1981VA1E; theor.).

72. (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 $E(^{18}\text{O}) = 53.1$ to 89.3 MeV (reaction (b)): see (1977AJ02) and (1981CA1E; $E(^{18}\text{O}) = 35$ MeV). Yields and fusion cross sections are reported by (1980WI09) (reaction (a)) and (1978FR05) (reaction (b)). See also (1977CA1Q, 1979RA10), (1974FI1D, 1978HO1C) and (1977IM1B, 1978LE16, 1978LE17, 1979CR03, 1979LE1B; theor.).

73. ^{16}O(^{19}F, ^{19}F)^{16}O

Elastic scattering angular distributions have been studied at $E(^{16}\text{O}) = 21.4$ and 25.8 MeV and at $E(^{19}\text{F}) = 33$ and 36 MeV: see (1977AJ02). See also (1977SC1K, 1980OH05; theor.).

74. ^{16}O(^{20}Ne, ^{20}Ne)^{16}O

Elastic scattering angular distributions have been measured at $E(^{16}\text{O}) = 40.7$, 51.1 and 59.4 MeV (see (1977AJ02)), 94.8 MeV (1977MO1A, 1979MO14; also excited states of ^{20}Ne) and at $E(^{20}\text{Ne}) = 50$ MeV (1976ST18; also excited states of ^{20}Ne). See also (1980GA1F). For yield and fusion cross-section measurements see (1978SH1P, 1978GA1G, 1979GA1K, 1979GA1F, 1979KO2H, 1979RE1E, 1980DI1B, 1980GA1F, 1981GA1D, 1981GA1F; all abstracts). See also (1979VA1B) and (1979JA11, 1979LE1B, 1980GA1E, 1980OH05, 1981AN1D; theor.).

75. (a) ^{16}O(^{24}Mg, ^{24}Mg)^{16}O
(b) ^{16}O(^{26}Mg, ^{26}Mg)^{16}O

Elastic angular distributions are reported at $E(^{16}\text{O}) = 35$ to 50 MeV (1979FO13), 46.3 and 60.3 MeV (1980PA08; also 2^+ in ^{24}Mg) and 67 MeV (1981EC02; also various ^{24}Mg states) for reaction (a), and at 35 to 50 MeV (1979FO13) and 27.4 to 48.4 MeV (1980RO16; also 2^+ in ^{26}Mg) for reaction (b). Yield and fusion measurements have been carried out by (1978HO20, 1978TA05, 1979FO13, 1979LE02, 1979PE1J, 1980KO1D, 1980PA08, 1980RO16, 1981DR02). See also (1980RA1F), (1978TA1B) and (1978HO13, 1980GA1J, 1980LO02, 1980PA1H, 1980SA1G, 1981DE16; theor.).

76. ^{16}O(^{27}Al, ^{27}Al)^{16}O

An elastic angular distribution has been measured at $E(^{16}\text{O}) = 46.5$ MeV (1978PE13). For yield and fusion cross-section measurements see (1977EI01, 1979RA21, 1980SH10, 1981LE04). See also (1978KE1H, 1979VA12, 1980MI1B, 1980SA1L, 1980TA1B), (1977SC1G, 1978HO1C, 1978MA1F, 1979HU1E) and (1977AF04, 1978BI1G, 1978VA1A, 1979KA27, 1980LO02, 1980SA1G, 1981AC1A, 1981DE16, 1981SA02, 1981VA1H; theor.).

77. (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(^{32}S, ^{32}S)^{16}O

Angular distributions for reaction (a) are reported at $E(^{16}\text{O}) = 32$ MeV (1978CA07; also ^{28}Si* 2^+), 33 to 81 MeV [(1973GA09) and see (1976CR04)], 33, 36 and 38 MeV (1977EC04), 35.7 and 38.2 MeV (1979RE1D), 41.23 to 63 MeV (1977BR10, 1978GE14, 1978SH02, 1980SH1D, 1980SH1L), 56 MeV (1979ME04; also ^{28}Si*), 60 MeV (1978DU07; also ^{28}Si*), 141.5 MeV (1978SA06; also ^{28}Si*) and 215.2 MeV (1976CR04). For reaction (c) see (1979RE1D). For yield and fusion cross-section measurements see (1978BA02, 1979BA49, 1979FO13, 1979JO07, 1979KU09, 1979RA21, 1980BE03). See also (1979BR1G).

