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ENERGY LEVELS OF LIGHT NUCLEI $A = 16$–17†

F. AJZENBERG-SELOVE

University of Pennsylvania, Philadelphia, Pennsylvania 19104

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Abstract: Compilation of energy levels of $A = 16$ and 17 nuclei, with emphasis on the review of material leading to information about the structure of the $A = 16$ and 17 systems.

Introduction

The first section [1]) in the present generation of review papers summarizing the information on the light nuclei covered $A = 5$–10. The reader is referred to that article for an exposition of the style, format and conventions used here. We list below some other recent compilations of similar character:

$A = 3$ and 4: Fiarman, Hanna and Meyerhof [2,3]),

$A = 11$–12, 13–15, 18–20: Ajzenberg-Selove [4–6]),

$A = 21$–44: Endt and Van der Leun [7]).

Information about mass chains with $A > 44$ can be found in *Nuclear Data Sheets.*

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References to Introduction

1) F. Ajzenberg-Selove, Nucl. Phys. **A320** (1979) 1
2) S. Fiarman and S. S. Hanna, Nucl. Phys. **A251** (1975) 1
3) S. Fiarman and W. E. Meyerhof, Nucl. Phys. **A206** (1973) 1
4) F. Ajzenberg-Selove and C. L. Busch, Nucl. Phys. **A336** (1980) 1
5) F. Ajzenberg-Selove, Nucl. Phys. **A360** (1981) 1
6) F. Ajzenberg-Selove, Nucl. Phys. **A300** (1978) 1
7) P. M. Endt and C. Van der Leun, Nucl. Phys. **A310** (1978) 1

TABLE 1

Parameters of the ground states of the light nuclei

	Atomic mass excess (keV)[a])	$\tau_{1/2}$[b]) or $\Gamma_{c.m.}$	Decay	J^{π}[b,c]); T
^{16}He	see text		n	$(0^+); 6$
^{16}Be	see text		n	$(0^+); 4$
^{16}B	see text		n	$T=3$
^{16}C	$13\,694 \pm 4$ [b])	0.747 ± 0.008 sec	β^-	$0^+; 2$
^{16}N	5681.6 ± 2.3 [d])	7.13 ± 0.02 sec	β^-	$2^-; 1$
^{16}O	-4737.02 ± 0.04 [d])	stable		$0^+; 0$
^{16}F	$10\,692 \pm 14$ [d])	40 ± 20 keV	β^+	$(0)^-; 1$
^{16}Ne	$24\,020 \pm 40$ [b])	50^{+50}_{-45} keV	p	$0^+; 2$
^{17}Be	see text		n	$T=\frac{9}{2}$
^{17}B	see text		(β^-)	$(\frac{3}{2}^-); \frac{7}{2}$
^{17}C	$21\,023 \pm 35$ [b])		(β^-)	$(\frac{1}{2}, \frac{3}{2}, \frac{5}{2})^+; \frac{5}{2}$
^{17}N	7870 ± 15 [d])	4.173 ± 0.004 sec	β^-	$\frac{1}{2}^-; \frac{3}{2}$
^{17}O	-809.9 ± 0.8 [d])	stable [e])		$\frac{5}{2}^+; \frac{1}{2}$
^{17}F	1951.66 ± 0.18 [d])	64.49 ± 0.16 sec [f])	β^+	$\frac{5}{2}^+; \frac{1}{2}$
^{17}Ne	$16\,480 \pm 50$ [b])	109.0 ± 1.0 msec	β^+	$\frac{1}{2}^-; \frac{3}{2}$
^{17}Na	see text		p	$T=\frac{5}{2}$

[a]) The values of the mass excess shown here were used to calculate Q_m.
[b]) From data reviewed in the present article.
[c]) J^{π} values in parentheses are derived from systematics.
[d]) (Wa 77).
[e]) $\mu = -1.89379 \pm 0.00009$ n.m. [see (Le 78n)] and $Q = -25.78$ mb (Sc 69u).
[f]) $\mu = 4.7223 \pm 0.0012$ n.m. [see (Le 78n)] and $Q = 100 \pm 20$ mb (Mi 741).

TABLE 2

Electromagnetic transitions in $A = 16$–17 [a]

Nucleus	$E_{x_i} \to E_{x_f}$ (MeV)	$J_i^\pi(T_i) \to J_f^\pi(T_f)$	Γ_γ (eV)	Branching ratio (percent)	Multipol.	Γ_γ/Γ_W (W.u.)
^{16}N [b]	$0.12 \to 0$	$0^-(1) \to 2^-(1)$	$(8.7 \pm 0.1) \times 10^{-11}$	100	E2	1.7 ± 0.1
	$0.40 \to 0$	$1^- \to 2^-$	$(3.1 \pm 0.2) \times 10^{-5}$	26.6 ± 0.6	M1	0.023 ± 0.001
	$\to 0.12$	$\to 0^-$	$(8.6 \pm 0.5) \times 10^{-5}$	73.4 ± 1.6	M1	0.19 ± 0.01
^{16}O [c]	$6.13 \to 0$	$3^-(0) \to 0^+(0)$	$(2.60 \pm 0.13) \times 10^{-5}$	100	E3	13.5 ± 0.7
	$6.92 \to 0$	$2^+ \to 0^+$	0.100 ± 0.004	>99	E2	3.1 ± 0.1
	$\to 6.05$	$\to 0^+$	$(2.7 \pm 0.3) \times 10^{-5}$	$(2.7 \pm 0.3) \times 10^{-2}$	E2	27 ± 3
	$\to 6.13$	$\to 3^-$	$\leq 9 \times 10^{-6}$	$\leq 8 \times 10^{-3}$	E1	$\leq 4 \times 10^{-5}$
	$7.12 \to 0$	$1^- \to 0^+$	$(5.7 \pm 0.6) \times 10^{-2}$	>99	E1	$(3.6 \pm 0.4) \times 10^{-4}$
	$\to 6.05$	$\to 0^+$	$< 3 \times 10^{-7}$	$\leq 6 \times 10^{-4}$	E1	$< 6 \times 10^{-7}$
	$\to 6.13$	$\to 3^-$	$(4 \pm 1) \times 10^{-5}$	$(7.0 \pm 1.4) \times 10^{-2}$	E2	21 ± 5
	$8.87 \to 0$	$2^- \to 0^+$	$(2.4 \pm 0.4) \times 10^{-4}$	7.2 ± 0.8	M2	0.046 ± 0.008
	$\to 6.05$	$\to 0^+$	$(4.0 \pm 1.0) \times 10^{-6}$ [g]	0.122 ± 0.033	M2	0.24 ± 0.06
	$\to 6.13$	$\to 3^-$	$(8.5^{+4.5}_{-2.5}) \times 10^{-4}$	76.0 ± 3.0	M1	$(2.0^{+1.0}_{-0.6}) \times 10^{-3}$
			$(1.7 \pm 0.5) \times 10^{-3}$		E2	5.6 ± 1.6
	$\to 6.92$	$\to 2^+$	$(1.4 \pm 0.4) \times 10^{-4}$ [g]	4.2 ± 0.8	E1	$(4.4 \pm 1.2) \times 10^{-5}$
	$\to 7.12$	$\to 1^-$	$(4.2 \pm 0.8) \times 10^{-4}$ [g]	12.6 ± 2.0	M1 [k]	$(3.7 \pm 0.7) \times 10^{-3}$
	$9.63 \to 0$	$1^- \to 0^+$	$(2.3 \pm 0.3) \times 10^{-2}$	≈ 100	E1	$(6.0 \pm 0.9) \times 10^{-5}$
	$9.85 \to 0$	$2^+ \to 0^+$	$(6.0 \pm 0.5) \times 10^{-3}$	61 ± 4	E2	0.032 ± 0.003
	$\to 6.05$	$\to 0^+$	$(1.8 \pm 0.4) \times 10^{-3}$ [g]	18 ± 4	E2	1.1 ± 0.2
	$\to 6.92$	$\to 2^+$	$(2.1 \pm 0.4) \times 10^{-3}$ [g]	21 ± 4	M1 [k]	$(4.0 \pm 0.8) \times 10^{-3}$
	$10.36 \to 0$	$4^+ \to 0^+$	$(5.6 \pm 2.0) \times 10^{-8}$		E4	3.7 ± 1.3
	$\to 6.13$	$\to 3^-$	$< 1 \times 10^{-3}$		E1	$< 3 \times 10^{-5}$
	$\to 6.92$	$\to 2^+$	$(5.8 \pm 0.7) \times 10^{-2}$	≈ 100	E2	61 ± 7
	$10.96 \to 7.12$	$0^- \to 1^-$	$(8 \pm 5) \times 10^{-4}$	>99	M1	$(7 \pm 4) \times 10^{-4}$
	$11.096 \to 6.13$	$4^+ \to 3^-$	$(3.1 \pm 1.3) \times 10^{-3}$		E1	$(5.9 \pm 2.5) \times 10^{-5}$
	$\to 6.92$	$\to 2^+$	$(2.5 \pm 0.6) \times 10^{-3}$		E2	1.0 ± 0.3
	$11.52 \to 0$	$2^+ \to 0^+$	0.61 ± 0.02	91.7	E2	1.5 ± 0.5
	$\to 6.05$	$\to 0^+$	$(2.8 \pm 0.6) \times 10^{-2}$ [g]	4.2 ± 0.7	E2	2.9 ± 0.6
	$\to 6.92$	$\to 2^+$	$(2.7 \pm 0.7) \times 10^{-2}$ [g]	4.0 ± 1.0	M1 [k]	0.013 ± 0.003

TABLE 2—continued

Nucleus	$E_{x_i} \to E_{x_f}$ (MeV)	$J_i^\pi(T_i) \to J_f^\pi(T_f)$	Γ_γ (eV)	Branching ratio (percent)	Multipol.	Γ_γ/Γ_W (W.u.)
	$\to 7.12$	$\to 1^-$	$\leq 5 \times 10^{-3}$	≤ 0.8	E1	$\leq 1 \times 10^{-4}$
	$12.44 \to 0$	$1^- \to 0^+$	12 ± 2	$\simeq 100$	E1	0.014 ± 0.002
	$\to 6.05$	$\to 0^+$	0.12 ± 0.04	1.2 ± 0.4	E1	$(1.1 \pm 0.4) \times 10^{-3}$
	$12.53 \to 0$	$2^- \to 0^+$	[h]		M2	
	$\to 6.13$	$\to 3^-$	2.1 ± 0.2	60 ± 6	M1 [k]	0.38 ± 0.04
	$\to 6.92$	$\to 2^+$	≤ 0.34	≤ 10	E1	$\leq 4.5 \times 10^{-3}$
	$\to 7.12$	$\to 1^-$	0.5 ± 0.1	15 ± 3	M1 [k]	0.15 ± 0.03
	$\to 8.87$	$\to 2^-$	0.9 ± 0.1	25 ± 3	M1	0.9 ± 0.1
	$12.80 \to 7.12$	$0^-(1) \to 1^-(0)$	2.5 ± 0.2	$\simeq 100$	M1	0.65 ± 0.06
	$12.97 \to 0$	$2^-(1) \to 0^+(0)$	$(7.1 \pm 0.2) \times 10^{-2}$		M2	2.0 ± 0.1
	$\to 6.13$	$\to 3^-(0)$	2.3 ± 0.2	63 ± 6	M1	0.34 ± 0.03
	$\to 7.12$	$\to 1^-(0)$	0.44 ± 0.10	12 ± 3	M1	0.10 ± 0.02
	$\to 8.87$	$\to 2^-(0)$	0.90 ± 0.10	25 ± 3	M1	0.62 ± 0.07
	$13.09 \to 0$	$1^-(1) \to 0^+(0)$	35 ± 5	$\simeq 100$	E1	0.036 ± 0.005
	$\to 6.05$	$\to 0^+(0)$	0.21 ± 0.07 [g]	0.58 ± 0.12	E1	$(1.4 \pm 0.5) \times 10^{-3}$
	$\to 7.12$	$\to 1^-(0)$	1.1 ± 0.3 [g]	3.1 ± 0.8	M1	0.25 ± 0.07
	$13.26 \to 6.13$	$3^-(1) \to 3^-(0)$	9.2 ± 1.5	>85	M1	1.2 ± 0.2
^{17}N [d]	$1.37 \to 0$	$\frac{3}{2}^-(\frac{3}{2}) \to \frac{1}{2}^-(\frac{3}{2})$	$(7 \pm 3) \times 10^{-3}$	100	M1	0.13 ± 0.06
	$1.85 \to 0$	$\frac{1}{2}^+ \to \frac{1}{2}^-$	$(1.4^{+0.7}_{-0.3}) \times 10^{-5}$	86.5 ± 2.5	E1	$(5.0^{+2.5}_{-1.0}) \times 10^{-6}$
	$\to 1.37$	$\to \frac{3}{2}^-$	$(2.2^{+1.1}_{-0.5}) \times 10^{-6}$	13.5 ± 2.5	E1	$(4.4^{+2.2}_{-1.0}) \times 10^{-5}$
	$1.91 \to 0$	$\frac{5}{2}^- \to \frac{1}{2}^-$	$(4.6 \pm 0.9) \times 10^{-5}$	77.0 ± 2.5	E2	0.8 ± 0.2
	$\to 1.37$	$\to \frac{3}{2}^-$	$(1.4 \pm 0.3) \times 10^{-5}$	23.0 ± 2.5	M1	$(4.2 \pm 0.9) \times 10^{-3}$
					E2	$(0.4^{-0.4}_{+1.3})$ [i]
	$2.53 \to 0$	$\frac{5}{2}^+ \to \frac{1}{2}^-$	$(2.2 \pm 0.3) \times 10^{-6}$ [l]	11 ± 1	M2	0.21 ± 0.03
	$\to 1.37$	$\to \frac{3}{2}^-$	$(6.9 \pm 1.0) \times 10^{-6}$ [l]	34 ± 3	E1	$(9.8 \pm 1.5) \times 10^{-6}$
	$\to 1.85$	$\to \frac{1}{2}^+$	$(2.4 \pm 0.5) \times 10^{-6}$ [l]	12.0 ± 1.5	E2	7.7 ± 1.5
	$\to 1.91$	$\to \frac{5}{2}^-$	$(8.4 \pm 1.0) \times 10^{-6}$ [l]	41.0 ± 2.5	E1	$(7.8 \pm 0.9) \times 10^{-5}$
	$3.13 \to 1.91$	$\frac{7}{2}^- \to \frac{5}{2}^-$	$(2.4 \pm 0.7) \times 10^{-3}$	100	M1	0.063 ± 0.018
	$3.63 \to 1.91$	$(\frac{7}{2}, \frac{9}{2})^- \to \frac{5}{2}^-$	$(2.6 \pm 0.8) \times 10^{-5}$	47 ± 10	(E2) [j]	0.8 ± 0.3
	$\to 3.13$	$\to \frac{7}{2}^-$	$(2.9 \pm 1.0) \times 10^{-5}$	53 ± 10	M1 [j]	0.011 ± 0.004

^{17}O [e])	$0.87 \to 0$	$\frac{1}{2}^+(\frac{1}{2}) \to \frac{5}{2}^+(\frac{1}{2})$	$(2.55 \pm 0.03) \times 10^{-6}$	100	E2	2.39 ± 0.03
	$3.06 \to 0.87$	$\frac{1}{2}^- \to \frac{1}{2}^+$	$(5.5^{+3.7}_{-2.8}) \times 10^{-3}$	100	E1	$(1.2^{+0.8}_{-0.6}) \times 10^{-3}$
	$3.84 \to 0$	$\frac{5}{2}^- \to \frac{5}{2}^+$	>0.026	100	E1	$>1 \times 10^{-3}$
^{17}F [f])	$0.50 \to 0$	$\frac{1}{2}^+(\frac{1}{2}) \to \frac{5}{2}^+(\frac{1}{2})$	$(1.60 \pm 0.03) \times 10^{-6}$	100	E2	25.0 ± 0.5
	$3.10 \to 0.50$	$\frac{1}{2}^- \to \frac{1}{2}^+$	$(12 \pm 2) \times 10^{-3}$	100	E1	$(1.5 \pm 0.3) \times 10^{-3}$
	$3.86 \to 0$	$\frac{5}{2}^- \to \frac{5}{2}^+$	0.11 ± 0.02	100	E1	$(4.3 \pm 0.8) \times 10^{-3}$
	$11.19 \to 0.50$	$\frac{1}{2}^-(\frac{3}{2}) \to \frac{1}{2}^+(\frac{1}{2})$	6.0 ± 2.5	100	E1	0.011 ± 0.005

[a]) See also (En 79a). The last columns give the γ-ray strengths expressed in Weisskopf units [see D. H. Wilkinson, in Nuclear spectroscopy B, ed. F. Ajzenberg-Selove, Academic Press, NY, 1960)]. The Weisskopf estimates (Γ_W in eV, E_γ in MeV) are

$$\Gamma_W(E1) = 6.8 \times 10^{-2} A^{2/3} E_\gamma^3,$$
$$\Gamma_W(E2) 4.9 \times 10^{-8} A^{4/3} E_\gamma^5,$$
$$\Gamma_W(E3) = 2.3 \times 10^{-14} A^2 E_\gamma^7,$$
$$\Gamma_W(E4) = 6.8 \times 10^{-21} A^{8/3} E_\gamma^9,$$
$$\Gamma_W(M1) = 2.1 \times 10^{-2} E_\gamma^3,$$
$$\Gamma_W(M2) = 1.5 \times 10^{-8} A^{2/3} E_\gamma^5.$$

The values for these γ-ray strengths are occasionally different from those listed in other tables of this paper because different values of r were used. In this table $r_0 = 1.2$ fm is used consistently. The multipolarities in the next to the last column were used to calculate the Γ_W.

[b]) See also table 16.4.

[c]) See also table 16.12.

[d]) See also table 17.5. Γ_γ based on τ_m and mean value of branching ratio if more than one measurement is reported. See table 17.5 also for the γ-decay of other ^{17}N states.

[e]) See also table 17.7.

[f]) See reaction 10 in ^{17}F and table 17.11. For other resonances in ^{16}O(p, γ)^{17}F see table 17.20.

[g]) Based on branching ratio in table 16.12 and on Γ_γ shown here for ground state transition.

[h]) See table 16.12.

[i]) (Gu 76d).

[j]) $\frac{9}{2}^-$ assumed for ^{17}N*(3.63).

[k]) Assumed, but δ is not known. I am indebted to Professor P. M. Endt for his comments.

[l]) Values corrected for sum of branching ratios = 100%.

^{16}He, ^{16}Be, ^{16}B, ^{16}C MASTER TABLE

^{16}He

(Not illustrated)

This nucleus has not been observed. See also (Na 78e; 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 (Th 74). See also (Se 81c; 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 (Bo 74a). 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] (Th 74, Je 75). See also (Se 81c; theor.).

^{16}C

(Figs. 1 and 5)

GENERAL[†]

Experimental work: (Ar 77b, Ch 81e).

Theory: (Al 79n).

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

† See also (Aj 77).

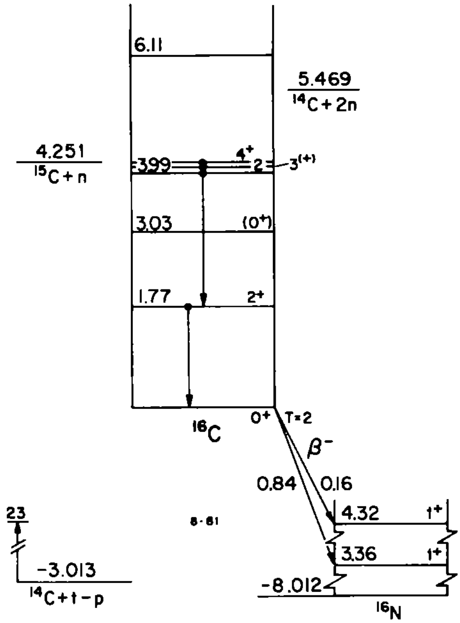

Fig. 1. Energy levels of ^{16}C. For notation see fig. 2.

Mass of ^{16}C: The atomic mass excess of ^{16}C based on the ^{14}C (t, p) Q_0 measurements of (Fo 77d, Se 78a) and on the (Wa 77) masses for ^{14}C, t and p is 13 694 ± 4 keV.

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

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 (Al 76). See also (Fo 78g).

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]) (Al 76).
[b]) The combined branching to $^{16}N^*$(0.120, 0.297, 0.398) is <1.2% (Al 76).

TABLE 16.3

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

E_x (keV) (Fo77d)	(Se 78a)	L [a])	J [b]) (Ba 77qq)
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 (Fo 77d) and 23 MeV (Se 78a).

[b]) From $\gamma\gamma$ correlation measurements at $E_t = 12$ MeV (Ba 77qq).

[c]) This state is weakly excited.

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

[e]) State observed but E_x not determined.

[f]) (Se 78a) 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. (Se 78a).

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

$$Q_0 = -3015 \pm 8 \text{ keV (Fo 77d)}$$

$$Q_0 = -3013 \pm 4 \text{ keV (Se 78a)}$$

Observed proton groups are displayed in table 16.3 (Fo 77d, Se 78a), together with the angular correlation results of (Ba 77qq). The similarities in the spectra of ^{14}C and ^{16}C are discussed by (Fo 78f, Se 78a). See also (Fo 77g, Fo 78g).

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

See (Aj 77).

^{16}N

(Figs. 2 and 5)

GENERAL†

Model calculations: (Ro 79c, Ha 80p).

Reactions involving muons: (Bo 77o, Er 77d, Na 77a, Gu 78c, Pa 78h, Ro 78l, Er 79c, Gu 79, Gu 79c, Ho 79d, Ki 79m, Rh 79, St 79l, Wu 79d, Br 80, Ch 80b, Gr 80, Ei 81).

† See also (Aj 77).

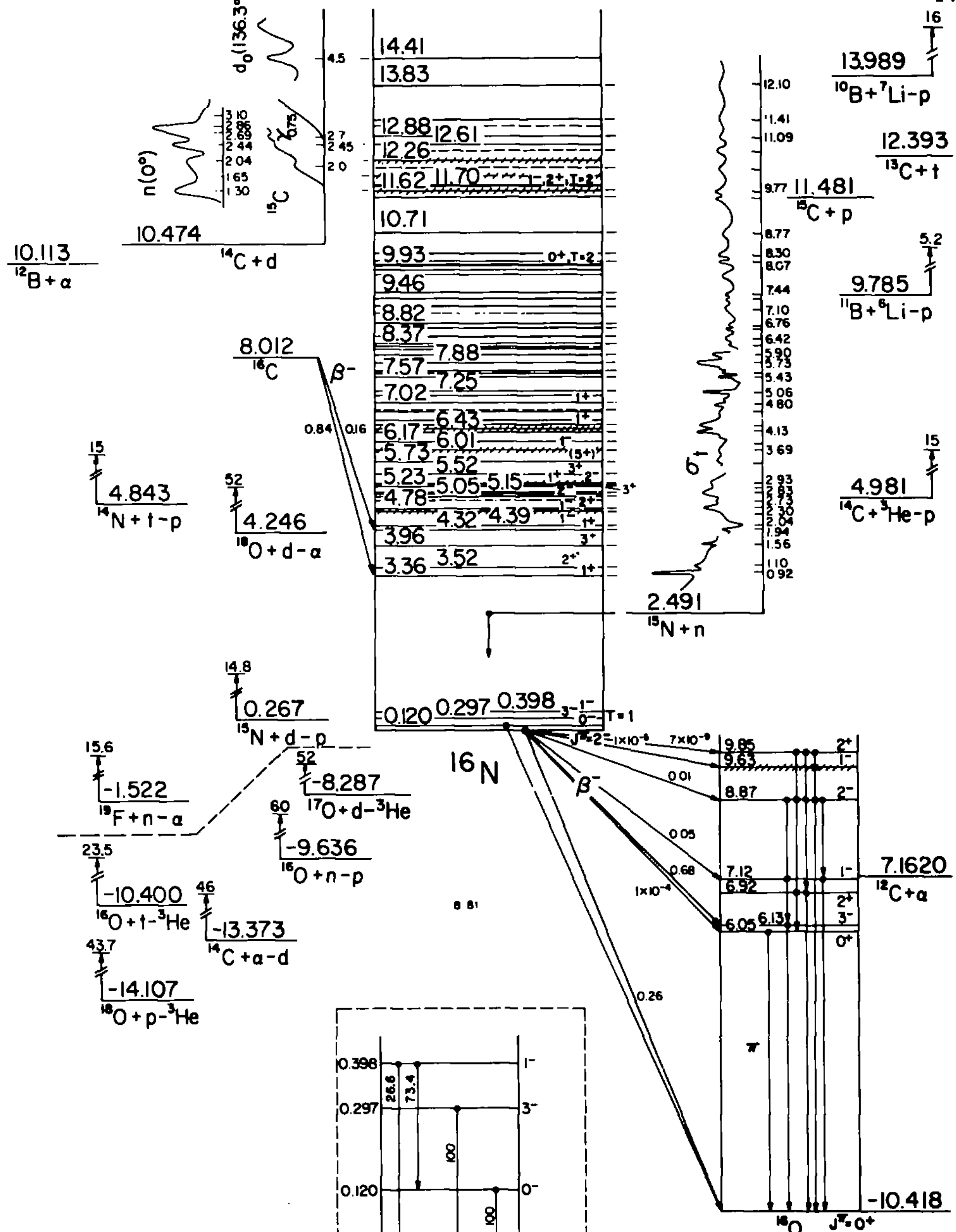

Fig. 2. Energy levels of ^{16}N. In these diagrams, energy values are plotted vertically in MeV, based on the ground state as zero. Uncertain levels or transitions are indicated by dashed lines; levels which are known to be particularly broad are cross-hatched. Values of total angular momentum *J*, parity, and isobaric spin *T* which appear to be reasonably well established are indicated on the levels; less certain assignments are enclosed in parentheses. For reactions in which ^{16}N is the compound nucleus, some typical thin-target excitation functions are shown schematically, with the yield plotted horizontally and the bombarding energy vertically. Bombarding energies are indicated in laboratory coordinates and plotted to scale in c.m. coordinates. Excited states of the residual nuclei involved in these reactions have generally not been shown; where transitions to such excited states are known to occur, a brace is sometimes used to suggest reference to another diagram. For reactions in which the present nucleus occurs as a residual product, excitation functions have not been shown; a vertical arrow with a number indicating some bombarding energy, usually the highest, at which the reaction has been studied, is used instead. Further information on the levels illustrated, including a listing of the reactions in which each has been observed, is contained in the master table, entitled "Energy levels of ^{16}N".

Reactions involving pions: (Al 77aa, Ba 77xx, Be 77aa, Er 77d, Ho 77f, Sh 77n, Su 77h, Fu 78g, Na 78i, Oh 78, Bo 79ee, De 79k, Er 79c, Kn 79c, Na 79q, Pe 79a, Sr 79a, Tr 79h, Wi 79d, Wi 79e, Bo 80a, Bo 80q, De 80bb, Gr 80, St 80d, Wu 80, Ya 81).

Other topics: (Le 76t, Ar 77b, Ba 77t, Br 77, Ha 77i, Bu 78k, Fo 78g, Ga 78c, Ge 78b, He 78h, Ko 78a, Le 78r, Ab 79a, Al 79n, Gr 81b).

TABLE 16.4

Energy levels of ^{16}N

E_x (MeV ± keV)	J^π; 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 → 15, 18, 19, 24 → 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 $\lvert g \rvert = 1.5 \pm 0.1$	γ	5, 10 → 14, 18, 21, 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	≤7 ± 4	n	10, 12, 16, 18
5.150 ± 7	$(2, 3)^-$	≤7 ± 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^+	≤7 ± 4	n	10, 12, 16, 18, 28
5.730 ± 6	(5^+)	≤7 ± 4	n	7, 10, 11, 12, 16, 18, 28
6.009 ± 10	1^-	270 ± 30	n	12, 16, 28
6.168 ± 4	(4^-)	≤7 ± 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		≤7 ± 4		12, 13, 14, 18, 28
6.848 ± 6		≤7 ± 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		≤7 ± 4		10, 12, 18, 28
7.250 ± 7	≥2	17 ± 5	n	12, 16, 18, 28
7.573 ± 6	≥3	≤7 ± 4	n	10, 12, 16, 18, 28
7.637 ± 5	$(3, 4, 5)^+$	≤7 ± 4		7, 10, 11, 12, 18, 28
7.675 ± 5		≤7 ± 4	n	7, 12, 13, 16, 18, 28
7.877 ± 9	≥4	100 ± 15	n	12, 16, 18, 28

TABLE 16.4—continued

E_x (MeV ± keV)	$J^\pi; T$	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
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
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 (Aj 71) for the previously reported value.

1. $^{16}N(\beta^-)^{16}O$ $\qquad Q_m = 10.418$

The half-life of ^{16}N is 7.13±0.02 sec: see table 16.3 in (Aj 71). See also (Sa 75i). From the character of the beta decay [see table 16.21] it is concluded that $^{16}N_{g.s.}$ 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 $^{16}O_{g.s.}$ has been studied: the β-decay rate $\lambda_\beta = 0.43 \pm 0.10$ sec^{-1} (Pa 75a). See also (Ak 77a; applications) and (Bo 77o, Gu 78c, Gu 79c, Ko 79bb, Mu 79b, Rh 79, Ch 80b, Ch 81, To 81e; theor.).

2. (a) $^9Be(^7Li, t)^{13}C$ $\qquad Q_m = 8.181$ $\qquad E_b = 20.575$
   (b) $^9Be(^7Li, \alpha)^{12}B$ $\qquad Q_m = 10.462$
   (c) $^9Be(^7Li, ^8Li)^8B$ $\qquad Q_m = -17.613$

The yields of t_0 and of α_0, α_1 and α_2 have been measured for $E(^7\text{Li}) = 4$ to 14 MeV at 0^0: several broad peaks are observed (Wy 71). The yields of α_0 and α_2 have also been studied for $E(^7\text{Li}) = 3.3$ and 5.0 to 6.2 MeV (Sn 69b). The cross section for reaction (c) rises monotonically for $E(^7\text{Li}) = 1.1$ to 4 MeV (No 57a, No 59a).

3. ^{10}B(^{7}Li, p)^{16}N $Q_m = 13.989$

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 (Fo 75i). See also (Aj 71).

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

See (Mc 66a).

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

See (Mc 66a) and (Th 69a: $E_x = 297.6 \pm 0.9$ and 397.8 ± 1.0 keV).

6. ^{13}C(α, p)^{16}N $Q_m = -7.421$

At $E_\alpha = 50$ MeV proton groups are reported to ^{16}N*(5.1, 5.6, 7.6, 11.4, 12.1) (Bu 76k). See also (Fo 77g, Ha 81d).

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

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 (Ma 77l; prelim.).

8. ^{14}C(d, γ)^{16}N $Q_m = 10.474$

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	(Ch 61a, Im 63)
1.65	n_0	390	11.92	(Ch 61a)
2.04	n_0, p	290	12.26	(Ch 61a, Im 63, Do 56b)
2.44	n_0, p	180	12.61	(Ch 61a, Do 56b)
2.75	n_0, p	155	12.88	(Ch 61a, Im 63, Do 56b)
2.86	n_0	175	12.97	(Ch 61a)
(3.10)	n_0	(175)	(13.18)	(Ch 61a)
4.50 ± 0.05	d_0	180 [a])	14.41	(Co 73u)

[a]) $\Gamma_d = 45$ keV; $l_d = 4$; $J^\pi = 3^+$, $(4^+, 5^+)$ (Co 73u: $E_d = 4$ to 10 MeV).

The cross section has been measured for $1.2<E_d<2.6$ MeV. It shows some evidence of structure (Ne 64f). See also (Aj 71).

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

Observed resonances for n_0, p and d_0 are displayed in table 16.5. For polarization measurements in reaction (a) see (Aj 77). For reaction (b) see also (Aj 77). See also ^{12}B in (Aj 68) and ^{13}C, ^{14}C, ^{15}C and ^{15}N in (Aj 81).

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

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.

TABLE 16.6

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

E_x (MeV ± keV) (Ga 66d)	(He 68d, Fr 72b)	Γ (keV)	J^π; T
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 $^{14}N(t, p)^{16}N$

(He 66a)		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	$(3, 4, 5)^+$
7.675 ± 10	≤7 ± 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 (He 66a): see (Cr 75a, Fo 78c).

[b]) Identified with shell-model counterparts (Cr 75a).

[c]) Results are ambiguous (Cr 75a).

[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 (Fo 78c).

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

At $E_\alpha = 46$ MeV the angular distributions of the groups to $^{16}N^*(0.30, 3.96, 5.73, 7.60)$ have been determined: the most strongly populated state is the (5^+) state $^{16}N^*(5.73)$ (Lu 69a).

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

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 (Fo 79). These distributions have also been compared with those in the $(^3He, p)$ reaction to analog states in ^{16}O: see reaction 38 in ^{16}O (Fo 78r). τ_m for $^{16}N^*(0.40) = 5.1 \pm 0.3$ psec (He 77e, He 77b). See also (Aj 77).

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

At $E_\alpha = 65$ MeV strong transitions are observed to the unresolved ground state quartet and to $^{16}N^*(5.25, 6.61, 7.68)$ (Ja 78i).

14. (a) $^{14}N(^{10}B, {}^8B)^{16}N$ $Q_m = -13.688$
(b) $^{14}N(^{13}C, {}^{11}C)^{16}N$ $Q_m = -10.343$

At $E(^{10}B) = 100$ MeV strong transitions are observed to the unresolved ground state quartet and to $^{16}N^*(5.14, 6.59, 7.65)$ (Ha 78a). For reaction (b) see (Pr 80c).

15. $^{15}N(n, \gamma)^{16}N$ $Q_m = 2.491$

The thermal cross section is 24 ± 8 μb (Mu 73i).

16. $^{15}N(n, n)^{15}N$ $E_b = 2.491$

The scattering amplitude (bound) $a = 6.44 \pm 0.03$ fm, $\sigma_{free} = 4.59 \pm 0.05$ b, σ_{inc}^{spin} (bound nucleus) < 1 mb (Ko 79w). The total cross section has been measured for $E_n = 0.4$ to 32 MeV: see (Aj 71, Ga 76f) and (Ze 71). 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 (Ze 71, Do 71a). See also (Aj 77) and (Ro 76u, Ro 77k, Ro 78j, Ab 79e, Ro 79d, Ha 80p; theor.).

17. (a) $^{15}N(n, p)^{15}C$ $Q_m = 8.9893$ $E_b = 2.491$
(b) $^{15}N(n, d)^{14}C$ $Q_m = -7.9828$
(c) $^{15}N(n, t)^{13}C$ $Q_m = -9.9020$
(d) $^{15}N(n, \alpha)^{12}B$ $Q_m = -7.621$

For reaction (b) see (Aj 76, Ba 78e). For reaction (c) see (Ba 78e). For reactions (a) and (d) see (Aj 77).

TABLE 16.8

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

E_n (MeV ± keV)	Γ_{lab} (keV)	E_x (MeV)	J^{π}
0.921	14	3.354	1^+ [c]
1.095	3	3.517	1
1.563	≤2	3.955	1
1.944	29	4.312	1^+ [d]
2.038	56	4.400	1^- [d]
2.30 ± 70 [e]	410 ± 100 [e]	4.65	1^- [d]
2.399	107	4.738	2^+ [d]
2.732	35	5.050	1^- [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	
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	

18. $^{15}N(d, p)^{16}N$ $Q_m = 0.267$

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: (Pa 71f) report that the branchings of $^{16}N^*(0.40)$ to $^{16}N^*(0, 0.12, 0.30)$ are, respectively, $26.6 \pm 0.6\%$, $73.4 \pm 1.6\%$ and $\leq 0.15\%$. The $0.30 \rightarrow 0.12$ transition is $\leq 1\%$ (Pa 71f).

The mean life of $^{16}N^*(0.12)$ is 7.58 ± 0.09 μsec (Be 67j); 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 (Aj 71). See also (Ba 77t, Pa 78b, Pa 79a; theor.).

19. (a) $^{15}N(^{11}B, ^{10}B)^{16}N$ $Q_m = -8.964$
(b) $^{15}N(^{13}C, ^{12}C)^{16}N$ $Q_m = -2.455$

See (Pr 80c).

20. $^{16}C(\beta^-)^{16}N$ $Q_m = 8.012$

See ^{16}C.

21. $^{16}O(\mu^-, \nu)^{16}N$ $Q_m = 95.241$

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 (Gu 79). See also (Gi 81c), (Gu 78c; theor.) and p. 8.

22. $^{16}O(\pi^-, \gamma)^{16}N$ $Q_m = 129.148$

See (Tr 79h).

23. $^{16}O(n, p)^{16}N$ $Q_m = -9.636$

See (Ne 78, Ne 78b; $E_n = 60$ MeV). See also (Aj 77).

24. $^{16}O(t, ^3He)^{16}N$ $Q_m = -10.400$

At $E_t = 23.5$ 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

Footnotes to table 16.8

[a]) (Ze 71, Do 71a). See table 16.7 in (Aj 71) for the earlier work.

[b]) Below $E_n = 4.5$ MeV, the multilevel R-matrix formalism was used to determine E_λ, Γ_λ and whenever possible J^π by a χ^2 fitting and minimization technique. Above this energy the $2J+1$ dependence was used; the parity cannot be determined because no marked interference effects are observed between resonance and potential scattering. Above 5.65 MeV all J-values are lower limits because the inelastic channel is open. [A channel radius $a = 4.69$ fm was used.] (Ze 71)

[c]) Parity determined from angular distribution.

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

[e]) The phase-shift analysis indicates that the resonance is at $E_n = 2.42 \pm 0.08$ MeV with $\Gamma = 250 \pm 50$ keV. This is one of two $(d_{3/2}p_{1/2}^{-1})$ single-particle resonances (Ze 71).

[f]) The phase-shift analysis finds $E_\lambda = 2.94 \pm 0.1$ MeV, $\Gamma = 320 \pm 80$ keV. This is the other $(d_{3/2}p_{1/2}^{-1})$ single-particle resonance (Ze 71).

[g]) See also (Pa 79a).

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] (Fl 74a). See also ^{16}O(^{3}He, t) in ^{16}F.

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

At $E(^{11}\mathrm{B}) = 115$ MeV unresolved groups near $E_x = 0$ and 6 MeV are relatively strongly populated (Ra 79c).

