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Energy Levels of Light Nuclei
$A = 18$

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Abstract: An evaluation of $A = 18$–19 was published in *Nuclear Physics A*595 (1995), p. 1. This version of $A = 18$ differs from the published version in that we have corrected some errors discovered after the article went to press. The introduction and introductory tables have been omitted from this manuscript. Reference key numbers are in the NNDC/TUNL format.

(References closed October 31, 1994)

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Table of Contents for $A = 18$

Below is a list of links for items found within the PDF document. The introductory Table 3 *is available on this website via the link.*

^{18}He

(Not illustrated)

Not observed: See (1982AV1A, 1983ANZQ).

^{18}Li

(Not illustrated)

^{18}Li has not been observed. Shell model calculations described in (1988POZS) predict the ground-state magentic dipole moment and charge and matter radii.

^{18}Be

(Not illustrated)

^{18}Be has not been observed. It is predicted to have a mass excess of 78.43 MeV: see (1978AJ03). ^{18}Be is then unstable with respect to breakup into ^{16}Be $+$ 2n, ^{15}Be $+$ 3n, ^{14}Be $+$ 4n, ^{13}Be $+$ 5n, ^{12}Be$+$6n, ^{11}Be$+$7n and ^{10}Be$+$8n by, respectively 3.01, 3.04, 6.26, 2.92, 4.93, 1.76 and 1.26 MeV, using the masses for the residual nuclei adopted by (1991AJ01, 1993AU05, 1993TI07). See also (1983ANZQ, 1989OG1B).

^{18}B

(Not illustrated)

^{18}B has not been observed in the bombardment of Ta by 44 MeV/A Ar ions (1985DE60, 1985LA03, 1986PO13) or in the bombardment of Be by 12 MeV/A ^{56}Fe ions (1984MU27). ^{18}B has been predicted to have a mass excess of 52.3 MeV (1993AU05). It would then be unstable with respect to ^{17}B $+$ n by 0.5 MeV: see (1978AJ03, 1985WA02). ^{18}B is calculated to have $J^\pi = 4^-$ and to have excited states at 0.62, 0.86 and 1.59 MeV with $J^\pi = 1^-$, 2^- and 2^- (1985PO10). The shell model calculations of (1992WA22) predict $J^\pi = 2^-$ for the ground state with the first three excited states at 0.45, 0.52, 0.839 MeV with $J^\pi = 4^-$, 2^-, 3^-. See also (1987AJ02, 1988GUZT).

^{18}C

(Figs. 1 and 5)

GENERAL: See Table 18.1.

Mass of ^{18}C: The atomic mass excess of ^{18}C adopted by (1993AU05) is 24.920 ± 0.030 MeV, based on the Q-value of the ^{48}Ca(^{18}O, ^{18}C)^{48}Ti reaction. ^{18}C is then bound by 4.188 MeV with respect to breakup into ^{17}C $+$ n. See also (1982FI10, 1987AJ02, 1992WA22).

Table 18.1: ^{18}C – General

Reference	Description
Reviews:	
1987GI1C	Pion-nucleus interactions
1989AJ1A	Summary of recent work involving light nuclei (Sec. 4.2 covers ^{18}C)
1989DE52	Exotic light nuclei: production, mass meas., decay, & complex reactions
1989VOZM	History of & future prospects for production of nuclei far from stability
1994BO1H	Summary of recent research employing radioactive nuclear beams
Other Articles:	
1987BL18	Gogny's effective interaction used to calc. ground & excited states of light nuclei
1987SN01	Partitioning of 2 component particle syst. & isotope distrib. in nucl. fragmentation
1988POZS	Shell-model calcs. of exotic light nucl. ground state props. compared to exp. data
1989RA16	Predxns. from systematics & tabulation of B(E2; $0_1^+ \rightarrow 2_1^+$) values for even-even nucl.
1989SA10	Total cross sections of reactions induced by neutron-rich light nuclei
1990LO11	Self-consistent calcs. of light neutron-rich nuclei using density-functional method
1990ST08	2nd-generation microscopic predictions of β-decay half-lives of neutron-rich nuclei
1991RE02	Meas. half-lives & neutron emission probabilities of neutron-rich Li-Al nuclei
1992LA13	Influence of separation energy on the radius of neutron-rich nuclei
1992WA22	Effective interactions for the 0p1s0d nuclear shell-model space
1993PA14	Relativistic mean field theory; calc. binding energy, rms radii, deformation parameters

1. ^{18}C(β^-)^{18}N $\qquad Q_{\rm m} = 11.807$

The half-life of ^{18}C has been measured to be 66^{+25}_{-18} ms (1988MU08), 78^{+20}_{-15} ms (1989LE16), 94 ± 27 ms (1991RE02), (95 ± 10) ms (1991PR03).

Branching to states in ^{18}N has been measured by (1991PR03) and is presented here in Table 18.6. These authors also measured the total branching probability to gamma emitting states plus the ground state of ^{18}N to be $\mathrm{P}_\gamma = (81 \pm 5)$%. The β-delayed neutron emission probability is $\mathrm{P_n} = 1 - \mathrm{P}_\gamma = (19 \pm 5)$%. Other values reported for $P_{\rm n}$ are (25 ± 4.5)% (1988MU08), (50 ± 10)% (1989LE16), (43.3 ± 6.5)% (1991RE02). The ^{18}C(β^-) decay is also discussed in the analysis of Gamow-Teller rates presented in (1993CH06). Experimental Gamow-Teller matrix elements are compared with results of shell-model calculations.

2. ^{18}O(π^-, π^+)^{18}C $\qquad Q_{\rm m} = -25.706$

Table 18.2: Energy levels of ^{18}C

E_x in ^{18}C (MeV $\pm$ keV)	$J^\pi; T$	$\tau_{1/2}$ (ms)	Decay	Reactions
0	$(0^+); 3$	95 ± 10	(β^-)	2, 3
1.62 ± 20	$(2^+); 3$			2, 3

The angular distribution of the π^+ to the ground state of ^{18}C has been measured at $E_{\pi^-} = 164$ MeV by (1984GI10) [see also for excitation function at $\theta = 5°$ for $E_{\pi^-} \approx 140$ to 240 MeV]. There is also some indication of the population of an excited state at $E_x = 1.55$ MeV (1984GI10). See also (1983AJ01).

3. ^{48}Ca(^{18}O, ^{18}C)^{48}Ti $\qquad Q_m = -21.434$

At $E(^{18}\text{O}) = 112$ MeV the ground state and an excited state at 1.62 ± 0.024 MeV are observed by (1982FI10). See also (1983AJ01).

^{18}N

(Figs. 1 and 5)

GENERAL: See Table 18.3.

Mass of ^{18}N: The atomic mass excess derived from the Q-value of the ^{18}O(^{7}Li, ^{7}Be)^{18}N reaction and adopted by (1993AU05) is 13.117 ± 0.020 MeV (1983PU01). ^{18}N is then stable with respect to breakup into $^{17}\text{N} + \text{n}$ by 2.825 MeV. See (1983AJ01) for the earlier work.