See also (1977ZE1F, 1978ST1F, 1979DE1N, 1979HE1M, 1980ZI02) and (1977UD1A, 1978DE09, 1978DU10, 1978FR1B, 1978LE21, 1978SH23, 1978TA14, 1978TE04, 1978VA1A, 1979AN1N, 1979FR01, 1979KA27, 1979KOZW, 1979KR08, 1979LA03, 1979LI05, 1979SA27, 1980BA44, 1980CR01, 1980DR08, 1980FA1D, 1980FR1F, 1980GA1E, 1980GO08, 1980LA1M, 1980MA34, 1980TO1E, 1981FR12, 1981ME03, 1981RA08, 1981VI01; theor.).

78. (a) ^{16}O(^{40}Ca, ^{40}Ca)^{16}O
(b) ^{16}O(^{44}Ca, ^{44}Ca)^{16}O
(c) ^{16}O(^{48}Ca, ^{48}Ca)^{16}O

Elastic angular distributions are reported on ^{40}Ca at $E(^{16}\text{O}) = 50$ MeV (1979KU02), 51.5 and 54 MeV (1981AL12; also ^{40}Ca*), 56.8 to 62.8 MeV (1978GE09), 60 MeV (1978RE02; also ^{40}Ca*) and 55.6, 74.4, 103.6, 139.6 and 214.1 MeV (1979VI13), while the elastic scattering on ^{48}Ca has been studied at 60 MeV (1978KO01; also ^{40}Ca*). Yield and fusion cross-section measurements are reported by (1978GE09, 1979KU02, 1979VI13, 1980KU1F). See also (1978OL1B), (1977ZE1F, 1979HE1M) and (1977AF04, 1977WE1M, 1978KO1U, 1978PA1G, 1978PE1E, 1979BA38, 1979BA41, 1979BE32, 1979BO18, 1979LE1B, 1979PE1K, 1979WO1C, 1980BE19, 1980IZ1A, 1980LA1M, 1980LE11, 1980MA34, 1980RH1A, 1980WO06, 1981VA1H; theor.).

79. ^{17}O(γ, n)^{16}O $\qquad Q_{\rm m} = -4.1443$

See ^{17}O.

80. ^{17}O(p, d)^{16}O $\qquad Q_{\rm m} = -1.9197$

Angular distributions for the ground state deuteron group have been studied at $E_p = 8.62$ to 11.44 MeV (1975CR05). At $E_p = 31$ MeV, angular distributions are reported for the deuterons corresponding to ^{16}O*(0, $6.05 + 6.13$, 7.12, 8.87, 10.35, 12.97, 13.26). States at $E_x = 15.22$ and 15.42 MeV were also observed. Spectroscopic factors were obtained from a DWBA analysis (1970ME01).

81. ^{17}O(d, t)^{16}O $\qquad Q_m = 2.1130$

Information obtained from this reaction at $E_d = 52$ 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 reaction 26 in ^{16}N and Table 16.10] (1977WA11, 1978MA16). See also (1981MA1E). A study of this reaction, the (d, ^{3}He) reaction, and reaction 82 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 (1977WA11). An isospin mixing matrix element of 110 ± 10 keV for the 4^- states ^{16}O*(17.79, 18.98, 19.80) is compatible with the results from this reaction and with pion scattering (1981CU04). [See also reaction 58.] See also (1980BR1H) below and ^{19}F in (1983AJ01).

82. ^{17}O(^{3}He, α)^{16}O $\qquad Q_m = 16.4335$

Angular distributions are reported at $E(^3\text{He}) = 11$ MeV (1971BO02). Angular correlations have been studied by (1980BR1H) [see for spectroscopic factors relating to a number of states of ^{16}O with $E_x > 12.9$ MeV with the $^{17}\text{O}_{\text{g.s.}}$ as well as with states of ^{15}N]. Table 16.20 displays some of the information derived from this reaction. For polarization measurements see (1981KA1L, 1981RO1H) and ^{20}Ne in (1983AJ01).