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

(He 66a) [a]) E_x (MeV ± keV)	l_n [a,b])	(He 66a) [c])	(Bo 70b) [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])	
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		

TABLE 16.9—continued

(He 66a) [a]) E_x (MeV ± keV)	l_n [a,b])	(He 66a) [c])	(Bo 70b) [c])	J^π [d])
7.840 ± 10			7.88 ± 15 [i])	
			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) (Fu 72c, Fu 71a; $E_d = 12$ MeV). I am very much indebted to H. Fuchs for his comments.
c) ^{18}O(d, α)^{16}N.
d) J^π assignment from angular distribution analyses and γ-decay; see (Aj 77) for references.
e) From γ-decay studies (Gi 63e).
f) Angular distribution reported in ^{18}O(d, α)^{16}N at $E_d = 10.0 \rightarrow 11.2$ MeV but L not determined (Bo 70b).
g) Alpha group seen but E_x not determined.
h) Γ for this level and the ones listed below $\leq$40–50 keV (Bo 70b).
i) These levels appear to be correlated with thresholds for neutron emission to excited states of ^{15}N (Bo 70b, Bo 70c).
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 (Bo 73o: average values in the range $E_d = 5$ to 6 MeV).
l) Polarization measurements at $E_{\vec{d}} = 52$ 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 of L = 0 + 2] (Ma 81c).
m) Polarization measurements at $E_{\vec{d}} = 8.5$ 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 (Ba 78r).
n) A closely spaced doublet appears to be present. At least one of the states has unnatural parity (Ba 78r).

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

^{3}He groups observed in this reaction are displayed in table 16.10 (Ma 78p). 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$_{g.s.}$. There is no significant deviation for a pure $1p_{3/2}$ VAP for the groups to ^{16}N*(6.17, 6.36) [$J^\pi = 4^-, 3^-$] (Ma 81d). Comparisons of the ^{16}N states with T = 1 states in ^{16}O are discussed by (Wa 771, Ma 78p): see reaction 81 in ^{16}O and table 16.20. See also (Aj 77).

27. ^{18}O(p, ^{3}He)^{16}N $Q_m = -14.107$

At $E_p = 43.7$ MeV, the angular distribution of the ^{3}He nuclei corresponding to a state at $E_x = 9.9$ 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 (Ce 64b). See also (Fo 78g).

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^-
≈0.30	1	1.33	3^-
3.35	2	0.02	1^+
3.52	2	0.06	$(2)^+$
≈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]) (Ma 78p; $E_d = 52$ 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 $Q_m = 4.246$

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 (Ba 78r) and at 52 MeV (Ma 81c): see footnotes j), k) and l) to 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) (Bo 70c, Bo 70b). (As 75a) 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. [Based on $\tau_m = 5.6 \pm 0.3$ psec, $|g| = 1.5 \pm 0.1$.]

29. ^{19}F(n, α)^{16}N $Q_m = -1.522$

Angular distributions have been reported for $E_n = 4.7$ to 14.4 MeV [see (Aj 71, Aj 77)] and at $E_n = 13.9$ and 15.6 MeV (Ro 77i; $\alpha_{0+1+2+3}$). See also ^{20}F in (Aj 83).

^{16}O

(Figs. 3 and 5)

GENERAL[†]

Shell model: (Ap 76a, Be 76v, Na 76p, Ap 77, Br 77q, Ca 77, Ca 77c, Ca 77u, Go 77p, He 77i, He 77k, Li 77l, Sa 77dd, Wa 77k, Zh 77, Ap 78, Ba 78aa, Ch 78z, Da 78n, He 78a, Ho 78f, Ay 79, Ha 79v, Jo 79i, Ka 79a, Pe 79b, Ro 79c, Sa 79u, St 79q, Va 79a, An 80k, Gi 80a, Ha 80p, Mc 80a, Pe 80j, Wa 80j, Ka 81e).

Collective, deformed and rotational models: (Ho 75m, Ca 77c, Vo 77b, Ra 78i, Ma 79f, Vl 79, Ba 80o, Be 80t, Fu 80i, Ku 80d, Ok 80d, Pe 80j, Ka 81e).

Cluster and α-particle models: (Fa 75i, Ho 75m, Ap 76, Ap 76a, Ap 76b, Fl 76b, Ho 76j, Su 76e, Ba 77rr, Be 77n, He 77i, Ho 77l, Ho 77m, Sa 77v, Sa 77cc, Su 77f, Ap 78, Ch 78z, He 78a, Is 78a, Kh 78b, Ad 79, Go 79t, Gr 79q, In 79b, Ro 79p, Wi 79o, Za 79b, Ag 80, Du 80b, Fu 80h, Fu 80i, Gu 80b, Ik 80a, Su 80d, El 81c, Em 81, Em 81a, Ma 81g, Wi 81b).

Special states: (Fa 75i, Br 75s, Si 75f, Ap 76, Ap 76a, Ap 76b, Ba 76cc, Bo 76z, Fa 76f, He 76k, Li 76s, St 761, Su 76e, Ap 77, Bl 77b, Bu 77s, Ca 77c, Fa 77a, Go 77p, Gr 77k, He 77h, Ka 77ee, Kn 77, Kr 77, Mo 77v, Pe 77i, Su 77f, Su 77g, Wa 77k, Al 78f, Ap 78, Ba 78aa, Ba 78f, Be 78cc, Ch 78b, Co 78p, Da 78n, De 78n, En 78c, Ha 78w, Ka 78w, Mc 78d, Ra 78i, Sa 78n, Sc 78i, Sh 78d, Ab 79a, Ch 79j, Gm 79, In 79d, Ka 79n, Ki 79k, Ku 79l, Pe 79b, Pr 79c, Ro 79c, Ro 79l, Ro 79p, Sh 79t, Vl 79, Be 80t, Br 80n, Ca 80e, Fu 80i, Go 80n, Ha 80p, Hi 80c, Ka 80n, Me 80b, Ok 80d, Ov 80, Sh 80n, Sp 80c, Su 80d, Ta 80p, Wa 80e, Wa 80j, Ch 81, Cu 81f, Em 81a, Ka 81e, Ro 81l, Sp 81a, Wi 81b).

Electromagnetic transitions: (Ba 76cc, He 76k, Ho 76h, St 76l, Su 76e, An 77a, Be 77n, Bi 77d, Bl 77b, Br 77, De 77d, Do 77a, Go 77, Gr 77k, He 77l, Ko 77g, Kr 77, Pe 77i, Wa 77k, Ad 78b, Ba 78aa, Sc 78i, Tr 78d, Ka 79n, Ku 79l, Mo 79g, Mo 79p, Ar 80d, Du 80b, Mu 80, Pe 80j, To 80e, Sp 81a).

Giant resonances[††]: (Ge 75o, Kr 75f, Kr 75g, Am 76b, Be 76bb, Mu76b, Ab 77a, Br 77, De 77d, Gm 77, Go 77, He 77i, Kn 77, Kr 77, Li 77g, Sa 77ee, Ad 78b, He 78a, Ro 78j, St 78j, Yu 78a, Bl 79c, Bo 79g, Do 79o, Fa 79b, Gm 79, Go 79c, Ha 79k, Im 79b, Iz 79, Ki 79e, Kn 79j, Ko 79o, Kr 79a, Sh 79t, Wa 79c, Ar 80d, Ba 80o, Bo 80l, Go 80f, Mu 80, Sh 80n, Sp 80d, Kh 81b, Li 81d).

Astrophysical questions: (Bo 76cc, No 76l, Qu 76a, Si 76g, Va 76m, Ar 77a, Au 77f, Au 77h, Au 77i, Au 77j, Bu 77l, Ca 77n, Ca 77q, Cl 77i, En 77a, Fr 77g, Ib 77a,

[†] See also (Aj 77).
[††] See also reactions 54 and 58.

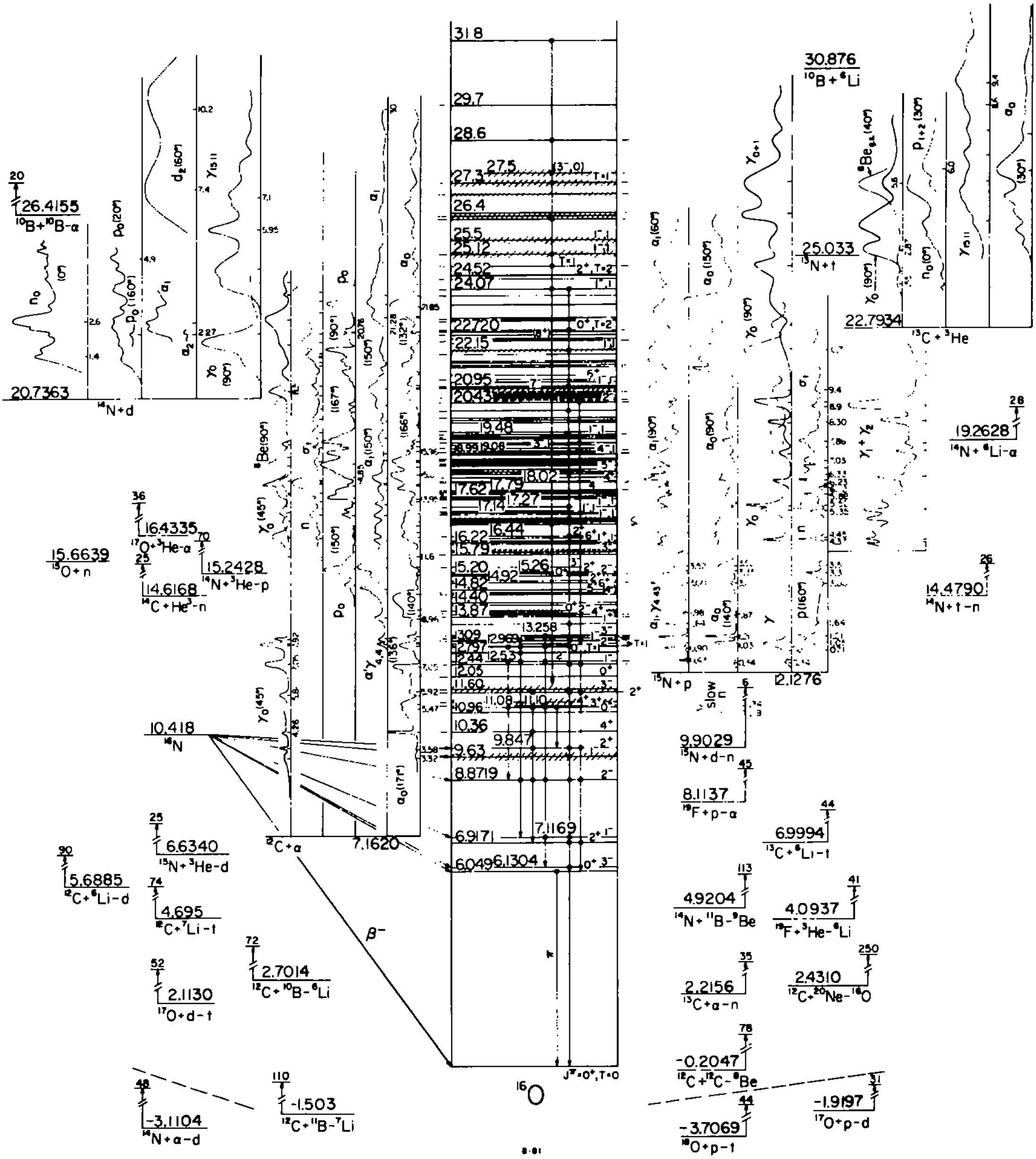

Fig. 3. Energy levels of ^{16}O. For notation see fig. 2.

Jo 77c, Ki 77, Pa 77c, Pr 77h, Si 77e, St 77e, To 77g, Vo 77, Wa 77t, Bu 78g, Bu 78k, By 78a, Cl 78g, Di 78d, Fe 78e, Gl 78b, Ib 78, Ib 78a, Ka 78s, La 78a, Le 78t, Lu 78, Mc 78a, Me 78f, Or 78, Pe 78i, Po 78b, St 78i, To 78d, Tr 78, Wo 78f, Ch 79i, De 79n, Gl 79a, Ka 79c, La 79c, La 79f, Le 79m, Ma 79c, Mc 79b, Pe 79e, Ra 79h, Sa 79c, Sw 79, Ti 79a, We 79, Wi 79m, Ca 80k, Cl 80c, Co 80s, Ka 80p, Mc 80d, Me 80, Mo 80n, Re 80, Du 81c, Ga 81b, Gu 81b, Wi 81c, Wi 81i).

Applications: (Ch 76r, Ch 76u, Le 76q, Ep 77a, Gr 77j, Lo 77h, Ma 77ww, Mo 77a, Th 77c, Em 78, He 78d, Tr 78h, Gr 79c, Ja 79h, Le 79e, Sp 79a, He 80d, La 80i, Mc 80f).

Special reactions involving ^{16}O: (Ch 76n, Da 76p, Ho 76f, Ja 76q, Le 76t, Ar 77b, Ce 77, Ch 77e, Co 77m, Fe 77e, Ga 77l, Ha 77h, Ha 77aa, Ho 77o, Ja 77, Ka 77cc, Li 77k, Ma 77e, Ma 77f, Mo 77p, Na 77, Ob 77, Pr 77a, Sh 77o, St 77e, To 77j, Tr 77g, Va 77, Ar 78l, Ba 78p, Bh 78b, Bi 78a, Co 78e, Fr 78j, Go 78n, Gy 78, He 78b, He 78c, He 78m, Ja 78o, Ko 78a, Ku 78e, Ku 78h, Ob 78a, Vo 78, Vo 78a, Ba 79mm, Be 79u, Bl 79f, De 79f, Dy 79, Ga 79, Ge 79b, Go 79j, He 79i, Ko 79s, Mc 79d, Me 79q, Mo 79v, Po 79a, Sa 79l, Sa 79m, Sc 79c, St 79j, St 79m, Va 79h, Ak 80b, Ba 80a, Ce 80a, Gr 80d, Ko 80e, Mi 80a, Ol 80, Ov 80, Sa 80i, Sc 80f, Bh 81, Bo 81k, Ci 81, Eg 81b, Ma 81g, Si 81, Ta 81, Tr 81a, Uc 81).

Muon and neutrino capture and reactions: (Ko 74v, Da 76q, Ba 77ww, Bo 77o, Er 77d, Gr 77m, La 77a, Mu 77b, Wa 77o, Ba 78ff, Gu 78c, Gu 78f, It 78, Pa 78h, Ro 78l, Bu 79e, Do 79o, Er 79c, Fr 79g, Gm 79a, Gu 79, Gu 79c, Ho 79d, Ki 79m, Ko 79bb, Me 79r, Mu 79b, Rh 79, St 79l, Su 79d, Ve 79a, Wu 79d, Ba 80aa, Br 80, Ch 80b, Ch 80m, Ch 80n, Er 80b, Gr 80, Ko 80s, Su 80c, Ch 81, Ei 81, Er 81a, Gi 81c, To 81e, Va 81e, Va 81g).

Pion capture and reactions: (Bu 76i, De 76l, Li 76r, Li 76t, Ro 76r, Al 77f, Al 77aa, Ba 77m, Ba 77kk, Ba 77xx, Ba 77ab, Ba 77aj, Be 77gg, Be 77hh, Bo 77d, Bo 77s, Br 77a, Bu 77c, Ch 77q, Co 77v, Do 77a, Er 77d, Gi 77a, Gi 77c, Hi 77f, Ho 77f, Ho 77p, Ka 77c, Ko 77cc, Le 77p, Ma 77h, Ma 77gg, Ma 77ww, Mc 77, Mi 77c, Mi 77e, Na 77a, Na 77d, Na 77r, Pr 77g, Ro 77u, Sa 77dd, Sc 77d, Si 77, Sm 77c, Sp 77d, St 77o, Su 77h, Vi 77a, Wa 77p, Wa 77r, Al 78a, Ba 78l, Ba 78w, Be 78a, Be 78p, Be 78z, Bo 78, Bo 78r, Bo 78s, Br 78a, Br 78c, Er 78b, Er 78c, Fu 78c, Fu 78g, Ga 78, Gi 78b, Gi 78c, Gr 78g, In 78, Ja 78f, Ja 78j, Ja 78k, Ko 78n, Kw 78, Li 78d, Ma 78g, Me 78j, Mo 78b, Na 78, Na 78i, Oh 78, Ro 78h, Sc 78b, Sh 78e, Sh 78g, Sh 78j, Sp 78, We 78d, We 78h, Yo 78c, Ab 79c, Al 79k, Am 79e, An 79d, An 79l, Ar 79k, Ba 79i, Bl 79e, Bo 79j, Bo 79k, Bo 79r, Bo 79ee, Br 79h, Bu 79, Ch 79a, De 79k, Di 79b, Do 79o, Dy 79a, Ep 79a, Er 79c, Gi 79c, Hi 79c, Hu 79b, Hu 79c, In 79c, Ja 79f, Ja 79j, Jo 79g, Kl 79e, Kl 79f, Kn 79, Ko 79p, Li 79a, Li 79g, Ma 79j, Ma 79q, Na 79c, Na 79q, Oh 79, Os 79c, Os 79i, Pi 79f, Re 79a, Ro 79e, Sc 79b, Sh 79g, Sh 79j, Sr 79a, St 79, Tr 79d, Tr 79h, Ul 79, Wa 79b, Wa 79g, Wi 79d, Wi 79e, Al 80e, Al 80g, Ar 80, As 80, Ba 80f, Ba 80y, Be 80q, Be 80s, Be 80u, Bh 80, Bh 80b, Br 80a, Bu 80b, Ch 80n, Co 80a, Cr 80a, De 80m, De 80aa, Er 80b, Fr 80h, Gr 80, Gr 80b, Gr 80f, Ho 80k, Ho 80l, Je 80c, Ka 80h, La 80a, Le 80c, Li 80j, Li 80k, Li 80n, Mi 80f, Na 80a, Na 80i, Ob 80a, Sc 80, Sc 80j, Se 80e, Si 80c, Sp 80, St 80d, St 80g, Th 80, Th 80a, Tr 80h, Wu 80, As 81a, Ba 81l, Bo 81, Bu 81e, Cu 81b, Do 81, Do 81a, Fr 81e, Fr 81f, Gi 81b, Gr 81c, Io 81, Ki 81a, Le 81e, Li 81b, Li 81h, Ma 81h, Mo 81e, Mo 81f, Os 81a, Sa 81g, Th 81b, Th 81d, We 81e, Wh 81, Wh 81b).

K-mesons and other meson interactions: (Bo 76y, Br 76q, Da 76o, Ba 77aj, Bo 77u, Ju 77c, Ki 77j, La 77j, Po 77e, Th 77f, At 78, Co 78o, Gr 78g, Po 78a, Sc 78b, So 78d, Ba 79hh, Bo 79k, Ch 79u, Ga 79e, Ga 79k, Gi 79, Ki 79g, Po 79, Ra 79f, Ba 80v, Do 80g, Ga 80, Po 80, Be 81u, Bo 81j, Hu 81a, Hu 81b).

Antiproton interactions: (Ba 77yy, We 77g, Gr 78g, Po 78, Au 81).

Other topics: (Er 75b, Go 75cc, Bo 76y, Bo 76z, Da 76o, Fu 76g, Go 76k, Kn 76g, Li 76s, Lo 76g, Na 76p, Pr 76a, St 76g, Ak 77, Au 77d, Bo 77u, Br 77k, Bu 77s, Ca 77, Ca 77u, De 77f, Go 77, Go 77p, Ho 77b, Ho 77h, Je 77a, Ka 77ff, Ki 77h, Ki 77j, Kr 77, Li 77e, Li 77l, Mo 77v, Ne 77c, Os 77b, Po 77e, Pr 77, Sa 77aa, Sm 77, So 77a, Su 77g, Tr 77a, Va 77d, Wa 77k, Za 77, An 78f, Au 78b, Ba 78f, Be 78v, Bi 78l, Bi 78n, Br 78m, Da 78s, De 78h, De 78n, En 78c, Fa 78d, Ga 78d, Ha 78o, Ha 78w, Ho 78f, Ka 78r, Ka 78w, Kh 78a, Ko 78h, Kw 78, Le 78c, Mc 78d, Mi 78e, Mu 78e, On 78, Po 78a, Ro 78p, Sc 78i, Sh 78d, Sh 78q, Si 78b, Si 78d, So 78c, So 78d, St 78j, Ul 78, Ab 79a, Ay 79, Be 79k, Bi 79b, Bo 79d, Bo 79g, Bo 79y, Br 79j, Ch 79u, De 79o, Du 79a, Fl 79, Ga 79e, Ga 79k, Go 79c, Go 79t, Go 79u, Gu 79g, Ha 79v, He 79, Ja 79m, Ja 79u, Ka 79a, Ka 79d, Ka 79n, Ka 79s, Ki 79g, Ki 79n, Ko 79r, Ko 79gg, Ko 79ll, Le 79g, Mu 79c, No 79c, Pe 79b, Sa 79u, St 79q, Ta 79h, To 79d, Va 79a, Va 79l, Za 79a, Za 79b, An 80k, Bo 80f, Bo 80n, Br 80n, Ca 80e, Da 80b, De 80, Dw 80, Fa 80b, Fa 80e, Gi 80a, Go 80n, He 80o, Hi 80c, Hy 80a, Ja 80e, Ka 80m, Me 80c, Mu 80, Mu 80g, Ng 80, Po 80, Qu 80, Sh 80n, Ta 80p, To 80e, Va 80b, Zo 80, Bl 81, Bo 81r, Br 81d, Cu 81f, Da 81c, Du 81b, Li 81d, Ro 81l, Sh 81h, Za 81a).

Ground state of ^{16}O: (Fu 76h, Ga 76k, Gi 76e, Sa 76i, An 77b, An 77f, Br 77, Bu 77s, Dy 77c, Go 77n, Gr 77b, Je 77a, Ma 77gg, No 77d, Pi 77d, Va 77e, Al 78f, Al 78k, An 78b, An 78f, Be 78v, Be 78cc, Bi 78l, Bi 78m, Br 78j, Ch 78y, Ch 78z, Fa 78d, He 78k, Ka 78r, Ko 78h, Mu 78e, Ne 78a, On 78, Ro 78p, Sh 78q, Si 78d, Sm 78d, So 78c, St 78g, Ul 78, Za 78a, Za 78b, Ay 79, Be 79q, Bi 79b, Br 79i, Br 79j, Du 79a, Fi 79d, Go 79u, Gu 79c, Gu 79g, Ha 79v, In 79d, Ja 79m, Ka 79n, Ko 79ll, Ma 79ll, Sa 79l, Sa 79u, St 79q, Va 79l, An 80l, Ar 80d, Bo 80n, Br 80i, De 80m, Fa 80b, Gi 80a, Go 80f, Hi 80c, Ho 80d, Hy 80a, Me 80b, My 80, Va 80a, Wa 80e, Ar 81, At 81, Br 81d, Du 81a, Si 81b, Za 81a).

$\langle r^2 \rangle^{1/2} = 2.710 \pm 0.015$ fm (Ki 78a). See also (Ba 80aa).

$g = +0.55 \pm 0.03$ for $^{16}O^*(6.13)$ (Br 73m, Ra 73c, Ka 77).

TABLE 16.11

Energy levels of ^{16}O [a])

E_x (MeV ± keV)	$J^\pi; T$	K^π	$\Gamma_{c.m.}$ or τ_m (keV)	Decay	Reactions
0	$0^+; 0$		stable		2, 3, 9→18, 25→28, 30, 31, 38, 40, 42, 48→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 $\|g\| = 0.55 \pm 0.03$	γ	2, 3, 9, 10, 14, 18, 26, 38, 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
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

TABLE 16.11—continued

E_x (MeV ± keV)	$J^\pi; T$	K^π	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
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
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

TABLE 16.11—continued

E_x (MeV ± keV)	$J^\pi; T$	K^π	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
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
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	$(1 \to 4)$		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
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

TABLE 16.11—continued

E_x (MeV ± keV)	J^π; T	K^π	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
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.

TABLE 16.12

Radiative decays in ^{16}O [a])

E_i (MeV)	J_i^π; T	E_f (MeV)	J_f^π; 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	$(2.60±0.13)\times10^{-5}$
6.92	2^+; 0	0	0^+; 0	>99	0.100±0.004 [e])
		6.05	0^+; 0	$(2.7±0.3)\times10^{-2}$	$(2.7±0.3)\times10^{-5}$
		6.13	3^-; 0	$\leq 8\times10^{-3}$	
7.12	1^-; 0	0	0^+; 0	>99	0.057±0.006 [f])
		6.05	0^+; 0	$<6\times10^{-4}$	
		6.13	3^-; 0	$(7.0±1.4)\times10^{-2}$	
8.87	2^-; 0	0	0^+; 0	7.2±0.8	$(2.4±0.4)\times10^{-4}$
		6.05	0^+; 0	0.122±0.033	$(2.9±1.0)\times10^{-6}$
		6.13 [h])	3^-; 0	76.0±3.0	[g])
		6.92	2^+; 0	4.2±0.8	$(1.72±0.25)\times10^{-4}$
		7.12	1^-; 0	12.6±2.0	
9.63	1^-; 0	0	0^+; 0	~100	$(23±3)\times10^{-3}$
9.85	2^+; 0	0	0^+; 0	61±4	$(6.0±0.4)\times10^{-3}$
		6.05	0^+; 0	18±4	$(1.9±0.4)\times10^{-3}$
		6.92	2^+; 0	21±4	$(2.2±0.4)\times10^{-3}$

TABLE 16.12—continued

E_i (MeV)	$J_i^\pi;T$	E_f (MeV)	$J_f^\pi;T$	Branch (%)	Γ_{rad} (eV)
10.35	$4^+;0$	0	$0^+;0$		$(5.6\pm2.0)\times10^{-8}$
		6.13	$3^-;0$		$<1.0\times10^{-3}$
		6.92	$2^+;0$	~100	$(5.8\pm0.7)\times10^{-2}$
10.96	$0^-;0$ c)	7.12	$1^-;0$	>99	$(0.08\pm0.05)\times10^{-2}$
11.10	$4^+;0$	6.13	$3^-;0$	g)	$(3.1\pm1.3)\times10^{-3}$
		6.92	$2^+;0$	g)	$(2.5\pm0.6)\times10^{-3}$
11.52	$2^+;0$	0	$0^+;0$	91.7	0.61 ± 0.02 f)
		6.05	$0^+;0$	4.2 ± 0.7	$(2.8\pm0.6)\times10^{-2}$
		6.92	$2^+;0$	4.0 ± 1.0	$(29\pm7)\times10^{-3}$
		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	$0^+;0$		$(108\pm15)\times10^{-3}$ e)
		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	$0^+;0$		$(71\pm2)\times10^{-3}$
		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 (Aj 71) and 16.15 in (Aj 77) 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 (Al 78d).
d) For the radiative decay of higher states see tables 16.13, 16.18 and 16.22.
e) See also (La 77f: 94 ± 10 meV).
f) "Best" value based on (La 77f: 60 ± 10 meV) and earlier values displayed in (Aj 77).
g) $(1.70^{+0.35}_{-0.50})\times10^{-3}$ (E2), $(8.5^{+4.5}_{-2.5})\times10^{-4}$ (M1).
h) $E_\gamma=2471.5\pm0.5$ keV for $(8.87\to6.13)$ transition (Ga 70).

1. (a) $^{10}B(^6Li, p)^{15}N$ $Q_m=18{:}748$ $E_b=30.876$
   (b) $^{10}B(^6Li, d)^{14}N$ $Q_m=10.140$
   (c) $^{10}B(^6Li, t)^{13}N$ $Q_m=5.843$
   (d) $^{10}B(^6Li, {}^3He)^{13}C$ $Q_m=8.083$
   (e) $^{10}B(^6Li, \alpha)^{12}C$ $Q_m=23.714$
   (f) $^{10}B(^6Li, {}^6Li)^{10}B$

At $E(^6Li)=4.9$ MeV, the cross sections for reactions (a) to (e) leading to low-lying states in the residual nuclei are proportional to $2J_f+1$: 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 $2J_f+1$ dependence (Mc 66a). For reaction (f) see (Po 76a). See also (Aj 77), and ^{12}C in (Aj 80), ^{13}C, ^{13}N, ^{14}N and ^{15}N in (Aj 81).

2. $^{10}B(^{10}B, \alpha)^{16}O$ $\qquad Q_m = 26.4155$

States of ^{16}O observed at $E(^{10}B) = 20$ MeV are displayed in table 16.10 of (Aj 77). 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 (Aj 76b). See also (Ma 78a) and ^{20}Ne.

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

The yield of capture γ-rays has been studied for $E_\alpha < 42$ MeV; see table 16.11 of (Aj 77) and (Sa 81e). Observed resonances are displayed in table 16.13 here.

This reaction plays an important role in astrophysical processes. (Dy 74) 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 (Ko 74) [used a hybrid R-matrix–optical-model analysis of (α, γ) and (α, α)], $0.08^{+0.14}_{-0.07}$ MeV · b (Hu 76h) [used a two channel, two level approximation of a modified K-matrix]. (Dy 74) state that S depends quite strongly on $\theta_\alpha^2(6.92)/\theta_\alpha^2(7.12)$: S may have to be increased to allow for the tail of $^{16}O^*(6.92)$. For astrophysical considerations see the above references, (Aj 71, Aj 77) and (Fo 76j, Ba 77a, Sa 77b, Ro 78b, Ro 78o, Ta 78s, Ba 80k, Kh 81).

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 ~17% of the sum rule. It appears from this and other experiments that the E2 centroid is at $E_x \sim 15$ MeV, with a 15 MeV spread (Sn 74). Structures are observed in the yield of γ-rays from the decay of $^{16}O^*(14.8 \pm 0.1)$ 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 (Sa 81e). See also (Ha 75ee, We 80d).

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

For cross-section measurements from threshold to $E_\alpha = 24.7$ MeV see (Aj 71) and table 16.11 in (Aj 77). Observed resonances are displayed in table 16.13 here. The production of neutrons at $E_\alpha = 710$ MeV has been studied by (Ce 80). See also (Aj 77, Gr 77i, Li 77j) and (We 78i; applications).

TABLE 16.13

Resonances in $^{12}C+\alpha$

No.	E_α (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Outoing particles [a]) (x)	Γ_x	Γ_α/Γ	$^{16}O^*$ (MeV)	$J^\pi; T$	Refs. [b])
						8.87		(Mc 77h) [k])
1	3.322±30	400	γ_0	23±3 meV		9.65 [h])	1^-	(Mc 77h)
			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	$1^-; 0$	(Op 76)
			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])	$1^-; 1$	(Op 76)
			γ_4	1.35±0.4 eV				
			p	100 keV				
			α_0	45±18 keV	0.3			
			α_1	1 keV				

TABLE 16.13—continued

No.	E_α (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Outoing particles [a]) (x)	Γ_x	Γ_α/Γ	$^{16}O^*$ (MeV)	$J^\pi; T$	Refs. [b])
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^+)	(Am 79a)
			α_1					
19	10.002	672±11	α_0		~0.95	14.660±11	5^-	(Am 79a)
			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^+	(Am 79a)
22	10.999	133±7	α_0, α_1, p_0		0.58	15.408±2	3^-	(Am 79a)
23	11.560	703±113	$\alpha_0, \alpha_1, \gamma_{4.4}$		0.21	15.828±30	3^-	(Am 79a)
24	11.6	~600	γ_0	$\Gamma_\alpha\Gamma_\gamma/\Gamma \sim 0.4$ eV		15.9	2^+	
25	12.156	422±14	α_0		0.93	16.275±7	6^+	(Am 79a)
26	12.272	65±45	$\alpha_0, \alpha_1, \alpha_2, p_0$		0.07	16.362±20	$(0^+, 1^-)$	(Am 79a)
27	12.380	22±3	γ_0, n, p_0, α_0,	$\Gamma_\alpha\Gamma_\gamma/\Gamma = 0.45$ eV	0.28	16.443±2 [i])	$2^+; (1)$	(Am 79a)
			$\alpha_1, \alpha_2, \gamma_{4.4}$					
28	12.5	730	p_0, α_0			(16.5)		

29	12.915	567±60	α_0		0.28	16.844±21	4^+	(Am 79a)
30	13.0	700	α_0			(16.9)	5^-	
31	13.05	~280	α_2, ^8Be			16.94	2^+	(Am 79a)
32	13.296	107±14	n, p_0, α_0, α_1, $\gamma_{4.4}$		0.37	17.129±5	2^+	(Am 79a)
33	13.32	36±5	α_0, α_1			17.15		(Am 79a)
34	13.35	160±60	α_2, ^8Be			17.17	2^+	(Am 79a)
35	13.50	<100	n			17.28		
36	13.805	182±56	α_0, (α_1), α_2		0.16	17.510±26	1^-	(Am 79a)
37	13.865	178±66	n, (α_0, α_1)		0.07	17.555±21	(6^+)	(Am 79a)
38	13.948	175±55	p_0, α_0		0.32	17.618±20	$0^+, 1^-$	(Am 79a)
39	14.08	(~75)	(p_0), ^8Be			17.72	$(0^+, 2^+)$	(Am 79a)
40	14.170	396±41	n, α_0, α_1, $\gamma_{4.4}$, ^8Be		0.34	17.784±15	4^+	(Am 79a)
41	14.480	14±2	(n), p_0, α_0, α_1, $\gamma_{4.4}$, ^8Be		0.36	18.016±1	4^+; (0)	(Am 79a)
42	14.577	248±90	(γ_0), n_0, p_0, α_0		0.31	18.089±25	(0^+)	(Am 79a, Mo 79e)
43	(14.62)	(~45)				(18.12)	$(\neq 4^+)$	(Am 79a)
44	14.85	~300	γ_0, p_0, (α_1, $\gamma_{4.4}$)	$\Gamma_\alpha\Gamma_\gamma/\Gamma = 0.95$ eV		18.29		(Am 79a)
45	14.997	544±39	α_0		0.40	18.404±12	5^-	(Am 79a)
46	15.2	~150	α_0, (α_1, α_2, $\gamma_{4.4}$)			18.6	$(1^-, 5^-)$	(Am 79a)
47	15.2	~300	α_2, ^8Be			18.6	(4^+)	(Am 79a)
48	15.490	215±45	p_0, α_0		0.26	18.773±22	1^-	(Am 79a)
49	15.506	260±16	n, p_0, α_0, (α_1), ^8Be		0.48	18.785±6	4^+	(Am 79a)
50	15.8	~550	(α_0), α_1, $\gamma_{4.4}$			19.0	(5^-)	(Am 79a)
51	15.96	41	(n), α_0			(19.12)	$(2^+, 4^+)$	
52	16.130	50±45	(n), (α_0)		0.04	19.253±30	(5^-)	(Am 79a)
53	16.137	155±23	p_0, α_0, (α_1)		0.34	19.257±9	2^+	(Am 79a)
54	16.219	63±33	p_0, (α_0), α_1, α_2, ^8Be		0.07	19.319±14	(6^+)	(Am 79a)
55	16.293	23±4	p_0, α_0, α_1, α_2		0.23	19.375±2	4^+	(Am 79a)
56	16.496	255±75	(n), α_0, (α_1, α_2)		0.20	19.527±26	2^+	(Am 79a)
57	16.799	286±44	p_0, α_0, α_1		0.29	19.754±16	2^+	(Am 79a)
58	(16.92)	(~175)	α_2			(19.85)		(Am 79a)
59	(17.05)	(~30)	(α_0)			(19.94)	$(\neq 3^-)$	(Am 79a)
60	17.201	432±40	γ_0, n, (p_0), α_0, (α_1)		0.43	20.055±13	2^+	(Am 79a)
61	(17.27)	(~45)	(α_0)			(20.11)	$(\pm 3^-)$	(Am 79a)
62	17.5	~1500	p_0			(20.3)		
63	(17.66)	(~150)	n, (p_0), α_2			(20.40)	(4^+)	(Am 79a)

TABLE 16.13—continued

No.	E_α (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Outoing particles [a]) (x)	Γ_x	Γ_α/Γ	$^{16}O^*$ (MeV)	$J^\pi; T$	Refs. [b])
64	(17.8)	(~300)	(α_0), α_1			(20.5)		(Am 79a)
65	17.849	11 ± 2	p_0, α_0, α_1, α_2		0.14 ± 0.02	20.541 ± 2	5^-	(Am 79a)
66	17.875	<5	α_0			20.560 ± 2	even	(Am 79a)
67	17.948	<10	α_0			20.615 ± 3	even	(Am 79a)
68	(18.2)	(~60)	n, (p_0)			(20.8)		(Am 79a)
69	18.271	904 ± 55	α_0		0.60	20.857 ± 14	7^-	(Am 79a)
70	(18.3)		α_0			(20.9)	(2^+)	(Am 79a)
71	(18.48)	(~50)	n, p_0, (α_0)			(21.01)		(Am 79a)
72	18.50 ± 25	240 ± 80	γ_0, (α_0, α_1)		0.20	21.03	(1^-)	(Am 79a)
73	18.5	900	α_0			(21.0)	(5^-)	
74	18.531	205 ± 14	α_0		0.50	21.052 ± 6	6^+	(Am 79a)
75	18.593	306 ± 46	(α_0)		0.21	(21.098)	4^+	(Am 79a)
76	19.14	61 ± 32	(n), α_0, α_2			21.52	7^-	(Am 79a, Fr 81h)
77	19.327	115 ± 8	n, α_0, α_1, α_2		0.41	21.648 ± 3	6^+	(Am 79a)
78	19.498	43 ± 20	n, p_0, α_0, α_1, α_2		0.07	21.776 ± 9	3^-	(Am 79a)
79	19.85	60	n			22.04		
80	19.89	340	n			22.07		
81	19.95	<150	n, ^8Be			22.11		
82	20.49	375	n			22.52		
83	20.71	60	n, ^8Be			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, ^8Be			23.11		
86	21.3	≤500	^8Be			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, ^8Be	[j])	0.06 ± 0.02	23.879	6^+	
92	22.37	165	n			23.93		

93	22.75	$\leqslant 500$	^{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	$\alpha_0, \gamma_{12.71}$	$\Gamma_\alpha \Gamma_\gamma / \Gamma = 1.2$ eV		26.3	2^+	
99	29[l])	4 MeV	α_0, α_1, p_3			29		(Bu 78j)

[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 (Aj 71) and 16.12 (Aj 77). Please note that (Am 79a) is an unpublished thesis. (Am.81b) has been submitted for publication.

[c]) 7040 ± 5 keV (Op 76).

[d]) 7880 ± 15 keV (Op 76).

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

[f]) $\Gamma_{\gamma 0} = 0.7 \pm 0.2$ eV (Ke 71e), based on $\Gamma_{\alpha 0}/\Gamma = 1.0$ (Mo 68h) and $\Gamma_{\mathrm{c.m.}} = 190 \pm 40$ keV (Ke 71e).