1. ^{18}N(β^-)^{18}O $\qquad Q_m = -13.899$

The half-life of ^{18}N is 0.624 ± 0.012 s (1982OL01). The decay branches are displayed in Table 18.18. The nature of the decay leads to $J^\pi = 1^-$ for the ^{18}N ground state (1982OL01). See also (1983SN03), and see the measurements on beta branching reported in (1989ZH04) which indicate a total branching ratio to alpha-particle-emitting states in ^{18}O of at least 12.2%. A delayed-neutron emission probablility $P_n = (14.3 \pm 2.0)$% was measured by (1991RE02). More recently a study reported by (1994SC01) gave $P_n = (2.2 \pm 0.4)$% for transitions to neutron unstable states in ^{18}O above $E_x = 9.0$ MeV. See also reaction 22 under ^{18}O.

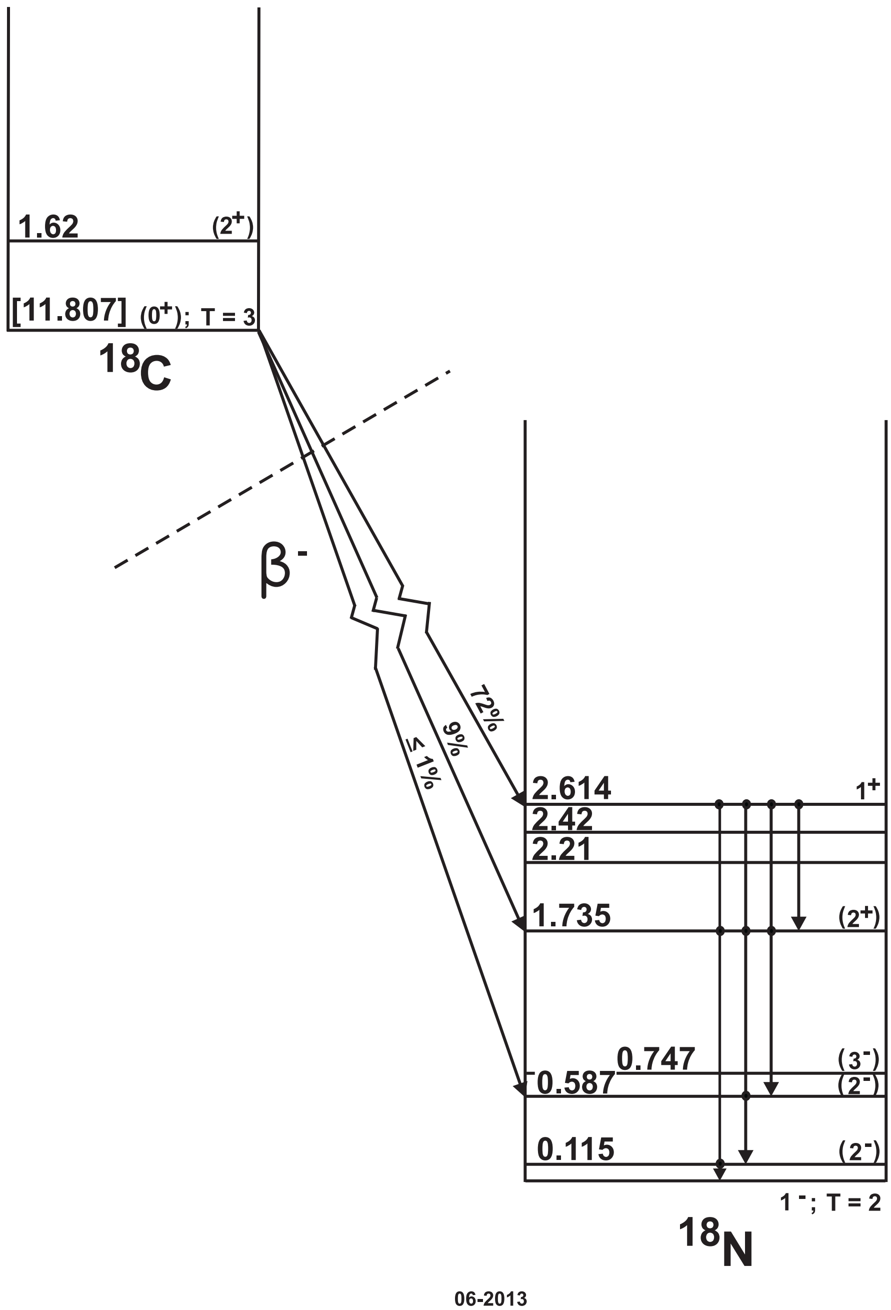

Fig. 1: Energy levels of ^{18}C and ^{18}N. For notation see Fig. 2. For more detailed β^- branching information see ^{18}C reaction 1.

Table 18.3: ^{18}N – General

Reference	Description
Reviews:	
1988MI1J	Shell model transition densities for electron and pion scattering
1990TH1E	Summary of topics presented at Workshop on Primordial Nucleosynthesis
1994BO1H	Summary of recent research employing radioactive nuclear beams
Other Articles:	
1987AN1A	Use of LISE spectrometer at GANIL for identification of exotic light nuclei
1987RI03	Isotopic distributions of fragments in ^{40}Ar + ^{68}Zn at 27.6 MeV/nucleon
1987SA25	LISE spectrometer at GANIL: results of search for new exotic nuclei
1989SA10	Total cross sections of reactions induced by neutron-rich light nuclei
1991RE02	Meas. half-lives & neutron emission probabilities of neutron-rich Li-Al nuclei
1993PA14	Relativistic mean field theory; calc. binding energy, rms radii, deformation parameters

2. ^{14}C(^{7}Li, ^{3}He)^{18}N $\qquad Q_{\rm m} = -10.121$

The preliminary work described in (1983AJ01) has not been published.

3. ^{14}C(^{18}O, ^{14}N)^{18}N $\qquad Q_{\rm m} = -13.740$

At $E(^{18}{\rm O}) = 92.2$ MeV groups are observed to the ground state of ^{18}N (unresolved) and to an excited state at $E_{\rm x} = 575 \pm 25$ keV (1980NA14).

4. ^{18}C(β^-)^{18}N $\qquad Q_{\rm m} = 11.807$

See reaction1 under ^{18}C. Branching to states in ^{18}N was measured by (1991PR03) and is presented here in Table 18.6. These authors measured the total branching probability to gamma emitting states of ^{18}N to be $P_\gamma = 81 \pm 5$ %. Measurements of γ-ray energies and branching lead to the level energies displayed in Table 18.7 and ^{18}N radiative decays in Table 18.5.

5. ^{18}O(π^-, π^0)^{18}N $\qquad Q_{\rm m} = -9.305$

Table 18.4: Energy levels of ^{18}N

E_x(MeV ± keV)	$J^\pi; T$	$\tau_{1/2}$ (ms)	Decay	Reactions
0	$1^-; 2$	624 ± 12	β^-	1, 3, 5, 6, 7
0.11490 ± 0.18 [a]	(2^-) [b]		γ	3, 4, 5, 7
0.58756 ± 0.24	(2^-) [b]		γ	3, 4, 7, 8
0.747 ± 10	(3^-) [b]			7
[c]				
1.73485 ± 0.22 [a]	(2^+) [d]		γ	4
2.21				7
2.42				7
2.61445 ± 0.23 [a]	1^+ [a,d]		γ	4

[a] Level energies determined from γ energies reported in (1991PR03).
[b] Suggested by (1984BA24). See also (1982OL01).
[c] See (1984BA24) for a calculation suggesting additional states in this energy region.
[d] (1993CH06).