83. ^{18}O(γ, 2n)^{16}O $\qquad Q_m = -12.1889$

See (1976BA41) and ^{18}O in (1983AJ01).

84. ^{18}O(p, t)^{16}O $\qquad Q_m = -3.7069$

Angular distributions of tritons have been measured for E_p to 43.7 MeV: see (1971AJ02, 1977AJ02) for the earlier references and (1980AN21; $E_p = 23$ MeV; t_0). 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^+ (1964CE05). The decay of ^{16}O*(22.7), [$J^\pi = 0^+$; $T = 2$], 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 $\Gamma_i(\text{eV}) = 190 \pm 100$,

230 ± 110 and 1680 ± 550 eV, respectively; via p_0, p_{1+2}, p_3 with 7 ± 2, 11 ± 2 and 5 ± 2% branches and $\Gamma_i(\text{eV}) = 840 \pm 343$, 1320 ± 454 and 600 ± 300 eV; and via n_{1+2} with a 23 ± 15% branch [$\Gamma_n = 2760 \pm 1970$ eV] (the n_0 branch is < 15%) (1979FR04) [Γ_i are based on a total width of 12 ± 3.5 keV]. See also (1977AJ02), ^{19}F in (1983AJ01) and (1977ST19, 1978KU03, 1979AM03, 1979BE34, 1980FE01, 1980WE03, 1980WE10, 1981BE09; theor.).

85. ^{18}O(α, ^{6}He)^{16}O $\quad Q_m = -11.215$

Angular distributions have been measured at $E_\alpha = 58$ MeV to ^{16}O*(0, 6.1, 6.92, 7.12). Groups at $E_x = 10.4$, 13.3 ± 0.1 and 16.3 ± 0.1 MeV were also observed (1975VA01).

86. ^{18}O(^{17}O, ^{19}O)^{16}O $\quad Q_m = -0.187$

Angular distributions are reported at $E(^{17}\text{O}) = 36$ MeV (1977KA1Y; to $^{16}\text{O}_{\text{g.s.}}$ and ^{19}O states). See also (1976DU04).

87. ^{18}O(^{18}O, ^{20}O)^{16}O $\quad Q_m = -0.628$

Angular distributions involving $^{16}\text{O}_{\text{g.s.}}$ and ^{20}O states are reported at $E(^{18}\text{O}) = 24$ to 36 MeV (1977KA21) and at 52 MeV (1979KU01).

88. ^{19}F(p, α)^{16}O $\quad Q_m = 8.1137$

Angular distributions have been reported at many energies to $E_p = 44.5$ MeV [see (1977AJ02)] and at $E_p = 0.83$ to 0.87 MeV (1974CA22: α_0), 1.5 to 3.8 MeV (1976CA1P: α_0), 2.06 to 2.68 MeV (1980CU09: α_0, α_1) and 13.5 to 18.0 MeV (1977ST03: α_0). Observed states of ^{16}O are displayed in Table 16.31 in (1971AJ02).

The E0 transition ($6.05 \to 0$; $0^+ \to 0^+$) has been investigated in some detail: the internal conversion to pair production ratio is $(4.00 \pm 0.46) \times 10^{-5}$ (1963LE06). The ratio of double γ-emission to pair production $\Gamma_{\text{E1E1}}/\Gamma_{\text{E0}(\pi)} = (2.5 \pm 1.1) \times 10^{-4}$ (1975WA20). τ_m for ^{16}O*(6.05) = 96 ± 7 psec (1973BI17). ^{16}O*(6.13) has also been studied extensively: $|g| = 0.55 \pm 0.04$, $\tau_m = 26.6 \pm 0.7$ psec (1973BR31). A search for double positron-electron pair creation by the 6.13 MeV γ-ray was unsuccessful: the ratio of the cross section for production of such a double pair to the cross section for formation of a single pair is $-(2 \pm 5) \times 10^{-5}$ (1972WI09). The previously reported ground state decay of ^{16}O*(10.95) [$0^- \to 0^+$] is not observed; neither is a pair peak due to a ($10.95 \to 7.12$) decay (1978AL19). For γ-ray branching ratios and lifetimes see Tables 16.10 and 16.11.