[g]) $\Gamma_{\alpha 0} \Gamma_{\gamma 0} / \Gamma^2 = (1.49 \pm 0.17) \times 10^{-4}$ (Ke 71e).

[h]) $\theta_\alpha^2(7.12)/\theta_\alpha^2(9.63) = 0.19^{+0.16}_{-0.11}$ (Ko 74). See also reactions 9 and 12.

[i]) See column 2 and footnote (d).

[j]) $\Gamma_{^8\mathrm{Be}}$, $\Gamma_{\alpha 0}$ and $\Gamma_{\alpha 2} \sim 3.5$, 1.5 ± 0.5 and ~6 keV, respectively (Br 76d).

[k]) An attempt is reported by (Mc 77h) to observe a 0^+ state in the vicinity of the known 2^- state at 8.87 MeV. No such state is seen: $\theta_\alpha^2 \leq 2 \times 10^{-4}$.

[l]) See (Sa 81e) for (α, $\gamma_{14.8}$) measurements which indicate an 8^+ GQR built on the 6_1^+ state ^{16}O*(14.82).

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

The yield of p_0 has been studied for $E_\alpha = 7.7$ to 23 MeV: see (Aj 77), (Am 79a, Am 81b; $15 \leq E_x \leq 22$ MeV) and (Mo 79e; $17.5 \leq E_x \leq 18.7$ 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 $E_x \sim 29$ MeV, $\Gamma \sim 4$ MeV. It is suggested that it is related to the GQR in ^{16}O (Bu 78j). For other resonances see table 16.13. See also ^{15}N in (Aj 81).

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

See (Aj 81).

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

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 (Aj 77), (Am 79a, Am 78a, Am 79, Am 81b; $E_\alpha = 15$ to 20 MeV), and (Ar 79e; 17 to 23 MeV) and (Fr 81h; 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 $^{16}N(\beta^-)$ [reaction 52] appears to be due to $^{16}O^*(8.87)$ ($J^\pi = 2^-$) and is thus parity forbidden (Mc 77h). No evidence is found by (Fr 81h) for 8^+ strength.

Total reaction cross-section measurements are reported at 1.55 and 2.89 GeV/c per nucleon (Ja 78m). See also (De 79w, De 79z, De 80b, De 80l, Ba81r, Pe 81). For π^0 measurements see (Wa 76k). For spallation measurements see (Fo 77b, Du 78h, Gl 79e, Vi 79, Ab 80b, Go 81b) and (Aj 77).

See also (Fr 78c, Wa79j), (Si 76i, De 80w), (Cu 76f, Ba77l, Ba 77oo, Ba 77rr, Br 77gg, Da 77h, Fr 77b, Hu 77b, Ik 77b, Sa 77p, Ze 77b, Fr 78g, Su 78d, Su 78f, Ve 79e, Ba 80kk, Dm 80, Fu 80e, Fu 80g, Li 80f, St 80i, Su 81a, Wi 81b; theor.) and ^{12}C in (Aj 80).

8. (a) $^{12}C(\alpha, {}^8Be)^8Be$ $Q_m = -7.4586$ $E_b = 7.1620$
   (b) $^{12}C(\alpha, 2\alpha)^8Be$ $Q_m = -7.3667$
   (c) $^{12}C(\alpha, 4\alpha)$ $Q_m = -7.2748$

The yield of ^{8}Be (reaction a) shows a number of resonances: see table 16.13. There is no evidence below $E_x \sim 24$ 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 (Br 76d). For reactions (b) and (c) see (Aj 77).

9. $^{12}C({}^6Li, d)^{16}O$ $Q_m = 5.6885$

This reaction has been studied at many energies: see the references in (Aj 77) 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 $E_x = 17$ to 24 MeV

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)	$\theta_\alpha^2/\theta_\alpha^2(2^+)$ [c])	$\Gamma_{\alpha 0}/\Gamma$ [d])	$J^\pi; K^\pi$
0		0.93, 0.18		0^+
6.05		0.38, 1.10		$0^+; 0^+$
6.13		0.23, 0.22		3^-
6.92		≡1.0		$2^+; 0^+$
7.12		0.53, 0.39		1^-
8.87	<20			2^-
9.63 ± 30 [i])	409 ± 10 [i])	0.30, 0.60		$1^-; 0^-$
9.85	<20	≤0.05, ≤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	≤0.06, ≤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	≤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])
(29.3) [g])				(7^-) [g])

[a]) E_x quoted without errors are from table 16.11. The others are from (Be 78u: $E(^6\text{Li}) = 42.1$ MeV) and (Be 80o: $E(^6\text{Li}) = 90.2$ MeV). The states with $E_x < 11.1$ MeV have also been studied by (Be 78t: $E(^7\text{Li}) = 34$ MeV). Angular distributions are reported in both reactions for the first nine states. See also (Cu 78c).

[b]) See (Be 78t, Be 78u, Be 80o): 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 $E(^6\text{Li}) = 42$ MeV (Be 78u), the second at $E(^6\text{Li}) = 90.2$ MeV (Be 80o).

[d]) (Cu 80b); d $-\alpha$ angular correlations. See also (Cu 77, Cu 78c, Ar 78h).

[e]) (Ba 71k).

[f]) (Ar 79e); d $-\alpha$ angular correlations.

[g]) (Ar 76h, Ar 76i); d $-\alpha$ angular correlations.

[h]) Observed at $E(^7\text{Li}) = 38$ MeV (Co 76c) 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 (Ov 81 and F. Becchetti, private communication).

[j]) Angular distributions are reported at $E(^6\text{Li}) = 35.5$–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 (Ke 80h, Cl 78f). See also (Cu 78c).

[k]) Angular distributions at $E(^6\text{Li}) = 35.5$ MeV (Cl 78f) and 28 and 34 MeV (Cu 78c).

by (d, α) angular correlations has been unsuccessful: see (Ar 76i; $E(^6Li)=29.0$ and 34.7 MeV). The ratio R [$=\theta_\alpha^2$ (7.1 MeV)/θ_α^2 (9.6 MeV)] is of astrophysical interest: an FRDW analysis by (Be 80o) leads to $R=0.7\pm0.2$ for $s=5.4$ fm. See also (Be 78u).

For analyzing power measurements see ^{18}F in (Aj 83): (Ma 78i; $E(^6Li)=20$ MeV; to ^{16}O states with $E_x<11.1$ MeV). See also (Be 79d, Fu 80c, Ma 80j), (Fo 77g, Be 78w, Fi 78a, Ma 79aa) and (St 76n, Ba 77mm, Ap 78, Cu 78g, Me 78d, Su 79g, Ze 79a, Ap 80; theor.).

10. $^{12}C(^7Li, t)^{16}O$ $Q_m=4.695$

This reaction has been studied extensively: see (Aj 77) for the earlier references. Observed states are displayed in table 16.14. Angular distributions have been reported recently at $E(^7Li)=34$ MeV (Be 78t; first nine states) and at 68 MeV (Br 79a; to $^{16}O^*$(6.92, 10.35, 16.3)). The value of R [see reaction 9] derived by (Be 78t) is 0.35 ± 0.13. See also ^{19}F in (Aj 83), (Sa 76m, Cl 78f, Ro 79j, De 80d, De 81i) and (Bi 77e; theor.).

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

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) (Hi 70b). 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 (Bi 81c). See also footnote (i) in table 16.14 and (Be 78j).

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

See (Be 78j). See also (Aj 77).

13. $^{12}C(^{12}C, ^8Be)^{16}O$ $Q_m=-0.2047$

Angular distributions have been reported at $E(^{12}C)$ to 63 MeV: see (Aj 77). Angular correlations at $E(^{12}C)=78$ MeV confirm $J^\pi=4^+$, 5^-, 6^+ and 7^- for $^{16}O^*$(10.35, 14.59, 16.3, 20.9). $\Gamma_{\alpha_0}/\Gamma=0.90\pm0.10$, 0.75 ± 0.15 and 0.90 ± 0.10, respectively, for the first three of these states. In addition a state is reported at $E_x=22.5\pm0.5$ MeV which may be the 8^+ member of the $K^\pi=0^+$, 4p-4h rotational band (Sa 79k, Sa 77j). For the decay of ^{20}Ne states see (Yo 79) and (Aj 83). For excitation function and fusion measurements see (Hi 77c, Wa 77e, Co 78e, Ja 78g, He 79a, Ko 80, Wa 80f, Wi 80b). See also (Ab 77e, To 78c; theor.).

14. $^{12}C(^{14}N, ^{10}B)^{16}O$ $Q_m=-4.4512$

Angular distributions are reported at $E(^{14}N)=53$ MeV involving $^{16}O^*$(0, 6.05, 6.13, 6.92) and various states of ^{10}B (Ze 76) and at $E(^{14}N)=78.8$ MeV (Mo 77y, Mo 79z) involving $^{16}O_{g.s.}$.

15. (a) $^{12}C(^{17}O, ^{13}C)^{16}O$ $Q_m = 0.8021$
    (b) $^{12}C(^{18}O, ^{14}C)^{16}O$ $Q_m = 0.9341$

Angular distributions are reported at $E(^{17}O) = 30.5$ and 33.8 MeV (Ch 78m). For reaction (b) see (Aj 77) and (Ta 78f; theor.).

16. $^{12}C(^{19}F, ^{15}N)^{16}O$ $Q_m = 3.1481$

Angular distributions have been measured at $E(^{19}F) = 40$, 60 and 68.8 MeV involving different states in ^{15}N and $^{16}O^*(0, 6.1, 7.0, 10.4)$ (Sc 72c).

17. $^{12}C(^{20}Ne, ^{16}O)^{16}O$ $Q_m = 2.4310$

Angular distributions have been measured to $E(^{20}Ne) = 147$ MeV see (Aj 77). Excitation functions are reported at $E(^{20}Ne) = 45.3$ to 93.3 MeV (Do 78) and 150 to 250 MeV (Or 79: $E_x = 10$–15 MeV and 20–25 MeV). For an experiment studying $^{16}O + \alpha$ coincidences see (Os 81g). See also (Pi 75f).

18. $^{13}C(^{3}He, \gamma)^{16}O$ $Q_m = 22.7934$

The yield of capture γ-rays has been studied for $E(^{3}He)$ to 16 MeV [see (Aj 77)], as have angular distributions. Observed resonances are displayed in table 16.15. It is suggested that the structures at $E_x \sim 26$–29 MeV are part of giant resonances built on the first few excited states of ^{16}O (Ve 79).

19. $^{13}C(^{3}He, n)^{15}O$ $Q_m = 7.1295$ $E_b = 22.7934$

The excitation functions to $E(^{3}He) = 11$ MeV are marked at low energies by complex structures and possibly by two resonances at $E(^{3}He) = 1.55$ and 2.0 MeV: see table 16.15. See also (Aj 77) for polarization measurements.

20. $^{13}C(^{3}He, p)^{15}N$ $Q_m = 10.6658$ $E_b = 22.7934$

Excitation functions for $E(^{3}He) = 3.6$ to 6.6 MeV have been measured for p_0, p_{1+2}, p_3: a resonance is reported at $E(^{3}He) = 4.6$ MeV (Ch 78p). A resonance at 6 MeV has also been observed: see table 16.15. See also ^{15}N in (Aj 81).

21. $^{13}C(^{3}He, d)^{14}N$ $Q_m = 2.0571$ $E_b = 22.7934$

See ^{14}N in (Aj 81).

22. (a) $^{13}C(^{3}He, t)^{13}N$ $Q_m = -2.2392$ $E_b = 22.7934$
    (b) $^{13}C(^{3}He, ^{3}He)^{13}C$

The excitation function for formation of $^{13}N_{g.s.}$ has been studied for $E(^{3}He) = 11$ to 17 MeV: see (Aj 77). Polarization measurements are reported by (Ba 81c) at $E(^{3}\overrightarrow{He}) = 33$ MeV (t_0, t_{2+3}). For reaction (b) see table 16.15.

23. $^{13}C(^{3}He, \alpha)^{12}C$ $Q_m = 15.6314$ $E_b = 22.7934$

TABLE 16.15

Resonances in $^{13}C+^{3}He$

$E(^3He)$ (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^-	(Ve 79)
~3.1		α_0, α_2	~25.3		
~3.5	~300	α_0	~25.6	(3^-)	
~4	~300	$\alpha_0, \alpha_1, \alpha_2$	~26	(3^-)	
4.0 ± 100	[b])	$\gamma_0, \gamma_{1+2}, \alpha\gamma_{15.1}$	26.0	$1^-; (1)$	(Ve 79)
4.6 ± 100 [c])	720 ± 160	γ_2, p_0	26.5	$2^+, 4^+$	(Ch 77b, Ch 78p, Ve 79)
5.2 ± 100	[b])	$\alpha\gamma_{15.1}$	27.0	$(T=1)$	
5.6 ± 100	~600	$\gamma_0, \gamma_{1+2}, \alpha\gamma_{15.1}, ^8Be$	27.3	(1^-)	(Ve 79)
~5.8	~2500	γ_{3+4}	27.5		(Ve 79)
6.0 ± 100	~500	$p_0, p_{1+2}, ^3He, \alpha_1, \alpha_2$	27.7	$(3^-; 0)$	
~6		γ_0	28		
6.5 ± 100	[b])	$\alpha\gamma_{15.1}$	28.1	$(T=1)$	
6.8 ± 100		$\alpha_0, \alpha_1, \alpha_2$	28.3	$(T=0)$	
7.1 ± 200		γ_{1+2}	28.6		(Ve 79)
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 (Aj 71) and 16.13 in (Aj 77).

[b]) Lab widths 0.5–1 MeV (Ta 69b).

[c]) Based on $\Gamma_{c.m.}=530\pm80$ keV [from $^{15}N(p, \gamma)$, see table 16.18], $\Gamma_{p_0}=150\pm45$ keV $[J^\pi=2^+]$, 110 ± 35 keV $[4^+]$, $\Gamma_{p_0}/\Gamma=0.29\pm0.10$ $[2^+]$, 0.21 ± 0.07 $[4^+]$, $\Gamma_{\gamma_2}=740\pm240$ eV $[2^+]$, 410 ± 140 eV $[4^+]$ (Ch 77b, Ch 78p).

Yields of $\alpha_0, \alpha_1, \alpha_2$ and γ-rays from the decay of $^{12}C^*(12.71, 15.11)$ have been studied up to $E(^3He)=12$ 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 $E(^3\overrightarrow{He})=33$ MeV to $^{12}C^*(4.4)$ (Ka 81c). See (Aj 71, Aj 77) for the earlier references and ^{12}C in (Aj 80).

24. $^{13}C(^3He, ^8Be)^8Be$ $\qquad Q_m=8.1728 \qquad E_b=22.7934$

The excitation function for ^8Be(g.s.) has been studied for $E(^3He)=2$ to 6 MeV. It shows a strong resonance at $E(^3He)=5.6$ MeV corresponding to a state in ^{16}O

at $E_x = 27.3$ MeV. J^π appears to be 2^+ from angular distribution measurements (Ja 68h).

25. $^{13}C(\alpha, n)^{16}O$ $Q_m = 2.2156$

Angular distributions for the n_0 group have been measured for $E_\alpha = 12.8$ to 22.5 MeV: see (Aj 71). See also (Aj 77), (Ha 81d), (Sc 77i, Co 80q, Tr 80j; astrophys.) and (Ge 78i, Ba 80l; applications).

26. $^{13}C(^6Li, t)^{16}O$ $Q_m = 6.9994$

Angular distributions have been studied at $E(^6Li) = 20$ 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 $E(^6Li) = 25$ MeV the excitation of $^{16}O^*$(14.52, 14.66) is also reported: see (Aj 77) and (Cu 80a). See also (Ma 77g) and ^{19}F in (Aj 83).

27. $^{13}C(^{12}C, ^9Be)^{16}O$ $Q_m = -3.4859$

Angular distributions have been measured at $E(^{12}C) = 87$ MeV and at $E(^{13}C) =$ 36 MeV: see (Aj 77). At $E(^{13}C) = 105$ MeV, $^{16}O^*$(6.05 + 6.13, 10.35, 16.3, 20.7) are strongly populated (Br 79a).

28. $^{13}C(^{17}O, ^{14}C)^{16}O$ $Q_m = 4.0322$

Angular distributions have been measured at $E(^{17}O) = 29.8$ and 32.3 MeV (Ch 77m, Ch 78m).

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

At $E(^3He) = 11$ 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 (Ad 70a). See also (Aj 71).

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

See ^{16}C.

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

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 (Aj 77) for references.

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

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 (Aj 77). See also ^{15}O in (Aj 81), (No 81) and (Yo 77k; applications).

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

TABLE 16.16

Structure in $^{14}N + d$

E_d (MeV)	Resonant channel	$\Gamma_{c.m.}$ (keV)	$J^\pi; T$	E_x (MeV)	Refs. [a])
1.4	n_0			22.0	
1.7±0.1	$\gamma_0, \alpha_0 \rightarrow \alpha_3$			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])	$p_0, p_{1+2}, (p_3)$ $p_4, p_5, \alpha_0, \alpha_2$	12±3	$0^+; 2$	22.722	(Ko 77h)
2.40±0.05 [c])	γ_0 [d])	600	$1^-; 1$	22.83	
2.5	α_0			22.9	
2.6	$(n_0), \alpha_1$			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	(Ko 77h)
4.2	$\gamma_0, (p_0), d_0, \gamma_{15.1}$			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 (Aj 77).
[b]) $(\Gamma_{d_0}\Gamma_i/\Gamma^2) \times 10^{-3}$ 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 $l = 1$ (We 72a).
[d]) The angular distribution of γ_0 is consistent with E1.

The yield of various proton groups for $E_d < 5.0$ MeV shows some fluctuations and two resonances: see table 16.16 and (Aj 71, Aj 77) for the earlier references. Recent work includes that of (Va 76h; 0.309 to 0.638 MeV; p_0, p_{1+2}, p_3, p_4, p_5), (Ni 80; 0.32 to 1.45 MeV; p_5), (Us 79; $E_d = 1.50$ to 3.00 MeV; p_5) and (Ko 77h; $E_d = 0.5$ to 5.0 MeV; p_0, p_{1+2}, $p_3 \rightarrow p_8$, p_{10}). Polarization measurements are also reported by (Kr 80; $E_d = 10$ 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 (Aj 77) and ^{15}N in (Aj 81).

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

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 (Aj 71, Aj 77). 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 (Du 70): see table 16.16. The yield of d_1 has also been studied for $E_d = 10.0$ to 17.9 MeV by (Ao 79). For polarization measurements, see (Aj 77) and (Kr 80: $E_d = 10$ MeV; d_0). See also ^{14}N in (Aj 81) and (Iz 77, Iz 77b, Se 79; theor.).

35. (a) ^{14}N(d, t)^{13}N $Q_m = -4.2963$ $E_b = 20.7363$
(b) ^{14}N(d, ^{3}He)^{13}C $Q_m = -2.0571$

For polarization measurements see (Aj 77) and (Ma 81). See also ^{13}C, ^{13}N in (Aj 81).

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

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 (Aj 71) for the earlier work, and (Ko 77h: 0.5 to 5.0 MeV; $\alpha_0 \to \alpha_3$, $\alpha_5 \to \alpha_7$). The latter group reports broad oscillations ($\Gamma \sim 0.5$ 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 (Aj 80).

For polarization measurements, see (De 79m: $E_d = 1.5$ to 3.0 MeV; α_0, α_1), (Kr 80h, Kr 81: $E_d = 10$ MeV; $\alpha_0 \to \alpha_5$) and (Aj 77). See also (Se 79; theor.).

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

See (Aj 77).

38. (a) ^{14}N(^{3}He, p)^{16}O $Q_m = 15.2428$
(b) ^{14}N(^{3}He, pα)^{12}C $Q_m = 8.0808$

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 (Aj 77) for the earlier work and (Sl 79a: 9.8 MeV; p_0), (Bi 78j, Fo 78r: 15 MeV; most states in table 16.17) and (Ma 77y; 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.

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] (Ho 69h). In a kinematically

TABLE 16.17

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

E_x [a,b] (MeV ± keV)	$\Gamma_{c.m.}$ [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	$(0\rightarrow4)^+$
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]
16.114±4 [i]			
16.209±2	40±10	0+2	
16.350±13			
16.440±3	~30	0+2	
16.817±2	70±10		

[a] (Br 64f): $E(^3\text{He}) = 3.74$ and 3.97 MeV.
[b] (Bi 78j): $E(^3\text{He}) = 15$ MeV. [c] (Bi 78j, Fo 78l, Fo 78r).
[d] See also (We 71q).
[e] Mostly compound nucleus. [f] Unresolved.
[g] (Fo 78r) 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] (Fo 78l) 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.

complete experiment at $E(^3\text{He}) = 13$ MeV, ^{16}O*(14.94, 18.04) are strongly populated (Fr 80j; prelim.). See also (Ha 79h).

39. (a) $^{14}\text{N}(\alpha, \text{d})^{16}\text{O}$ $Q_m = -3.1104$
(b) $^{14}\text{N}(\alpha, \text{d}\alpha)^{12}\text{C}$ $Q_m = -10.2724$

Angular distributions to states of ^{16}O have been reported at many energies to $E_\alpha = 48$ MeV: see (Aj 71, Aj 77). Among the states reported by (Lo 72b) [see table 16.17 in (Aj 77)] are ^{16}O*(11.094±3, 14.400±3, 14.815±2, 17.18±50) [MeV±keV]: the results of (Lo 72b) 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]. (Cl 79d) report $\Gamma_{\text{c.m.}} = 34 \pm 12$, 27 ± 5 and 70 ± 8 keV, respectively for ^{16}O*(14.31±10, 14.40±10, 14.81). For reaction (b) see (Aj 77).

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

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 (Aj 77).

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

See (Wu 78c). See also (Hi 77).

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

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] (Re 77b). For both reactions see (Pr 80c). See also (Aj 77).

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

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 (Aj 77) and (Sn 79: $E_p = 4$ to 9 MeV), (Ch 77j: 6 to 22 MeV; also γ_2), (Ca 77l: $E_p = 8.6$ to 11 MeV) and (Oc 78a; 8.6 to 18 MeV; also $\gamma_{1+2+3+4}$ for 12.7→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) (Oc 78a), the giant M2 resonance, based on ^{16}O*(6.13), is identified to be ^{16}O*(20.43) (Ch 77j), 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 (Oc 78a). (Sn 79) report that the total M1 transition strength, built on the 2p-2h ground state correlations, $B(\text{M1})\downarrow \geq 0.24$ n.m.^{2} for ^{16}O*(16.22, 17.14, 18.8).

A study of the M1 decays of ^{16}O*(16.22, 17.14) [both $J^\pi; T = 1^+; 1$] to ^{16}O*(6.05) finds $B(\text{M1}, 1^+ \to 0_2^+)/B(\text{M1}, 1^+ \to 0_1^+) \sim 0.7$ for both transitions. The M1 (E2) γ-decay of ^{16}O*(18.03, 18.98) [$J^\pi; T = 3^-; 1$ and $4^-; 1$, respectively] to ^{16}O*(6.13) [$J^\pi = 3^-$] are also reported by (Ik 80). See also (Sn 81).

TABLE 16.18

Levels of ^{16}O from $^{15}N(p, \gamma)$, $^{15}N(p, p)$ and $^{15}N(p, \alpha)$

No.	E_p (keV)	$\Gamma_{\gamma 0}$ [a]) (eV)	$\Gamma_{\gamma 1}$ [a]) (eV)	Γ_p [a]) (keV)	$\Gamma_p\Gamma_\gamma/\Gamma$ (eV)	$\Gamma_{\alpha 0}$ [a]) (keV)	$\Gamma_{\alpha 1}$ [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	$(21\pm6)\times10^{-3}$	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	$(78\pm16)\times10^{-3}$		1.2		nr	0.69±0.07	2.0±0.2	$2^-; 1$	12.9685	(Br 77s)
5	1028±10	32±5		100		40		140±10	$1^-; 1$	13.091	(Br 77s)
6	1050±150					$\Gamma_p\Gamma_{\alpha 0}=$	r		2^+	13.1	(Br 77s)
						500 keV^2					
7	1210±3			4.1		r	8.2±1.1	22.5±1	$3^-; 1$	13.261	(Br 77s)
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])	(Ja 77j,
											Fr 78b)
12	3170 [j])			12 [d])		152	163	327±100	0^+	15.10±50	(Fr 78b)
13	3260 [j])			48		nr	7	62±10	2^-	15.188±30 [c])	(Fr 78b)
14	3340 [j])			15 [d])		12	182	315±100	$2^+; (0)$	15.26±20 [c])	(Fr 78b)
15	3520±40			23		103	1	167±20	3^-	15.43 [c])	(Ja 77j,
											Fr 78b)
16	4380±20	3.6	r	16	2.65±0.22			19±3	$1^+; 1$	16.23	(Sn 79,
											Ik 80)
17	4620±20			r		(r)	r			16.46	(Ja 77j)
18	5010±20			r		nr	r	75±10	3^+	16.82	(Ja 77j)
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	(Sn 79,
											Ik 80)
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	(Ch 77j,
											Ik 80)
23	7310±20		≤2 [e,o])	≤40 [f])				≤40	$4^-; 1$	18.98	(Ch 77j,
											Ik 80)
24	7330±30	38		≤130	≥1.8±0.3			~260	1^+	18.99	(Sn 79)
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	(Ch 77j)
29	8860±30	nr	120±45 e)	86 f)				200±40	2^-; 1	20.43 g)	(Ch 77j)
30	8990			i)				160		20.55	
31	9410 j)	170		i)	21±1			320±10	1^-; 1	20.945±20	(Oc 78a, Ca 77l)
32	10 000 j)			k)				130	1→4	21.50	
33	10 180 j)			l)		r		<45	$T=0$	21.66	
34	10 700 j,m)	r		k)	488±20			730±10	1^-; 1	22.150±10	(Oc 78a)
35	11 490 j)	120	27 h)	k)	69±5			320±10	1^-; 1	22.89±10	(Oc 78a)
36	12 740 j)	r			130±13			590±40	1^-; 1	24.07±30	(Oc 78a)
37	13 490±60		230±90, or 130±50 e)	85 f)				360±60	(2, 4^+; 1	24.76	(Ch 77j)
38	13 870 j)	r	740±240, or		651±117		p)	3150±320	1^-; 1	25.12±60	(Oc 78a)
39	15 250±80		410±140 e)	122 f)			p)	565±85 n)	$(2, 4)^+$; 1	26.41	(Ch 77j)
40	16 250±100		1070±380, or 590±10 e)	206 f)			p)	880±125	$(2, 4)^+$; 1	27.35	(Ch 77j)

a) nr = non-resonant; r = resonant.
b) For earlier references see tables 16.21 in (Aj 71) and 16.19 in (Aj 77).
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 (Fr 78b): in addition to these states, others at $E_x = 14.0$ [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) (Ch 77j).
f) Γ_{p_0} based on $\Gamma_{c.m.}$ and values of Γ_{p_0}/Γ assumed by (Ch 77j).
g) This state is attributed to the giant M2 resonance based on ^{16}O*(6.13) [$J^\pi = 3^-$] (Ch 77j).
h) $\gamma_1 + \gamma_2$.
i) Resonant in p_2 (Dr 71b).
j) Nominal E_p calculated from E_x.
k) Resonant in p_1 (Dr 71b).
l) Resonant in p_0, p_1, p_6 (Dr 71b).
m) $\sigma = 12.9$ mb at peak of GDR (Oc 78a).
n) Average of values obtained in this experiment and in ^{12}C(α, γ_2) (Ch 77j).
o) Resonant in γ_2.
p) Apparent resonance in yield of (p, $\alpha\gamma_{15.1}$) (Oc 78a).

Below $E_p = 0.4$ MeV capture to the ground state is dominant: $S(0) = 64 \pm 6$ keV 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 $^{16}O_{g.s.}$ (Ro 74s).

TABLE 16.19

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

E_p (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	J^π; 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	≥1; 1	17.64
6.12 ± 15	101 ± 10	≥1; 1	17.86
6.23 ± 15 [c])	≤50	$T = 1$	17.96
6.33 ± 15	26 ± 5	≥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 (Ba 68qq); the higher energy resonances are from (Ch 78k: 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 (Ba 68qq).

[d]) Values of $(2J+1)\,\Gamma_{p0}\Gamma_{n0}/\Gamma^2$ are derived for this resonance and the ones below: see (Ch 78k).

[e]) See also (Ba 68qq).

For branching ratios and Γ_γ values for the low-energy resonances see table 16.12. See also (Wi 78a, Wi 79c), (Ha 75dd, Pa 75o, Ha 76t, Gl 79k, Ha 79k, Sn 79a, We 80d, Wi 81d), (Zi 75c, Bo 76cc, Ro 77aa, Ro 78b, Ba 80k; astrophysics) and (Ba 77f, Ho 77s, Ba 78aa, Ga 78b; theor.).

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

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 ± keV)	$J^\pi; T$	l [e]	C^2S [e]	l [f]	S [f]	Γ [i] (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); $E_{\mathrm{d}} = 4.8$ to 6 MeV; see (Aj 77) for references.

[b]) ^{15}N(^{3}He, d); $E(^3\mathrm{He}) = 11$, 16.0 and 24.0 MeV; see (Aj 77).

[c]) "Best" values as discussed by (Bo 73o) [from (d, n) and (^{3}He, d) data]. See table 16.22 in (Aj 77) for a more complete display.

[d]) Very small value of S: see (Aj 77).

[e]) ^{17}O(d, t); $E_{\mathrm{d}} = 52$ MeV (Ma 78p). See also (Ma 81d; $E_{\mathrm{d}} = 52$ MeV).

[f]) ^{17}O(^{3}He, α); $E(^3\mathrm{He}) = 11$ MeV (Bo 71b).

[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 (Ma 81d).

[i]) (Br 80j): ^{17}O(^{3}He, α). $\Gamma < 50$ keV for ^{16}O* (17.79).

[j]) See text (Wa 77l).

Elastic scattering studies are reported for $E_p = 0.6$ to 15 MeV: see table 16.20 in (Aj 71), 16.18 in (Aj 77), (Ja 77j; 2.50 to 5.14 MeV) and (Fr 78b: 2.88 to 3.64 MeV). See also (La 76j). Observed anomalies are displayed in table 16.18. For inelastic groups see (Dr 71b). See also (Fa 80) and (Do 80d, Ha 80p; 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 (Aj 77) and (Ch 78k; 8.5 → 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 (Mu 81) and 9.05 to 15.62 MeV (By 81). Polarization measurements are reported for the n_0 group at $E_p = 7$ to 17 MeV: see (Mu 81b, Wa 81a). See also (By 77, By 80, By 81b), (Wa 76p, By 79a, Wa 80l, Co 81, Wa 81b) and (Ba 77, Ho 77s, Ab 79e, Do 80d, Ha 80p, Ph 81a; 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 (Pi 74b, Mi 75). 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) (Ma 74c). See also ^{13}C, ^{13}N in (Aj 81).

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 (Aj 71), 16.18 in (Aj 77) and (Zy 79a: 93 to 418 keV; α_0), (Br 77s: 0.9 to 1.25 MeV; α_0, α_1), (Ja 77j: 2.5 to 5.14 MeV; α_0, α_1) and (Fr 78b: 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 (Oc 78a). Observed resonances are displayed in table 16.18.

A study of the α_0 cross section for $E_p = 93$ to 418 keV leads to S(0) = 78 ± 6 MeV · b (Zy 79a). For the $\alpha_1\gamma$-channel $S(0) \simeq 0.1$ keV · b (Ro 74s). See also (Aj 77), (Cl 79d), (Ro 77aa, Ba 80k; astrophysics), (Th 78d; applications) and (Ga 77g; theor.).

48. ^{15}N(d, n)^{15}O $Q_m = 9.9029$

Observed neutron groups, l-values and spectroscopic factors are displayed in table 16.20. Angular distributions are reported for E_d to 6 MeV: see (Aj 77).

49. ^{15}N(^{3}He, d)^{16}O $Q_m = 6.6340$

Angular distributions have been measured at $E(^3\text{He}) = 11$, 16.0 and 24.9 MeV [see (Aj 77)]: l- and S-values are shown in table 16.20.

50. ^{15}N(α, t)^{16}O $Q_m = -7.6865$

At $E_\alpha = 65$ MeV, the population of many ^{16}O states with $E_x < 22$ MeV is reported by (Ya 80a).

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

Angular distributions are reported at $E(^{11}\mathrm{B}) = 115$ MeV to ^{16}O*(6.13) and at $E(^{13}\mathrm{C}) = 105$ MeV to ^{16}O*(6.13, 8.87) (Pr 80c, Ra 79c).

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

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^+	$(1.2\pm0.4)\times10^{-2}$ [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^-	$(1.20\pm0.05)\times10^{-3}$ [e])	6.21 [h])
9.85	2^+	$(6.5\pm2.0)\times10^{-7}$ [f])	9.07 ± 0.13 [i])

[a]) See also reaction 1 in ^{16}N.
[b]) $\tau_{1/2} = 7.13\pm0.02$ sec: see table 16.3 in (Aj 71).
[c]) (Wi 56, Al 58c, Al 59f).
[d]) (Wa 68n).
[e]) (Ka 61c).
[f]) (Ha 69s).
[g]) (To 71h): $\log f_1 t$.
[h]) B. Zimmerman, private communication: $\log f_0 t$.
[i]) E. K. Warburton, private communication: $\log f_1 t$.

The ground state of ^{16}N decays to seven states of ^{16}O: reported branching ratios are listed in table 16.21. The ground state transition has the unique first-forbidden shape corresponding to $\Delta J = 2$, yes, fixing J^π of ^{16}N as 2^-: see (Aj 59). 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 (Aj 71). The parity-forbidden α-decay from the 2^- state ^{16}O*(8.87) has been reported: $\Gamma_\alpha = (1.03\pm0.28)\times10^{-10}$ eV [$E_\alpha = 1282\pm5$ keV] (Ne 74d).

Transition energies derived from γ-ray measurements are: $E_x = 6130.43\pm0.05$ keV [$E_\gamma = 6129.170\pm0.043$ keV (Sh 75h)] and 7116.85 ± 0.14 keV [$E_\gamma = 7115.15\pm0.14$ keV (Al 76d)].

53. (a) $^{16}O(\gamma, n)^{15}O$ $Q_m = -15.6639$
(b) $^{16}O(\gamma, 2n)^{14}O$ $Q_m = -28.8882$
(c) $^{16}O(\gamma, pn)^{14}N$ $Q_m = -22.9609$

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 $E_x = 17.3$ [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 (Be 76w, Aj 77). The cross section for (γ, n_0) decreases monotonically for $E_x = 25.5$ to 43.8 MeV. There is a significant E2 cross section in that region: it exhausts ~68% of the isovector E2 energy-weighted sum rule (Ph 79d). The differential (γ, n_0) cross sections have been measured for $E_\gamma = 60$ to 160 MeV (Go 80l).

The absorption cross section has been measured from $E_{bs} = 10$ MeV to above the meson threshold (Ah 75b). The yield of reaction (b) has been studied from threshold to $E_\gamma = 120$ MeV [see (Aj 77)] and for $E_{bs} = 100$ to 800 MeV (Jo 77). The (γ, Tn) cross section has recently been reported for $E_\gamma = 15.9$ to 39.7 MeV (Ju 80). See also (Be 76w). The polarization of n_0 has been studied for $E_\gamma = 21.6$ to 25.7 MeV (Na 79e). See also (Aj 77). For the decay of $^{16}O^*$ to ^{15}O states, see ^{15}O in (Aj 81). See also (Kn 75d), (Be 76w, Ki 76k, Da 77e, Ha 79k, Ca 80m, Sc 80d, Sc 81g) and (Ba 76kk, Ka 76q, Gr 77b, Ma 77oo, Co 78h, El 78a, Ka 78t, Sc 78e, Ma 79e, Ro 79d, Ro 79l, Bo 80o, Du 80d, Os 80c, Ta 80d, Ba 81a, Bo 81p, Ca 81d, Ko 81g, Ro 81j, We 81e; theor.).

54. (a) $^{16}O(\gamma, p)^{15}N$ $Q_m = -12.1276$
(b) $^{16}O(\gamma, \pi^+)^{16}N$ $Q_m = -149.986$

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 (De 68g). Recent measurements of the (γ, p_0) cross section are reported by (Fi 77b: $E_{bs} = 40$ to 105 MeV), (Sc 80i: $E_\gamma = 80$ MeV; forward angles) and (Ma 77: $E_{bs} = 100$ to 280 MeV). See also (Aj 77) and (Kh 80, Ki 80e). The momentum distribution for $p_{1/2}$ shell protons in ^{16}O up to 930 MeV/c has been derived by (Fi 78). See also (Ma 79ff). 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 (Aj 81).

The cross section for reaction (b) for $E_{bs} = 175$ MeV is reported by (Bo 79ee). See also (Be 77aa, Ya 81). For other π-emitting photonuclear reactions see (Ep 79a, Bo 80q) and p. 23. See also (Ha 76t, We 80d, Ha 81l) and (Ba 76kk, Ka 76q, Ne 77d, Fi 78c, Ro 78j, Sc 78e, Ko 79p, Le 79h, Lo 79b, Wa 79g, Mo 80o, Bo 81h, Bo 81p, Ca 81d, Co 81m; 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 (Aj 71, Aj 77). For reaction (a) see also (Wi 79c). 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 $E_x \simeq 21.1$ MeV is also observed (Sk 75a). For spallation see (Di 78f). See also (Ch 81g).

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

(Ah 70a) 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 (Is 80e). The integrated cross section to 31 MeV for elastic scattering is 0.62 ± 0.07 MeV · mb; the inelastic is $\leqslant 5\%$ of the elastic cross section (Is 80b). 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 (Sw 70). 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 (Ki 78a). Form factors for transitions to the ground and to excited states of ^{16}O have been reported in many studies: see (Aj 77) and (Mi 79d: $q = 0.5$ to $2.6\ \mathrm{fm}^{-1}$; 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 (Mi 75i, Mi 75l): the isovector contribution interferes destructively with the isoscalar part and has a strength $\simeq 1\%$ of the $T = 0$ amplitude (Mi 75i). The 0^+ states $^{16}O^*(6.05, 12.05, 14.00)$ saturate $\simeq 19\%$ of an isoscalar monopole sum rule (Be 73gg). 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 (De 78s) from studies on this and on other light nuclei. See also (De 80gg).