Table 18.5: Radiative decays in ^{18}N [a]

E_i (MeV)	J_i^π	E_f (MeV)	Branch (%)
0.115	(2^-)	0	100
0.587	(2^-)	0.115	100 ± 16
1.735	(2^+)	0	33 ± 8
		0.115	38 ± 9
		0.587	29 ± 10
2.614	1^+	0	49 ± 8
		0.115	22 ± 6
		0.587	3 ± 2
		1.735	26 ± 6

[a] (1991PR03).

Table 18.6: Branchings in ^{18}C(β^-)^{18}N

Decay to ^{18}N* (MeV)	Branch [a] (%)	log ft [b]
0.115		
0.587	≤ 1	≥ 6.4
1.735	9 ± 7	5.2 ± 0.4
2.614	72 ± 10	4.08 ± 0.08

[a] (1991PR03), calculated with the hypothesis that there is no direct β-feeding of the 0.115 MeV level. The total probability of β decay to gamma emitting states plus to the ground state is $P_\gamma = (81 \pm 5)$%. The β-delayed neutron probability is $P_{\rm n} = 1 - P_\gamma$.

[b] log ft's were recalculated by evaluators and are slightly different from those in (1991PR03) due to use of level energies from Table 18.4 and Q-values from (1993AU05).

Table 18.7: γ-ray intensities in ^{18}C(β^-)^{18}N [a]

E_γ (keV)	$E_{\rm i}$ (keV)	$E_{\rm f}$ (keV)	I_γ [b]
114.9 ± 0.2	115	0	36.5 ± 7.5
472.7 ± 0.2	587	115	10.2 ± 4.0
879.7 ± 0.2	2614	1735	18.7 ± 5.0
1147.8 ± 0.4	1735	587	8.0 ± 3.7
1619.9 ± 0.3	1735	115	10.5 ± 4.1
1734.8 ± 0.4	1735	0	9.1 ± 3.6
2025.3 ± 0.8	2614	587	2.2 ± 1.5
2499.3 ± 0.4	2614	115	15.8 ± 4.8
2614.2 ± 0.4	2614	0	35.3 ± 7.6

[a] (1991PR03).

[b] γ-ray intensities are per 100 parent decays.

See (1983AS01, 1984AS05).

6. ^{18}O(t, ^{3}He)^{18}N $Q_{\rm m} = -13.880$

See (1983AJ01).

7. ^{18}O(^{7}Li, ^{7}Be)^{18}N $Q_{\rm m} = -14.761$

$Q_0 = -14761 \pm 20$ keV (1983PU01)

At $E(^{7}\text{Li}) = 52$ MeV, ^{7}Be groups are observed corresponding to the excitation of the states displayed in Table 18.4 here (1983PU01).

8. ^{18}O(^{11}B, ^{11}C)^{18}N $Q_{\rm m} = -15.881$

See (1983PU01).

^{18}O

(Figs. 2 and 5)

GENERAL: See Table 18.8.

Isotopic abundance $= (0.200 \pm 0.012)$% (1984DE53).
$\langle r^2 \rangle^{1/2} = 2.784 \pm 0.020$ fm: see reaction 25.

^{18}O*(1.98)
g $= -0.287 \pm 0.015$ [see (1983AJ01)].
$Q = -0.042 \pm 0.008$ b. [weighted mean of -0.036 ± 0.009 and -0.058 ± 0.015 b: see (1983GR28); see also (1983AJ01)].

$$\begin{aligned} B(E2; 0^+ \rightarrow 2^+) &= 39.0 \pm 1.8\ e^2 \cdot \text{fm}^4 \ [(\text{1979FE06, 1983GR10});\ \text{see also (1983AJ01)}]; \\ &= 44.8 \pm 1.3\ e^2 \cdot \text{fm}^4 \ (\text{1982NO04}); \\ &= 47.6 \pm 1.0\ e^2 \cdot \text{fm}^4 \ (\text{1982BA06});\ \text{see also (1987RA01)}. \end{aligned}$$

For a discussion of the hexadecapole deformation see (1983GR10). See also (1987RA01).

1. (a) ^{7}Li(^{11}B, nn)^{16}O $\qquad Q_m = 12.171$
   (b) ^{9}Be(^{9}Be, nn)^{16}O $\qquad Q_m = 11.291$

Reactions (a) and (b) have been studied by (1993CU01, 1993DA17) in low energy heavy-ion fusion reactions. It is reported that the ≈ 3 MeV wide resonance observed at E_x(^{18}O) ≈ 28 MeV in the ^{7}Li $+$ ^{11}B $\rightarrow$ ^{18}O $\rightarrow$ ^{16}O $+$ nn and ^{9}Be $+$ ^{9}Be $\rightarrow$ ^{18}O $\rightarrow$ ^{16}O $+$ nn reactions overlap with the higher part of the $T_< = 1$, ^{18}O GDR observed in photonuclear excitation.

Fig. 2: Energy levels of ^{18}O. 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 ^{18}O 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 cm 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 ^{18}O". For more detailed β^- branching information, see ^{18}N reaction 1.