See also ^{20}Ne in (1983AJ01), (1966YO1A, 1976GO1M, 1976HE1N), (1978AK1A, 1978AN1M, 1978CH2D, 1978GO1F, 1978VO1G, 1980DI03, 1980KE02; applications) and (1979LE1M; theor.).

89. ^{19}F(^{3}He, ^{6}Li)^{16}O $\qquad Q_{\rm m} = 4.0937$

Angular distributions have been measured to $E(^{3}\text{He}) = 40.7$ MeV: see (1977AJ02).

90. ^{19}F(α, ^{7}Li)^{16}O $\qquad Q_{\rm m} = -9.234$

See (1977AJ02).

91. (a) ^{20}Ne(γ, α)^{16}O $\qquad Q_{\rm m} = -4.7309$
(b) ^{20}Ne(p, pα)^{16}O $\qquad Q_{\rm m} = -4.7309$
(c) ^{20}Ne(α, 2α)^{16}O $\qquad Q_{\rm m} = -4.7309$

For reaction (a) see ^{20}Ne in (1978AJ03, 1983AJ01). For reaction (b) see (1981CA02). For reaction (c) see (1977AJ02) and (1977CH02; theor.).

92. ^{20}Ne(d, ^{6}Li)^{16}O $\qquad Q_{\rm m} = -3.2574$

Angular distributions have been studied at $E_{\rm d}$ to 40 MeV [see (1977AJ02)] and at 80 MeV (1979OE02; ^{16}O$_{\rm g.s.}$; relative S_{α}). See also (1978BE1H) and (1977BI1F, 1978KA22, 1978SH1Q; theor.).

93. ^{20}Ne(^{3}He, ^{7}Be)^{16}O $\qquad Q_{\rm m} = -3.145$

At $E(^{3}\text{He}) = 30$ MeV angular distributions involving ^{16}O*(0, 6.1) and the first two states of ^{7}Be are reported by (1970DE12).

94. ^{23}Na(e, e$'^{7}$Li)^{16}O $\qquad Q_{\rm m} = -19.701$

See (1978SA1F). See also (1979CA1E).

95. ^{24}Mg(e, e$'^{8}$Be)^{16}O $\quad Q_{\rm m} = -14.135$

See (1979SA1G).

96. ^{24}Mg(α, ^{12}C)^{16}O $\quad Q_{\rm m} = -6.769$

Angular distributions are reported at $E_\alpha = 22.8$ to 25.4 MeV (1978SO10; ^{16}O$_{\rm g.s.}$) and at 90.3 MeV (1980BE04, 1980BE15; to ^{16}O*(0, 6.1, 7.0, 8.8, 9.8, 10.3)).

97. ^{24}Mg(^{12}C, ^{20}Ne)^{16}O $\quad Q_{\rm m} = -2.151$

See (1978NO02). See also (1980LE21; theor.).

98. ^{28}Si(e, e$'^{12}$C)^{16}O $\quad Q_{\rm m} = -16.7542$

See (1978SA1F). See also (1980SC1F; theor.).

^{16}F

(Figs. 4 and 5)

GENERAL: See also (1977AJ02).

See (1977LA04, 1977SI1D, 1978WO1E, 1980HA35, 1981OS04).

1. (a) ^{14}N(^{3}He, n)^{16}F $\quad Q_m = -0.969$

   (b) ^{14}N(^{3}He, np)^{15}O $\quad Q_m = -0.421$

Observed neutron groups and L-values derived from angular distribution measurements are displayed in Table 16.26 (1973BO50). For the results from reaction (b) see Table 16.26 (1976OT02). See also (1977AJ02).