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 (Tu 77a). See also (Be 77bb, Ba 80t). The virtual photon shape and intensity for (e, e′π) has been deduced at $E_e = 180.4$ MeV ($E_\pi = 28$ MeV, $\theta_\pi = 90°$) (St 80d). The ratio π^-/π^+ for $E_e = 280$ MeV ($E_\pi = 10$ MeV, $\theta_\pi = 90°$) is reported by (Je 79a). See also (Bu 76j, Sc 79b, Bu 80a, Bu 81a), (Tu 76a, Li 79h, Mo 79y, Ca 80h, Mo 80, Mo 81k) and (An 76c, Bh 76b, Fr 76e, Ga 76k, He 76k, Ra 76h, De 77f, He 77k, Wa 77o, Al 78f, Fu 78c, Ha 78n, Ha 78z, Ka 78r, Kr 78c, Ri 78, Bu 79j, Do 79o, In 79b, Kn 79, Ko 79ll, Li 79n, Wa 79g, Ro 79p, De 80z, Er 80b, Gr 80, Sa 80c, Sh 80n, Va 80b, Ag 81, Ba 81w, Bo 81m, Bu 81c, De 81p, Ka 81f, Or 81, Pe 81b; theor.).

TABLE 16.22

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

E_x (MeV ± keV)	J^π; 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,	1.5 ± 0.3
			850 ± 150	
19.50 ± 100	$1^-; 1$	E1	200 ± 70	40 ± 20
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	19 000

[a]) See also table 16.26 in (Aj 71). For references see table 16.24 in (Aj 77).

[b]) Monopole matrix element in fm^2.

[c]) See also text and (Mi 75l).

[d]) Measurements are also reported to $^{16}O^*$(17.79, 18.6, 18.98, 19.8) with $J^\pi = 4^-$ (Hy 81; prelim.).

58. (a) $^{16}O(\pi^+, \pi^+)^{16}O$
(b) $^{16}O(\pi^-, \pi^-)^{16}O$

Angular distributions of elastically scattered pions have been studied at $E_{\pi^+} =$ 20 MeV (Ob 81a), $E_{\pi^-} = 20$, 30, 40 and 50 MeV (Ka 81g), 29.2 MeV (Jo 79g), $E_{\pi^+} = 30.0$ and 49.7 MeV (Pr 81), 40 and 49.7 MeV (Ma 78g, Bl 79e), 46.8 MeV (Dy 79a), 79, 114, 163, 240 and 343 MeV (Al 78a, In 78, Ja 78k ($\pi^{\pm}$), Al 80g), at $E_{\pi^-} = 114$, 163 and 240 MeV (In 78) and at $E_{\pi^{\pm}} = 165$ and $E_{\pi^+} = 315$ MeV (Na 80i). At $E_{\pi^-} = 1$ GeV/c angular distributions of $^{16}O^*(0, 6.1)$ are reported. See also (Bu 78e) and (Aj 77) 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 (Ho 80c). [See also reaction 81]. See also (Mi 77e, Mi 80d, Ba 81k, Ba 81u, Ob 81), (De 80m, Cu 81b, Ta 81g; theor.) and p. 23.

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

Angular distributions have been measured at energies to $E_n = 24$ MeV: see tables 16.27 in (Aj 71) and 16.25 in (Aj 77) and (Be 75ee: 5.04, 6.25, 9.29 MeV), (No 78g: 8.85 MeV; 6.13 MeV γ-ray), (Gl 77: 9.25 to 15 MeV; n_0) and (Gr 80j: 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

TABLE 16.23

Recent [a]) $^{16}O(p, p)$, (d, d), (^3He, ^3He), (α, α), (^6Li, ^6Li), (^7Li, ^7Li), (^9Be, ^9Be), (^{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	(Sa 77gg
6.9	p_0	(Pr 79a)
27.2	p_1	(Ce 77a)
30.1	p_0	(Vo 79a)
35.2	p_0, p_3	(Fa 80a)
42.5, 44.0, 49.3	p_5	(Pe 77b)
65 [c])	p_0	(Sa 79p, Sa 81c)
135	p_0, p_2, p_4	(Ke 80g)
135	p to $^{16}O^*(17.79, 18.98, 19.80)$	(He 79g)
800 [c])	p_0, p_2, p_3, p_4, p_5	(Ad 79b)
E_d (MeV)	Angular distribution of group	Refs. [d])
12.00	d_0	(An 79o)
20.5 [c])	d_0, d_2	(Cl 80b)
52.0 [c])	d_0	(Ma 80e)
56.0 [c])	d_0	(Ha 80d)

TABLE 16.23—continued

$E(^3He)$ (MeV)	Angular distribution of ^3He group to	Refs. [e])
32.0 [c])	g.s.	(Lu 80)
41.0	g.s.	(Tr 80c)
44.04	g.s.	(Go 79d)
130.0	see table 16.24	(Bu 77a)
132	g.s.	(Ch 81b)
E_α (MeV)	Angular distribution of group	Refs.
6.9 → 10.2	α_0	(St 78a)
13.05 → 14.12	α_0	(Ce 75a)
14.6 → 20.4	$\alpha_0, \alpha_{1+2}, \alpha_3, \alpha_4, \alpha_5$	(Bi 79)
20.1 → 23.2	α_0	(En 77)
23.7	$\alpha_0, \alpha_{1+2}, \alpha_{3+4}, \alpha_5, \alpha_{6+7}$	(Fe 76e)
65	α^* [f])	(Ja 76n)
75	α_4, α to $^{16}O^*(12.44)$	see (Ha 80a)
$E(^6Li)$ (MeV)	Angular distribution of group to	
32	g.s.	(An 80f)
50.6	g.s.	(Ch 76p)
$E(^7Li)$ (MeV)	Angular distribution of group to	Refs.
68	g.s.	(Br 79b)
$E(^9Be)$ (MeV) (Reaction 66)		
20, 26	g.s.	(Un 79)
27.4	g.s.	(Gr 78h)
$E(^{16}O) = 15 \rightarrow 25$	g.s.	(Ba 70mm)
25.7 → 29.5	g.s.	(Fu 75c)
$E(^{10}B)$ (MeV)		
33.7, 41.6, 49.5	g.s.	(Pa 80a)
65.8	g.s.	(Mo 77y, Mo 79z)
100	$^{16}O^*(0, 6.1, 6.9)$	(Na 75j, To 77)
$E(^{11}B)$ (MeV) (Reaction 67) [g])		
41.6, 49.5	g.s.	(Pa 80a)
115	g.s.	(Br 79b, Ra 79c)

TABLE 16.23—continued

$E(^{12}C)$ or $E(^{16}O)$ (MeV) (Reaction 68)	Angular distribution of group to	Refs. [h])
$E(^{12}C) = 65$	g.s.	(Bo 78e)
77	g.s.	(Mo 77y, Mo 79z)
115	g.s.	(Ra 79c)
$E(^{16}O) = 30.8, 31.9, 33.9$	g.s.	(Sc 78a)
31.7, 46.0, 51.3, 52.7	g.s.	(Ma 78n)
46.0, 47.8, 49.7, 51.3, 52.7	$^{16}O^*(6.1, 7.0)$	(Ma 78n)
$33.2 \rightarrow 35.2$	g.s.	(Fr 80c)
52	$^{16}O^*(6.05, 6.13)$	(Sh 77k)
55.3, 56.7, 65.8	$^{16}O^*(6.05, 6.13)$	(Ka 78a)
$80 \rightarrow 122$	g.s.	(Co 77r)
140, 218, 315	g.s.	(Br 81b)
$E(^{13}C)$ (MeV) (Reaction 69)		
36	g.s.	(We 76j)
105	g.s.	(Br 79b, Ra 79c)
$E(^{16}O)$ (MeV) (Reaction 69)	Angular distribution of group to	Refs. [h])
14, 17, 20	g.s.	(Ba 70mm)
20, 25, 30	g.s.	(Sc 75q)
$E(^{14}N)$ (MeV) (Reaction 70)		
76.2	g.s.	(Mo 77y, Mo 79z)
79	g.s.	(Mo 76)
155	$^{16}O^*(0, 6.1, 6.9)$	(Na 75j, To 77)
$E(^{16}O)$ (MeV) (Reaction 71)		
$35 \rightarrow 80$	g.s.	(Fe 78b)
95.2	g.s.	(Mo 77y, Mo 79z)

[a]) See also tables 16.27 in (Aj 71) and 16.25 in (Aj 77).
[b]) See also (Da 76n, Se 77, Ma 79mm, Gl 79c).
[c]) Polarized.
[d]) See also (Ro 78e).
[e]) See also (Ch 78r).
[f]) $^4He^*(20.1)$ $[J^\pi = 0^+]$.
[g]) See also reaction 71 in (Aj 77).
[h]) See also (Ma 78c, Do 79, Wi 80h).
[i]) See also for population of ^{12}C states.

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^{π}; T [b,i])
1			6.05					
2	6.13 [a])		6.13	6.13 [c,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 [c])	11.09 ± 30 [c])	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 [c])	13.11 ± 30 [g])	13.07 ± 20 [c])	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 [c])	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 [c])	
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 [c,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
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

[$E_{\gamma} = 6127.8 \pm 1.2$ keV] (Be 66aa). See also (Be 78d), (Aj 77), (No 77d, Ph 77b, Ta 78u, Th 78e; 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) $^{16}O(p, p^3He)^{13}C$ $Q_m = -22.7934$
(f) $^{16}O(p, p\alpha)^{12}C$ $Q_m = -7.1620$

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 (Aj 71), 16.25 in (Aj 77) 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 $^{16}O^*(17.79)$ (He 79g). 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 $E_x \sim 40$ MeV (Pe 77b). 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 (Mo 78m, Co 81g). See also (Ki 77m; 3 GeV; intensity of 6.13 MeV γ-ray).

For reaction (b) see (Ki 80a, Ki 76m; $E_{\bar{p}} = 200$ MeV). See also (Na 77s, Na 78k, Sa 80j), ^{14}N in (Aj 81) and ^{17}F. For reactions (c), (d) and (e) see (Gr 77a; $E_p = 75$ MeV). For reaction (f) see (Ca 81; $E_p = 101.5$ MeV; to $^{12}C_{g.s.}$) and ^{12}C in (Aj 80). For the cross section for production of pions at $E_p = 585$ MeV see (Cr 79c). For antiproton scattering see (Au 81; theor.).

See also (No 76c, Ba 77ao, Kr 81a), (Ha 76t, Ba 77ab, Br 77z, Al 78i, De 79w, Li 79h, De 80p, Wh 80a, Mo 81, Ra 81b), (An 76d, Go 76n, Al 77d, Dy 77c, Ga 77h, Ko 77jj, Le 77c, Ma 77u, Ma 77qq, Mo 77w, Ph 77c, Va 77e, Vo 77b, Al 78k, Au 78b, Bi 78n, Br 78k, Br 78q, Ch 78y, Cu 78b, Go 78f, Ha 78f, Ha 78m, He 78g, Io 78a, Le 78c, Ma 78k, Ph 78, Pi 78a, Wr 78, Ab 79d, Bi 79b, He 79e, Ja 79d, Ki 79k, Ko 79e, Ko 79ff, Ko 79kk, Ku 79g, Ma 79p, Ma 79ii, Mi 79i, Ph 79c,

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Footnotes to table 16.24

[a]) See also tables 16.28 and 16.29 in (Aj 71) and 16.26 in (Aj 77).
[b]) (p, p'): (Bu 75d, Bu 76e; $E_p = 45$ MeV).
[c]) (p, p'): (He 79g; $E_p = 135$ MeV).
[d]) (d, d'): (Du 74c; $E_d = 81.6$ MeV). Energies are nominal (± 100 to ± 260 keV); angular distributions reported to all but last state.
[e]) Unresolved states.
[f]) (^{3}He, ^{3}He'): (Mo 74c; $E(^3He) = 71$ MeV). Angular distributions are reported to states labelled by [f]).
[g]) (^{3}He, ^{3}He'): (Bu 77a; $E(^3He) = 130$ MeV); measured angular distributions.
[h]) (α, α'): (Bu 76e; $E_{\alpha} = 60$ MeV).
[i]) (α, α'): (Ha 76n, Ha 76o; $E_{\alpha} = 104$ MeV).
[j]) See also (Ba 81u; theor.).

Wa 79c, Wa 79g, Am 80e, Ay 80, De 80v, Ko 80cc, Ma 80ee, Mc 80, Wu 80a, Ba 81u, Mi 81a, Pe 81b, Ro 81m, Th 81b, Tu 81; theor.) and ^{17}F.

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 (Aj 71), 16.25 in (Aj 77) and 16.23 here. Observed deuteron groups are displayed in table 16.24. See also ^{18}F in (Aj 83), (Te 77b) and (Co 76u, Le 76p, Dm 77, Le 78k, Ta 78u, Th 78e, Gr 79m, Ay 80, Ni 80d; theor.).

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

Angular distributions are reported for E_t to 20.01 MeV: see tables 16.27 in (Aj 71) and 16.25 in (Aj 77). See also (Le 78k, Kh 80a; theor.). See also ^{19}F in (Aj 78).

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 (Aj 71), 16.25 in (Aj 77) and 16.23 here. Inelastic groups are shown in table 16.24. The total E2 strength exhausted to $E_x = 30$ MeV is ~37% of the quadrupole EWSR (Bu 77a; see also for $\beta_2 R$). See also (Se 77), (Au 75: S_α), (Ha 76t, Ka 79q, Tr 80f) and (Le 77c, Le 78k, Ta 78u, Th 78e, Be 79dd, Le 79o; theor.).

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

Angular distributions of α-particles have been measured up to $E_\alpha = 146$ MeV: see tables 16.27 in (Aj 71), 16.25 in (Aj 77) 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 ~40% of the E2 EWSR, rather than via the α_0 and p_0 channels (Kn 78a; $E_\alpha = 155$ MeV). See also (Ha 76o, Ha 80a, Ha 81g). Reaction (b) has also been studied by (Wa 80b; $E_\alpha = 140$ MeV) and (Do 79e; $E_\alpha = 700$ MeV): values of S_α and N_{eff} are derived. See also (Wo 76c, Aj 77). For the (α, αp) reaction see (Sa 80b).

See also ^{20}Ne in (Aj 83), (Vo 75i, Sh 78p, Sh 80), (Po 78c; applied), (Re 80; astrophysics), (Be 76bb, Ha 76t, Ma 77uu, Ch 78s, Be 79ee, Kn 79i, Ma 79kk, Sp 80d, We 80d, Ca 81b) and (Co 75p, Am 76b, Ba 76dd, Cu 76f, He 76j, Lo 76f, Mi 76i, Pa 76i, Ab 77, Ba 77l, Br 77c, Bu 77, Cl 77b, Dm 77, Ik 77, Ho 77k, Le 77c, Oh 77c, Sa 77v, Tr 77c, We 77l, Ch 78b, Le 78k, Ma 78ii, Ta 78u, Th 78e, Ze 78c, Co 79o, Gr 79m, Iz 79, Ja 79a, Ja 79g, La 79j, Le 79a, Le 79d, Ve 79c, Dm 80, Kh 80a, Le 80t, To 80f, Dy 81a; 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 tables 16.25 in (Aj 77) and 16.23 here. For studies of (d-α) angular correlations see ^{20}Ne in (Aj 83). See also (Sa 77c, Kn 79k), (Og 76, Fi 78a) and (Me 78i, Pe 78a, Su 79g, Kh 80a, Me 81c, Dy 81a, Gu 81; theor.).

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

For angular distributions see table 16.23. For fusion cross sections see (Sw 77, Ch 78e). See also (Pa 78, Hu 79, Ma 79cc, Pa 79, Gu 81; 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 measurement [reaction (a)] see (Go 79i, Wi 80e, Th 81a). See also (Go 79n) and (Va 80c, Va 81b; theor.).

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

Angular distributions have been reported at many energies to $E(^{16}\mathrm{O}) = 315$ MeV: see reaction 64 (Aj 71) and tables 16.25 (Aj 77) 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 (Aj 77) and (Br 77w, Co 77r, Na 77f, Ta 77, Ch 78l, Fe 78b, Ja 78a, Ka 78a, Ma 78j, Ma 78n, Sc 78a, Ch 79c, Fu 79g, Ja 79w, Ko 79b, Ko 79y, Be 80c, Fr 80a, Fr 80c, Ja 80b, Fu 81b). See also (Fr 76d, Ci 78, Ma 78c, Sh 78a, Fr 79b, Lu 79a, Uz 79, Fr 80g, Wi 80h, Sc 81b, Wi 81f).

At $E(^{16}\mathrm{O}) = 77$ 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)] (Fu 79g). At $E(^{16}\mathrm{O}) = 140$ MeV the breakup is interpreted as proceeding via ^{16}O*(11.6, 13.1, 15.8) (Ra 80e). See also (Sc 79d). For the excitation of the GQR in ^{12}C see (Do 79: $E(^{16}\mathrm{O}) = 315$ MeV).

See also (La 78, Ga 79c, Sa 79n, Ta 80a), (Ga 77n, Ga 78h, Ho 78n, Le 78g, Ma 78hh, Ta 78m, Ts 78a, Ga 79g, Er 80c, Ga 80b), (Ro 78b; astrophysics) and (Ba 76dd, Ch 76s, Ba 77r, Ba 77w, Ch 77g, Cl 77b, Fr 77b, Ja 77c, Pa 77j, Ro 77w, Ab 78a, Av 78, Ba 78y, Bh 78c, Bi 78, Fr 78n, Go 78k, Ma 78h, Ma 78l, Ma 78ii, Ta 78c, Ta 78e, Va 78g, Go 79t, Kr 79b, Na 79, St 79d, Ta 79c, Ta 79e, Ta 79f, Te 79, Ve 79e, Ab 80d, De 80aa, Dr 80d, Fu 80g, Ga 80i, Hu 80, Ko 80u, La 80g, La 80l, Ta 80e, Ta 80k, Va 80c, Vo 80e, Ga 81c, Gu 81, Ha 81k, Hu 81c, Sc 81d, Ta 81a, To 81b, Ub 81, Wi 81b; 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 (Ch 79c; fusion), (Ra 80e; α-breakup) and (Du 76b, Ga 79c). For reaction (b) see (Be 78ff, Ko 81a). For theoretical papers see (Pa 78, Sc 78m, He 79d, Pa 79, Ha 81k).

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 (Aj 77). For total fusion cross-section measurements (reaction a) see (Sw 77b, Vo 77e, Vo 81). See also (Av 78, Va 78g; theor.).

71. $^{16}O(^{16}O, ^{16}O)^{16}O$

The angular distributions for elastic scattering have been measured with E(^{16}O) up to 140.4 MeV: see reaction 66 in (Aj 71), table 16.25 in (Aj 77) 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 (Aj 77). For yield and total fusion cross sections see (Ko 77j, Fe 78b, Ts 78a, Ch 79k, Ko 79m, Ko 79y, Fr 80a, Hu 80g, La 81c). See also (Ch 80c, We 80a, Vo 81b).

See also (Co 77p, Ha 78aa, Ga 79c, La 79p, Sa 79m, Sa 79n, Co 80t, De 81r), (Ho 78n), (Ro 78b; astrophysics) and (Al 76k, Ar 76g, Ba 76dd, Ch 76s, Cu 76f, Lo 76f, Mi 76i, Mo 76m, Ba 77b, Br 77c, Ca 77d, Ch 77g, Cl 77b, Fl 77, Fr 77b, Fr 77e, Fr 77f, Fu 77l, Ga 77e, Ha 77n, Ho 77r, Ik 77b, Ko 77d, La 77j, Os 77a, Pl 77, Sa 77a, Sa 77g, Sa 77h, Sa 77cc, To 77d, We 77l, Zi 77c, An 78, An 78a, Ar 78g, Av 78, Ba 78j, Be 78b, Bo 78d, Br 78j, Ch 78o, Cu 78e, Cu 78f, Da 78p, Fl 78c, Fr 78i, Gu 78a, Ko 78h, Kr 78d, Le 78q, Pa 78a, Sc 78c, Sc 78l, Sc 78m, Si 78b, Su 78c, Va 78a, Va 78g, Vo 78b, Vo 78f, An 79g, Be 79t, Ch 79k, Dh 79, Fr 79k, Ja 79, Mu 79d, Ph 79, Si 79c, Si 79f, Ta 79e, Ve 79e, Ab 80d, An 80n, Ba 80jj, Be 80g, Fa 80d, Fl 80, Ga 80b, Ko 80c, Ko 80h, Ko 80k, Ko 80u, La 80k, Oh 80, Pr 80b, Si 80d, Si 80i, Ta 80c, Ta 80e, Ta 80n, To 80d, Va 80c, Vi 80a, Wo 80a, Ab 81a, Ba 81, De 81g, Dy 81a, Ha 81k, He 81, Ma 81g, Sa 81f, Sa 81i, Si 81e, Ta 81j, Ub 81, Va 81b; 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 $E(^{16}O) =$ 24, 28 and 32 MeV and $E(^{17}O) = 53.0$ to 66 MeV [reaction a] and at $E(^{16}O) = 24$ to 54.8 MeV and $E(^{18}O) = 53.1$ to 89.3 MeV [reaction b]: see (Aj 77) and (Ca 81c; E(^{18}O = 35 MeV)). Yields and fusion cross sections are reported by (Wi 80e) (reaction a) and (Fr 78f) (reaction b). See also (Ca 77j, Ra 79c), (Fi 74f, Ho 78n) and (Im 77b, Le 78q, Cr 79b, Le 79a; theor.).

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

Elastic scattering angular distributions have been studied at $E(^{16}O) = 21.4$ and 25.8 MeV and at $E(^{19}F) = 33$ and 36 MeV: see (Aj 77). See also (Sc 77e, Oh 80; theor.).

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

Elastic scattering angular distributions have been measured at $E(^{16}O) = 40.7$, 51.1 and 59.4 MeV (see Aj 77), 94.8 MeV (Mo 77y, Mo 79z; also excited states of ^{20}Ne) and at $E(^{20}Ne) = 50$ MeV (St 76i; also excited states of ^{20}Ne). See also (Ga 80c). For yield and fusion cross-section measurements see (Sh 78i, Ga 78e, Ga 79a, Ga 79g, Ko 79t, Re 79d, Di 80a, Ga 80c, Ga 81c, Ga 81e; all abstracts). See also (Va 79k) and (Ja 79f, Le 79a, Ga 80b, Oh 80, An 81c; 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 $E(^{16}O) = 35$ to 50 MeV (Fo 79f), 46.3 and 60.3 MeV (Pa 80c; also 2^+ in ^{24}Mg) and 67 MeV (Ec 81; also various ^{24}Mg states) for reaction (a), and at 35 to 50 MeV (Fo 79f) and 27.4 to 48.4 MeV (Ro 80g; also 2^+ in ^{26}Mg) for reaction (b). Yield and fusion measurements have been carried out by (Ho 78k, Ta 78b, Fo 79f, Le 79b, Pe 79c, Ko 80b, Pa 80c, Ro 80g, Dr 81b). See also (Ra 80f), (Ta 78m) and (Ho 78h, Ga 80i, Lo 80, Pa 80g, Sa 80h, De 81k; theor.).

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

An elastic angular distribution has been measured at $E(^{16}O) = 46.5$ MeV (Pe 78d). For yield and fusion cross-section measurements see (Ei 77, Ra 79i, Sh 80e, Le 81c). See also (Ke 78b, Va 79h, Mi 80b, Sa 80m, Ta 80a), (Sc 77o, Ho 78n, Ma 78hh, Hu 79d) and (Af 77, Bi 78, Va 78g, Ka 79m, Lo 80, Sa 80h, Ac 81, De 81k, Sa 81a, Va 81f; 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 $E(^{16}O) = 32$ MeV (Ca 78f; also $^{28}Si^*\ 2^+$), 33 to 81 MeV [(Ga 73n) and see (Cr 76d)], 33, 36 and 38 MeV (Ec 77), 35.7 and 38.2 MeV (Re 79c), 41.23 to 63 MeV (Br 77e, Ge 78f, Sh 78f, Sh 80c, Sh 80l), 56 MeV (Me 79; also $^{28}Si^*$), 60 MeV (Du 78a; also $^{28}Si^*$), 141.5 MeV (Sa 78i; also $^{28}Si^*$) and 215.2 MeV (Cr 76d). For reaction (c) see (Re 79c). For yield and fusion cross-section measurements see (Ba 78, Ba 79ee, Fo 79f, Jo 79h, Ku 79j, Ra 79i, Be 80b). See also (Br 79e).

See also (Ze 77d, St 78l, De 79t, He 79h, Zi 80a) and (Ud 77, De 78g, Du 78c, Fr 78o, Le 78s, Sh 78o, Ta 78j, Te 78a, Va 78g, An 79c, Fr 79a, Ka 79m, Ko 79h, Kr 79c, La 79, Li 79i, Sa 79l, Ba 80oo, Cr 80, Dr 80d, Fa 80d, Fr 80e, Ga 80b, Go 80e, La 80k, Ma 80y, To 80f, Fr 81g, Me 81, Ra 81f, Vi 81; 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 $E(^{16}O) = 50$ MeV (Ku 79b), 51.5 and 54 MeV (Al 81d; also ^{40}Ca*), 56.8 to 62.8 MeV (Ge 78c), 60 MeV (Re 78b; also ^{40}Ca*) and 55.6, 74.4, 103.6, 139.6 and 214.1 MeV (Vi 79c), while the elastic scattering on ^{48}Ca has been studied at 60 MeV (Ko 78a; also ^{40}Ca*). Yield and fusion cross-section measurements are reported by (Ge 78c, Ku 79b, Vi 79c, Ku 80g). See also (Ol 78a), (Ze 77d, He 79h) and (Af 77, We 77l, Ko 78j, Pa 78a, Pe 78c, Ba 79gg, Ba 79kk, Be 79t, Bo 79z, Le 79a, Pe 79d, Wo 79b, Be 80d, Iz 80, La 80k, Le 80g, Ma 80y, Rh 80, Wo 80f, Va 81f; theor.).

79. $^{17}O(\gamma, n)^{16}O$ $Q_m = -4.1443$

See ^{17}O.

80. $^{17}O(p, d)^{16}O$ $Q_m = -1.9197$

Angular distributions for the ground state deuteron group have been studied at $E_p = 8.62$ to 11.44 MeV (Cr 75e). 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 (Me 70).

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

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 25 in ^{16}N and table 16.10] (Wa 77l, Ma 78p). See also (Ma 81d). 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 (Wa 77l). 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 (Cu 81b). [See also reaction 58.] See also (Br 80j) below and ^{19}F in (Aj 83).

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

Angular distributions are reported at $E(^3He) = 11$ MeV (Bo 71b). Angular correlations have been studied by (Br 80j) [see for spectroscopic factors relating to a number of states of ^{16}O with $E_x > 12.9$ MeV with the $^{17}O_{g.s.}$ as well as with states of ^{15}N]. Table 16.20 displays some of the information derived from this reaction. For polarization measurements see (Ka 81d, Ro 81c) and ^{20}Ne in (Aj 83).

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

See (Ba 76ii) and ^{18}O in (Aj 83).

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

Angular distributions of tritons have been measured for E_p to 43.7 MeV: see (Aj 71, Aj 77) for the earlier references and (An 80j; $E_p = 23$ 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^+ (Ce 64b). The decay of $^{16}O^*(22.7)$, $J^\pi; T = 0^+; 2$, is via α_0, α_1 and α_2 [$^{12}C^*(0, 4.4, 7.7)$] with 1.6 ± 0.7, 1.9 ± 0.7 and $14 \pm 2\%$ branches and Γ_i (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 $5 \pm 2\%$ branches and Γ_i (eV) $= 840 \pm 343$, 1320 ± 454 and 600 ± 300 eV; and via n_{1+2} with a $23 \pm 15\%$ branch [$\Gamma_n = 2760 \pm 1970$ eV] (the n_0 branch is $<15\%$) (Fr 79c) [Γ_i are based on a total width of 12 ± 3.5 keV]. See also (Aj 77), ^{18}F in (Aj 83) and (St 77n, Ku 78d, Am 79b, Be 79z, Fe 80a, We 80, We 80e, Be 81e; theor.).

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

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 (Va 75e).

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

Angular distributions are reported at $E(^{17}O) = 36$ MeV (Ka 77bb; to $^{16}O_{g.s.}$ and ^{19}O states). See also (Du 76b).

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

Angular distributions involving $^{16}O_{g.s.}$ and ^{20}O states are reported at $E(^{18}O) = 24$ to 36 MeV (Ka 77v) and at 52 MeV (Ku 79).

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

Angular distributions have been reported at many energies to $E_p = 44.5$ MeV [see (Aj 77)] and at $E_p = 0.83$ to 0.87 MeV (Ca 741: α_0), 1.5 to 3.8 MeV (Ca 76s: α_0), 2.06 to 2.68 MeV (Cu 80d: α_0, α_1) and 13.5 to 18.0 MeV (St 77: α_0). Observed states of ^{16}O are displayed in table 16.31 in (Aj 71).

The E0 transition ($6.05 \to 0$; $0^+ \to 0^+$) has been investigated in some detail: the internal conversion to pair production ratio is $(4.00 \pm 0.46) \times 10^{-5}$ (Le 63b). The ratio of double γ-emission to pair production $\Gamma_{E1E1}/\Gamma_{E0(\pi)} = (2.5 \pm 1.1) \times 10^{-4}$ (Wa 75h). τ_m for $^{16}O^*(6.05) = 96 \pm 7$ psec (Bi 73q). $^{16}O^*(6.13)$ has also been studied extensively: $|g| = 0.55 \pm 0.04$, $\tau_m = 26.6 \pm 0.7$ psec (Br 73m). 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 $-(2\pm5)\times10^{-5}$ (Wi 72b). The previously reported ground state decay of ^{16}O*(10.95) [$0^-\rightarrow0^+$] is not observed; neither is a pair peak due to a (10.95→7.12) decay (Al 78d). For γ-ray branching ratios and lifetimes see tables 16.10 and 16.11.

See also ^{20}Ne in (Aj 83), (Yo 66m, Go 76q, He 76m), (Ak 78, An 78h, Ch 78t, Go 78c, Vo 78c, Di 80, Ke 80; applications) and (Le 79g; theor.).

89. ^{19}F(^{3}He, ^{6}Li)^{16}O $\quad Q_m = 4.0937$

Angular distributions have been measured to $E(^3\mathrm{He}) = 40.7$ MeV: see (Aj 77).

90. ^{19}F(α, ^{7}Li)^{16}O $\quad Q_m = -9.234$

See (Aj 77).

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

For reaction (a) see ^{20}Ne in (Aj 78, Aj 83). For reaction (b) see (Ca 81). For reaction (c) see (Aj 77) and (Ch 77a; theor.).

92. ^{20}Ne(d, ^{6}Li)^{16}O $\quad Q_m = -3.2574$

Angular distributions have been studied at E_d to 40 MeV [see (Aj 77)] and at 80 MeV (Oe 79a; $^{16}\mathrm{O}_{\mathrm{g.s.}}$; relative S_α). See also (Be 78w) and (Bi 77e, Ka 78i, Sh 78k; theor.).

93. ^{20}Ne(^{3}He, ^{7}Be)^{16}O $\quad Q_m = -3.145$

At E(^{3}He) = 30 MeV angular distributions involving ^{16}O*(0, 6.1) and the first two states of ^{7}Be are reported by (De 70e).

94. ^{23}Na(e, e′ ^{7}Li)^{16}O $\quad Q_m = -19.701$

See (Sa 78c). See also (Ca 79j).

95. ^{24}Mg(e, e′ ^{8}Be)^{16}O $\quad Q_m = -14.135$

See (Sa 79i).

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

Angular distributions are reported at $E_\alpha = 22.8$ to 25.4 MeV (So 78b; $^{16}\mathrm{O}_{\mathrm{g.s.}}$) and at 90.3 MeV (Be 80a, Be 80f; to ^{16}O*(0, 6.1, 7.0, 8.8, 9.8, 10.3)).

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

See (No 78a). See also (Le 80r; theor.).

98. ^{28}Si(e, e$'$ ^{12}C)^{16}O $Q_m = -16.7542$

See (Sa 78c). See also (Sc 80e; theor.).

^{16}F

(Figs. 4 and 5)

GENERAL†

See (La 77a, Si 77d, Wo 78f, Ha 80p, Os 81a).

1. (a) ^{14}N(^{3}He, n)^{16}F $Q_m = -0.969$
   (b) ^{14}N(^{3}He, np)^{15}O $Q_m = -0.421$

Observed neutron groups and L-values derived from angular distribution measurements are displayed in table 16.26 (Bo 73hh). For the results from reaction (b) see table 16.26 (Ot 76a). See also (Aj 77).

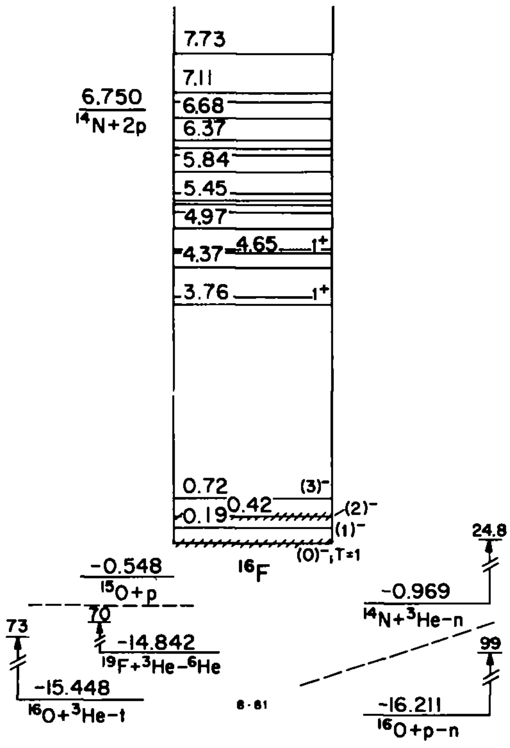

Fig. 4. Energy levels of ^{16}F. For notation see fig. 2.

† See also (Aj 77).

TABLE 16.25

Energy levels of ^{16}F

E_x (MeV ± keV)	$J^\pi; T$	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
0	$(0)^-; 1$	40 ± 20	p	1 → 5
0.194 ± 9	$(1)^-$	<40	p	1 → 5
0.424 ± 5	$(2)^-$	40 ± 30	p	1 → 5
0.720 ± 6	$(3)^-$	<15	p	1 → 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

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

At $E(^{10}\mathrm{B}) = 100$ MeV unresolved structures to ^{16}F*(0.4, 0.7, 5.5, 6.3, 6.8, 7.8) are reported (Ha 78a).

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

Observed neutron groups are listed in table 16.26 (Mo 71l). See also (An 80g, An 81, Ma 81k) and (Aj 77).

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

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 23 in ^{16}N (Fl 74a)] 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). (Pe 65) suggest, on the basis of angular distribu-

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 (Aj 71).
[b]) ^{14}N(^{3}He, n)^{16}F (Bo 73hh; $E(^3\mathrm{He})=13$ MeV).
[c]) ^{14}N(^{3}He, np)^{15}O (Ot 76a; $E(^3\mathrm{He})=6.5\rightarrow7.8$ MeV).
[d]) From angular correlation studies (Ot 76a).
[e]) ^{16}O(p, n)^{16}F (Mo 71l; $E=23.9$ MeV).
[f]) ^{16}O(^{3}He, t) and ^{19}F(^{3}He, ^{6}He)^{16}F (Na 77c; $E(^3\mathrm{He})=35$ and 70 MeV, respectively).
[g]) ^{14}N(^{3}He, n)^{16}F (Za 65, Ot 76a).
[h]) See (Pe 65, Bo 73hh, Fl 74a, Ot 76a, Na 77c).
[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 (An 81: abstract).

tions, that the ordering is $J^\pi=0^-, 1^-, 2^-, 3^-$ for the first four states of ^{16}N. At $E(^3\mathrm{He})=35$ MeV, ^{16}F*(0.43, 0.72) are most strongly populated (Na 77c).

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

Observed states of ^{16}F are displayed in table 16.26. At $E(^3\mathrm{He})=70$ MeV the transition strengths favor the sequence $0^-, 1^-, 2^-, 3^-$ for the first four states of ^{16}F (Na 77c).

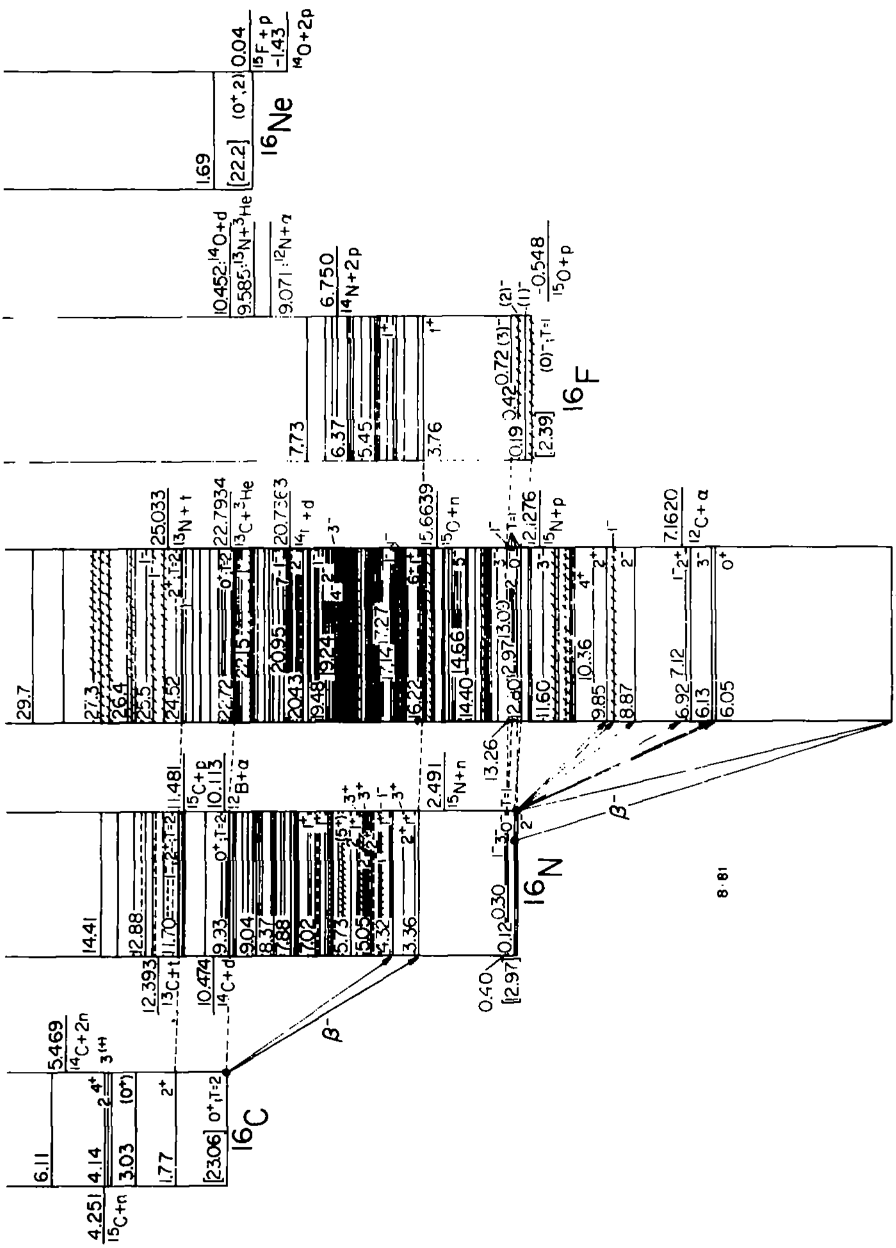

Fig. 5. Isobar diagram, $A = 16$. The diagrams for individual isobars have been shifted vertically to eliminate the neutron–proton mass difference and the Coulomb energy, taken as $E_C = 0.60Z(Z-1)/A^{1/3}$. Energies in square brackets represent the (approximate) nuclear energy, $E_N = M(Z, A) - ZM(H) - NM(n) = E_C$, minus the corresponding quantity for ^{16}O: here M represents the atomic mass excess in MeV. Levels which are presumed to be isospin multiplets are connected by dashed lines.