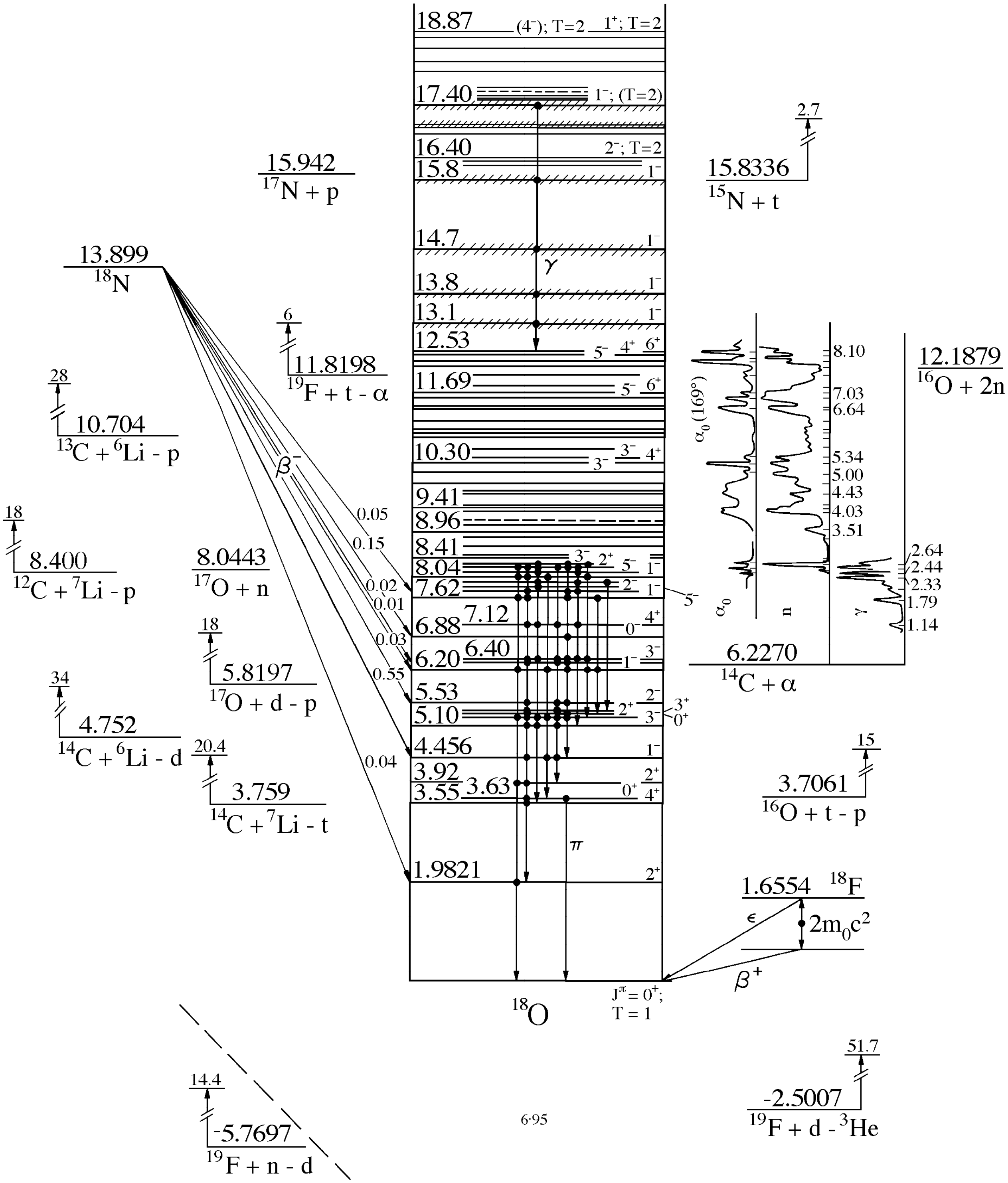
18.87
(4⁻); T=2
1⁺; T=2
17.40
1⁻; (T=2)
16.40
2⁻; T=2
15.8
1⁻
14.7
1⁻
13.8
1⁻
13.1
1⁻
12.53
5⁻ 4⁺ 6⁺
11.69
5⁻ 6⁺
10.30
3⁻ 3⁻ 4⁺
9.41
8.96
8.41
8.04
7.62
7.12
6.88
6.40
6.20
5.53
5.10
4.456
3.92
3.63
3.55
1.9821
2⁺
γ
π
β⁻
0.05
0.15
0.02
0.01
0.03
0.55
0.04
15.942
17N + p
13.899
18N
6
11.8198
19F + t - α
28
10.704
13C + 6Li - p
18
8.400
12C + 7Li - p
8.0443
17O + n
18
5.8197
17O + d - p
34
4.752
14C + 6Li - d
20.4
3.759
14C + 7Li - t
14.4
-5.7697
19F + n - d
2.7
15.8336
15N + t
12.1879
16O + 2n
α0 (169°)
α0
n
γ
8.10
7.03
6.64
5.34
5.00
4.43
4.03
3.51
2.64
2.44
2.33
1.79
1.14
6.2270
14C + α
15
3.7061
16O + t - p
1.6554
18F
ε
2m0c2
β⁺
Jπ = 0⁺;
T = 1
18O
51.7
-2.5007
19F + d - 3He
6·95

Table 18.8: ^{18}O – General

Reference	Description
	Shell model
Review:	
1988BR1P	Status of the nuclear shell model
Other articles:	
1987CH1J	Nucl. struc. calcs. using mixed-config. shell model: effective & surface δ-interactions
1987LE1L	Low-lying non-normal parity states of ^{18}O & ^{18}F calculated in shell model + tensor force
1987MU16	Relativistic effects in the low-energy spectra of 1s0d-shell nuclei
1987SH1O	Validity of M-3Y force equivalent G-matrix element for s-d shell nucl. struc. calcs.
1988BR11	Semi-empirical effective interactions for the 1s-0d shell
1988FI01	Effective interactions for sd-shell-model calculations
1988HI05	Effect on Gamow-Teller strength of config. mixing and p-n correl. in e-e sd-shell nucl.
1989GU06	Hartree-Fock & shell-model charge densities calc. for ^{16,18}O, ^{32,34}S, ^{40,48}Ca
1989HJ03	Effective interactions through 3rd order for $A = 18$ nuclei with the Paris potential
1989OR02	Empirical isospin-nonconserving Hamiltonians for shell-model calculations
1990HJ01	3rd order number-conserving sets & effective interactions calc. with Bonn-Jülich potential
1990HJ03	Choice of single-particle potential & the convergence of the effective interaction
1990MI01	Shell model states in the ^{18}O three-body wave function from Faddeev formalism
1990SK04	Study of $A = 18$ nuclei and the effective interaction in the sd shell
1992FR01	Nuclear charge radii systematics in the sd shell from muonic atom measurements
1992HJ01	Folded-diagram effective interactions with the Bonn meson-exchange potential model
1992JI04	Bonn potential used to evaluate energy spectra of some light sd-shell nuclei
1992OS01	Spin-tensor analysis of realistic shell model interactions
1994VE04	Exp. meas. & calc. of spectroscopic factors from one-proton stripping rxns. on sd-shell nucl.
	Cluster models
1988KU17	Microscopic boson descrip. of p-n systems applied to electron scat. from ^{18}O, ^{20}Ne
1989FU08	Microscopic multichannel calc. of the molecular dipole degree of freedom in ^{18}O
1989TR18	2-nucleon and 4-nucleon clusters in light & heavy nuclei
1990OS03	Cluster-stripping reactions in the heavy-ion collisions (includes ^{14}C(^{6}Li, d)^{18}O)

Reference	Description

Special states

Review:

1988BR1P	Status of the nuclear shell model
1989RA17	Compilation of exp. data on nuclear moments for ground & excited states of nucl.

Other articles:

1987BL18	Gogny's effective inter. used to calc. gnd. & excited states of specific spin-isospin order
1987CH1J	Nucl. struc. calcs. using mixed-config. shell model: effective & surface δ-interactions
1987LE1L	Non-normal parity states of ^{18}O & ^{18}F calculated in shell model + tensor force
1987LI1F	Double delta & surface delta interactions used to calc. low-lying spectra of $^{17-22}$O
1987MU16	Relativistic effects in the low-energy spectra of 1s0d-shell nuclei
1987SH1O	Validity of M-3Y force equivalent G-matrix element for s-d shell nucl. struc. calcs.
1987VA19	Microscopic analysis of excitation of first 2^+ state of ^{18}O on ^{64}Ni
1988KU17	Microscopic boson descrip. of p-n systems applied to electron scat. from ^{18}O & ^{20}Ne
1989FU08	Microscopic multichannel calculation of the molecular dipole degree of freedom in ^{18}O
1989HJ03	Effective interactions through 3rd order for $A = 18$ nuclei with the Paris potential
1989OR02	Empirical isospin-nonconserving Hamiltonians for shell-model calculations
1990MI01	Shell model states in the ^{18}O three-body wave function from Faddeev formation
1990SK04	Study of $A = 18$ nuclei and the effective interaction in the sd shell

Electromagnetic

Review:

1989RA17	Compilation of exp. data on nuclear moments for ground & excited states of nucl.
1993EN03	Strengths of γ-ray transitions in $A = 5 - 44$ nuclei

Other articles:

1987CH1J	Nucl. struc. calcs. using mixed-config. shell model: effective & surface δ-interactions
1989FU08	Microscopic multichannel calc. of the molecular dipole degree of freedom in ^{18}O
1989RA16	Predxns. from systematics & tabulation of B($E2$; $0^+_1 \rightarrow 2^+_1$) values for even-even nucl.
1989SP01	Reduced electric-octupole transition probabilities, B($E3$; $0^+_1 \rightarrow 3^-_1$), for even-even nucl.
1990NO1A	Calcs. of electric quadrupole excitations in relativistic nucleus-nucleus collisions
1993EG04	Calc. of transition probs. with angular-momentum-projected wave functions & realistic forces

Table 18.8 from (1995TI07): ^{18}O – General (continued)

Reference	Description
	Astrophysics
Reviews:	
1988HU1E	Chrondrules: chemical, mineralogical & isotopic constraints on theories of their origin
1989GU1L	Chemical analyses of cool stars (includes isotopic abundance ratios)
1989WH1B	Abundance ratios as a function of metallicity
1990AR10	Nuclear reactions in astrophysics
1990TH1E	Summary of topics presented at Workshop on Primordial Nucleosynthesis
1993MA1M	Review of primordial nucleosynthesis beyond the standard big bang
Other articles:	
1987BE1H	^{12}C/^{13}C & ^{16}O/^{18}O ratios in Venus' atmosphere from high-res. 10-μm spectroscopy
1987FA1C	^{16}O excess in hibonites discredits late supernova injection origin of isotopic anomalies
1987SO1E	Interstellar shock waves related to high ^{10}Be & ^{18}O concentrations in ice cores
1987WA1F	Abundances in red giant stars: C & O isotopes in carbon-rich molecular envelopes
1988BE1B	Past solar activity & geomagnetism info. from ^{10}Be & ^{18}O concentrations in ice cores
1988BU01	Stellar reaction rates of α capture on light $N \neq Z$ nuclei & astrophysical implications
1988CA26	Analytic expressions for thermonuclear reaction rates involving $Z \leq 14$ nucl.
1989JI1A	Nucleosynthesis inside thick accretion disks around massive black holes
1989ME1C	Isotope abundances of solar coronal material derived from solar energetic particle meas.
1990MA1Z	Nuclear reaction uncertainties in standard & non-standard cosmologies
1990ST1G	High spatial resolution isotopic CO & CS observations of M17 SW
1990TO1F	C^{18}O in the Chameleon 1 dark cloud (a nearby site of low-mass star formation)
1991KO31	^{17}O(n, α)^{14}C cross section measured from 25 meV to approximately 1 MeV
1991SA1F	Extragalactic ^{18}O/^{17}O ratios imply high-mass stars preferred in starburst systems
1992GA11	Implications of the ^{14}C(α, γ)^{18}O reaction for nonstandard big bang nucleosynthesis
1992GO14	Alpha capture on ^{14}C from $E_\alpha = 1.14$ to 2.33 MeV and its astrophysical implications
1993GA1G	Secondary radioactive beams used to measure cross sections of astrophysical importance
1994BE29	Neutron capture rates of light isotopes for inhomogeneous Big Bang nucleosythesis
	Applications
Reviews:	
1987SE1D	Progress in the field of accelerator mass spectrometry (1977 – 1987)
1989KU1P	Production and application of stable enriched isotopes in the USSR

Table 18.8 from (1995TI07): ^{18}O – General (continued)

Reference	Description
	Applications – continued
Other articles:	
1987MC1A	O isotopes in refractory stratospheric dust particles: proof of extraterrestrial origin
1987ZU1A	Oxygen isotope effect in high-temperature oxide superconductors
1988FA1A	Extreme ^{18}O depletion in calcite & chert clasts from Elephant Moraine (in Antarctica)
1988FI1C	Assessment of ^{18}O enriched water as a marker of total body water (A)
1988HI1F	Design & uses of target systems used to produce positron emitters (A)
1988HI1G	The oxygen isotope effect in $Ba_{0.625}K_{0.375}BiO_3$ (a high-temp. superconducting oxide)
1988KH06	Threshold track detectors used to study interaction of ^{18}O ions w/ light & heavy targets
1988MI1B	O-isotope analyses & deep-sea temp. changes: implications for rates of oceanic mixing
1988NW1A	Measurement of oil reservoir rock dispersivity by nuclear reaction analysis (A)
1989GR1F	Brachiopod calcite record of oceanic C & O isotope shifts at Permian/Triassic transition
1989NW1A	Assessment of ^{18}O enriched water as a marker of total body water
1989TA1Y	Separation of N & O isotopes by liquid chromatography
1990CH1I	^{18}O isotope studies on redistribution of O obtained in O ion implantation
1990CO1K	Determination of ^{18}O concentrations in microsamples of biological fluids
1990MI15	Determination of absolute oxygen coverage by nuclear reaction analysis
1990SA1J	O isotope evidence for a stronger winter monsoon current during the last glaciation
	Complex reactions
1986MA13	Experimental search for nonfusion yield in heavy residues emitted from $^{11}B + ^{12}C$
1987BE1I	Search for a nucleon-participant multiplicity effect on anomalous fragment production
1987BU07	Projectile-like fragments from $^{20}Ne + ^{197}Au$ – counting simultaneously emitted neutrons
1987HE1H	Search for anomalously heavy isotopes of low Z nuclei
1987VA19	Microscopic analysis of excitation of first 2^+ state of ^{18}O on ^{64}Ni
1988BE56	Light nuclei formation in reactions of B & Ne ions with Ta & Th at $E = 18 - 20$ MeV/A

Table 18.8 from (1995TI07): ^{18}O – General (continued)

Reference	Description
	Complex reactions – continued
1988BL11	Systematics of cluster-radioactivity-decay constants as suggested by microscopic calcs.
1988KH06	Threshold track detectors used to study interaction of ^{18}O ions w/ light & heavy targets
1988PR1C	Target & projectile mass dependence of charge pickup reactions by $\approx$ GeV/N nuclei (A)
1988UT02	Extended Serber model applied to quasi-free stripping reactions
1989GE11	Complex fragments emitted in excited states
1989SA10	Total cross sections of reactions induced by neutron-rich light nuclei
1989TE02	Dissipative mechanisms in the 120 MeV ^{19}F + ^{64}Ni reaction
1989YO02	Quasi-elastic & deep inelastic transfer in ^{16}O + ^{197}Au for $E < 10$ MeV/u
1990LE08	Statistical equilibrium in the ^{40}Ar + ^{12}C system at $E/A = 8$ MeV
1990LI1J	Z dependence of Coulomb dissociation cross sections in heavy ion reactions
	Antimatter
Reviews:	
1986KO1E	Search for $\overline{\text{p}}$-atomic X-rays at LEAR
1987GR1I	Low energy antiproton physics in the early LEAR era
1987VO1B	Interaction and annihilation of anitprotons and nuclei
1987YA1E	Summary of scattering results at LEAR & unique features of the ($\overline{\text{p}}$, $\overline{\text{n}}$) reaction
Other articles:	
1987AD04	Microscopic analysis of antiproton-nucleus elastic scattering
1987GR20	Widths of $4f$ antiprotonic levels in the oxygen region
1987HA1J	Widths of $4f$ antiprotonic levels in the O region using realistic nucl. wavefunctions
1988LI1O	Optical model analysis of antiproton-nucleus elastic scattering (in Chinese)
1989CH13	Phenomenological model analysis of scattering of ≈ 180 MeV antiprotons from nuclei
1989HE21	Microscopic analysis of antiproton elastic scattering on even-even nuclei
1989MA24	Microscopic analysis of antiproton-nucleus inelastic scattering at 600 MeV/c
1992TA08	Eikonal and Glauber calculations of scattering of antiprotons on ^{18}O at 180 MeV