2. ^{14}N(^{10}B, ^{8}Li)^{16}F $\quad Q_m = -16.724$

At $E(^{10}\text{B}) = 100$ MeV unresolved structures to ^{16}F*(0.4, 0.7, 5.5, 6.3, 6.8, 7.8) are reported (1978HA10).

3. ^{16}O(p, n)^{16}F $\quad Q_m = -16.211$

Observed neutron groups are listed in Table 16.26 (1971MO34). See also (1980AN1G, 1981AN1A, 1981MA1J) and (1977AJ02).

4. ^{16}O(^{3}He, t)^{16}F $\quad Q_m = -15.448$

Observed triton groups are displayed in Table 16.26. Comparisons of relative populations of the first four states in this reaction and in the analog reaction (^{16}O(t, ^{3}He)^{16}N) to known states in ^{16}N [see reaction 24 in ^{16}N (1974FL06)] suggest that ^{16}F*(0, 0.20) are 0^- and 1^- and that ^{16}F*(0.42, 0.72) are 2^- and 3^- (the relative ordering of the J^π is ambiguous). (1965PE04) suggest, on the basis of angular distributions, that the ordering is $J^\pi = 0^-, 1^-, 2^-, 3^-$ for the first four states of ^{16}N. At $E(^{3}\text{He}) = 35$ MeV, ^{16}F*(0.43, 0.72) are most strongly populated (1977NA19).

5. ^{19}F(^{3}He, ^{6}He)^{16}F $\quad Q_m = -14.842$

Table 16.25: Energy levels of ^{16}F

E_x (MeV $\pm$ keV)	$J^\pi; T$	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
0	$(0)^-$; 1	40 ± 20	p	1, 2, 3, 4, 5
0.194 ± 9	$(1)^-$	< 40	p	1, 2, 3, 4, 5
0.424 ± 5	$(2)^-$	40 ± 30	p	1, 2, 3, 4, 5
0.720 ± 6	$(3)^-$	< 15	p	1, 2, 3, 4, 5
3.762 ± 7	1^+	< 40	p	1, 3, 4, 5
3.869 ± 7	$(2)^+$	< 20	p	1, 4, 5
4.372 ± 7		50 ± 20	p	1, 4, 5
4.654 ± 7	1^+	60 ± 20	p	1, 3, 4, 5
4.71 ± 20				5
4.973 ± 10	$\pi = +$			1, 5
5.264 ± 20				1
5.390 ± 14	$\pi = +$			1, 5
5.448 ± 20				1
5.529 ± 14	$\pi = +$			1, 4, 5
5.840 ± 40				1
6.05 ± 20				5
6.230 ± 50				1, 3
6.371 ± 20				1
6.678 ± 10				1, 4, 5
6.93 ± 20				5
7.110 ± 20				1
7.730 ± 40				1, 3

Table 16.26: ^{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)

^{16}F* [b] (MeV ± keV)	L [b]	^{16}F* [c] (MeV ± keV)	J^π [d]	^{16}F* [e] (MeV ± keV)	^{16}F* [f]	$\Gamma_{c.m.}$ [g] (keV)	J^π [h]
0	1	0	(1^-)	0	0	40 ± 20	$(0)^-$
0.192 ± 15	1	0.190 ± 20	(0^-)	0.197 ± 12	0.19 ± 20	40	$(1)^-$
0.425 ± 15	3	0.425 ± 10	(≥ 2)	0.424 ± 5	0.425 ± 20	40 ± 30	$(2)^-$
0.722 ± 10	(3)	0.725 ± 10	(≥ 2)	0.720 ± 6	0.72 ± 20	< 15	$(3)^-$
3.751 ± 10	0	3.775 ± 10	(1)	[j]	3.75 ± 20	< 40	1^+
3.861 ± 10	2	3.880 ± 10			3.86 ± 20	< 20	$(2)^+$
4.370 ± 10		4.375 ± 10	(≥ 2)		4.37 ± 20	50 ± 20	
4.646 ± 10	0	4.661 ± 10		[j]	4.66 ± 20	60 ± 20	1^+
					4.71 ± 20 [i]		
4.973 ± 10	2				4.97 ± 20 [i]		$\pi = +$
5.264 ± 20							
5.390 ± 20	2				5.39 ± 20 [i]		$\pi = +$
5.448 ± 20							
5.528 ± 20	2				5.53 ± 20		$\pi = +$
5.840 ± 40							
					6.05 ± 20 [i]		
6.230 ± 50				[j]			
6.371 ± 20							
6.678 ± 10					6.68 ± 20		
					6.93 ± 20 [i]		
7.110 ± 20							
7.730 ± 40				[j]			