^{16}Ne

(Fig. 5)

GENERAL†

Theoretical work: (Gu 78d, Sp 78, Li 81h)

Reviews: (Ce 77c, Al 79k, Tr 80d)

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^π; T	$\Gamma_{c.m.}$ (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 $\qquad Q_m = -28.76$

$$Q_0 = -28.785 \pm 0.045 \text{ MeV (Bu 80b).}$$

At $E_{\pi^+} = 180$ MeV ^{16}Ne$_{g.s.}$ is populated. The cubic factor, d, in the IMME is calculated to be 2.5 ± 3.7 keV based on Q_0 (Bu 80b). See also (Ho 77f, Bu 78e, Mi 80d, Gr 81a, Gr 81c).

2. ^{20}Ne(α, ^{8}He)^{16}Ne $\qquad Q_m = -60.23$

$$Q_0 = -60.15 \pm 0.08 \text{ MeV}$$

At $E_\alpha \simeq 117.5$ 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 $\Gamma_{c.m.}$ 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 (Ke 78c).

† See also (Aj 77).

^{17}Be

(Not illustrated)

This nucleus has not been observed. Its atomic mass excess is calculated to be 70.67 MeV. It is then unstable with respect to breakup into ^{16}Be + n and ^{15}Be + 2n by 3.37 and 3.34 MeV, respectively (Th 74).

^{17}B

(Not illustrated)

^{17}B has been observed in the 4.8 GeV proton bombardment of uranium: it is particle stable and its ground state J^{π} is probably $\frac{3}{2}^-$ (Bo 74a). Its atomic mass excess is calculated to be 44.37 MeV (transverse form of the mass equation): it is then stable with respect to decay into ^{15}B + 2n by 0.73 MeV (Th 74, Je 75). The E_{β^-} (max) for the decay to ^{17}C would then be 23.3 MeV. See also (Wa 77) and (Se 81c; theor.).

^{17}C

(Fig. 9)

The Q-value of the ^{48}Ca(^{18}O, ^{17}C)^{49}Ti reaction, studied at $E(^{18}\mathrm{O}) = 102$ MeV, $\theta \sim 8°$, leads to an atomic mass excess of 21 023 ± 35 keV. A group is also observed corresponding to an excited state of ^{17}C with $E_x = 292 \pm 20$ keV. Three closely spaced states with $J^{\pi} = \frac{1}{2}^+, \frac{3}{2}^+, \frac{5}{2}^+$ are predicted, based on systematics. The cross sections for formation of ^{17}C*(0, 0.29) are 3 and 9 μb/sr, respectively, at $\theta_{\mathrm{c.m.}} = 10.5°$ (No 77c). On the basis of the atomic mass excess given above, E_{β^-} (max) to $^{17}\mathrm{N}_{\mathrm{g.s.}} = 13.15$ MeV. ^{17}C is stable with respect to ^{16}C + n by 0.74 MeV. The Q-value of the ^{207}Pb(^{18}O, ^{17}C)^{208}Po reaction is −26.87 ± 0.22 MeV, leading to a mass excess of 21.10 ± 0.22 MeV for the ground state (doublet) of ^{17}C (Ba 79aa). See also (Aj 77) and (Ar 77b, Al 80h).

^{17}N

(Figs. 6 and 9)

GENERAL[†]

Theoretical papers and reviews: (Kr 78f, Al 79n, Be 79a, Bo 79gg, Mi 80h, Os 81a)

Experimental papers: (Ar 77b, Ba 77al, Ge 78b, Ko 78a, Ol 80, Gr 81b)

1. (a) $^{17}\mathrm{N}(\beta^-)^{17}\mathrm{O}^* \rightarrow {}^{16}\mathrm{O} + \mathrm{n}$ $\quad Q_m = 4.536$
   (b) $^{17}\mathrm{N}(\beta^-)^{17}\mathrm{O}$ $\quad Q_m = 8.680$

† See also (Aj 77).

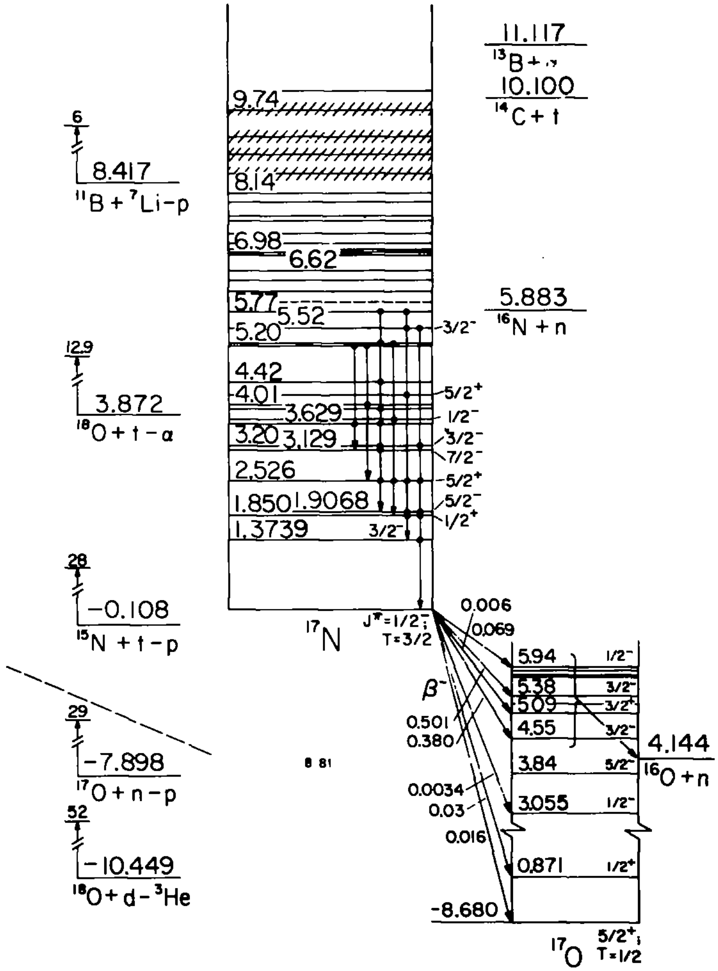

Fig. 6. Energy levels of ^{17}N. For notation see fig. 2.

The half-life of ^{17}N is 4.173 ± 0.004 sec (Oh 76e, Al 72m). See also (Aj 71). The decay is principally [see table 17.2] to the neutron unbound states ^{17}O*(4.55, 5.38, 5.94) [$J^\pi = \frac{3}{2}^-, \frac{3}{2}^-, \frac{1}{2}^-$]. The nature of the decay is in agreement with $J^\pi = \frac{1}{2}^-$ for $^{17}N_{g.s.}$ (Po 73d, Al 76). For a comparison of the ^{17}N and ^{17}Ne decays see table 17.3 (Al 76, Oh 76e).

2.† ^{9}Be(^{9}Be, p)^{17}N $\qquad Q_m = 7.537$

Angular distributions are reported at $E(^{9}\mathrm{Be}) = 5.0$ MeV to ^{17}N*(0, 1.37, 2.53) (Yo 77d).

† See (Aj 77) for several other reactions leading to ^{17}N.

TABLE 17.1

Energy levels of ^{17}N [a]

E_x in ^{17}N (MeV ± keV)	$J^\pi; T$	τ	Decay	Reactions
0	$\frac{1}{2}^-; \frac{3}{2}$	$\tau_{1/2} = 4.173 \pm 0.004$ sec	β^- [b]	1→10
1.3739±0.3	$\frac{3}{2}^-$	$\tau_m = 93 \pm 35$ fsec	γ	2, 3, 4, 6, 9, 10
1.8496±0.3	$\frac{1}{2}^+$	41^{+20}_{-9} psec	γ	3, 4, 9, 10
1.9068±0.3	$\frac{5}{2}^-$	11±2 psec	γ	3, 4, 6, 10
2.5260±0.5	$\frac{5}{2}^+$	33±3 psec	γ	2, 3, 4, 9, 10
3.1289±0.5	$\frac{7}{2}^-$	275±80 fsec	γ	3→6, 10
3.2042±0.9	$\frac{3}{2}^-$	<30 fsec	γ	3, 4, 9, 10
3.6287±0.7	$(\frac{7}{2}, \frac{9}{2})^-$	12±2 psec	γ	3→6
3.663±4	$\frac{1}{2}^-$	<350 fsec	γ	3, 4
3.9060±2.0	$(\frac{3}{2}, \frac{5}{2})^-$	52±22 fsec	γ	3, 4
4.0064±2.0	$\frac{3}{2}^{(-)}$	<15 fsec	γ	3, 4, 9
4.209±3	$\frac{5}{2}^+$	<70 fsec	γ	3, 4
4.415±3	$(\frac{3}{2}, \frac{5}{2})^-$	(<60 fsec)	γ	3, 4
5.170±2	$(\frac{9}{2}^+)$	<60 fsec	γ	3, 4, 9
5.195±3	$(\frac{1}{2}, \frac{3}{2})^+$	<95 fsec	γ	3, 4
5.515±3	$\frac{3}{2}^-$	<100 fsec	γ	3, 4, 9
5.772±3	$\leq\frac{7}{2}$	<120 fsec	γ	3, 4
(6.08±30)				3
E_x in ^{17}N (MeV ± keV)	**$J^\pi; T$**	**Γ**	**Decay**	**Reactions**
6.233±8				3, 4
6.449±3				3, 4
6.615±19				3, 4
6.938±15				4
6.981±20	$(\frac{3}{2})^-$			3, 4, 9
7.013±22				3, 4, 9
7.17±40				3
7.37±40				3
7.63±40				3
7.73±40				3
8.00±25				3
8.14±40				3
8.55±40		broad		3
8.93±40		broad		3
9.26±40		broad		3
9.74±40		broad		3
10.14	$(\frac{1}{2}, \frac{3}{2})^-$			9

[a] See also table 17.5.

[b] See also tables 17.2 and 17.3.

TABLE 17.2
Beta decay of ^{17}N

Decay to ^{17}O* (keV)	J^π	Branch (%)	log ft
0	$\frac{5}{2}^+$	1.6 ± 0.5 [c])	7.29 ± 0.11 [c,f])
871	$\frac{1}{2}^+$	3.0 ± 0.5 [c])	6.80 ± 0.07 [c])
3055.2 ± 0.3 [a])	$\frac{1}{2}^-$	0.34 ± 0.06 [c])	7.08 ± 0.08 [c])
3841	$\frac{5}{2}^-$	$<7 \times 10^{-3}$ [c])	>8.5 [c])
4551.2 ± 1.3 [b])	$\frac{3}{2}^-$	38.0 ± 1.3 [d])	4.41 ± 0.02 [g])
5083 ± 21 [b])	$\frac{3}{2}^+$	0.6 ± 0.4 [e])	5.9 ± 0.5 [e])
5389.0 ± 1.2 [b,h])	$\frac{3}{2}^-$	50.1 ± 1.3 [d])	3.86 ± 0.02 [g])
5738	$(\frac{1}{2}^+)$	<0.23 [e])	>6.0 [e])
5868	$\frac{3}{2}^+$	<0.15 [e])	>6.0 [e])
5951.8 ± 1.9 [b,h])	$\frac{1}{2}^-$	6.9 ± 0.5 [d])	4.35 ± 0.03 [g])
6356	$\frac{1}{2}^+$	<0.08 [e])	>6.0 [e])

[a]) (Al 76): direct ground state decay $<1.5\%$.
[b]) (Oh 76e): from neutron groups. [The E_x have been recalculated here on the basis of 4144.3 ± 0.8 keV for E_b for a neutron in ^{17}O.] Γ_n for ^{17}O*(4.55, 5.08, 5.38, 5.94) are, respectively, 54.8 ± 0.4, 113 ± 55, 63.2 ± 1.1 and 60.5 ± 3.2 keV (Oh 76e). See also table 17.12.
[c]) (Al 76). See also (Aj 77).
[d]) Calculated from the mean of the values from (Po 73d, Al 76, Oh 76e), renormalized here, together with the new branch to ^{17}O*(5.08), to lead to a total neutron emission probability of $95 \pm 1\%$ [100% less the branches to ^{17}O*(0, 0.87, 3.06)].
[e]) (Oh 76e).
[f]) $\log f_1 t = 9.56 \pm 0.13$ (To 71h).
[g]) Calculated using the tables of (Go 71t).
[h]) See, however, tables 17.12 and 17.7.

TABLE 17.3
Comparison of ^{17}N and ^{17}Ne β-decay [a])

Final state in		J^π	Γ_n [b,c]) (keV)	Γ_p [b]) (keV)	$(ft)^-$ [d,e])	$(ft)^+$ [d])	δ [f])
^{17}O	^{17}F						
3.06	3.10	$\frac{1}{2}^-$	0	19	$(1.2 \pm 0.2) \times 10^7$	$(2.78 \pm 0.40) \times 10^6$	-0.77 ± 0.08
4.55	4.70	$\frac{3}{2}^-$	55	230	$(2.57 \pm 0.13) \times 10^4$	$(3.92 \pm 0.18) \times 10^4$	0.53 ± 0.11
5.38	5.52	$\frac{3}{2}^-$	63	69	$(7.2 \pm 0.3) \times 10^3$	$(7.22 \pm 0.15) \times 10^3$	0.00 ± 0.04
5.94	6.04	$\frac{1}{2}^-$	61	28	$(2.24 \pm 0.16) \times 10^4$	$(2.61 \pm 0.07) \times 10^4$	0.17 ± 0.09

[a]) (Al 76, Oh 76e). I am indebted to Dr. D. E. Alburger for his comments.
[b]) Γ_n and Γ_p are the neutron and proton widths of the ^{17}O and ^{17}F states, respectively.
[c]) Γ_n for ^{17}O*(4.55, 5.08, 5.38, 5.94) are reported to be, respectively 54.8 ± 0.4, 113 ± 55, 63.2 ± 1.1 and 60.5 ± 3.2 keV (Oh 76e).
[d]) $(ft)^-$ and $(ft)^+$ are for the ^{17}N and ^{17}Ne decays, respectively.
[e]) See table 17.2.
[f]) $\delta = [(ft)^+/(ft)^-] - 1$.

TABLE 17.4

Excited states of ^{17}N from $^{11}B(^7Li, p)$, $^{18}O(d, ^3He)$ and $^{18}O(t, \alpha)$ [a]

E_x (keV)		l [f]	J^π [g]	C^2S [f]
A	B			
	0	1	$\frac{1}{2}^-$	2.02
1373.7±0.5	1374.1±0.4 [e]	1	$\frac{3}{2}^-$	0.38
1850.0±0.5	1849.5±0.3 [e]	0 [h]	$\frac{1}{2}^+$	0.41±0.14
1906.8±0.4	1906.9±0.5 [e]		$\frac{5}{2}^-$	
2526.3±1.0	2525.9±0.6 [e]	2	$\frac{5}{2}^+$	0.53±0.17
3128.7±0.6	3129.2±0.6 [e]		$\frac{7}{2}^{(-)}$	
3203±2	3204.4±0.9 [e]	1	$\frac{3}{2}^-$	0.05
3628.7±0.7			$>\frac{3}{2}$ [i]	
3663±4			$(\frac{1}{2}, \frac{3}{2})^-$	
3906.0±2.0			$\leq\frac{7}{2}$	
4006.4±2.0	4000 [f]	(1)	$\frac{3}{2}^{(-)}$	0.04
4208±3			$\leq\frac{5}{2}$	
4415±3			$\leq\frac{7}{2}$	
5170±2	5170 [f]	(2)	$\frac{3}{2}\leq J\leq\frac{9}{2}$ [j]	0.08
5195±3			$(\frac{1}{2}, \frac{3}{2}, \frac{5}{2})^+$	
5514±3	≈5523 [f]	1	$\frac{3}{2}^-$ [k]	1.83
5770±3			$\leq\frac{7}{2}$	
6080±30 [b,c]				
6240±25 [b,c]				
6430±30 [b,c]				
6610±25 [b,c]				
6990±20 [b,c]	6990 [f,h]	1	$(\frac{3}{2})^-$ [k]	0.32
7170±40 [c]				
7370±40 [c]				
	7510 [f]	(1)	$(\frac{1}{2}, \frac{3}{2})^-$	0.09
7630±40 [c]				
7730±40 [c]				
8000±25 [b,c]				
8140±40 [c]				
8550±40 [c,d]				
8930±40 [c]				
9260±40 [c]				
9740±40 [c]				
	10 140 [f]	(1)	$(\frac{1}{2}, \frac{3}{2})^-$	0.5

A $^{11}B(^7Li, p)^{17}N$: (Ro 74j), except for states labelled [b]) and [c]).
B $^{18}O(t, \alpha)^{17}N$ (Gu 76d) and $^{18}O(d, ^3He)^{17}N$ (Ma 77k).
a) See also table 17.4 in (Aj 77).
b) (Ha 65c).
c) (Mc 66a).
d) This state and the ones below are broad.
e) (Gu 76d).
f) $^{18}O(d, ^3He)^{17}N$ (Ma 77k); $E_d = 52$ MeV; DWBA analysis.
g) (Ro 74j, Gu 76d, Ma 77k).
h) Unresolved.
i) Probably $(\frac{7}{2}, \frac{9}{2})^-$ (Ro 74j).
j) Probably $(\frac{7}{2}, \frac{9}{2})^+$ (Ro 74j); see, however, (Ma 77k).
k) $^{18}O(d, ^3He)^{17}N$ (Ma 81); $E_d = 52$ MeV.

TABLE 17.5

Radiative transitions and lifetimes of ^{17}N states [a])

E_i (MeV)	E_f (MeV)	Mtpl.	Branch (%)	Γ_γ/Γ_W [b]) (W.u.)	τ_m
1.37	0	M1	100	0.13 ± 0.05	93 ± 35 fsec
1.85	0	E1	86.5 ± 2.5		41^{+20}_{-9} psec
	1.37	E1	13.5 ± 2.5	$(3.2 \pm 1.5) \times 10^{-5}$	
1.91	0	E2	77.0 ± 2.5	0.9 ± 0.2	11 ± 2 psec
	1.37	M1	23.0 ± 2.5	$(5 \pm 1) \times 10^{-3}$ [c])	
2.53	0	M2	11 ± 1	0.22 ± 0.04	33 ± 3 psec
	1.37	E1	34 ± 3	$(1.0 \pm 0.2) \times 10^{-5}$	
	1.85	E2	12.0 ± 1.5	8.1 ± 1.6	
	1.91	E1	41.0 ± 2.5		
3.13 [d])	1.91	M1	100	0.06 ± 0.02	275 ± 80 fsec
3.20 [e])	0	M1	88 ± 4	>0.025 [f])	<30 fsec
	1.91	M1	12 ± 4	>0.05	
3.63 [g])	1.91	E2	47 ± 10	0.8 ± 0.2	12 ± 2 psec
	3.13	M1	53 ± 10	0.010 ± 0.03	
3.66	1.85	E1	100	$>7 \times 10^{-4}$	<350 fsec
3.91	1.91	M1	100	$(8^{+5}_{-3}) \times 10^{-2}$ [h])	52 ± 22 fsec
4.01	1.85		$\leq 15 \pm 5$ [i])		
	2.53	(M1)	85 ± 5	0.55	<15 fsec
4.21	1.37		100		<70 fsec
4.42	1.91		100		(<60 fsec)
5.17	2.53	E2	37 ± 7	>15	<60 fsec
	3.13		63 ± 7		
5.20	1.85		~ 42		<95 fsec
	1.91		~ 58		
5.52	0		~ 50		<100 fsec
	1.37		~ 50		
5.77	1.37		~ 25		<120 fsec
	1.91		~ 25		
	4.01		~ 50 [i])		

[a]) See table 17.5 in (Aj 77) for references and additional detail.

[b]) Assuming pure multipole transitions and J^π from table 17.1: see also table 2.

[c]) $\Gamma_\gamma/\Gamma_W = 0.4^{-0.4}_{+1.3}$ (E2) (Gu 76d).

[d]) Branches to ^{17}N*(0, 1.37, 1.85, 2.53) are, respectively, <2, <5, <2 and <3% (Gu 76d).

[e]) Branches to ^{17}N*(1.37, 1.85, 2.53) are, respectively, <5, <6 and <3% (Gu 76d).

[f]) $\delta = -0.06 \pm 0.08$ or 2.1 ± 0.4 (Gu 76d). All other δ reported by (Gu 76d) are consistent with 0.

[g]) Branches to ^{17}N*(0, 1.37, 1.85, 2.53, 3.20) are, respectively, <10, <10, <7, <3, ≤2% (Ro 74k).

[h]) This number appears to be in error: see table 2.

[i]) This branch is uncertain.

3. ^{11}B(^{7}Li, p)^{17}N $Q_m = 8.417$

Observed proton groups and γ-rays are displayed in table 17.4. Table 17.5 shows branching ratio and lifetime measurements (Ro 74j, Ro 74k).

4. ^{15}N(t, p)^{17}N $Q_m = -0.108$

Observed proton groups are displayed in table 17.6. See also (Aj 71).

5. ^{15}N(α, 2p)^{17}N $Q_m = -19.922$

At $E_\alpha = 65$ MeV ^{17}N*(3.13, 3.63) are the only states of ^{17}N which are strongly populated (Ja 78i).

TABLE 17.6

States of ^{17}N from ^{15}N(t, p) [a])

E_x (keV)	L	J^π
0 [b])	0	$\frac{1}{2}^-$
1372±6 [b])	2	$(\frac{3}{2}, \frac{5}{2})$
1851±4	1	$(\frac{1}{2}, \frac{3}{2})^+$
1909±3 [b])	2	$(\frac{3}{2}, \frac{5}{2})^-$
2524±4	3	$(\frac{5}{2}, \frac{7}{2})^+$
3127±6 [b])	4	$(\frac{7}{2}, \frac{9}{2})^-$
3201±5 [b])	2	$(\frac{3}{2}, \frac{5}{2})^-$
3625±6 [b])	4	$(\frac{7}{2}, \frac{9}{2})^-$
3664±6 [b])	0	$\frac{1}{2}^-$
3906±5 [b])	2	$(\frac{3}{2}, \frac{5}{2})^-$
4011±6	(1)	
4213±6	3	$\frac{5}{2}^+$ [e])
4420±7 [b])	2	$(\frac{3}{2}, \frac{5}{2})^-$
5179±4 [c])	5	$(\frac{9}{2}^+)$
	1	$((\frac{1}{2}, \frac{3}{2})^+)$
5517±6	(2)	
5780±6	(1)	
6233±8 [d])	(2)	
6449±3	(4, 5)	
6627±30	weak	
6938±15, 6981±20, 7013±22	(3, 4)	

[a]) (Fo 79j): $E_t = 15.0$ MeV; DWBA analysis. See also (Mo 78g).

[b]) Predominantly 2p-1h states.

[c]) Unresolved states.

[d]) ^{17}N*(6.08) is not observed.

[e]) The $\frac{7}{2}^+$ possibility can be eliminated because the 4.21 → 1.37 MeV transition would then have too large an M2 strength (>500 W.u.) [P. M. Endt, private communication].

6. ^{15}N(^{13}C, ^{11}C)^{17}N $Q_m = -15.293$

At $E(^{13}\mathrm{C}) = 105$ MeV ^{17}N*(3.13, 3.63) are strongly populated (Ra 79c).

7. ^{17}O(n, p)^{17}N $Q_m = -7.898$

See ^{18}O in (Aj 78).

8. ^{18}O(γ, p)^{17}N $Q_m = -15.942$

See (Ba 76ii) and ^{18}O in (Aj 83).

9. ^{18}O(d, ^{3}He)^{17}N $Q_m = -10.449$

Observed groups of ^{3}He ions are displayed in table 17.4: the $\frac{1}{2}^-$ ground state contains the full $1p_{1/2}$ strength. The strength of all other observed $l = 1$ transitions is assumed to originate from pickup from the $1p_{3/2}$ shell (Ma 77k). Analyzing powers have been obtained at $E_d = 52$ MeV to ^{17}N*(0, 1.37, 1.85, 2.53, 5.51, 6.99) (Ma 81).

10. ^{18}O(t, α)^{17}N $Q_m = 3.872$

At $E_t = 3.5$ MeV (Gu 76d) have studied $\alpha - \gamma$ angular correlations and γ-ray branching ratios for the first six excited states of ^{17}N: see tables 17.4 and 17.5. See also (Aj 71).

^{17}O

(Figs. 7 and 9)

GENERAL[†]

Shell model: (Ba 76gg, Du 77b, Ha 77w, Po 77c, Ch 78z, Kr 78, Ka 79a, Br 80i, Va 80a).

Collective and cluster models: (Ch 78z, Ta 78u, Th 78e, Fu 80h).

Special states: (He 77h, Sh 77m, Al 78r, En 78c, Ta 78u, Ma 79bb, Za 79b, Ch 80o, Fu 80h, Hi 80c, Va 80a, Ta 81i).

Electromagnetic transitions: (Mc 76m, Al 77i, An 77a, Br 77, Ha 77w, Ho 77, Za 78, Su 79a, Ch 80o).

Complex reactions involving ^{17}O: (Du 76b, Le 76t, Ar 77b, Pe 77[††], Re 77, Ko 78a, Se 78d, Sa 79l, La 80j, Ol 80, Sh 81e).

† See also (Aj 77).
†† See also for spectroscopic factors.

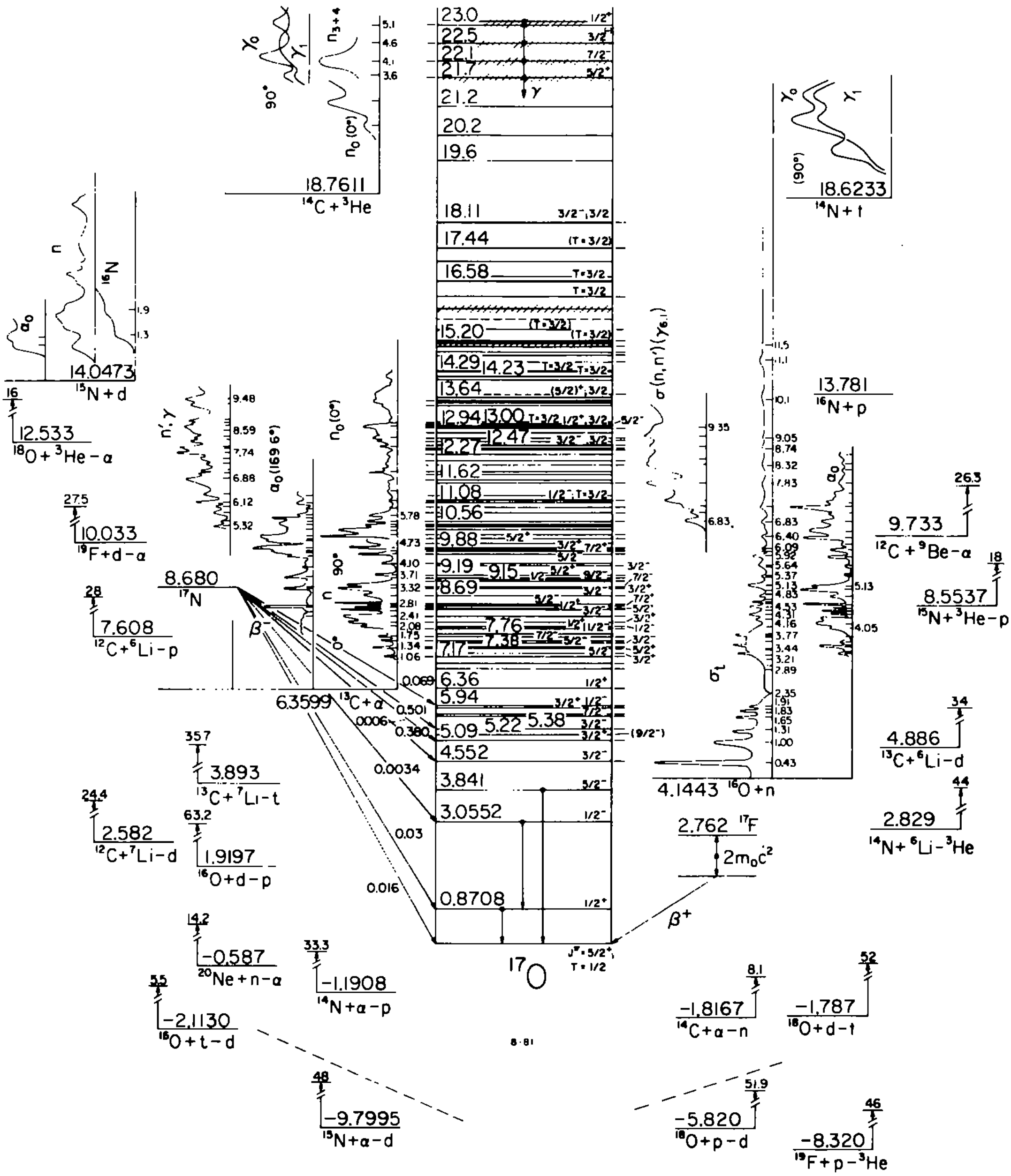

Fig. 7. Energy levels of ^{17}O. For notation see fig. 2.

Astrophysical questions: (Bo 76cc, No 76l, Au 77h, Ca 77q, Co 77h, Co 77z, De 77p, Di 77e, En 77a, No 77, Pr 77h, Ra 77, Tr 77i, Wa 77t, Bu 78k, Cl 78g, Le 78t, Po 78b, St 78i, Tr 78i, Wo 78f, Ch 79i, Ja 79v, La 79f, Le 79m, Pe 79e, Ro 79m, Sw 79, Au 80e, Cl 80c, Pe 80d, Wa 80n, Gu 81b, Wi 81c, Wi 81i).

Applications: (Am 78c).

Pion and other meson capture and reactions†: (Ho 77p, Si 77, Ga 78c, Jo 79g, Do 80e, Os 81a).

Other topics: (Ba 76gg, Bi 76e, Of 76, Sa 76i, Ba 77v, Gr 77h, Sh 77m, Su 77e, En 78c, Ga 78c, Kr 78, Mc 78d, Sh 78q, Be 79a, Br 79j, Co 79c, He 79, Ka 79a, Ma 79bb, Pi 79g, Va 79b, Zo 79, Hi 80c, Zo 80, Ta 81i).

Ground state of ^{17}O: (Du 76b, Fu 76h, Jo 76c, Mc 76m, Sa 76i, An 77f, Br 77, Du 77b, Ha 77w, Ko 77w, No 77d, Po 77c, Sh 77i, An 78b, Ar 78a, Ar 78b, Ch 78z, Fo 78o, He 78k, Sl 78, Za 78b, Br 79i, Br 79j, Sa 79l, Su 79a, Va 79b, Bo 80b, Br 80i, Ch 80o, Hi 80c, Av 81b, Si 81b, Ta 81i, Va 81c).

$$\mu = -1.89379 \pm 0.00009 \text{ n.m. (see Le 78n).}$$

$$Q = -25.78 \text{ mb (Sc 69u).}$$

1. ^{7}Li(^{14}N, α)^{17}O $\qquad Q_m = 16.157$

The angular distribution of the α_{0+1} group has been measured at $E(^{14}\mathrm{N}) = 27.6$ MeV (Wa 64g).

2. ^{9}Be(^{16}O, ^{8}Be)^{17}O $\qquad Q_m = 2.479$

Angular distributions have been studied at $E(^{16}\mathrm{O}) = 11$, 15 and 18 MeV, involving ^{17}O*(0, 0.87): see (Aj 77). The cross section for the population of ^{17}O*(0.87) has been measured for $E(^{16}\mathrm{O}) = 5.5$ to 22 MeV: see (Sw 77, Ba 70v). See also (Ch 79f). For astrophysical questions see (Sw 77, Cu 80). At $E(^{9}\mathrm{Be}) = 50$ MeV the population of ^{17}O*(5.09, 5.7, 7.6) is also reported (St 77p).

3. (a)	^{10}B(^{7}Li, p)^{16}N	$Q_m = 13.989$	$E_b = 27.770$
(b)	^{10}B(^{7}Li, d)^{15}N	$Q_m = 13.723$	
(c)	^{10}B(^{7}Li, t)^{14}N	$Q_m = 9.147$	
(d)	^{10}B(^{7}Li, α)^{13}C	$Q_m = 21.4099$	

Cross sections to various of the final states have been measured at $E(^{7}\mathrm{Li}) = 5.20$ MeV (Mc 66a).

† See also reactions 38 and 68.