Table 18.8 from (1995TI07): ^{18}O – General (continued)

Reference	Description
	Other topics
Review:	
1988BA82	Use of reactions involving pions & kaons in the study of heavy hypernuclei
1993PE19	Overview of new experimental results in meson-nucleus interactions & future opportunities
Other articles:	
1987BL18	Gogny's effective interaction used to calc. ground & excited states of light nuclei
1988HI05	Effect on Gamow-Teller strength of config. mixing & p-n correl. in e-e sd-shell nucl.
1988KA39	Coulomb effects in the 4-body model of simultaneous 2n transfer induced by heavy ions
1988TR02	Interacting boson scheme for light nuclei
1989BA92	Evaluation of hypernucleus production cross-sections in relativistic heavy-ion collisions
1989OR02	Empirical isospin nonconserving Hamiltonians for shell-model calculations
1989TA32	Schmidt diagrams & configuration mixing effects on hypernuclear magnetic moments
1990BR13	Empir. p-n interactions: global trends, configuration sensitivity & $N = Z$ enhancements
1990HJ01	3rd order number-conserving sets & effective interactions calc. with Bonn-Jülich potential
1990KA1F	Theoretical aspects of nuclear parity violation
1990SK04	Study of the $A = 18$ nuclei and the effective interaction in the sd shell
1994CI02	Specific heat and shape transitions in light sd nuclei
1994LU01	Deep pionic bound states in a nonlocal optical potential
	Ground state properties
Review:	
1989RA17	Compilation of exp. data on nuclear moments for ground & excited states of nucl.
Other articles:	
1987BL18	Gogny's effective inter. used to calc. gnd. & excited states of specific spin-isospin order
1988GU03	Charge-density distribution of 1s-1p & 1d-2s shell nuclei & filling numbers of the states
1989CH1P	1s-0d effective interxns. of isospin triplet & ^{18}Ne-^{18}O Coulomb displacmt. energ. (in Chin.)
1989GU06	Hartree-Fock & shell-model charge densities calc. for ^{16,18}O, ^{32,34}S, ^{40,48}Ca
1989SA10	Total cross sections of reactions induced by neutron-rich light nuclei
1989TR18	2-nucleon & 4-nucleon clusters in nuclei

Table 18.8 from (1995TI07): ^{18}O – General (continued)

Reference	Description
	Ground state properties – continued
1990GU10	Charge densities of sp- and sd-shell nuclei & occupation numbers of 2s states
1990LO11	Self-consistent calcs. of light neutron-rich nuclei using density-functional method
1992FR01	Behavior of nuclear charge radii systematics in the sd shell from muonic atom meas.
1993PA14	Relativistic mean field theory; calc. binding energy, rms radii, deformation parameters
1993PA19	Continuation of 1993PA14: effects of pairing correlation

(A) denotes that only an abstract is available for this reference.

2. (a) ^{10}B(^{9}Be, p)^{18}O $\quad Q_{\rm m} = 16.892$
(b) ^{11}B(^{9}Be, d)^{18}O $\quad Q_{\rm m} = 7.662$

See (1986CU02) for production cross sections of 1.98 MeV γ-rays.

3. ^{12}C(^{7}Li, p)^{18}O $\quad Q_{\rm m} = 8.401$

Observed proton groups are displayed in Table 18.5 od (1987AJ02). See also (1983AJ01).

In a recent experiment, the 4^{+} state at 7117 keV in ^{18}O was studied by (1994ME02) and an E2 strength for the 7117–5060 branches of B(E2) $= 6.4 \pm 1.6$ W.u. was deduced in agreement with results of (1989GA01). It was concluded that it is highly improbable that the 7117 keV state is energetically degenerate with a state of different decay properties.

4. ^{13}C(^{6}Li, p)^{18}O $\quad Q_{\rm m} = 10.704$

See (1986SM01) and Table 18.5 in (1987AJ02). It is noted there that existing data indicate that when $\sigma_{\rm tot}$ to a particular state in ^{18}O is large in this reaction, it is also large in the ^{12}C(^{7}Li, p) reaction. More recent data are reported in (1988SM01) (see Table 18.11 here). Differential cross sections were measured and compared with results of Hauser-Feshbach calculations. The results suggest the presence of an additional non-statistical mechanism.

Table 18.9: Energy levels of ^{18}O [a]

E_x (MeV ± keV)	$J^\pi; T$	τ [b] or $\Gamma_{c.m.}$	Decay	Reactions
0	$0^+; 1$		stable	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 15, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52
1.98207 ± 0.09	2^+	$\tau_m = 2.80 \pm 0.07$ ps (g $= -0.287 \pm 0.015$) ($Q = -0.042 \pm 0.008$ b)	γ	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 15, 17, 19, 20, 21, 22, 25, 26, 27, 28, 29, 30, 32, 33, 39, 40, 42, 44, 45, 47, 48, 49, 50, 51, 52
3.55484 ± 0.40	4^+	$\tau_m = 24.8 \pm 1.2$ ps (g $= -0.62 \pm 0.10$)	γ	3, 4, 7, 9, 10, 15, 16, 17, 19, 20, 21, 22, 25, 28, 33, 39, 40, 51, 52
3.63376 ± 0.11	0^+	$\tau_m = 1.38 \pm 0.16$ ps	γ	3, 4, 7, 9, 10, 15, 19, 22, 25, 28, 33, 39, 40, 50, 51, 52
3.92044 ± 0.14	2^+	$\tau_m = 26.5 \pm 2.9$ fs	γ	3, 4, 7, 9, 10, 15, 19, 22, 25, 28, 33, 39, 51
4.45554 ± 0.10	1^-	$\tau_m = 65 \pm 15$ fs	γ	3, 4, 7, 9, 10, 15, 19, 22, 25, 28, 33, 39, 40, 50, 51
5.09778 ± 0.54	3^-	$\tau_m = 62 \pm 25$ fs	γ	3, 4, 7, 9, 10, 15, 19, 22, 25, 26, 27, 28, 33, 39, 40, 45, 51, 52
5.2548 ± 0.9	2^+	$\tau_m = 10.1 \pm 0.5$ fs	γ	3, 4, 7, 9, 10, 15, 17, 19, 25, 28, 33, 50, 51
5.3364 ± 0.6	0^+	$\tau_m = 200 \pm 40$ fs	γ	3, 4, 9, 15, 19, 25, 33, 51
5.3778 ± 1.2	3^+	$\tau_m < 30$ fs	γ	3, 4, 15, 19, 20, 51
5.53024 ± 0.29	2^-	$\tau_m < 25$ fs $\Gamma < 50$ keV	γ	3, 4, 15, 22, 25, 28, 33, 51
6.19822 ± 0.40	1^-	$\tau_m = 3.7 \pm 0.6$ fs	γ	3, 4, 9, 15, 19, 22, 24, 25, 33, 51
6.3513 ± 0.6	(2^-)	$\tau_m < 35$ fs $\Gamma < 50$ keV	γ	3, 4, 15, 19, 22, 25, 33, 51, 52