[a] See also Table 16.33 in (1971AJ02).
[b] ^{14}N(^{3}He, n)^{16}F (1973BO50; $E(^3\text{He}) = 13$ MeV).
[c] ^{14}N(^{3}He, np)^{15}O (1976OT02; $E(^3\text{He}) = 6.5 - 7.8$ MeV).
[d] From angular correlation studies (1976OT02).
[e] ^{16}O(p, n)^{16}F (1971MO34; $E = 23.9$ MeV).
[f] ^{16}O(^{3}He, t) and ^{19}F(^{3}He, ^{6}He)^{16}F (1977NA19; $E(^3\text{He}) = 35$ and 70 MeV, respectively).
[g] ^{14}N(^{3}He, n)^{16}F (1965ZA01, 1976OT02).
[h] See (1965PE04, 1973BO50, 1974FL06, 1976OT02, 1977NA19).
[i] Observed only in ^{19}F(^{3}He, ^{6}He).
[j] Strongly excited states at $E_x = 7.6$, 9.4 and 11.5 MeV (with $\Delta l = 1$ distributions) and weakly excited states at $E_x = 3.76$, 4.65 and 6.23 MeV ($l = 0$) are reported by (1981AN1A: abstract).

Observed states of ^{16}F are displayed in Table 16.26. At $E(^{3}\text{He}) = 70$ MeV the transition strengths favor the sequence 0^-, 1^-, 2^-, 3^- for the first four states of ^{16}F (1977NA19).

^{16}Ne
(Fig. 5)

GENERAL: See also (1977AJ02).

Theoretical work: (1978GU10, 1978SP1C, 1981LI1M).

Reviews: (1977CE05, 1979AL1J, 1980TR1E).

Mass of ^{16}Ne: The Q-values of the ^{20}Ne(α, ^{8}He) and ^{16}O(π^+, π^-) reactions lead to an atomic mass excess of 24.02 ± 0.04 MeV for ^{16}Ne. ^{16}Ne is then unbound with respect to decay into ^{14}O + 2p by 1.43 MeV and is bound with respect to decay into ^{15}F + p by 0.04 MeV.

Table 16.27: Energy levels of ^{16}Ne

E_x (MeV ± keV)	$J^\pi; T$	$\Gamma_{\text{c.m.}}$ (keV)	Decay	Reactions
0	0^+; 2	50^{+50}_{-45}	p	1, 2
1.69 ± 0.07	(2^+); 2			2

1. ^{16}O(π^+, π^-)^{16}Ne $\quad Q_m = -28.76$
$Q_0 = -28.785 \pm 0.045$ MeV (1980BU15).

At $E_{\pi^+} = 180$ MeV $^{16}\text{Ne}_{\text{g.s.}}$ is populated. The cubic factor, d, in the IMME is calculated to be 2.5 ± 3.7 keV based on Q_0 (1980BU15). See also (1977HO13, 1978BU09, 1980MI05, 1981GR1J, 1981GR1K).

2. ^{20}Ne(α, ^{8}He)^{16}Ne $\quad Q_m = -60.23$
$Q_0 = -60.15 \pm 0.08$ MeV.

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 $\Gamma_{\text{c.m.}}$ 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, d, in the IMME is 8 ± 5 keV, 15 ± 6 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 $E_x = 10.08 \pm 0.02$ and 11.87 ± 0.03 MeV (1978KE06).

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(Closed 01 July 1981)

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

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