^{17}O MASTER TABLE

TABLE 17.7
Energy levels of ^{17}O

E_x in ^{17}O (MeV±keV)	$J^\pi; T$	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
0	$\frac{5}{2}^+; \frac{1}{2}$		stable	1, 2, 5→9, 12, 13, 15, 16, 18→24, 29→32, 38→73
0.87081±0.12	$\frac{1}{2}^+$	$\tau_m = 258.6 \pm 2.6$ psec	γ	1, 2, 5→7, 12, 13, 15, 16, 18→22, 29→32, 38, 39, 42→44, 46→48, 50, 52, 54, 56, 57, 61, 62, 63, 68→73
3.0552±0.3	$\frac{1}{2}^-$	$\tau_m = 120^{+80}_{-60}$ fsec	γ	5→7, 12, 13, 18, 21, 22, 29, 31, 32, 38, 39, 42, 48, 50, 52, 61, 62, 70, 71
3.841±3	$\frac{5}{2}^-$	$\tau_m \leq 25$ fsec	γ	5→7, 12→14, 18, 21, 22, 29, 30, 39, 42, 50, 61, 62, 70, 71
4.552±2	$\frac{3}{2}^-$	$\Gamma = 40 \pm 5$	γ, n	5, 7, 12, 13, 21, 22, 29, 30, 33, 39, 42, 48, 49, 50, 61, 62, 71
5.085±2	$\frac{3}{2}^+$	96±5	γ, n	2, 6, 7, 12, 13, 21, 22, 29, 33, 39, 48, 49, 50, 61, 62
5.218	$(\frac{9}{2}^-)$	<0.1	γ, n	6, 7, 12→14, 21, 22, 29, 30, 33, 39, 50, 61, 71
5.378±2	$\frac{3}{2}^-$	28±7	γ, n	7, 21, 22, 29, 33, 39, 42, 48, 49, 50, 61, 62, 71
5.697±2	$\frac{7}{2}^-$	3.4±0.3	γ, n	2, 6, 12, 13, 21, 22, 29, 30, 33, 39, 49, 50, 62
5.733±2		<1	n	2, 5, 6, 12, 13, 21, 22, 33, 39, 71
5.868±2	$\frac{3}{2}^+$	6.6±0.7	n	6, 7, 12, 13, 21, 22, 29, 33, 39, 71
5.939±4	$\frac{1}{2}^-$	32±3	γ, n	5, 6, 12, 13, 21, 22, 29, 33, 39, 48, 50, 62, 71
6.356±8	$\frac{1}{2}^+$	124±12	γ, n	5, 7, 21, 29, 33, 50
6.862±2	$(\frac{1}{2}^-)$	<1	γ, n	5, 6, 7, 12, 13, 21, 22, 29, 33, 39, 50, 62, 71
6.972±2	$(\frac{5}{2}^+)$	<1	γ, n	6, 7, 12, 13, 21, 22, 29, 33, 50, 71
7.1657±0.8	$\frac{5}{2}^-$	1.38±0.05	n, α	5, 6, 7, 10, 12, 13, 21, 29, 33, 37
7.202±10	$\frac{3}{2}^+$	280±30	n, α	12, 13, 21, 33, 37
7.3792±1.0	$\frac{5}{2}^+$	0.64±0.23	(γ), n, α	5, 6, 7, 10, 12, 13, 29, 30, 33, 37, 50, 62, 71
7.3822±1.0	$\frac{5}{2}^-$	0.96±0.20	γ, n, α	5, 7, 10, 12, 13, 21, 30, 33, 37, 49, 50, 62, 71
7.559±20	$\frac{3}{2}^-$	500±50	n, α	33, 37, 39
7.576±2	$\frac{7}{2}^-$	<0.1	γ, n, α	5, 6, 10, 12, 13, 21, 29, 33, 50
7.6882±0.9	$\frac{7}{2}^-$	14.4±0.3	γ, n, α	5, 6, 10, 12, 13, 29, 33, 37, 49
7.757±9	$\frac{11}{2}^-$		γ	29, 30, 50

TABLE 17.7—continued

E_x in ^{17}O (MeV ± keV)	$J^{\pi}; T$	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
7.956 ± 6	$\frac{1}{2}^+$	90 ± 9	n, α	10, 29, 33, 37
7.99 ± 50	$\frac{1}{2}^-$	270 ± 30	n, α	33, 37
8.070 ± 10	$\frac{3}{2}^+$	85 ± 9	n, α	10, 29, 33, 37
8.200 ± 7	$\frac{3}{2}^-$	60	γ, n, α	10, 29, 33, 37, 49, 62
8.3424 ± 0.9	$\frac{1}{2}^+$	11.4 ± 0.5	n, α	10, 29, 33, 37, 50
8.4023 ± 0.8	$\frac{5}{2}^+$	6.17 ± 0.13	n, α	6, 10, 12, 13, 29, 33, 37, 50
8.4660 ± 0.8	$\frac{7}{2}^+$	2.13 ± 0.11	n, α	5, 6, 10, 12, 13, 29, 33, 37, 50, 62
8.5007 ± 0.8	$\frac{5}{2}^-$	6.89 ± 0.22	γ, n, α	6, 10, 12, 13, 29, 33, 37, 49, 50
8.6870 ± 1.0	$\frac{3}{2}^-$	55.3 ± 0.6	γ, n, α	10, 29, 33, 37, 49, 62
8.897 ± 8	$\frac{3}{2}^+$	101 ± 3	n, α	6, 10, 12, 13, 29, 30, 33, 37
8.9672 ± 1.7	$\frac{7}{2}^-$	26 ± 2	γ, n, α	6, 10, 12, 13, 29, 33, 37, 49
9.147 ± 4	$\frac{1}{2}^-$	4 ± 3	n, α	6, 10, 12, 13, 62
9.15 ± 20	$\frac{9}{2}^-$			29, 30
9.18	$\frac{7}{2}^-$	3	α	10, 12, 13
9.1939 ± 0.8	$\frac{5}{2}^+$	3.53 ± 0.13	n, α	10, 12, 13, 33
9.42	$\frac{3}{2}^-$	120	n	33
9.492 ± 4	$\frac{5}{2}^-$	15 ± 1	n, α	5, 10, 13, 29, 33, 62
9.7119 ± 0.9	$\frac{7}{2}^+$	23.1 ± 0.3	n, α	10, 13, 29, 33
9.7833 ± 0.9	$\frac{3}{2}^+$	11.7 ± 0.3	n, α	10, 13, 33
9.8589 ± 0.9	$(\frac{5}{2}^-)$	4.01 ± 0.23	n, α	10, 13, 29, 33
9.8765 ± 1.3	$(\frac{1}{2}^-)$	16.7 ± 1.7	n, α	10, 13, 29, 33
9.976 ± 20	$\frac{5}{2}^+$	~80	n, α	10
10.045 ± 20		~100	n, α	10
10.1678 ± 1.0	$\frac{7}{2}^-$	49.1 ± 0.8	n, α	10, 33
10.336 ± 15	$\frac{5}{2}^+, \frac{7}{2}^-$	150	n, α	10, 29
10.423 ± 3		14 ± 3	n, α	10
10.49	$\frac{5}{2}^+, \frac{7}{2}^-$	75 ± 30	n, α	10
10.5591 ± 1.0	$(\frac{7}{2}^-)$	42.5 ± 1.1	n, α	10, 14, 29, 33, 34
10.777 ± 3	$\frac{1}{2}^+, \frac{7}{2}^-$	74 ± 3	n, α	10, 13, 29, 34
10.9129 ± 2.8	$(\frac{5}{2}^+)$	41.7 ± 1.4	n, α	10, 29, 33, 34
11.036 ± 3	$T = \frac{1}{2}$	31 ± 3	n, α	10, 29
11.0787 ± 0.9 [a])	$\frac{1}{2}^-; \frac{3}{2}$	2.4 ± 0.3	n, α	10, 29, 33, 62, 63
11.238		80 ± 3	n, α	5, 10
11.51	$\geq\frac{3}{2}$	190	n	33, 34
11.622		65 ± 2	n, α	10
11.750 ± 10		40 ± 25	γ, n, α	10, 50
11.815 ± 15		12 ± 3	n, α	10
12.005 ± 15	$\geq\frac{3}{2}$	270	n, α	10, 33, 34, 50
12.11 ± 20		150 ± 50	n, α	10, 14, 34
12.274 ± 15		100 ± 30	n, α	10
12.38 ± 20			n, α	10, 33
12.420 ± 15			n, α	10
12.4660 ± 1.0	$\frac{3}{2}^-; \frac{3}{2}$	6.9 ± 1.1	n, α	10, 33, 34, 62, 63
12.595 ± 15		75 ± 30	n, α	10

TABLE 17.7—continued

E_x in ^{17}O (MeV ± keV)	J^π; T	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
12.669 ± 15		≃5	n, α	10, 33, 34
12.81 ± 25			n, α	10
12.93 ± 20		≥150	n, α	10
12.944 ± 5	$\frac{1}{2}^+;\frac{3}{2}$	6 ± 2	n, α	10, 33, 34, 62, 63
12.9982 ± 1.0	$\frac{5}{2}^-;\frac{3}{2}$	2.5 ± 1.0	n, α	10, 33, 63
13.076 ± 15		16 ± 4	n, α	10
13.484 ± 15		≃120	n, α	10
13.58 ± 20	$(\frac{11}{2}^-, \frac{13}{2}^-)$			12, 13
13.609 ± 15		250 ± 100	n, α	10
13.6353 ± 2.5	$(\frac{5}{2})^+;\frac{3}{2}$	9 ± 5	n, α	33, 62, 63
(13.67)		400	n	33
14.15 ± 100	$(\frac{9}{2}^+, \frac{11}{2}^+)$	~100		12
14.2303 ± 1.7	$(\frac{7}{2}^-);\frac{3}{2}$	20.5 ± 1.6	n, α	33, 63
14.286 ± 3	$T=\frac{3}{2}$	7.5 ± 4	n, α	33, 63
14.451 ± 3		40 ± 6	n, α	33
14.76 ± 100	$(\geq\frac{3}{2})$	340	γ, n	33, 50
14.791 ± 3	$(\frac{1}{2}^-;\frac{3}{2})$	36 ± 13	n, α	33
15.00		180	n, d, α	28, 33
15.1 ± 100	$(\frac{9}{2}^+, \frac{11}{2}^+)$	~500		12
15.199 ± 3	$(\frac{3}{2};\frac{3}{2})$	52 ± 14	γ, n, d, α	28, 33, 50
15.368 ± 3	$(\frac{5}{2}^+;\frac{3}{2})$	40 ± 6	n, d, α	27, 33
(15.6)		~300	p, d, α	26, 27, 28
15.95 ± 150	$(\frac{9}{2}^+, \frac{11}{2}^+)$	~700		12
16.243 ± 4	$(\frac{9}{2}^+;\frac{3}{2})$	21 ± 10	n, p, d, α	26, 33
16.58 ± 10	$(\frac{1}{2}, \frac{3}{2})^-;\frac{3}{2}$			62
16.6 ± 150	$(\frac{11}{2}^-, \frac{13}{2}^-)$			12
17.1 ± 150	$(\frac{11}{2}^-, \frac{13}{2}^-)$			12
17.436 ± 11	$(T=\frac{3}{2})$	66 ± 20	n, α	33
18.110 ± 4	$\frac{3}{2}^-;\frac{3}{2}$	46 ± 12	n, α	33, 62
19.6 ± 150	$(\frac{13}{2}^+, \frac{15}{2}^+)$	~250		12
20.2 ± 150	$(\frac{13}{2}^+, \frac{15}{2}^+)$	~250		12
21.2	$(\frac{13}{2}^+, \frac{15}{2}^+)$			12
21.7 ± 100	$\frac{5}{2}^+$	~750	γ, ^{3}He, α	16, 17
22.1 ± 100	$\frac{7}{2}^-$	~750	γ, n, ^{3}He, α	12, 16, 17
22.5 ± 200	$\frac{3}{2}^{(-)}$	~1000	γ, ^{3}He	16
23		~6000	γ, n	49, 50
23.0	$\frac{1}{2}^+$	~400	γ, ^{3}He	16, 17
23.5			γ, ^{3}He	16
24.4			γ, ^{3}He	16

^{a}) See also table 17.11, and see table 17.6 in (Aj 77).

4. (a) ^{11}B(^{6}Li, p)^{16}N $Q_m = 9.785$ $E_b = 23.565$
   (b) ^{11}B(^{6}Li, d)^{15}N $Q_m = 9.5178$
   (c) ^{11}B(^{6}Li, t)^{14}N $Q_m = 4.9418$
   (d) ^{11}B(^{6}Li, α)^{13}C $Q_m = 17.205$

Cross sections to various of the final states have been measured at $E(^6\text{Li}) = 4.72$ MeV (Mc 66a).

5. ^{12}C(^{6}Li, p)^{17}O $Q_m = 7.608$

Angular distributions have been studied for $E(^6\text{Li}) = 3$ to 20 MeV (see Aj 71) and at 28 MeV (Wa 80i: p_0, p_1, p_2 and p to ^{17}O*(8.47, 11.8, 12.4)). See also ^{18}F in (Aj 78, Aj 83).

6. ^{12}C(^{7}Li, d)^{17}O $Q_m = 2.582$

Angular distributions have been measured at $E(^7\text{Li}) = 3.24 \rightarrow 3.64$ MeV and at 21.1 MeV: see table 17.7 in (Aj 77). See also ^{19}F in (Aj 78, Aj 83).

7. ^{12}C(^{9}Be, α)^{17}O $Q_m = 9.733$

Angular distributions of the α_0 and α_1 groups are reported at $E(^9\text{Be}) = 20$ MeV (Ja 79t) and 16.1, 17.0 and 17.9 MeV (De 81h; also α_2). The yield of α-particles has been studied for $E(^9\text{Be}) = 9.0$ to 20 MeV (De 81h; α to ^{17}O* < 7.5 MeV), 10.5 to 26.3 MeV (Hu 80e; α_0) and 17.5 to 26.3 MeV (Ma 78v; $\alpha_0 \rightarrow \alpha_3$). See also (Aj 77), (Bo 79bb) and (Br 80q; theor.).

8. ^{12}C(^{18}O, ^{13}C)^{17}O $Q_m = -3.098$

See (Ch 78m).

9. ^{12}C(^{20}Ne, ^{15}O)^{17}O $Q_m = -9.089$

See (Or 79).

10. (a) ^{13}C(α, n)^{16}O $Q_m = 2.2156$ $E_b = 6.3599$
(b) ^{13}C(α, α)^{13}C

The yield of neutrons increases monotonically for $E_\alpha = 0.475$ to 1 MeV: $S(E) = [(5.48 \pm 1.77) + (12.05 \pm 3.91)E] \times 10^5$ MeV · b (Da 68; $E_\alpha = 0.48$ to 0.70 MeV), $[(4.87 \pm 1.28) + (10.86 \pm 2.46)E] \times 10^5$ MeV · b (Ra 76g, Ra 77; $E_\alpha = 0.60$ to 0.90 MeV). Astrophysical considerations are discussed by (Ra 76g, Co 77h, Ra 77) and see (Aj 77). Yield curves for reaction (a) have been measured for $E_\alpha = 1.0$ to 22.5 MeV: see (Aj 71, Aj 77) and (Be 75bb; $\alpha\gamma_{6.13}$; thresh. to 7.2 MeV). Elastic scattering studies [(reaction b)] have been studied at $E_\alpha = 2.0$ to 26.6 MeV: see (Aj 71, Aj 77). Observed resonances are displayed in table 17.8.

11. (a) ^{13}C(α, p)^{16}N $Q_m = -7.421$ $E_b = 6.3599$
(b) ^{13}C(α, d)^{15}N $Q_m = -7.6874$
(c) ^{13}C(α, t)^{14}N $Q_m = -12.2634$

For reaction (b) see (Aj 77). For all three reactions see ^{16}N, and ^{15}N and ^{14}N in (Aj 81).

12. ^{13}C(^{6}Li, d)^{17}O $Q_m = 4.886$

Angular distributions of deuteron groups to many states of ^{17}O have been measured earlier at $E(^6\mathrm{Li}) = 18$ and 25.6 MeV: see table 17.7 in (Aj 77). At $E(^6\mathrm{Li}) = 35.5$ MeV angular distributions are reported to ^{17}O*(13.58±0.02) which is strongly populated. Comparisons with ^{12}C(^{6}Li, d)^{16}O*(16.29) and with the results of reaction 13 here suggest that the peak corresponding to ^{17}O*(13.58) contains a state or states of spin $\frac{11}{2}^-$, $\frac{13}{2}^-$, or both, based on ^{16}O*(16.29) (Cl 78f). (d, α) angular correlations [$E(^6\mathrm{Li}) = 26$, 29 and 34 MeV] indicate the involvement of ^{17}O states at 13.6±0.1 [$l = 6$], 14.15±0.1[5], 15.1±0.1[5], 15.95±0.15[5], 16.6±0.15[6], 17.1±0.15[6], 19.6±0.15[7], 20.2±0.15[7], 21.2[7] and 22.1 MeV. $\Gamma \approx 0.1$, 0.5, 0.7, 0.25 and 0.25 MeV for ^{17}O*(14.2, 15.1, 16.0, 19.6, 20.2) (Ar 78j). See also (St 76n; theor.).

TABLE 17.8

Resonances in ^{13}C(α, n) and ^{13}C(α, α) [a])

E_{res} (MeV±keV)	$\Gamma_{c.m.}$ (keV)	Γ_α/Γ	J^π	E_x (MeV)
1.0563±1.5 [b])	1.5±0.2		$\frac{5}{2}$	7.1676
1.3367±1.5	$0.6^{+0.2}_{-0.1}$			7.3820
1.3406±1.5	$0.8^{+0.3}_{-0.2}$			7.3849
1.590±2	≤1		$\frac{7}{2}^-$	7.576
1.745±6	≤15		$\frac{5}{2}^+$	7.694
2.083±8	75	0.03	$\frac{1}{2}^-$	7.953
2.250±8	110	0.05	$\frac{3}{2}^+$	8.080
2.407±8	70	0.11	$\frac{3}{2}^-$	8.200
2.604±4	9±3	0.44	$\frac{1}{2}^+$	8.351
2.680±3	4±3	0.08	$\frac{5}{2}^+$	8.409
2.763±3	7±3	0.97	$\frac{7}{2}^+$	8.472
2.808±3	5±3	0.26	$\frac{5}{2}^-$	8.507
3.059±5	50±3	0.06	$\frac{3}{2}^-$	8.699
(3.1)	broad		$\frac{1}{2}^-$	(8.7)
3.318±8	101±3	0.50	$\frac{3}{2}^+$	8.897
3.415±4	21±3	0.04	$\frac{7}{2}^-$	8.971
3.645±4	4±3	0.45	$\frac{1}{2}^-$	9.147
(3.69)	3	1.00	$\frac{7}{2}^-$	(9.18)
3.714±4	5.5±1	0.20	$\frac{5}{2}^+$	9.200
4.096±4	15±1	0.85	$\frac{5}{2}^-$	9.492
(4.3)			$\frac{3}{2}^-$	(9.6)
4.394±5	16±1	0.70	$\frac{7}{2}^+$	9.719
4.465±15	≈25	0.90	$\frac{3}{2}^+$	9.774
4.583±5	14			9.864
4.600±15	≈10			9.877
4.730±20	≈80	0.78	$\frac{5}{2}^+$	9.976
4.820±20	≈100			10.045
(4.94)	138	0.85	$\frac{5}{2}^+$	(10.14)
4.993±5	45	0.15	$\frac{7}{2}^-$	10.177
(5.08)	122	0.60	$\frac{7}{2}^+$	(10.2)
5.200±15	150		$\frac{5}{2}^+, \frac{7}{2}^-$	10.336
5.315±3 [c])	14±3			10.423
5.40	75±30		$\frac{5}{2}^+, \frac{7}{2}^-$	10.49

TABLE 17.8—continued

E_{res} (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Γ_α/Γ	J^π	E_x (MeV)
5.492 ± 3 [c]	51 ± 2		$\frac{7}{2}^-, \frac{9}{2}^+$	10.559
(5.68)	≤25	1.00	$(\frac{7}{2}^+)$	(10.70)
5.778 ± 3 [c]	74 ± 3		$\frac{1}{2}^+, \frac{7}{2}^-$	10.777
5.945 ± 3 [c]	46 ± 2		$\frac{5}{2}$	10.905
6.117 ± 3 [c]	31 ± 3			11.036
6.167	5.0 ± 1.1		$\frac{1}{2}^-; T=\frac{3}{2}$	11.075 ± 0.005
6.380 ± 3 [c]	80 ± 3			11.238
6.883 ± 3 [c]	65 ± 2			11.622
7.051 ± 10	40 ± 25			11.750
7.136 ± 15	12 ± 3			11.815
7.384 ± 15				12.005
7.52 ± 20	150 ± 50			12.11
7.736 ± 15	100 ± 30			12.274
7.88 ± 20				12.38
7.927 ± 15				12.420
7.975	8 ± 2		$\frac{3}{2}^-; T=\frac{3}{2}$	12.457 ± 0.005
8.156 ± 15	75 ± 30			12.595
8.253 ± 15	≈5			12.669
8.44 ± 25				12.81
8.59 ± 20	≥150			12.93
8.611	6 ± 2		$\frac{1}{2}^+; T=\frac{3}{2}$	12.943 ± 0.006
8.675	≤3		$\frac{5}{2}^-; T=\frac{3}{2}$	12.992 ± 0.006
8.72 ± 20				13.03
8.785 ± 15	16 ± 4			13.076
9.319 ± 15	≈120			13.484
9.483 ± 15	250 ± 100			13.609

[a]) See references listed in tables 17.8 of (Aj 77) and 17.6 of (Aj 71). See also table 17.12 here.
[b]) See also (Ra 76g).
[c]) (Be 75bb).

13. $^{13}C(^7Li, t)^{17}O$ $\quad Q_m = 3.893$

Angular distributions of triton groups to many states of ^{17}O have been measured earlier at $E(^7Li) = 17$, 20.5 and 30.1 MeV: see table 17.7 in (Aj 77). At $E(^7Li) = 35.7$ MeV angular distributions are reported to $^{17}O^*(3.06)$ and to $^{17}O^*(13.58)$ which is preferentially populated (see discussion in reaction 12). Narrow states at $E_x = 14.86$, 18.17 and 19.24 MeV are also strongly excited (Cl 78f). See also (Ma 78b).

14. $^{13}C(^{13}C, ^9Be)^{17}O$ $\quad Q_m = -4.288$

At $E(^{13}C) = 105$ MeV states of ^{17}O with $E_x = 3.9$, 5.2, 5.8 ± 0.1, 7.2, 7.6, 8.4 ± 0.06, 8.9, 9.8 ± 0.07, 10.55 ± 0.06, 12.1 ± 0.06, 13.3, 14.6 and 18.9 ± 0.14 MeV are reported (Br 79a).

15. (a) ^{13}C(^{16}O, ^{12}C)^{17}O $\qquad Q_m = -0.8021$
    (b) ^{13}C(^{18}O, ^{14}C)^{17}O $\qquad Q_m = 0.132$

Angular distributions for reaction (a) have been studied at $E(^{16}\text{O}) = 12$ to 25 MeV [^{17}O*(0, 0.87): see (Aj 77)] and at 13 and 14 MeV (Du 76b; see also for r_n). For reaction (b) see (Ch 78m). See also (Go 80j, Pa 80; theor.).

16. ^{14}C(^{3}He, γ)^{17}O $\qquad Q_m = 18.7611$

The capture cross sections at 90° for γ_0 and for γ_1 have been studied for $E(^3\text{He}) = 3.2$ to 7.5 MeV and angular distributions of the γ-rays have been studied at the six observed resonances: see table 17.9 (Ch 76).

17. (a) ^{14}C(^{3}He, n)^{16}O $\qquad Q_m = 14.6168 \qquad E_b = 18.7611$
    (b) ^{14}C(^{3}He, p)^{16}N $\qquad Q_m = 4.981$
    (c) ^{14}C(^{3}He, d)^{15}N $\qquad Q_m = 4.7139$
    (d) ^{14}C(^{3}He, ^{3}He)^{14}C
    (e) ^{14}C(^{3}He, α)^{13}C $\qquad Q_m = 12.4013$

See (Aj 77) and table 17.9. See also ^{16}N, ^{16}O, and ^{15}N, ^{14}C and ^{13}C in (Aj 81).

18. ^{14}C(α, n)^{17}O $\qquad Q_m = -1.8167$

The upper limits to the decays 3.06 → 0 and 3.84 → 0.87 are, respectively, 2 and 5%. A study of n-γ correlations leads to $J^\pi = \frac{1}{2}^-$ and $(\frac{5}{2}^-)$ for ^{17}O*(3.06, 3.84) (Al 64g).

TABLE 17.9
States of ^{17}O from ^{14}C + ^{3}He [a])

E_{res} (MeV)	Resonant for	$\Gamma_{c.m.}$ (MeV)	E_x (MeV)	J^π
3.6 ± 0.1	γ_0, (γ_1), α_0, α_1	0.75	21.7	$\frac{5}{2}^+$
4.1 ± 0.1	γ_0, n_0, n_{3+4}, α_0, α_1	0.75	22.1	$\frac{7}{2}^-$
4.6 ± 0.2	γ_1	$\simeq 1$	22.5	$\frac{3}{2}^{(-)}$
5.1 ± 0.1	γ_0, ^{3}He	$\simeq 0.4$	23.0	$\frac{1}{2}^+$
5.7 ± 0.1	γ_1		23.5	
6.9 ± 0.1	γ_1		24.4	

[a]) For references see table 17.9 in (Aj 77).

19. ^{14}C(^{16}O, ^{13}C)^{17}O $\qquad Q_m = -4.0322$

Angular distributions have been measured at $E(^{16}\text{O}) = 20$, 25 and 30 MeV (^{17}O*(0, 0.87)): see (Aj 77). See also (We 77k; theor.).

20. (a) ^{14}N(t, γ)^{17}O $\qquad Q_m = 18.6233$
    (b) ^{14}N(t, p)^{16}N $\qquad Q_m = 4.843 \qquad E_b = 18.6233$

(c) $^{14}N(t, d)^{15}N$ $Q_m = 4.5760$
(d) $^{14}N(t, t)^{14}N$
(e) $^{14}N(t, \alpha)^{13}C$ $Q_m = 12.2634$

The excitation functions for γ_0 and γ_1 have been measured for $E_t = 0.8$ to 3.3 MeV: broad resonances are observed at 2.2 and 2.8 MeV in the γ_0 cross section, and at 2.4 and 2.8 MeV in the γ_1 cross section. Both also exhibit a structure at 1.5 MeV. The data are consistent with states at $E_x = 19.76 \pm 0.06$ [$J = \frac{3}{2}$], 20.39 ± 0.05 [$\frac{5}{2}, \frac{7}{2}^-$], 20.58 ± 0.05 [$\frac{1}{2}$] and 21.05 ± 0.05 MeV [$\frac{3}{2}$] with $\Gamma = 0.55 \pm 0.05$, 0.66 ± 0.07, 0.57 ± 0.08 and 0.47 ± 0.06 MeV, and possibly with a state at $\sim$19.3 MeV. $\Gamma_{\gamma_0} > 1.0$, 4.3 and 5.8 eV for $^{17}O^*$(19.8, 20.4, 21.1) and $\Gamma_{\gamma_1} > 2.3$, 5.1 and 6.5 eV for $^{17}O^*$(19.8, 20.6, 21.1) (Li 80b). For reactions (b)$\rightarrow$(e) see (Aj 77). See also ^{16}N, and ^{15}N, ^{14}N and ^{13}C in (Aj 81).

21. (a) $^{14}N(\alpha, p)^{17}O$ $Q_m = -1.1908$
(b) $^{14}N(\alpha, \alpha p)^{13}C$ $Q_m = -7.55063$

Angular distributions have been measured for ^{17}O states with $E_x < 7.6$ MeV in the range $E\alpha = 8.1 \rightarrow 33.3$ MeV: see a listing of the references in (Aj 71). The sequential decay [reaction (b)] appears to take place via ^{17}O states with $8.46 \leq E_x \leq 13.57$ MeV. Those involved are believed to have $J \geq \frac{5}{2}$, $\Gamma_\alpha/\Gamma \geq 0.6$ (Ba 69n).

22. $^{14}N(^6Li, ^3He)^{17}O$ $Q_m = 2.829$

At $E(^6Li) = 18$ MeV, the ^3He groups in this reaction and the triton groups in the mirror reaction (see ^{17}F, reaction 8) have been compared: $^{17}O^*$(3.84, 4.55, 5.22, 5.70+5.73) are strongly excited. $^{17}O^*$(0, 0.87, 3.06, 5.09, 5.38, 5.87+5.94, 6.86, 6.97) are also populated (Bi 73a). See also (Ma 77g, Ma 78b).

23. $^{14}N(^{10}B, ^7Be)^{17}O$ $Q_m = -0.045$

See (Mo 77y).

24. $^{15}N(d, \gamma)^{17}O$ $Q_m = 14.0473$

See (Aj 77) [paper quoted there has not been published].

25. $^{15}N(d, n)^{16}O$ $Q_m = 9.9029$ $E_b = 14.0473$

Excitation functions have been measured for a number of neutron groups for $E_d = 0.5$ to 5.9 MeV: a great deal of unresolved structure is apparent. Polarization measurements are reported for $E_d = 1.6$ to 5.5 MeV and at 10.0 and 11.8 MeV. See (Aj 77) for a listing of the work. See also ^{16}O.

26. $^{15}N(d, p)^{16}N$ $Q_m = 0.267$ $E_b = 14.0473$

Excitation functions have been obtained for $E_d = 0.3$ to 6.3 MeV: [see (Aj 77)] and at $E_d = 1.4$ to 2.7 MeV (Ca 77b; $p_0 \rightarrow p_3$). Structures are reported at $E_d = 1.8$ [p_0, p_1, p_3] and 2.4 MeV [p_2] [$^{17}O^*$(15.6, 16.2)] (Ca 77b).

27. ^{15}N(d, d)^{15}N $E_b = 14.0473$

Excitation functions for d_0 have been measured for $E_d = 4.25$ to 6.25 MeV [see (Aj 77)] and 1.4 to 2.7 MeV (Ca 77b). The latter report structures at ~1.4 and 1.8 MeV.

28. ^{15}N(d, α)^{13}C $Q_m = 7.6874$ $E_b = 14.0473$

Yield curves have been measured for $E_d = 0.8$ to 2.5 MeV [see (Aj 77)] and 1.2 to 2.7 MeV (Ca 76r: $\alpha_0 \rightarrow \alpha_3$): structures have been reported at $E_d = 1.06$ and 1.25 MeV, and at ~1.8 MeV. The latter has $\Gamma \sim 300$ keV (Ca 76r).

29. ^{15}N(^{3}He, p)^{17}O $Q_m = 8.5537$

Observed proton groups are displayed in table 17.10. See also (Aj 77). For the parameters of the first $T = \frac{3}{2}$ state see table 17.11.

30. ^{15}N(α, d)^{17}O $Q_m = -9.7995$

TABLE 17.10
Levels of ^{17}O from ^{15}N(^{3}He, p)^{17}O [a]

E_x [b] (MeV)	L	E_x [b] (MeV)	L
0	(1+3)	8.192	0
0.874	1	8.322	
3.053	0	8.390	
3.845	2	8.492	(2)
4.549	0	8.682	
5.081	(1)	8.900	
5.215	(4)	8.955	
5.381	0	9.16	(4)
5.698	2	9.495	
5.873	(1)	9.712	
5.938	0	9.856	
6.37		(10.24)	
6.861	(0)	10.33	
6.973	(1+3)	10.57	
7.162	2	10.782	
7.382	2	10.913	
7.561		11.032±0.004 [c]	
7.687		11.075±0.004 [d]	
7.761	4		
7.938			
8.054	(1)		

[a]) (Le 72c). $E(^3\text{He}) = 18$ MeV.
[b]) ±10 keV, except where shown otherwise.
[c]) See also (Mc 70b): $T = \frac{1}{2}$.
[d]) $J^\pi = \frac{1}{2}^-$; $T = \frac{3}{2}$: see table 17.11 (Le 72c, Ad 73b).

TABLE 17.11

Decay properties of the lowest $T = \frac{3}{2}$ states in $A = 17$ [a])

	^{17}O*(11.0787 ± 0.0008) [b])	^{17}F*(11.1928 ± 0.0021) [c])
J^π	$\frac{1}{2}^-$	$\frac{1}{2}^-$
$\Gamma_{c.m.}$ (keV)	2.4 ± 0.3 [b])	0.20 ± 0.04
Branching ratio (%) to		
^{16}O*(MeV) J^π		
0 0^+	81 ± 6 [e])	9.3 ± 1.3
6.05 0^+ }		<3
6.13 3^- }	5 ± 2	22 ± 2
6.92 2^+		24 ± 6
7.12 1^-		44 ± 4
^{13}C + α_0 or ^{13}N + α_0	6	<7
Partial widths [Γ_p or Γ_n] to		
^{16}O(0)	1.88 ± 0.12 keV	19 ± 3 eV
^{16}O*(6.05) }		<8 eV
^{16}O*(6.13) }	0.12 ± 0.05 keV	45 ± 14 eV [d])
^{16}O*(6.92)		49 ± 19 eV [d])
^{16}O*(7.12)		90 ± 27 eV [d])
$\Gamma_{\alpha 0}$	0.14 keV	<19 eV [d])
$\Gamma_{\gamma 1}$		6.0 ± 2.5 eV
θ^2(g.s.)/θ^2(6.13)	0.31 ± 0.14	0.065 ± 0.019

[a]) See also table 2 in (Ad 73b) and reaction 63. See also (Mc 78d).

[b]) (Hi 81a): $\Gamma_{n0} = 1.88 \pm 0.12$ keV. See also for IMME parameters for six $T = \frac{3}{2}$ states.

[c]) (Ha 71b, Ad 73b, Sk 74, Ha 75g, Hi 76d).

[d]) Note that the total width is 200 ± 40 eV.

[e]) Weighted mean of 91 ± 15 (Ad 73b) and 79 ± 7% (Hi 81a, and F. Hintenberger, private communication).

At $E_\alpha = 45.4$ MeV, the deuteron spectrum is dominated by the groups corresponding to states with $E_x = 7.742 \pm 0.020$ and 9.137 ± 0.030 MeV. These states are assigned $J^\pi = (\frac{11}{2}^-)$ and $(\frac{9}{2}^-)$ and arise from a dominant $(d_{5/2})^2_5 p^{-1}_{1/2}$ configuration. Angular distributions were measured as well for the deuterons corresponding to ^{17}O$_{g.s.}$ and to states with $E_x = 0.87 \pm 0.05$, 5.22, 5.70, 7.38, 8.46, 8.89 and 9.81 [±0.03] MeV. In addition the population of ^{17}O*(3.84, 4.55, 8.15 ± 0.03) is also reported (Lu 69a).

31. ^{15}N(^{11}B, ^{9}Be)^{17}O $Q_m = -1.769$

At $E(^{11}$B) = 115 MeV angular distributions have been studied to ^{17}O*(5.23, 7.75, 9.18) [$J^\pi = \frac{9}{2}^-, \frac{11}{2}^-, \frac{9}{2}^-$] (Pr 80c, Ra 79c). See also (Aj 77).

32. ^{16}O(n, γ)^{17}O $Q_m = 4.1443$

$$\sigma_{capt.} = 202 \pm 28\ \mu b \text{ (Mc 77e)}.$$

At thermal energies the branchings via ^{17}O*(0.87, 3.05) are (18±3) and (82±3)%; $E_\gamma = 870.89 \pm 0.22$ keV. The cross section for two-photon emission $\sigma_{2\gamma} < 3 \pm 19$ μb for $1200 < E_\gamma < 2943$ keV. The two-photon branching ratio is $(1.6 \pm 10) \times 10^{-2}$ (Mc 77e). See also (Le 76r; theor.).

33. ^{16}O(n, n)^{16}O $E_b = 4.1443$

The scattering amplitude (bound) $a = 5.805 \pm 0.005$ fm, $\sigma_{free} = 3.761 \pm 0.007$ b (Ko 79w). High resolution cross-section measurements and analyses of the elastic scattering and of the (n, α) and ^{13}C(α, n) data have led to a much better understanding of the ^{17}O structure below $E_x = 18.2$ MeV: see table 17.12 (Fo 73g, Jo 73, Ci 80, Hi 81a). (Jo 73) has performed a multilevel two-channel R-matrix analysis. Five states contain nearly 100% of the $1d_{3/2}$ strength and have their eigenenergy at $E_x \simeq 5.7$ MeV [the dominant state is ^{17}O*(5.08)]. Spectroscopic factors are deduced for 26 states in ^{17}O for $4.5 < E_x < 9.5$ MeV [see table 17.12 in (Aj 77)]: the sum of these factors is 1% for $J^\pi = \frac{1}{2}^+$, 5% for $\frac{1}{2}^-$, 12% for $\frac{3}{2}^-$, 99% for $\frac{3}{2}^+$, 0.1% for $\frac{5}{2}^+$, 1% for $\frac{5}{2}^-$ and 14% for $\frac{7}{2}^-$ (Jo 73). $T = \frac{3}{2}$ resonances are discussed by (Hi 81a): see tables 17.11 and 17.12.

Cross-section measurements are listed in table 17.10 of (Aj 71) and in (Aj 77). At $E_n = 23.5$ keV, $\sigma_t = 3.736 \pm 0.007$ b (Bl 75i; elemental O). σ_t has also been

TABLE 17.12

Resonances [a]) in ^{16}O(n, n) and ^{16}O(n, α)

E_n (keV)	$\Gamma_{c.m.}$ (keV)	$\Gamma_{\lambda n}$ (keV)	$\Gamma_{\lambda\alpha}$ (keV)	J^π	E_x (keV)
433±2 [b])	45	45 [j])		$\frac{3}{2}^-$	4552
1000±2	96	96 [j])		$\frac{3}{2}^+$	5085
1140 [c])	<0.1				5218
1312±2	42	41.5 [j])		$\frac{3}{2}^-$	5378
1651±2	3.4±0.3	3.4		$\frac{7}{2}^-$	5697
1689±2	<1			[d])	5733
1833±2	6.6±0.7	6.6		$\frac{3}{2}^+$	5868
1908±4	32±3	31.5 [j])		$\frac{1}{2}^-$	5939
2351±8	124±12	124		$\frac{1}{2}^+$	6356
2889±2	<1			[d])	6862
3006±2	<1			[d])	6972
3211.70±0.17	1.38±0.05	1.38±0.05 [e])	0.0033	$\frac{5}{2}^-$	7165.2
3250±10	280±30	280	0.07	$\frac{3}{2}^+$	7202
3438.38±0.19	0.64±0.23	0.64±0.23 [e])	0.01	$\frac{5}{2}^+$	7378.4
3441.73±0.14	0.96±0.20	0.96±0.20 [e])	0.003	$\frac{5}{2}^-$	7381.5
3630±20	500±50	500	0.08	$\frac{3}{2}^-$	7559
3647 [c])	<0.1				7576
3767.76±0.22	14.4±0.3	13.0±0.6 [e])	0.01	$\frac{7}{2}^-$	7688.2
4053±8	90±9	84	6.7	$\frac{1}{2}^+$	7958
4090±50	270±30	250	16	$\frac{1}{2}^-$	7990
4162±8	85±9	71	15	$\frac{3}{2}^+$	8059
4290±20	69±7	68	0.8	$\frac{1}{2}^-$	(8180)
4310±10	52	48	4.0	($\frac{3}{2}^-$)	8199

TABLE 17.12—continued

E_n (keV)	$\Gamma_{c.m.}$ (keV)	$\Gamma_{\lambda n}$ (keV)	$\Gamma_{\lambda\alpha}$ (keV)	J^π	E_x (keV)
4463.41±0.26	11.4±0.5	8.1±0.3	2.2	$\frac{1}{2}^+$	8342.4
4527.12±0.07	6.17±0.13	4.75±0.11	0.54	$\frac{5}{2}^+$	8402.3
4594.83±0.09	2.13±0.11	1.18±0.04	(7.6)	$\frac{7}{2}^+$	8466.0
4631.78±0.12	6.89±0.22	2.86±0.08	1.9	$\frac{3}{2}^-$	8500.7
4829.9±0.4	55.3±0.6	48.9±1.1	1.8	$\frac{3}{2}^-$	8687.0
5050	78	68	9.5	$\frac{3}{2}^+$	8895
5127.0±1.6	26.3±1.9	23.5±1.9		$\frac{7}{2}^-$	8966.4
5368.90±0.09	3.53±0.13	2.37±0.08		$\frac{5}{2}^+$	9193.9
5610	120	120		$\frac{3}{2}^-$	9420
5640	140			$\geq\frac{3}{2}$	9450
5919.67±0.14	23.1±0.3	18.0±0.6		$\frac{7}{2}^+$	9711.9
5995.68±0.15	11.7±0.3	10.3±0.3		$\frac{3}{2}^+$	9783.3
6076.08±0.15	4.01±0.23	3.37±0.23		$(\frac{5}{2}^-)$	9858.9
6094.8±1.0	16.7±1.7	10.9±1.2		$(\frac{1}{2}^-)$	9876.5
6404.6±0.5	49.1±0.8	22.3±0.6		$(\frac{7}{2}^-)$	10 167.8
6820.7±0.6	42.5±1.1	17.2±0.7 [e]		$(\frac{7}{2}^-)$	10 559.1
7199.3±1.3	41.7±1.4	26.4±0.9 [e]		$(\frac{5}{2}^+)$	10 915.1
7373.31±0.18	2.4±0.3	1.88±0.12 [e]		$\frac{1}{2}^-$ [g]	11 078.7
7830	190			$\geq\frac{3}{2}$	11 509
8320	270			$\geq\frac{3}{2}$	11 970
8740	130				12 365
8848.8±0.6	6.9±1.1	1.27±0.14 [e]		$\frac{3}{2}^-$ [g]	12 466.0
9050	95				12 656
9353±6	6±2 [f]	0.21±0.14 [e]		$\frac{1}{2}^+$ [g]	12 940±6
9414.9±0.6	2.5±1.0	0.40±0.06 [e]		$\frac{5}{2}^-$ [g]	12 998.2
10 092.5±2.4	9±5	0.24±0.09 [e]		$(\frac{5}{2}^+)$ [g]	13 635.3
10 130	400				13 672
10 725.5±1.5	20.5±1.6	2.07±0.16 [e]		$(\frac{7}{2}^-)$ [g]	14 230.3
10 785±3	7.5±4	0.80±0.16 [h]		[g]	14 286
10 960±3	40±6	13±6 [h]			14 451
11 140	340			$(\geq\frac{3}{2})$	14 621
11 322±3	36±13	3.2±1.0 [h]		$(\frac{1}{2}^-)$ [i]	14 791
11 540	180				14 997
11 756±3	52±14	11±3 [h]		$(\frac{3}{2})$ [i]	15 199
11 936±3	40±6	7±1 [h]		$(\frac{5}{2}^+)$ [i]	15 368
12 867±4	21±10	2±0.5 [h]		$(\frac{9}{2}^+)$ [i]	16 243
14 136±11	66±20	8.0±2.4 [h]		[g]	17 436
14 853±4	43±12	1.0±0.3 [e]		$\frac{3}{2}^-$	18 110

[a]) (Fo 73g, Jo 73, Ci 80, Hi 81a). See also table 17.12 in (Aj 77).
[b]) $\Gamma_\gamma < 4.0$ eV, $\Gamma_n = 60 \pm 15$ keV (Al 71c).
[c]) Not observed in σ_t: see (Fo 73g).
[d]) Not $\frac{1}{2}^+$ (Fo 73g).
[e]) Γ_{n0} (Ci 80, Hi 81a, and F. Hintenberger, private communication).
[f]) (Mc 76i).
[g]) $T = \frac{3}{2}$.
[h]) $(J \pm \frac{1}{2})\Gamma_{n0}$ (Hi 81a).
[i]) J^π assignment by comparison with ^{17}N states presumed to be analogs; then $T = \frac{3}{2}$ (Hi 81a).
[j]) See also table 17.2.

measured with high resolution for $E_n = 4.5$ to 8 MeV (Ci 80). At $E_n = 40.3$ and 50.4 MeV, σ_{non} is reported for elemental O (Za 81). See also ^{16}O, (Fi 75e, Su 78e, La 79o, Fr 80k, La 80b, Pa 80e), (Ci 76, Ki 76k), (Li 77i, Jo 79d; applications) and (Le 76p, Ba 77oo, Ho 77c, Th 77d, Fe 78c, Le 78f, Ba 79dd; theor.).