Table 18.9: Energy levels of ^{18}O [a] (continued)

E_x (MeV ± keV)	$J^\pi; T$	τ [b] or $\Gamma_{c.m.}$	Decay	Reactions
6.4044 ± 1.2	3^-	$\tau_m = 30 \pm 15$ fs	γ	3, 4, 15, 33, 51
6.88045 ± 0.27	0^-	$\tau_m < 25$ fs	γ	3, 4, 15, 22, 33, 50, 51
7.1169 ± 1.2	4^+	$\tau_m < 25$ fs	γ, α	3, 4, 7, 9, 10, 15, 17, 19, 20, 25, 28, 33, 37, 39, 40, 51
7.6159 ± 0.7	1^-	$\Gamma < 2.5$ keV	γ, α	3, 4, 7, 9, 15, 22, 25, 33, 37, 39, 40, 51
7.77107 ± 0.50	2^-	$\Gamma < 50$ keV	γ	3, 4, 15, 22, 25, 51
7.864 ± 5	5^-		γ	3, 4, 7, 9, 10, 15, 19, 20, 25, 33, 37, 39, 40, 51, 52
7.977 ± 4	$(3^+, 4^-)$		γ	3, 4, 15, 19, 51
8.0378 ± 0.7	1^-	$\Gamma < 2.5$ keV	γ, α	3, 4, 7, 8, 15, 16, 17, 22, 25, 37, 39, 40, 51
8.125 ± 2	5^-		γ, α	3, 4, 7, 9, 10, 15, 25, 51
8.213 ± 4	2^+	$\Gamma = 1.0 \pm 0.8$ keV	γ, n, α	3, 4, 7, 8, 15, 25, 28, 33, 37, 39, 40, 51
8.282 ± 3	3^-	$\Gamma = 8 \pm 1$ keV	γ, n, α	3, 4, 7, 8, 9, 10, 15, 25, 33, 51
8.410 ± 8	(2^-)	$\Gamma = 8 \pm 6$ keV	γ, n, α	8, 15, 25, 51
8.521 ± 6	(4^-)	$\Gamma < 50$ keV	γ	15, 25, 51
8.660 ± 6				15, 51
8.817 ± 12	(1^+)	$\Gamma = 70 \pm 12$ keV	n, α	8, 20, 28, 33
8.955 ± 4	(4^+)	$\Gamma = 43 \pm 3$ keV	γ, n, α	8, 15, 25, 33
(9.0 ± 200) [d]	(1^-)		α	22
9.03				15, 19, 33
(9.10)				33
9.27 ± 20 [d]	$(0, 1, 2)^-$		n	22
9.361 ± 6	2^+	$\Gamma = 27 \pm 15$ keV	γ, n, α	8, 10, 15, 25, 33, 37, 39, 40
9.414 ± 18		$\Gamma \approx 120$ keV	n, α	8, 10, 15, 33
9.48 ± 24		$\Gamma \approx 65$ keV	n, α	8, 15
9.672 ± 7	(3^-)	$\Gamma = 60 \pm 30$ keV	n, α	8, 15, 33, 37, 39, 40
9.713 ± 7	(5^-)	$\Gamma < 50$ keV	γ	15, 25, 33
9.890 ± 11		$\Gamma \approx 150$ keV	n, α	8, 15, 33

Table 18.9: Energy levels of ^{18}O [a] (continued)

E_x (MeV ± keV)	$J^\pi; T$	τ [b] or $\Gamma_{c.m.}$	Decay	Reactions
10.118 ± 10	3^-	$\Gamma = 16 \pm 4$ keV	n, α	8, 9, 15, 33
10.24 ± 20 [d]	(0, 1, 2)$^-$		n	22
10.295 ± 14	4^+	$\Gamma < 50$ keV	γ, n, α	8, 9, 10, 15, 16, 25, 33, 37, 39, 40
10.396 ± 9	3^-		n, α	8, 15, 33
10.43 ± 40	(2^-)	$\Gamma < 50$ keV	γ	25
10.595 ± 15			n, α	8, 15
10.67 ± 20	(2^-)	$\Gamma < 50$ keV	γ	25
10.82 ± 20			n, α	8
10.91 ± 20			n, α	8, 10
10.99 ± 20	(2^-)	$\Gamma < 50$ keV	γ, n, α	8, 25
11.06	(6^-)			20
11.13 ± 20			n, α	8, 10, 50
11.39 ± 20	(2^+)		n, α	8, 9
11.41 ± 20	(4^+)		n, α	8, 9
11.49 ± 30 [d]	(0, 1, 2)$^-$		n	22
11.52 ± 50	(2^-)	$\Gamma < 50$ keV	γ	25
11.62 ± 20	5^-		n, α	8, 9, 10, 33, 37, 39, 40
11.67 ± 20	(3^-)	$\Gamma = 112 \pm 0.02$ keV		25
11.69 ± 20	6^+		n, α	8, 9, 10, 33
11.82 ± 20	(3^-)		n, α	8
11.90 ± 30	(2^-)	$\Gamma < 50$ keV	γ	25
12.04 ± 20	(2^+)		n, α	8, 9
12.09 ± 20	$(1^-, 2^+)$	$\Gamma < 50$ keV		25
12.25 ± 20	(1^-)		n, α	8, 9
12.33 ± 20	5^-		n, α	8, 9, 10
12.41 ± 20	(3^-)	$\Gamma = 143 \pm 24$ keV	γ	25
12.50 ± 20	4^+		n, α	8, 37, 39, 40
12.52 ± 20		$\Gamma < 50$ keV	γ	25
12.53 ± 20	6^+		n, α	8, 9, 10, 37, 39, 40

Table 18.9: Energy levels of ^{18}O [a] (continued)

E_x (MeV ± keV)	$J^\pi; T$	τ [b] or $\Gamma_{c.m.}$	Decay	Reactions
12.66 ± 20	(2^-)	$\Gamma < 50$ keV	γ	25
12.99 ± 20	(4^-)	$\Gamma = 68 \pm 18$ keV	γ	25
13.1 [c]	1^-	$\Gamma = 700$ keV	γ, n	23
13.40 ± 20	(2^-)	$\Gamma = 108 \pm 20$ keV	γ	25
13.8	1^-	$\Gamma = 600$ keV	γ, n	23
13.85 ± 13	(6^-)	$\Gamma \approx 200$ keV	γ	20, 25
14.17 ± 40	(6^-)	$\Gamma = 140 \pm 50$ keV	γ	20, 25
14.45 ± 50		$\Gamma \approx 1070$ keV	γ	25
14.7	1^-	$\Gamma = 800$ keV	γ, n	23
15.23 ± 40		$\Gamma \approx 300$ keV	γ	25
15.8	1^-	$\Gamma = 700$ keV	γ, n	23
15.95 ± 30		$\Gamma < 50$ keV	γ	25
16.210 ± 10	$1^{(-)}$		γ	25
16.315 ± 10	$(3,2)^-$		γ	25
16.399 ± 5	2^-; 2	$\Gamma < 20$ keV	γ	25, 28
16.88 ± 30	$(4^-, 2^-)$; (1)	$\Gamma < 50$ keV	γ	25
16.948 ± 10	$(3,2)^-$		γ	25
17.025 ± 10	(3^-); 2	$\Gamma = 20 \pm 6$ keV	γ	25
17.05	(7^-)	$\Gamma \approx 350$ keV		9
17.398 ± 10	1^-; (2)	$\Gamma = 600$ keV	γ, n, p	23, 25
17.450 ± 10	$(2,1,3)^-$		γ	25
17.46 ± 30	(4^-); 1	$\Gamma \approx 600$ keV	γ	25
17.5		$\Gamma \approx 150$ keV	γ	25
17.502 ± 10	$(1,2,3)^-$		γ	25
(17.6 ± 200)	(8^+)			9
17.635 ± 10			γ	25
18.049 ± 10			γ	25
18.2		$\Gamma \approx 150$ keV	γ	25
18.45 ± 20	(3^-); (1)	$\Gamma = 75 \pm 27$ keV	γ	25
18.5		$\Gamma \approx 4300$ keV	γ	25