34. ^{16}O(n, n')^{16}O* $E_b = 4.1443$

A number of resonances have been observed in the cross sections for production of 6.13 and (6.92+7.12) γ-rays: see table 17.13 in (Aj 77) and (No 78g). For cross-section measurements see table 17.10 in (Aj 71), (Aj 77) and (No 78g: $E_n =$ 6.95 to 10.25 MeV; $\gamma_{6.13}$, $\gamma_{6.92+7.12}$). See also (Ya 78b).

35. ^{16}O(n, 2n)^{15}O $Q_m = -15.6639$ $E_b = 4.1443$

See (Aj 77).

36. (a) ^{16}O(n, p)^{16}N $Q_m = -9.636$ $E_b = 4.1443$
(b) ^{16}O(n, d)^{15}N $Q_m = -9.9029$
(c) ^{16}O(n, t)^{14}N $Q_m = -14.4790$

For cross sections of reaction (a) see (Aj 77). See also (Sl 76a). For reaction (b) see ^{15}N in (Aj 81) and (Sl 76a). For triton emission see (Qa 78).

37. ^{16}O(n, α)^{13}C $Q_m = -2.2156$ $E_b = 4.1443$

Table 17.12 displays the results from a multilevel two-channel R-matrix analysis of the data from this reaction and from the elastic scattering of neutrons (Jo 73). For cross-section measurements see table 17.10 in (Aj 71), (Aj 77) and (No 78g; $E_n = 8.06$ to 10.25 MeV; $\gamma_{3.09}$, $\gamma_{3.68+3.85}$). See also (Su 78, Ya 78b, Ro 79b) and (Sl 76a).

38. ^{16}O(p, π^+)^{17}O $Q_m = -136.205$

At $E_p = 185$ MeV (Da 74i) and 800 MeV (Ho 79i) angular distributions of pions to ^{17}O*(0, 0.87, 3.05) are reported. The cross section for π^+ production near threshold has been studied by (Ma 79gg, Ma 79hh). For polarization measurements see (Sj 81: to ^{17}O*(0, 0.87)). See also (So 79a, Sj 80a), (Jo 79a, Au 81a) and (Br 77a; theor.).

39. ^{16}O(d, p)^{17}O $Q_m = 1.9197$

Observed proton groups are displayed in table 17.14 of (Aj 77). Angular distributions have been measured at many energies in the range of $E_d = 0.3$ to 63.2 MeV: see table 17.13 in (Aj 71) and (Aj 77), and at $E_d = 698$ MeV (Bo 81a: p_0, p_1). At $E_d = 12$ MeV angular distributions are reported for the proton groups to ^{17}O*(0, 0.87, 5.09): Γ_n for ^{17}O*(5.09) $= 97 \pm 5$ keV (An 79o). Reported parameters for ^{17}O*(0.87) are $\tau_m = 258.6 \pm 2.6$ psec [see table 17.7 in (Aj 71)] and

$E_\gamma = 870.81 \pm 0.22$ keV [see (Aj 77)], $E_\gamma = 870.725 \pm 0.020$ keV (Wa 80k) [$E_x = 870.749 \pm 0.020$ keV (E. K. Warburton, private comm.)].

See also ^{18}F in (Aj 83), (Ro 78e, So 79c, Fl 80b), (Am 78c, Bo 78l, Hi 78c, Ni 78; applications), (Te 77b) and (Co 76u, Gr 77g, Ka 77k, Ko 77mm, Mu 77, Ka 78u, Gr 79m, Am 80a, Ay 80, Kr 80i, Sh 81e; theor.).

40. ^{16}O(t, d)^{17}O $Q_m = -2.1130$

The angular distribution of the d_0 group has been studied at $E_t = 5.5$ MeV (Ba 61c).

41. ^{16}O(α, ^{3}He)^{17}O $Q_m = -16.434$

See (Aj 77) and (Gr 79m; theor.).

42. ^{16}O(^{7}Li, ^{6}Li)^{17}O $Q_m = -3.106$

The angular distribution involving $^{17}O_{g.s.}$ has been studied at $E(^7\text{Li}) = 36$ MeV. The population of ^{17}O*(0.87, 3.06, 3.84, 4.55, 5.38) is also reported (Sc 73m).

43. ^{16}O(^{11}B, ^{10}B)^{17}O $Q_m = -7.311$

Angular distributions are reported at $E(^{11}\text{B}) = 115$ MeV to $^{17}O_{g.s.}$ (Ra 79c). See also (Aj 77).

44. (a) ^{16}O(^{12}C, ^{11}C)^{17}O $Q_m = -14.577$
(b) ^{16}O(^{13}C, ^{12}C)^{17}O $Q_m = -0.802$

Angular distributions have been measured at $E(^{13}\text{C}) = 36$ MeV [(We 76j); to ^{17}O*(0.87)] and 105 MeV [(Ra 79c); to ^{17}O*(0, 0.87)]. See also (Aj 77) and (Du 77b, Si 80g; theor.). For reaction (b) see (Ze 77c; theor.).

45. ^{16}O(^{14}C, ^{13}C)^{17}O $Q_m = -4.032$

See (Ko 81a).

46. ^{16}O(^{14}N, ^{13}N)^{17}O $Q_m = -6.409$

At $E(^{14}\text{N}) = 79$ MeV angular distributions involving ^{17}O*(0, 0.87) have been studied: an anomaly is observed in the phase behavior of the distribution to the excited state. From this and other studies it is concluded that a multistep process via inelastic scattering is unlikely to occur in the excitation of $2s_{1/2}$ states (Mo 76). An angular distribution involving ^{16}O*(0 + 0.87) has also been reported at $E(^{14}\text{N}) = 155$ MeV (Na 76h). See also (Iz 80a; theor.).

47. ^{16}O(^{18}O, ^{17}O)^{17}O $Q_m = -3.900$

At $E(^{18}\text{O}) = 42$ and 52 MeV, the angular distributions involving ^{17}O*(0, 0.87) have been studied (Re 75d).

48. $^{17}N(\beta^-)^{17}O$ $Q_m = 8.680$

The decay is principally to $^{17}O^*(4.55, 5.38, 5.94)$: see table 17.2.

49. (a) $^{17}O(\gamma, n)^{16}O$ $Q_m = -4.1443$
(b) $^{17}O(\gamma, 2n)^{15}O$ $Q_m = -19.808$
(c) $^{17}O(\gamma, \alpha)^{13}C$ $Q_m = -6.3599$

Forty-five resonances are reported for E_x up to 26.9 MeV in the differential cross section for (γ, n_0). $T = \frac{1}{2}$ components of the giant resonance are observed at $E_x =$ 19.8, 21.5 and ~26 MeV (Jo 79; brems.). Monoenergetic photons with $E_\gamma = 8.5$ to 39.7 MeV have been used to measure the (γ, n) and the $(\gamma, 2n)$ [above 10 MeV] cross sections. The giant dipole resonance, 6 MeV broad, is centered at 23 MeV; a pigmy resonance is also observed at 13 MeV. Most of the GDR strength decays to $T = 1$ states in ^{16}O: this implies at $T = \frac{3}{2}$ assignment for the main part of the GDR. A broad structure, of $T = \frac{1}{2}$ nature, with $28 < E_x < 36$ MeV is also reported (Ju 80). For radiative widths see table 17.13. See also (Aj 77).

TABLE 17.13

Radiative widths from resonances in $^{17}O(\gamma, n)$

E_x [a] (MeV)	J^π [a]	$\Gamma_{\gamma 0}$ [b] (eV)	$\Gamma_{\gamma 0}$ [c] (eV)
4.55	$\frac{3}{2}^-$	0.42	
5.09	$\frac{3}{2}^+$	1.0	
5.38	$\frac{3}{2}^-$	0.06	0.7 ± 0.4
5.70	$\frac{7}{2}^-$	0.4	1.1 ± 0.4
6.36	$\frac{1}{2}^+$	<0.07	
7.38	$\frac{5}{2}^-$		0.8 ± 0.4
7.69	$\frac{7}{2}^-$		1.5 ± 0.5
8.20	$\frac{3}{2}^-$		1.4 ± 0.5
8.50	$\frac{5}{2}^-$		6.6 ± 1.8
8.69	$\frac{3}{2}^-$		1.2 ± 0.6
8.97	$\frac{7}{2}^-$		4.1 ± 0.8

[a]) Values from table 17.7.
[b]) (Ho 78i).
[c]) (Jo 79; bremsstrahlung radiation): thirty-seven additional resonances are reported with E_x to 26.9 MeV.

50. $^{17}O(e, e)^{17}O$

The ^{17}O charge radius, $\langle r^2 \rangle^{1/2} = 2.710 \pm 0.015$ fm, based on $\langle r_{17}^2 \rangle^{1/2} / \langle r_{16}^2 \rangle^{1/2} =$ 1.0015 ± 0.0025 (Ki 78a). (Mi 79d) report $\langle r_{17}^2 \rangle^{1/2} - \langle r_{16}^2 \rangle^{1/2} = -0.008 \pm 0.007$ fm. Considerable deviation from single-particle predictions is observed in the elastic scattering for an effective momentum transfer range of 0.55 to 2.8 fm^{-1} (Hy 79). Inelastic scattering is reported to a number of ^{17}O states: see tables 17.14 and

TABLE 17.14

Transition probabilities and ground state radiative widths from ^{17}O(e, e) a)

E_x (MeV)	J^{π} a)	Mtpl	$\Gamma_{\gamma 0}(\mathrm{C}\lambda)$ (eV)	$B(\mathrm{C}\lambda\uparrow)$ ($e^2\cdot\mathrm{fm}^{2\lambda}$)	Mtpl	$\Gamma_{\gamma 0}(\mathrm{M}\lambda)$ (eV)	$B(\mathrm{M}\lambda\uparrow)$ ($e^2\cdot\mathrm{fm}^{2\lambda}$)
0.87	$\frac{1}{2}^+$	C2					
3.06	$\frac{1}{2}^-$	C3	$(8.7\pm1.7)\times10^{-8}$	31 ± 6			
3.84	$\frac{5}{2}^-$	C3	$(7.1\pm0.3)\times10^{-7}$	153 ± 6	M2	$(4.6\pm1.8)\times10^{-3}$	$(5\pm2)\times10^{-2}$
4.55	$\frac{3}{2}^-$	C3	$(2.2\pm0.2)\times10^{-6}$	98 ± 8	M2	$(1.8\pm0.7)\times10^{-2}$	$(5.4\pm2.1)\times10^{-2}$
5.09	$\frac{3}{2}^+$	C2	$(1.0\pm0.3)\times10^{-2}$	2.5 ± 0.7			
5.22	$(\frac{9}{2}^-)$	C3	$(8.5\pm0.3)\times10^{-6}$	360 ± 11	M2	$<1\times10^{-2}$	$<4\times10^{-2}$
5.38	$\frac{3}{2}^-$	C3	$(3.3\pm0.9)\times10^{-6}$	45 ± 12	M2	$(4.5\pm2.2)\times10^{-2}$	$(6\pm3)\times10^{-2}$
5.70	$\frac{7}{2}^-$	C3	$(1.5\pm0.2)\times10^{-5}$	270 ± 32	M2	0.15 ± 0.10	0.3 ± 0.2
5.94	$\frac{1}{2}^-$	C3	$(5.0\pm2.9)\times10^{-6}$	17 ± 10			
6.36	$\frac{1}{2}^+$	C2	$(5.3\pm3.3)\times10^{-2}$	2.1 ± 1.3			
6.86 c)	$(\frac{1}{2}^-)$	C3	$(1.2\pm0.3)\times10^{-4}$	147 ± 34			
6.97 c)	$(\frac{5}{2}^+)$	C2	$(2.5\pm1.3)\times10^{-2}$	1.9 ± 1.0			
7.38 c)	$\frac{5}{2}^+$	CO, or		5.5 ± 1.0			
		C2	$(6.3\pm1.8)\times10^{-2}$	3.6 ± 1.0			
7.38 c)	$\frac{5}{2}^-$	C3	$(2.1\pm1.7)\times10^{-5}$	47 ± 38			
7.58	$\frac{7}{2}^-$	C1	$(7.8\pm2.0)\times10^{-2}$	26 ± 7			
		C3	$(4.3\pm1.0)\times10^{-5}$	109 ± 26			
7.76	$(\frac{11}{2}^-)$	C3	$(1.16\pm0.05)\times10^{-4}$	369 ± 15			
8.35 c)	$\frac{1}{2}^+$	CO, or		7.6 ± 1.4			
8.40 c)	$\frac{5}{2}^+$	C2		8.3 ± 2.6			
8.47 c)	$\frac{7}{2}^+$						
8.50 c)	$\frac{5}{2}^-$						

a) (Ki 78a). See also table 17.15 in (Aj 77).
b) Used to evaluate the widths.
c) These levels were unresolved and were analyzed as a group.

17.15. The data of (No 77b) show a broad dipole resonance centered at 22–23 MeV with strength extending down to 10–12 MeV. A smaller resonance, with a form factor consistent with C2, is found between $E_x=17.5$ and 19.6 MeV (No 77b). The transitions to ^{17}O*(0.87, 5.08) can be described as single-particle transitions (Ki 78a). See also (Hy 80) and (Ar 78b, Ar 79n, Za 79, Bo 80b, Li 81j; theor.).

51. ^{17}O(n, n)^{17}O

See (No 77d; theor.).

52. ^{17}O(p, p)^{17}O

Angular distributions of elastically scattered protons have been measured at a number of energies in the range $E_p=8.6$ to 65.8 MeV [see (Aj 77)] and at $E_p=35.2$ MeV (Fa 80a). See also ^{18}F in (Aj 83), (No 78e, Se 78f, Ke 80c, Pu 81) and (Co 76u, To 77i, Am 78b, Ka 78u, Gr 79m, Am 80a; theor.).

TABLE 17.15

Inelastic groups observed in ^{17}O(e, e') [a])

E_x (MeV)	Γ (keV)
11.71±0.05	narrow
11.95±0.05	~250
12.66±0.05	~90
12.96±0.05	~200
13.56±0.05	~150
14.14±0.10	~100
14.76±0.10	>300
15.24±0.10	~200
16.52±0.05	~300
17.09±0.05	narrow
17.5–19.6 [b])	
20.5	
22.0 [c])	
23.0 [c])	

[a]) (No 77b). Other inelastic groups are displayed in table 17.14.
[b]) C2.
[c]) C1.

53. ^{17}O(d, d)^{17}O

The angular distribution of elastically scattered deuterons has been studied at $E_d = 18$ MeV (Li 76).

54. (a) ^{17}O(^{3}He, ^{3}He)^{17}O
(b) ^{17}O(α, α)^{17}O

Elastic angular distributions have been measured at $E(^3\text{He}) = 11.0$ and 17.3 MeV [see (Aj 77)] and at $E(^3\overrightarrow{\text{He}}) = 33.3$ MeV (Le 81f; also polarization; to both ^{17}O*(0, 0.87)). In a study of the (^{3}He, p) reaction, (Fo 78o) find 3–4% core excitation [3p−2h configuration] in the ground state of ^{17}O. For reaction (b) see (Kn 79i, Kn 77c). See also (Ma 77uu).

55. (a) ^{17}O(^{9}Be, ^{9}Be)^{17}O
(b) ^{17}O(^{10}B, ^{10}B)^{17}O

For reaction (a) see (Pa 79; theor.). For fusion cross sections in reaction (b) see (Wi 80e, Ch 81c).

56. (a) ^{17}O(^{12}C, ^{12}C)^{17}O
(b) ^{17}O(^{13}C, ^{13}C)^{17}O

Elastic angular distributions are reported at $E(^{17}\text{O}) = 30.5$ and 33.8 MeV for reaction (a) and 29.8 and 32.3 for reaction (b) [also ^{17}O*(0.87)] (Ch 78f, Ch 77m).

For fusion cross section measurements see (He 78j; reaction a) and (Wi 80e; reactions a and b). See also (Pa 78, Va 78g, Pa 79; theor.).

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

Angular distributions involving $^{17}O^*(0, 0.87)$ in reaction (a) have been studied at $E(^{16}O) = 22$ to 32 MeV and $E(^{17}O) = 25.7$ to 32.0 MeV: see (Aj 77). The elastic scattering angular distribution in reaction (b) has been reported at $E(^{17}O) = 36$ MeV (Ka 77bb). For fusion cross sections see (Wi 80e; reaction a). See also (Fi 74f, Ho 78n) and (Im 77b, Cr 79b, Le 79a, Sa 79l; theor.).

58. (a) $^{17}O(^{24}Mg, ^{24}Mg)^{17}O$
    (b) $^{17}O(^{27}Al, ^{27}Al)^{17}O$
    (c) $^{17}O(^{40}Ca, ^{40}Ca)^{17}O$

For reaction (a) see (Pa 80g; theor.). For reaction (b) see (Ei 77) for fusion cross sections. See also (Sa 80m) and (Va 78g; theor.). For reaction (c) see (La 80f; elastic $\sigma(\theta)$; $E(^{17}O) = 61.1$ MeV).

59. $^{17}F(\beta^+)^{17}O$ $Q_m = 2.762$

See ^{17}F.

60. $^{18}O(\gamma, n)^{17}O$ $Q_m = -8.0446$

See (Ba 76ii) and ^{18}O in (Aj 78, Aj 83).

61. $^{18}O(p, d)^{17}O$ $Q_m = -5.820$

Angular distributions have been measured at a number of energies for $E_p = 17.6$ to 43.6 MeV [see (Aj 77)], at $E_p = 24.4$ MeV (Pi 73d: $d_0 \to d_7$) and at $E_p = 51.9$ MeV (Oh 77: $d_0 \to d_2$). See also ^{19}F in (Aj 83).

62. $^{18}O(d, t)^{17}O$ $Q_m = -1.787$

Angular distributions of tritons have been measured at $E_d = 17$ MeV [see (Aj 77)] and at $E_d = 17$ and 52 MeV: see table 17.16. Comparisons of the analog reactions (d, t) and (d, ^{3}He) have been made at $E_d = 52$ MeV (Ma 77k): see also reaction 9 in ^{17}N.

63. $^{18}O(^3He, \alpha)^{17}O$ $Q_m = 12.533$

The $T = \frac{3}{2}$ states reported by (De 69c) are displayed in table 17.17 [the isospin identification is based on the enhanced excitation and the narrow widths of these states]. The branching ratios for the various decays of $^{17}O^*(11.08)$ [the lowest $T = \frac{3}{2}$ state in ^{17}O] and for the analog state in ^{17}F are displayed in table 17.11: the decay width of the ^{17}O state is approximately 200 times greater than that of the ^{17}F state (Ad 73b).

TABLE 17.16
States of ^{17}O from ^{18}O(d, t) [a])

E_x [b]) (MeV)	$J^\pi; T$ [b])	l	C^2S
0	$\frac{5}{2}^+; \frac{1}{2}$	2	1.53 [d])
0.87	$\frac{1}{2}^+; \frac{1}{2}$	0	0.21 [d])
3.06	$\frac{1}{2}^-; \frac{1}{2}$	1	1.08
3.84	$\frac{5}{2}^-; \frac{1}{2}$	>2	
4.55	$\frac{3}{2}^-; \frac{1}{2}$	1	0.12
5.09	$\frac{3}{2}^+; \frac{1}{2}$	2	0.10
5.38	$\frac{3}{2}^-; \frac{1}{2}$	1	0.53
5.70	$\frac{7}{2}^-; \frac{1}{2}$		
5.94	$\frac{1}{2}^-; \frac{1}{2}$	1	0.06
6.86		≠1	
7.38 [c])	$\frac{5}{2}^+ + \frac{5}{2}^-$	≠2	
8.20	$\frac{3}{2}^-; \frac{1}{2}$	1	0.15
8.47	$\frac{7}{2}^+; \frac{1}{2}$		
8.69	$\frac{3}{2}^-; \frac{1}{2}$	1	0.10
9.15	$\frac{1}{2}^-; \frac{1}{2}$	1	0.10
9.49	$\frac{5}{2}^-; \frac{1}{2}$		
11.08	$\frac{1}{2}^-; \frac{3}{2}$	1	0.96
11.41±0.01 [a])	$T=\frac{1}{2}$ [a])	(1)	0.04
12.12±0.01 [a])	$T=\frac{1}{2}$ [a])	(1)	0.24
12.47	$\frac{3}{2}^-; \frac{3}{2}$	1	0.24
12.76±0.01 [a])	$T=\frac{1}{2}$ [a])	(1)	0.17
12.94	$\frac{1}{2}^+; T=\frac{3}{2}$	0	0.19±0.05
13.64	$(\frac{5}{2})^+; \frac{3}{2}$	2	0.29±0.12
16.58±0.01 [a])	$(\frac{1}{2}, \frac{3}{2})^-; \frac{3}{2}$ [a])	1	0.93
18.14±0.01 [a])	$(\frac{1}{2}, \frac{3}{2})^-; \frac{3}{2}$ [a])	1	0.17

[a]) (Ma 77k): $E_d = 52$ MeV; DWBA analysis.
[b]) From table 17.7, unless footnote is shown.
[c]) Unresolved.
[d]) (Fo 78d; $E_d = 17$ MeV) report spectroscopic factors of 1.48± 0.27 and 0.29±0.05 (DWBA), 1.30 and 0.31 (CCBA), respectively, for ^{17}O*(0, 0.87).

64. ^{18}O(^{9}Be, ^{10}Be)^{17}O $\qquad Q_m = -1.233$

Angular distributions have been studied at $E(^{18}\mathrm{O}) = 16$ and 20 MeV: see (Aj 77).

65. (a) ^{18}O(^{10}B, ^{11}B)^{17}O $\qquad Q_m = 3.411$
(b) ^{18}O(^{11}B, ^{12}B)^{17}O $\qquad Q_m = -4.675$

Angular distributions (reaction a) have been measured at $E(^{18}\mathrm{O}) = 20$ and 24 MeV: see (Aj 77). For S-factor measurements see (Sw 74a). Cross sections for reaction (b) are several orders of magnitude less than those for reaction (a) for $E(^{18}\mathrm{O})_{\mathrm{c.m.}} = 3 \rightarrow 7.7$ MeV (Sw 74a).

TABLE 17.17

$T = \frac{3}{2}$ states of ^{17}O from ^{18}O(^{3}He, α)^{17}O [a,b]

E_x (MeV ± keV)	l_n	J^π	C^2S [c]
11.082 ± 6	1	$(\frac{1}{2})^-$	0.49
12.471 ± 5	1	$(\frac{3}{2})^-$	0.27
12.950 ± 8	0	$\frac{1}{2}^+$	0.096
12.994 ± 8			
13.640 ± 5	2	$(\frac{5}{2})^+$	0.39
14.219 ± 8			
14.282 ± 12			
15.101 ± 8			

[a]) See also table 17.11.
[b]) (De 69c).
[c]) Calculated assuming $C^2S = 4$ for ^{15}O*(6.18) in ^{16}O(^{3}He, α)^{15}O.

66. (a) ^{18}O(^{12}C, ^{13}C)^{17}O $Q_m = -3.098$
(b) ^{18}O(^{13}C, ^{14}C)^{17}O $Q_m = 0.132$
(c) ^{18}O(^{14}N, ^{15}N)^{17}O $Q_m = 2.789$

For reactions (a) and (b) see (Aj 77). For reaction (c) see (Sw 74a).

67. ^{18}O(^{18}O, ^{19}O)^{17}O $Q_m = -4.088$

See (Ka 77v). See also (Aj 77).

68. ^{19}F(π^-, 2n)^{17}O $Q_m = 122.747$

The 0.87 MeV γ-ray is observed (En 76).

69. ^{19}F(n, t)^{17}O $Q_m = -7.5560$

Angular distributions of the t_0 and t_1 groups are reported at $E_n = 14.4$ MeV: see (Aj 77).

70. ^{19}F(p, ^{3}He)^{17}O $Q_m = -8.320$

Angular distributions have been reported at $E_p = 30.5$ and 42.4 MeV: see (Aj 77). See also ^{20}Ne in (Aj 78).

71. ^{19}F(d, α)^{17}O $Q_m = 10.033$

Observed α-groups are displayed in table 17.14 of (Aj 77). Angular distributions have been measured at many energies in the range $E_d = 0.3$ to 27.5 MeV: see table 17.16 in (Aj 71) and (Aj 77). See also (An 79r).

72. ^{19}F(α, ^{6}Li)^{17}O $Q_m = -12.340$

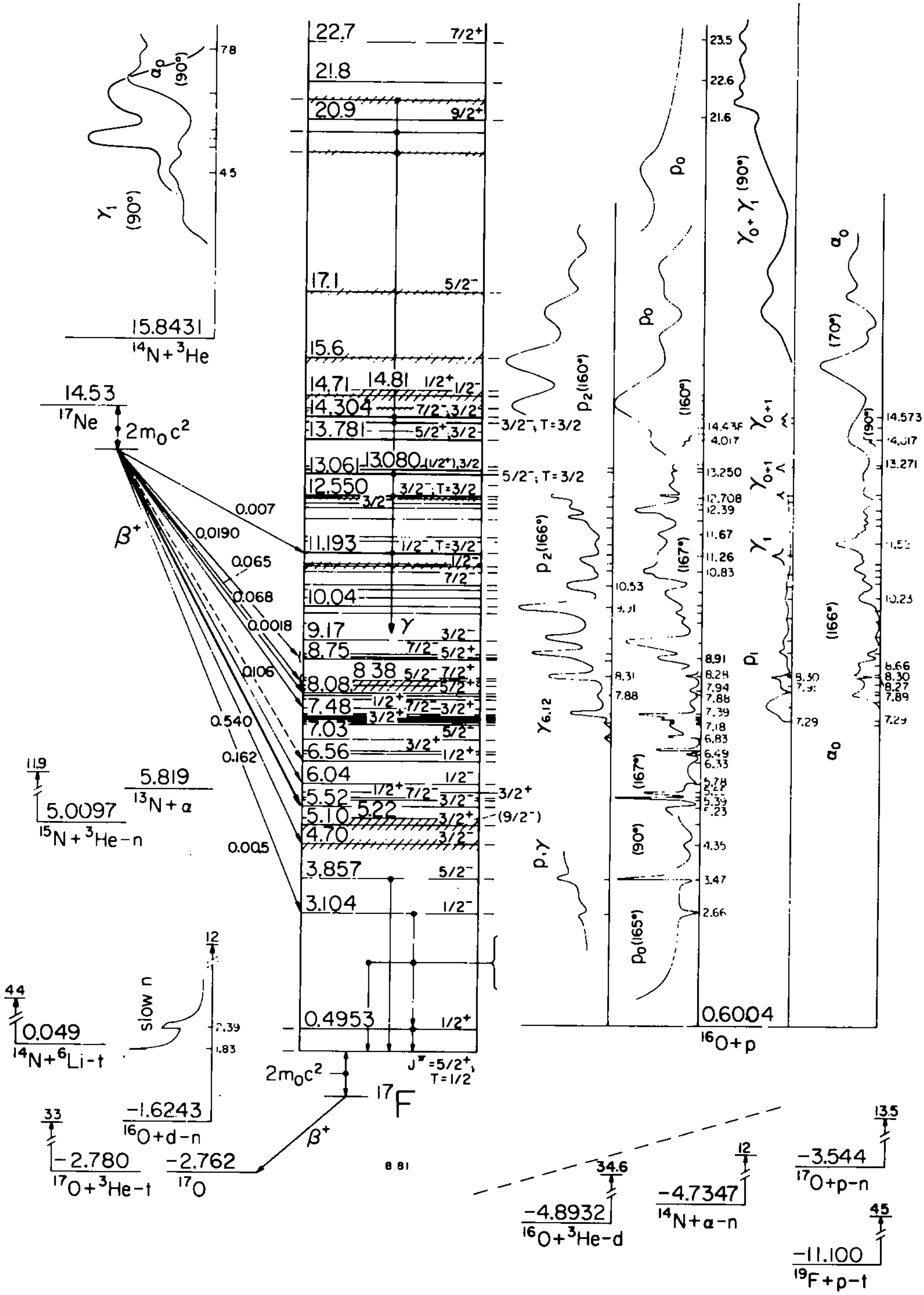

Fig. 8. Energy levels of ^{17}F. For notation see fig. 2.

Angular distributions are reported at $E_\alpha = 28$ and 42 MeV, involving $^{17}O^*(0, 0.87)$: see (Aj 77).

73. $^{20}Ne(n, \alpha)^{17}O$ $Q_m = -0.587$

At $E_n = 14.1$ MeV angular distributions of α_0 and α_1 are reported: see (Aj 77).

74. $^{29}Si(^{16}O, ^{28}Si)^{17}O$ $Q_m = -4.330$

See (Si 80g; theor.).

^{17}F

(Figs. 8 and 9)

GENERAL[†]

Shell and cluster models: (Du 77b, Ha 77w, Po 77c, Th 78e).

Special states: (He 77h, En 78c, Ch 80o, Ta 81i).

Electromagnetic transitions: (Mc 76m, Br 77, Ha 77w, Ho 77, Ch 80o).

Complex reactions involving ^{17}F: (Ar 77b).

Astrophysical questions: (Si 77d, Wo 78f).

Reactions involving pions: (Os 81a, Pu 81).

Other topics: (Sa 76i, Ba 77v, En 78c, Sh 78q, Sl 78, Be 79a, Ta 81i).

Ground state of ^{17}F: (Jo 76c, Mc 76m, Sa 76i, An 77b, Br 77, Du 77b, Ha 77w, Ko 77w, Po 77c, Sh 77i, Ar 78a, Sl 78, Ch 80o, Ta 81i).

$$\mu = 4.7223 \pm 0.0012 \text{ n.m. (Le 78n).}$$

$$Q = 0.10 \pm 0.02 \text{ b (Mi 74l).}$$

1. $^{17}F(\beta^+)^{17}O$ $Q_m = 2.762$

Two recent measurements of the half-life of ^{17}F are 64.31 ± 0.09 sec (Az 77) and 64.80 ± 0.12 sec (Al 77g): the weighted mean of these is 64.49 ± 0.16 sec; $\log ft = 3.488 \pm 0.001$. Earlier values are listed in (Aj 71, Aj 77). The upper limit for the β^+ decay to $^{17}O^*(0.87)$ is $< 3.4 \times 10^{-4}$ per decay (Ga 69e) [$\log ft > 8.6$]. See also (Ra 78f) and (Az 77a, Br 78d, Ba 79j, Os 79, To 79; theor.).

2. $^{12}C(^{12}C, ^{7}Li)^{17}F$ $Q_m = -16.860$

See (Aj 71).

[†] See also (Aj 77).

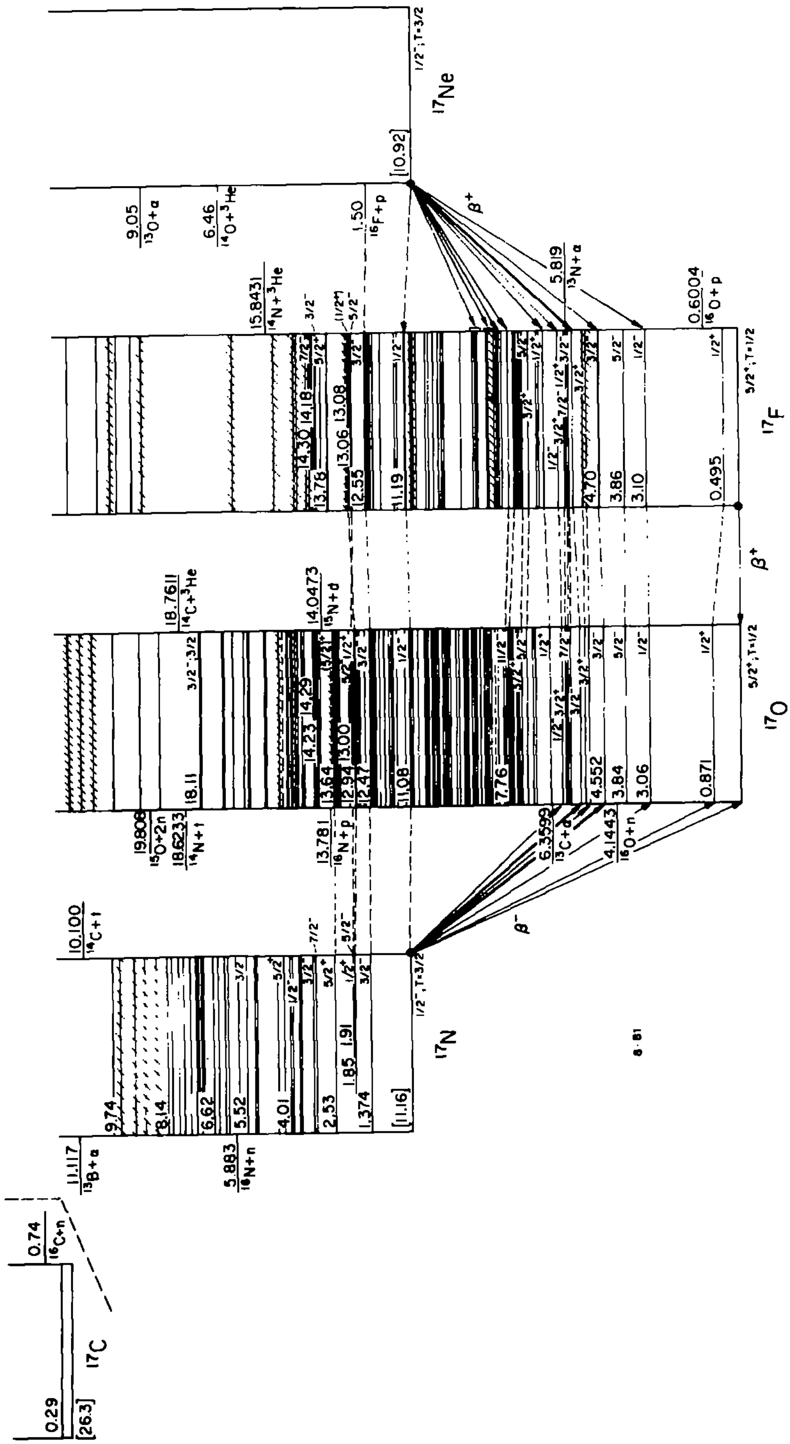

Fig. 9. Isobar diagram, $A = 17$. For notation see fig. 5.

TABLE 17.18

Energy levels of ^{17}F

E_x in ^{17}F (MeV ± keV)	$J^\pi; T$	τ or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
0	$\frac{5}{2}^+; \frac{1}{2}$	$\tau_{1/2} = 64.49 \pm 0.16$ sec	β^+	1→5, 7→12, 18→32
0.49533±0.10	$\frac{1}{2}^+$	$\tau_m = 412 \pm 9$ psec	γ	3, 5, 8, 10, 12, 18, 19, 22→28, 30, 32
3.104±3	$\frac{1}{2}^-$	$\Gamma = 19 \pm 1$	γ, p	5, 8, 10, 12, 13, 18, 19, 28, 30
3.857±4	$\frac{5}{2}^-$	1.5±0.2	γ, p	5, 8, 10, 12, 13, 18, 19, 30
4.696±10	$\frac{3}{2}^-$	225	p	8, 10, 13, 18, 28
5.103±10	$\frac{3}{2}^+$	1530	p	12
5.22±10	$(\frac{9}{2}^-)$			8, 10, 11
5.521±10	$\frac{3}{2}^-$	68	p	8, 10, 13, 28
5.672±10	$\frac{7}{2}^-$	40	p	8, 10, 13
5.682±10	$\frac{1}{2}^+$	<0.6	p	8, 10, 13
5.817±10	$\frac{3}{2}^+$	180	p	8, 13
6.036±10	$\frac{1}{2}^-$	30	p	8, 10, 13, 28
6.556±10	$\frac{1}{2}^+$	200	p	13
6.7087±0.3	$(\frac{3}{2}, \frac{5}{2})^+$	<3	p	8, 10, 13
6.774±10	$\frac{3}{2}^+$	4.5	p	13
7.027±10	$\frac{5}{2}^-$	3.8	p	10, 13
7.356±10	$\frac{3}{2}^+$	10±2	p, α	10, 13, 17
7.448±7		≤5	p	13
7.454±7		7±2	p, α	13, 17
7.471±7		5±2	p	13
7.479±10	$\frac{3}{2}^+$	795	p	13
7.546±10	$\frac{7}{2}^-$	30	p	13
7.75±20	$\frac{1}{2}^+$	179±3	p, α	13, 17, 28
7.95±15		10±3	p	13
8.01±20		50±20	p, α	13, 17
8.075±10	$\frac{5}{2}^+$	100±20	p, α	10, 13, 17, 28
8.2	$\frac{3}{2}^-$	700±250	p, α	13, 17
8.383±5	$\frac{5}{2}^-$	11±5	p, α	13, 17
8.416±10	$\frac{7}{2}^+$	45±10	p, α	13, 17, 28
8.75±30	$\frac{5}{2}^+$	170±30	p, α	13, 17
8.76	$\frac{3}{2}^+$	90±20	p	13
8.98±20	$\frac{7}{2}^-$	165±30	p, α	13, 17
9.17±60	$\frac{3}{2}^-$	140±30	p, α	13, 17
9.92	$\frac{9}{2}^+$	90±30	p, α	13, 17
10.04±20	$\frac{7}{2}$	280±100	p	13
10.22±20		250±80	α	17
10.40±20	$(\frac{5}{2}^+)$	160±40	p	13
10.499±15	$\frac{7}{2}^-$	165±25	p, α	13, 17
10.79±20		120±40	p, (α)	13, 17
10.91±100	$\frac{1}{2}^-$	560±100	p	13
10.95±20		190±50	p, (α)	13, 17
11.1928±2.3	$\frac{1}{2}^-; \frac{3}{2}$	0.20±0.04	γ, p, α	10, 12, 13, 17, 28
11.43±20		240±50	p, α	13, 17
11.58±40		160±30	p	13
12.00±20		120±40	p, α	13, 17
12.25±20	$\frac{3}{2}^-$	300±30	p	13

TABLE 17.18—continued

E_x in ^{17}F (MeV ± keV)	$J^\pi; T$	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
12.355 ± 10	$\frac{1}{2}^-$	190 ± 20	p	13
~12.50	$\frac{7}{2}^-$	~600	p	13
12.5501 ± 0.9	$\frac{3}{2}^-; \frac{3}{2}$	2.83 ± 0.12	γ, p, α	10, 12, 13, 17
13.061 ± 4	$\frac{5}{2}^-; \frac{3}{2}$	2 ± 1	γ, p, α	10, 12, 13, 17
13.080 ± 4	$(\frac{1}{2}^+); \frac{3}{2}$	2 ± 1	p, α	13, 17
13.13 ± 100	$\frac{5}{2}^-$	520 ± 50	p	13
13.781 ± 4	$\frac{5}{2}^+; \frac{3}{2}$	12 ± 5	p, α	13, 17
14.00 ± 50	$\frac{7}{2}^-$	260 ± 30	p	13
14.176 ± 6	$\frac{3}{2}^-; \frac{3}{2}$	30 ± 5	γ, p	12, 13
14.3037 ± 3.1	$\frac{7}{2}^-; \frac{3}{2}$	19.3 ± 1.6	γ, p, α	12, 13, 17
14.38 ± 50	$\frac{5}{2}^-$	610 ± 50	p	13
14.71 ± 100	$\frac{1}{2}^-$	470 ± 100	p	13
14.809 ± 20	$\frac{1}{2}^+$	190 ± 25	p	13
15.6		~550	p	13
17.1	$\frac{5}{2}^-$	1500	p	13
20.1 ± 200		1070 ± 160	γ, ^{3}He	5
20.4 ± 100		700 ± 100	γ, ^{3}He	5
20.9	$\frac{9}{2}^+$	600	p	13
21.3 ± 100		900 ± 100	γ, ^{3}He	5
21.8	$(\frac{9}{2}^+)$	400	p	13
22.7	$\frac{7}{2}^+$	600	p	13
23.8	$\frac{7}{2}^+$	600	p	13
25.4	$\frac{7}{2}^-$	1500	p	13
27.2	$\frac{5}{2}^-$	1500	p	13
28.9	$\frac{5}{2}^+$	2000	p	13

TABLE 17.19

States of ^{17}F from ^{14}N(^{3}He, γ) [a]

$E(^3$He) (MeV)	$\Gamma_{c.m.}$ (MeV)	Res. in	$(2J+1)\Gamma_{^3He}\Gamma_\gamma$ (keV^2)	E_x (MeV)
(4.5) [b]	1.0 ± 0.3	γ_1, α [c]	32 ± 20	(19.5 ± 0.2)
5.2	1.07 ± 0.16	γ_2	63 ± 26	20.1 ± 0.2
(5.4) [b]	1.2 ± 0.4	γ_0	46 ± 32	(20.2 ± 0.3)
5.6	0.7 ± 0.1	γ_1	33 ± 11	20.4 ± 0.1
6.6	0.9 ± 0.1	γ_1	74 ± 18	21.3 ± 0.1
(7.8) [b]	2.0 ± 0.5	γ_0	260 ± 140	(22.2 ± 0.3)

[a]) (Wa 81). See also (Ch 79h, Ch 80h). See, however, (Mo 73h).
[b]) Uncertain: J. Lowe, private communication.
[c]) See reaction 6.

3. $^{12}C(^{14}N, {}^{9}Be)^{17}F$ $\qquad Q_m = -10.4362$

Angular distributions are reported to $^{17}F^*(0, 0.50)$ at $E(^{14}N) = 53$ MeV (Ze 76) and 78.8 MeV (Mo 77y; unresolved).

4. $^{12}C(^{20}Ne, {}^{15}N)^{17}F$ $\qquad Q_m = -9.0962$

See (Or 79).

5. $^{14}N(^{3}He, \gamma)^{17}F$ $\qquad Q_m = 15.8431$

Excitation functions for γ_0, γ_1, γ_2 and γ_3 have been studied for $E(^3He) = 3$ to 19 MeV: observed resonances are displayed in table 17.19 (Wa 81). [The earlier work by (Mo 73h), who studied the γ_{0+1} yield at 90°, indicated several sharp resonances].

6. (a) $^{14}N(^{3}He, n)^{16}F$ $\qquad Q_m = -0.969$ $\qquad E_b = 15.8431$
 (b) $^{14}N(^{3}He, p)^{16}O$ $\qquad Q_m = 15.2428$
 (c) $^{14}N(^{3}He, d)^{15}O$ $\qquad Q_m = 1.8035$
 (d) $^{14}N(^{3}He, {}^{3}He)^{14}N$
 (e) $^{14}N(^{3}He, \alpha)^{13}N$ $\qquad Q_m = 10.024$

Excitation functions for protons have been measured for $E(^3He) = 2.5$ to 18 MeV [see (Aj 77)]: some large structures are observed. The polarization of the p_0 group has been studied at $E(^3He) = 9.8$ MeV. The elastic scattering of ^{3}He (reaction d) and the yield of α-particles (reaction e), studied in the ranges $E(^3He) = 4$ to 7 MeV and 2.5 to 8.5 MeV, respectively, show some evidence of structures (Kn 70a, Mo 73h): see the discussion in (Aj 77). See also ^{16}O, ^{16}F, and ^{13}N, ^{14}N and ^{15}O in (Aj 81).

7. $^{14}N(\alpha, n)^{17}F$ $\qquad Q_m = -4.7347$

See ^{18}F in (Aj 78).

8. $^{14}N(^{6}Li, t)^{17}F$ $\qquad Q_m = 0.049$

At $E(^6Li) = 18$ MeV $^{17}F^*(3.86, 5.22 \pm 0.01, 5.67 + 5.68)$ are strongly excited. $J^\pi = \frac{9}{2}^-$ is suggested for $^{17}F^*(5.22)$ (Bi 73a). See also (Ma 77g).

9. $^{14}N(^{10}B, {}^{7}Li)^{17}F$ $\qquad Q_m = -1.945$

See (Aj 77).

10. $^{15}N(^{3}He, n)^{17}F$ $\qquad Q_m = 5.0097$

Angular distributions have been reported to most of the states of ^{17}F with $E_x < 8.1$ MeV at $E(^3He) = 3.8$ and 4.8 MeV: see (Aj 77). Neutron groups have also been reported to ^{17}F states at $E_x = 11.195 \pm 0.007$, 12.540 ± 0.010 and 13.059 MeV, with $\Gamma < 20$, <25 and <25 keV, respectively. Angular distributions at $E(^3He) =$

10.36 and 11.88 MeV lead to $J^\pi = \frac{1}{2}^-$ for ^{17}F*(11.20) [$L = 0$], $\frac{3}{2}^-$ or $\frac{5}{2}^-$ for ^{17}F*(12.54) and ($\frac{3}{2}^-$, $\frac{5}{2}^-$) for ^{17}F*(13.06). These three states are probably the first three $T = \frac{3}{2}$ states in ^{17}F (Ad 69). The branching ratios for transitions to ^{16}O*(0, 6.05, 6.13) for ^{17}F*(11.20) and for the analog $T = \frac{3}{2}$ state in ^{17}O are displayed in table 17.11: the ratios of the reduced widths are quite different in the two mirror nuclei (Mc 70b, Ad 73b).

11. ^{15}N(^{11}B, ^{9}Li)^{17}F $\qquad Q_m = -18.138$

At $E(^{11}\text{B}) = 115$ MeV ^{17}F*(0, 5.22) are strongly populated (Ra 79c).

12. ^{16}O(p, γ)^{17}F $\qquad Q_m = 0.6004$

$$Q_0 = 600.35 \pm 0.28 \text{ keV (Ro 76t)}$$

At low energies the direct capture to ^{17}F*(0, 0.50) is observed: see (Aj 71, Aj 77). Extrapolation of cross-section data leads to $S(0) \approx 8$ keV · b: see (Aj 77). In addition to two $T = \frac{1}{2}$ resonances, five resonances corresponding to $T = \frac{3}{2}$ states are observed in the γ_1 and $\gamma_0 + \gamma_1$ yields: see table 17.20 for the reported parameters. The lowest $T = \frac{3}{2}$ states of even parity at $E_x = 13.27$ and 14.02 MeV [$J^\pi = (\frac{1}{2}^+)$ and $\frac{5}{2}^+$] (see table 17.21) are not observed here: $\Gamma_\gamma \leq 7$ and ≤ 11.8 eV, respectively (Ha 75g). The (E1) values for the $T = \frac{3}{2}$ states are in good agreement with shell model 2p-1h calculations using realistic Kuo–Brown interaction matrix elements (Ha 75g).

TABLE 17.20

Resonances in ^{16}O(p, γ)^{17}F [a])

E_p (MeV ± keV)	Resonant [b]) in	Γ_γ (eV)	Γ (keV)	E_x (MeV)	J^π; T	Refs.
2.66	γ_1	$(12 \pm 2) \times 10^{-3}$		3.11	$\frac{1}{2}^-$; $\frac{1}{2}$	A, (Ro 73aa) [g])
3.47	γ_0	0.11 ± 0.02	<1.5	3.86	$\frac{5}{2}^-$; $\frac{1}{2}$	(Se 63e)
11.275 ± 6	γ_1	6.0 ± 2.5 [c])	≤ 1.6	11.204	$\frac{1}{2}^-$; $\frac{3}{2}$	(Ha 75g)
12.707 ± 1	$\gamma_0 + \gamma_1$	11.3 ± 3.4 [c])	1.8 ± 0.5	12.550	$\frac{3}{2}^-$; $\frac{3}{2}$	(Ha 75g, Kh 79b)
13.255 ± 6	$\gamma_0 + \gamma_1$	2.8 ± 1.8 [c])	5.0 ± 1.5	13.065	$\frac{5}{2}^-$; $\frac{3}{2}$	(Ha 75g)
14.435 ± 10	γ_0	72 ± 37 [e])	41 ± 10	14.174	$\frac{3}{2}^-$; $\frac{3}{2}$	(Ha 75g, Kh 79b)
14.583 ± 6 [d])	$\gamma_0 + \gamma_1$	13.4 ± 7.0 [c])	28 ± 5	14.313	$\frac{7}{2}^-$; $\frac{3}{2}$	(Ha 75g)

A See (Aj 71).

[a]) See also table 17.21.

[b]) γ_0 and γ_1 correspond to transitions to ^{17}F*(0, 0.50), respectively.

[c]) These Γ_γ are based on J^π and Γ_{p_0}/Γ determinations by (Sk 74) and R. G. Van Bree (unpublished) [quoted by (Ha 75g)]. The B(E1) values for these four states are 4.7 ± 2.0, 5.4 ± 1.6, 1.2 ± 0.8 and $4.4 \pm 2.3 [\times 10^{-3}]\, e^2 \cdot \text{fm}^2$.

[d]) See the text of reaction 12 for discussion of the observed pigmy and giant resonances (Ha 75h).

[e]) See also table 17.18 in (Aj 77).

[f]) $\Gamma_{\gamma_1}/\Gamma_{\gamma_0} \leq 0.14$. $(2J+1)\Gamma_p\Gamma_\gamma/\Gamma = 11.4 \pm 2.6$ eV.

[g]) $C^2S = 0.90$ and 1.00, respectively, for ^{17}F*(0, 0.50).

TABLE 17.21
Resonances in $^{16}O(p, p)^{16}O$ and $^{16}O(p, \alpha)^{13}N$ [a])

E_p (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Particles out	Γ_{p_0}/Γ	$^{17}F^*$ (MeV)	J^π; T
2.663 ± 7	19 ± 1	p_0		3.105	$\frac{1}{2}^-$
3.47	1.53 ± 0.2	p_0		3.86	$\frac{5}{2}^-$
4.354 ± 10	225	p_0		4.696	$\frac{3}{2}^-$
4.787 ± 10	1530	p_0		5.103	$\frac{3}{2}^+$
5.231 ± 10	68	p_0		5.521	$\frac{3}{2}^-$
5.392 ± 10	40	p_0		5.672	$\frac{7}{2}^-$
5.402 ± 10	<0.6	p_0		5.682	$\frac{1}{2}^+$
5.546 ± 10	180	p_0		5.817	$\frac{3}{2}^+$
5.779 ± 10	30	p_0		6.036	$\frac{1}{2}^-$
6.332 ± 10	200	p_0		6.556	$\frac{1}{2}^+$
6.4944 ± 0.1 [b])	<3	p_0		6.7087	(j)
6.564 ± 10	4.5	p_0		6.774	$\frac{3}{2}^+$
6.833 ± 10	3.8	p_0, $\gamma_{6.13}$		7.027	$\frac{5}{2}^-$
7.183 ± 10	10 ± 2	p_0, p_2, α_0		7.356	$\frac{3}{2}^+$
7.280 ± 7	≤5	p_0		7.448	
7.287 ± 7	7 ± 2	p_0, p_1, p_2, α		7.454	
7.305 ± 7	5 ± 2	p_0, p_2		7.471	
7.313 ± 10	795	p_0		7.479	$\frac{3}{2}^+$
7.385 ± 10	30	p_0, p_2, $\gamma_{6.13}$		7.546	$\frac{7}{2}^-$
7.60 ± 20	179 ± 3	p_0, p_1, α_0		7.75	$\frac{1}{2}^+$
7.81 ± 15	10 ± 3	p_2		7.95	
7.88 ± 20	50 ± 20	p_0, $\gamma_{6.13}$, $\gamma_{6.92}$, α_0		8.01	
7.94 ± 15	100 ± 20	p_0, p_1, α_0		8.07	$\frac{5}{2}^+$
8.1	700 ± 250	(p_0), p_1, α_0		8.2	$\frac{3}{2}^-$
8.275 ± 4	11 ± 5	$p_0 \to p_3$, α_0		8.383	$\frac{5}{2}^-$
8.310 ± 10	45 ± 10	$p_0 \to p_3$, $\gamma_{6.13}$, $\gamma_{6.92}$, α_0		8.416	$\frac{7}{2}^+$
8.66 ± 30	170 ± 30	p_2, p_3, p_4, α_0		8.75	$\frac{5}{2}^+$
8.68	90 ± 20	p_0	0.2	8.76	$\frac{3}{2}^+$
8.91 [c])	165 ± 30	$p_0 \to p_4$, $\gamma_{6.13}$, $\gamma_{6.92}$, α_0	0.34 ± 0.05	8.98 ± 0.02	$\frac{7}{2}^-$
9.11 [c])	140 ± 30	$p_0 \to p_4$, $\gamma_{6.13}$, $\gamma_{6.92}$, α_0	0.55 ± 0.05	9.17 ± 0.06 [d])	$\frac{3}{2}^-$

TABLE 17.21—continued

E_p (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Particles out	Γ_{p_0}/Γ	$^{17}F^*$ (MeV)	$J^\pi; T$
9.91 [c]	90 ± 30	p_0, p_2, α_0	0.095 ± 0.005	9.92	$\frac{9}{2}^+$
10.04 ± 20	280 ± 100	p_0, p_1		10.04	$\frac{7}{2}$
10.23 ± 20	250 ± 80	α_0		10.22	
10.42 ± 20	160 ± 40	p_0, p_1, p_3		10.40	$(\frac{5}{2}^+)$
10.525 ± 15	165 ± 25	p_0, p_2, α_0	0.28 ± 0.03	10.499	$\frac{7}{2}$
(10.75 ± 50)		p_0, p_1, α_0		(10.71)	$(\frac{7}{2}^-)$
10.83 ± 20	120 ± 40	p_0, p_2, $(p_3), (\alpha_0)$		10.79	
10.96 ± 100	560 ± 100	p_0	0.25 ± 0.07	10.91	$\frac{1}{2}$
11.00 ± 20	190 ± 50	(p_2), $p_3, (\alpha_0)$		10.95	
11.2636 ± 2.0 [e]	0.20 ± 0.04	p_0, p_2, p_4, α_0	0.093 ± 0.013	11.1928 ± 2.1	$\frac{1}{2}^-$; $\frac{3}{2}$
11.52 ± 20	240 ± 50	p_2, α_0		11.43	
11.67 ± 40	160 ± 30	p_0, p_3		11.58	
12.12 ± 20	120 ± 40	p_2, α_0		12.00	
12.39 ± 20	300 ± 30	p_0, p_2	0.26 ± 0.03	12.25	$\frac{3}{2}^-$
12.500 ± 10	190 ± 20	p_0, p_1, p_4	0.31 ± 0.03	12.355	$\frac{1}{2}^-$
≈12.65	≈600	p_0	≈0.09	≈12.50	$\frac{7}{2}^-$
12.7077 ± 2.0 [f]	2.83 ± 0.12	$p_0, p_2, p_4, p_5, \alpha_0, \alpha_1$	0.332 ± 0.018	12.5504 ± 2.3	$\frac{3}{2}^-$; $\frac{3}{2}$
(13.06 ± 100)		p_0		(12.88)	$(\frac{7}{2}^-)$
(13.06 ± 50)		p_0		(12.88)	$(\frac{1}{2}^+)$
13.250 ± 4	2 ± 1	$p_0, p_{1+2}, p_{3+4}, p_5, \alpha_0$	0.15 ± 0.04	13.060	$\frac{5}{2}^-$; $\frac{3}{2}$
13.271 ± 4	2 ± 1	$p_0 \rightarrow p_4, \alpha_0$	0.04 ± 0.02	13.080	$(\frac{1}{2}^+)$; $\frac{3}{2}$
13.32 ± 100	520 ± 50	p_0	0.163 ± 0.016	13.13	$\frac{5}{2}^-$
14.017 ± 4	12 ± 5	$p_0, p_{1+2}, p_{3+4}, \alpha_0$	0.02 ± 0.01	13.781	$\frac{5}{2}^+$; $\frac{3}{2}$
(14.20 ± 50)		p_0		(13.95)	$(\frac{1}{2}^+)$
14.25 ± 50	260 ± 30	p_0	0.08 ± 0.01	14.00	$\frac{7}{2}^-$
14.438 ± 6	27 ± 5	p_0, p_{3+4}	0.04 ± 0.02	14.177	$\frac{3}{2}^-$; $\frac{3}{2}$ [i]
14.5730 ± 3.0 [g]	19.3 ± 1.6	$p_0, p_{1+2}, p_{3+4}, p_5, \alpha_0$	0.085 ± 0.008	14.3037 ± 3.1	$\frac{7}{2}^-$; $\frac{3}{2}$
14.65 ± 50	610 ± 50	p_0	0.10 ± 0.01	14.38	$\frac{5}{2}^-$

TABLE 17.21—continued

E_p (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Particles out	Γ_{p0}/Γ	^{17}F* (MeV)	$J^\pi; T$
(14.94 ± 100)		p_0			$(\frac{3}{2}^-)$
15.00 ± 100	470 ± 100	p_0	0.25 ± 0.03	14.71	$\frac{1}{2}^-$
15.110 ± 20	190 ± 25	p_0	0.150 ± 0.015	14.809	$\frac{1}{2}^+$
(15.245 ± 100)		p_0		(14.94)	$(\frac{5}{2}^+)$
(15.30 ± 50)		p_0		(14.98)	$(\frac{3}{2}^+)$
(15.37 ± 100)		p_0		(15.05)	$(\frac{3}{2}^-)$
(15.545 ± 100)		p_0		(15.22)	$(\frac{7}{2}^-)$
15.9 [h]	≈550	p_0, p_{1+2}		15.6	
17.6	1500	p_0, p_{3+4}		17.1	$\frac{5}{2}^-$
20.4	600	p_0		19.8	$\frac{3}{2}^+$
21.6	600	p_0, (α)		20.9	$\frac{9}{2}^+$
22.6	400	p_0, (α)		21.8	$(\frac{9}{2}^+)$
23.5	600	p_0, p_5		22.7	$\frac{7}{2}^+$
24.7	600	p_0, (α)		23.8	$\frac{7}{2}^+$
26.4	1500	p_0, (α)		25.4	$\frac{7}{2}^-$
28.3	1500	p_0		27.2	$\frac{5}{2}^-$
30.1	2000	p_0		28.9	$\frac{5}{2}^+$

a) See earlier references in tables 17.20 (Aj 71) and 17.19 (Aj 77). See also table 17.20 here.
b) Preliminary value (Ba 80h). See also (St 81b).
c) (Kr 81a): polarized protons; preliminary results. $\Gamma_p = 51 \pm 8$, 143 ± 30 and 11.4 ± 2 keV for ^{17}F*(8.98, 9.17, 9.92).
d) (Kr 81a) report that there are indications of two very sharp resonances corresponding to ^{17}F*(9.10, 9.13) with $J^\pi = \frac{1}{2}^-$ and $\frac{3}{2}^-$.
e) $\Gamma_{p0} = 19 \pm 3$ eV (Hi 76d).
f) $\Gamma_{p0} = 0.94 \pm 0.06$ keV, $\Gamma_{\alpha 0} = 62 \pm 16$ eV, $\Gamma_{\alpha 1} = 53 \pm 22$ eV (Hi 76d); J. Lowe, private communication.
g) $\Gamma_{p0} = 1.65 \pm 0.12$ keV, $\Gamma_{\alpha 0} = 2.6 \pm 0.7$ keV (Hi 76d).
h) See also table 17.20 of (Aj 71), for possible other resonances.
i) (Da 79f) have confirmed $J^\pi = \frac{3}{2}^-$.
j) $J^\pi = (\frac{3}{2}, \frac{5}{2})^+$ (G. Bauer and H. T. Richards, private communication).

The $(\gamma_0 + \gamma_1)$ yield at 90° has been studied for $E_p = 15.75$ to 31.66 MeV: it shows the giant dipole resonance centered at $E_x = 22$ MeV with a width of ≈5 MeV and a pigmy resonance centered at 17.5 MeV. The integrated strength of the, mainly $T = \frac{1}{2}$, giant resonance is 10 MeV · mb: the observed strength distribution is in good agreement with odd parity 2p-1h, 1p excitation calculations. The pigmy resonance is due to $f_{7/2} \to d_{5/2}$: the main $f_{7/2}$ strength lies in two states at $E_x = 16.9$ and 18.0 MeV (Ha 75h). See also (Bl 79d), (Ca 81b) (Zi 75c; astrophys.) and (Al 77i; theor.).

13. (a) ^{16}O(p, p)^{16}O $E_b = 0.6004$
(b) ^{16}O(p, 2p)^{15}N $Q_m = -12.1276$

(c) $^{16}O(p, pn)^{15}O$ $Q_m = -15.6639$
(d) $^{16}O(p, p\alpha)^{12}C$ $Q_m = -7.1620$

Yield curves for elastic protons, protons scattered to $^{16}O^*(6.05, 6.13, 6.92, 7.12, 8.87)$ and for γ-rays from $^{16}O^*(6.13, 6.92)$ have been studied at many energies up to $E_p = 46$ MeV: see table 17.19 in (Aj 71) and (Aj 77) for the earlier work and (Kr 81a: $E_{\vec{p}} = 8.5$ to 10.6 MeV; p_0), (Da 79f: $E_{\vec{p}} \approx 14.4$ MeV; p_0). The observed resonances are displayed in table 17.21.

Polarization results have been reported at $E_p = 3.47$ to 49.4 MeV [see (Aj 77)] and at $E_p = 40$ MeV (Mo 78m; p_5), 42.5, 44.0 and 49.3 MeV (Pe 77b; p_5), 65 MeV (Sa 79p, Sa 81c; p_0), 135 MeV (Ke 80g; p_2, p_4), 800 MeV (Ad 79b, Gl 79c; p_0, p_{1+2}, p_3, p_4, p_5) and 1 GeV (Al 78q, Al 78t, Al 80b). For total reaction cross sections see (De 79z, Dy 81). See also (Aj 77).

Polarization in quasi-elastic scattering (reaction b) has been studied at $E_p = 200$ MeV by (Ki 80a, Ki 76m) and 635 MeV (Na 78k, Na 77s). For reactions (c) and (d) see (Aj 77). For reaction (d) see (Dy 81). For spallation measurements see (In 76d, Mo 77k) and (Vd 79). For antiproton scattering see (Au 81; theor.).

See also ^{16}O and (Go 78p, Sa 78k, Wi 79, Wi 79b, Le 80u), (Ra 79h; astrophys.), (Pl 77a, De 79w, Vo 79a, Mc 80, Wh 80a, Ra 81b) and (Je 76b, Le 76p, Ko 77jj, Ph 77c, Ab 78b, Al 78k, Bi 78n, Br 78q, Gr 78g, Ph 78, Re 78e, Sc 78g, Wu 78b, Bi 79b, Ch 79p, Er 79, Ko 79e, Ma 79mm, Ph 79c, Ra 79k, Au 80d, Ay 80, De 80ff, Dm 80, Ma 80cc, Ma 80ee, Ra 80, De 81n; theor.).

14. $^{16}O(p, n)^{16}F$ $Q_m = -16.211$ $E_b = 0.6004$

For analyzing power measurements see (Ma 81e, Ma 81k; $E_{\vec{p}} = 135$ MeV). See also ^{16}F.

15. $^{16}O(p, d)^{15}O$ $Q_m = -13.4392$ $E_b = 0.6004$

The excitation function for d_0 ($\theta = 70°$) has been measured for $E_p = 21$ to 38.5 MeV. A strong resonance is observed at $E_p = 24$ MeV: see table 17.21. Polarization measurements are reported at $E_p = 65$ MeV (Ho 81; d_0), 30.3 MeV [see (Aj 77)] and $E_{\vec{p}} = 200$ MeV (Li 81i). See also ^{15}O in (Aj 81) and (Ca 79e).

16. (a) $^{16}O(p, t)^{14}O$ $Q_m = -20.4062$ $E_b = 0.6004$
(b) $^{16}O(p, {}^3He)^{14}N$ $Q_m = -15.2428$

The excitation function ($\theta = 70°$) for tritons has been measured for $E_p = 32$ to 39.5 MeV: no structure is observed [see (Aj 77)]. Differential cross sections and analyzing powers have been studied at $E_p = 43.8$ MeV for the transitions to $^{14}O^*(0, 5.17, 6.29, 6.59, 7.78, 9.72)$ and $^{14}N^*(0, 2.31, 3.95, 5.11, 7.03, 9.17)$: attempts to fit the analyzing powers with zero-range DWBA were only successful for the first pair of analog states [$^{14}O_{g.s.}$, $^{14}N^*(2.31)$] (Ma 74c). For other polarization measurements see (Aj 77). See also ^{14}N and ^{14}O in (Aj 81) and (Ha 77v).

17. ^{16}O(p, α)^{13}N $Q_m = -5.2185$ $E_b = 0.6004$

Excitation functions of various α-groups and activation functions have been measured from threshold to $E_p = 44$ MeV: see table 17.19 in (Aj 71) and (Aj 77) for the earlier work and (Gr 77d; 6.6 to 10.4 MeV; σ_t). Observed resonances are displayed in table 17.21. Some broad structures have been reported above $E_p \simeq$ 15 MeV; particularly strong peaks appear at $E_p \sim 22$ and 25.5 MeV: see (Aj 77).

This reaction is involved in explosive burning in stars: see (Aj 77) for the earlier work and (Gr 77d: $S_0 = 4 \pm 3$ b at E_p(c.m.) = 6.5 MeV). See also (Cl 77c).

18. ^{16}O(d, n)^{17}F $Q_m = -1.6243$

Slow neutron thresholds have been observed corresponding to the ground and first excited states of ^{17}F: see (Aj 71). The E_x of ^{17}F*(0.50) is 495.33 ± 0.10 keV (Al 66g; from γ-measurement); $\tau_m = 407 \pm 9$ psec (Be 64f). Neutron groups have been observed corresponding to ^{17}F*(0, 0.50, 3.10, 3.86, 4.70). Angular measurements have been obtained for the n_0 and n_1 groups ($l_p = 2$ and 0, respectively: $J^\pi = \frac{5}{2}^+$ and $\frac{1}{2}^+$) for $E_d \leq 12$ MeV: see table 17.21 in (Aj 71) and (An 72j; $E_d = 3.10$, 3.40 and 3.66 MeV). For polarization measurements see ^{18}F in (Aj 83). See also (Hu 80c) and (Aj 77).

19. ^{16}O(^{3}He, d)^{17}F $Q_m = -4.8932$

At $E(^3\text{He}) = 18$ MeV, angular distributions of the deuterons to ^{17}F*(0, 0.50, 3.104 ± 0.003, 3.857 ± 0.004) have been measured. The spectroscopic factors for ^{17}F*(0, 0.50) are 0.94 and 0.83. Two-step processes appear to be involved in the excitation of ^{17}F*(3.10, 3.86) (Fo 75j). Angular distributions have also been measured at $E(^3\text{He}) = 30$ MeV (Ko 77k; to ^{17}F*(5.1, 5.7) and at $E(^3\overrightarrow{\text{He}}) = 33$ MeV (Lu 80a, Ro 81c; d_0, d_1). See also ^{19}Ne in (Aj 83) and (Co 77a; theor.).

20. ^{16}O(α, t)^{17}F $Q_m = -19.2137$

See (Aj 71, Aj 77).

21. ^{16}O(^{7}Li, ^{6}He)^{17}F $Q_m = -9.374$

The angular distribution involving ^{17}F$_{g.s.}$ has been measured at $E(^7\text{Li}) = 36$ MeV (Sc 73m).

22. (a) ^{16}O(^{10}B, ^{9}Be)^{17}F $Q_m = -5.985$
(b) ^{16}O(^{11}B, ^{10}Be)^{17}F $Q_m = -10.628$

Angular distributions have been measured at $E(^{10}\text{B}) = 100$ MeV for the transitions to ^{17}F*(0 + 0.50, 5.1, 8.1) (Na 75j), and at $E(^{11}\text{B}) = 115$ MeV for the transition to ^{17}F$_{g.s.}$ (Ra 79c).

23. (a) ^{16}O(^{12}C, ^{11}B)^{17}F $Q_m = -15.3566$
(b) ^{16}O(^{13}C, ^{12}B)^{17}F $Q_m = -16.933$

Angular distributions have been measured at $E(^{12}C) = 76.8$ MeV (Mo 77y, Mo 79z; $^{17}F^*(0, 0.5)$) and at $E(^{13}C) = 105$ MeV (Ra 79c; $^{17}F_{g.s.}$).

24. $^{16}O(^{14}N, ^{13}C)^{17}F$ $\qquad Q_m = -6.9503$

Angular distributions involving $^{17}F^*(0, 0.5)$ have been measured at $E(^{14}N) =$ 76.2 MeV (Mo 77y, Mo 79z) and 155 MeV (Na 75j, Na 76h).

25. $^{16}O(^{16}O, ^{15}N)^{17}F$ $\qquad Q_m = -11.5272$

Angular distributions involving $^{17}F^*(0+0.5)$ have been measured at $E(^{16}O) =$ 95.2 MeV (Mo 77y, Mo 79z).

26. $^{17}O(p, n)^{17}F$ $\qquad Q_m = -3.544$

Angular distributions of the n_0 and n_1 groups have been obtained for $E_p = 6.95$ to 13.50 MeV (n_0) and 6.95 to 12.45 MeV (n_1). There appears to be collective enhancement in the $L = 2$ transition to $^{17}F^*(0.5)$. A large spin–flip term in the effective two-body force is necessary to account for the strength of the ground state transition (An 69a). See also ^{18}F in (Aj 83).

27. $^{17}O(^3He, t)^{17}F$ $\qquad Q_m = -2.780$

Angular distributions have been studied for t_0 and t_1 at $E(^3He) = 17.3$ MeV [see (Aj 77)] and for t_0 at $E(^3\overrightarrow{He}) = 33$ MeV (Ba 81c).

28. $^{17}Ne(\beta^+)^{17}F$ $\qquad Q_m = 14.53$

See ^{17}Ne.

29. $^{19}F(\gamma, 2n)^{17}F$ $\qquad Q_m = -19.582$

See ^{19}F in (Aj 83).

30. $^{19}F(p, t)^{17}F$ $\qquad Q_m = -11.100$

Angular distributions have been measured for the $t_0 \rightarrow t_3$ groups at $E_p = 22.8$, 42.4 and 45 MeV: see (Aj 77).

31. $^{20}Ne(p, \alpha)^{17}F$ $\qquad Q_m = -4.1306$

See (Gr 77d, Ko 80w) and (Aj 77).

32. (a) $^{20}Ne(^3He, ^6Li)^{17}F$ $\qquad Q_m = -8.151$
(b) $^{22}Ne(^3He, ^8Li)^{17}F$ $\qquad Q_m = -15.993$

At $E(^3He) = 75$ and 88 MeV $^{17}F^*(0, 0.5)$ have been populated in both reactions (Ke 78c).

^{17}Ne

(Figs. 8 and 9)

GENERAL†

Theory and reviews: (Be 75cc, Ce 77c, Gu 78d, Wo 78f, Be 79a)

Other topics: (Gr 81b)

Mass of ^{17}Ne: The mass excess adopted by (Wa 77) is 16.478 ± 0.026 MeV, based on unpublished data. We retain the mass excess 16.48 ± 0.05 MeV based on the evidence reviewed in (Aj 77).

TABLE 17.22

Energy levels of ^{17}Ne [a]

E_x in ^{17}Ne (MeV)	$J^\pi; T$	$\tau_{1/2}$ (msec)	Decay	Reaction
0	$\frac{1}{2}^-; \frac{3}{2}$	109.0 ± 1.0	β^+ [b]	1

[a]) The evidence for excited states of ^{17}Ne has not been published: see (Aj 77).

[b]) See also tables 17.3 and 17.23.

1. (a) ^{17}Ne$(\beta^+)^{17}$F$^* \rightarrow {}^{16}$O$+$p $\qquad Q_m = 13.93$

   (b) ^{17}Ne$(\beta^+)^{17}$F $\qquad Q_m = 14.53$

The half-life of ^{17}Ne is 109.0 ± 1.0 msec (Ha 71b). Earlier values (see (Aj 71)) gave a mean value of 108.0 ± 2.7 msec. The decay is primarily to the proton unstable states of ^{17}F at 4.70, 5.52 and 6.04 MeV with $J^\pi = \frac{3}{2}^-, \frac{3}{2}^-$ and $\frac{1}{2}^-$: see table 17.23. The super-allowed decay to the analog state [^{17}F*(11.20)] has $\log ft = 3.29^{+0.04}_{-0.07}$. The character of the decay leads to $J^\pi = \frac{1}{2}^-$ for ^{17}Ne$_{\text{g.s.}}$ (Ha 71b). See table 17.3 for a comparison of the mirror ^{17}N and ^{17}Ne decays and table 17.11 for the decay of ^{17}F*(11.20). See also (Ra 78f).

2. ^{20}Ne(^{3}He, ^{6}He)^{17}Ne $\qquad Q_m = -26.19$

   See (Aj 77).

^{17}Na

(Not illustrated)

^{17}Na has not been observed: its mass excess is predicted to be 35.61 MeV by (Ke 66c). It is then unbound with respect to breakup into ^{16}Ne$+$p by 4.3 MeV and with respect to breakup into ^{14}O$+$3p by 5.7 MeV.

† See also (Aj 77).

TABLE 17.23

β^+ decay of ^{17}Ne [a])

Decay to $^{17}F^*$ (MeV ± keV)	J^π	Branching (%)	$\log ft$ [b])	Decay to $^{16}O^*$ (MeV)	Decay (%)
0	$\frac{5}{2}^+$	0.5 ± 0.2 [c])	6.95 ± 0.13		
0.50	$\frac{1}{2}^+$	1.1 ± 0.5 [c])	6.55 ± 0.21		
3.084 ± 30	$\frac{1}{2}^-$	0.48 ± 0.07	6.44 ± 0.06	0	100
4.609 ± 15	$\frac{3}{2}^-$	16.2 ± 0.7	4.59 ± 0.02	0	100
5.480 ± 10	$\frac{3}{2}^-$	54.0 ± 0.7	3.86 ± 0.01	0	100
6.037 ± 10	$\frac{1}{2}^-$	10.6 ± 0.2	4.42 ± 0.01	0	100
6.406 ± 30		0.35 ± 0.10	5.80 ± 0.13	0	100
7.708 ± 30	$\frac{1}{2}^+$	0.18 ± 0.05	5.67 ± 0.12	0	>95
				6.05	<5
8.075 ± 10	$\frac{5}{2}^+$	6.83 ± 0.11	3.96 ± 0.01	0	99.5
				6.05	0.49 ± 0.02
8.436 ± 10		6.51 ± 0.26	3.85 ± 0.02	0	94.3
				6.05	5.7 ± 0.5
8.825 ± 25		1.90 ± 0.06	4.23 ± 0.02	0	92.4
				6.05	7.6 ± 1.1
11.19 [e])	$\frac{1}{2}^-$; $T = \frac{3}{2}$	$0.71^{+0.10}_{-0.05}$	$3.29^{+0.04}_{-0.07}$	0	10 ± 2
				6.13	22 ± 2
				6.92	24 ± 6
				7.12	44 ± 4
[d])					

[a]) (Ha 71b). See also table 17.23 in (Aj 71).

[b]) $\log ft$ values calculated by (Ha 71b) using an atomic mass excess of 16.517 ± 0.026 MeV [and $\tau_{1/2} = 109.0 \pm 1.0$ msec] rather than the presently adopted 16.48 ± 0.05 MeV. Since this energy difference leads to quite small changes, the original calculations are quoted here. However, table 17.3 (which compares the analog decays) shows corrected ft values.

[c]) Calculated branchings, based on the mirror ^{17}N decay.

[d]) A proton group with $E_{c.m.} = 2.83$ MeV has been observed: the level in ^{17}F to which it corresponds is not known.

[e]) See also table 17.11.

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ERRATA†

Energy levels of light nuclei, $A = 13$–15, Nucl. Phys. **A360** (1981) 1

p. 144 Table 15.18

The J^{π} of $^{15}O^*(9.527)$ should be listed as $(\frac{3}{2})^+$ and reaction 16 should be added.

The level listed at 9.72 MeV should be entirely deleted.

p. 152 Table 15.23

The same changes should be made here also.

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† I am very indebted to Dr. E. K. Warburton for pointing out these errors to me.

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