Table 18.9: Energy levels of ^{18}O [a] (continued)

E_x (MeV ± keV)	$J^\pi; T$	τ [b] or $\Gamma_{c.m.}$	Decay	Reactions
18.70 ± 20	$(4^-); 2$	$\Gamma < 20$ keV	γ	25
18.871 ± 5	$1^+; 2$		γ	25
18.927 ± 10	$(1, 2^+)$		γ	25
18.95	(7^-)	$\Gamma \approx 350$ keV		9
19.027 ± 10	$(1, 3)^-$		γ	25
19.150 ± 10	$(1^-, 2^+, 3^-)$		γ	25
19.24 ± 20	$(> 2); 2$	$\Gamma < 20$ keV	γ	25
19.4	$1^-; (2)$	$\Gamma = 900$ keV	γ, p	23
19.7		$\Gamma \approx 200$ keV	γ	25
20.2		$\Gamma \approx 180$ keV	γ	25
20.36 ± 20	$(4^-); 2$	$\Gamma < 20$ keV	γ	25
20.86 ± 20		$\Gamma = 97 \pm 41$ keV	γ	25
21.0	$1^-; (1)$	$\Gamma \approx 150$ keV	γ, n, p	23, 25
21.42 ± 20	$(4^-); (2)$	$\Gamma < 50$ keV	γ	25
22.40 ± 20	$4^-; 2$	$\Gamma = 91 \pm 8$ keV	γ	25
22.7	1^-		γ, n, p	23
23.10 ± 20		$\Gamma = 49 \pm 24$ keV	γ	25
23.8	$1^-; (1)$	$\Gamma \approx 1500$ keV	γ, n, p	23, 25
27	$1^-; (2)$		γ, n, p	23
30			γ, n	23
36			γ	23

[a] See also Tables 18.10 and 18.21 here and 18.12 in (1983AJ01).

[b] See Table 18.14 in (1978AJ03) for a display of τ_m measurements.

[c] For additional states with $12.9 \leq E_x \leq 23.1$ MeV see (1983CU03) [reaction 9].

[c] See reaction 22 in ^{18}O and Table 18.18 for discussion of this level.

5. ^{13}C(^{9}Be, α)^{18}O $\quad\quad Q_m = 12.830$

See (1983AJ01, 1987AJ02).

6. ^{13}C(^{17}O, ^{12}C)^{18}O $\qquad Q_{\rm m} = 3.098$

See (1983AJ01, 1987AJ02).

7. ^{14}C(α, γ)^{18}O $\qquad Q_{\rm m} = 6.227$

Table 18.10: Radiative decays in ^{18}O [a]

$E_{\rm i}$ (MeV)	$J^{\pi}_{\rm i}$	$E_{\rm f}$ (MeV)	Branch (%)	δ
1.98	2^+	0	100	
3.55	4^+	1.98	100	
3.63	0^+	0	0.30 ± 0.06 [b]	
		1.98	99.70 ± 0.06	
3.92	2^+	0	12.4 ± 0.7	
		1.98	87.6 ± 0.7	[c]
4.46	1^-	1.98	27.1 ± 2.6	[c]
		3.63	70.4 ± 1.7	
		3.92	2.5 ± 0.9	
5.10	3^-	1.98	76.1 ± 0.8	[c]
		3.55	6.3 ± 0.8	[c]
		3.92	17.6 ± 0.7	[c]
5.26	2^+	0	30.3 ± 0.9	
		1.98	55.9 ± 1.0	0.15 ± 0.04
		3.55	1.1 ± 0.6	
		3.63	1.0 ± 0.6	
		3.92	8.7 ± 0.4	
		4.46	3.0 ± 0.3	
5.34	0^+	0	[d]	
		1.98	58 ± 2	
		4.46	42 ± 2	
5.38	3^+	1.98	86.5 ± 2.2	[c]
		3.92	13.5 ± 2.2	[c]
5.53	2^-	1.98	49 ± 2	[c]

Table 18.10: Radiative decays in ^{18}O [a] (continued)

E_i (MeV)	J^π_i	E_f (MeV)	Branch (%)	δ
		3.92	24 ± 2	
		4.46	27 ± 2	[c]
6.20	1^-	0	88.7 ± 0.9	
		3.63	2.5 ± 0.3	
		4.46	4.1 ± 0.4	
		5.26	3.6 ± 0.4	
		5.34	1.1 ± 0.3	
6.35	(2^-)	1.98	32 ± 2	[c]
		3.92	55 ± 2	[c]
		4.46	12 ± 2	[c]
6.40	3^-	1.98	68.1 ± 1.8	[c]
		3.55	7.4 ± 1.2	
		3.92	6.3 ± 1.0	[c]
		4.46	2.8 ± 1.0	
		5.10	9.8 ± 0.9	
		5.26	5.6 ± 0.9	
6.88	0^-	4.46	100	[c]
7.12 [c]	4^+	1.98	27.1 ± 0.4	$-(0.052 \pm 0.035)$
		3.55	69.2 ± 0.7	
		3.92	2.1 ± 0.2	
		5.10	1.3 ± 0.2	
		5.26	0.30 ± 0.06	
7.62	1^-	0	23 ± 2	
		1.98	62 ± 3 [f]	$-(0.027 \pm 0.008)$
		4.46	8 ± 1	$-(0.21 \pm 0.03)$
		5.34	6 ± 1	
		6.20	1 ± 1	
7.77	2^-	1.98	53 ± 3	
		4.46	11 ± 2	
		5.10	36 ± 3	
7.86	5^-	3.55	> 75	

Table 18.10: Radiative decays in ^{18}O [a] (continued)

E_i (MeV)	J_i^π	E_f (MeV)	Branch (%)	δ
7.98	$(3^+, 4^-)$	3.55	67 ± 2	
		5.10	12 ± 2	
		5.38	21 ± 2	
8.04	1^-	0	16 ± 1	
		1.98	70 ± 2 [g]	
		3.63	10 ± 1	
		5.26	4 ± 1	
8.13	5^-	3.55	99 ± 1 [h]	
		5.10	1 ± 1	
8.21	2^+	0	19 ± 4	
		1.98	29 ± 3	
		3.55	3 ± 1	
		3.92	3 ± 1	
		4.46	29 ± 3	
		5.10	17 ± 1	
8.28	3^-	3.55	61 ± 3	
		4.46	3 ± 3	
		5.26	36 ± 3	

[a] For references and additional information see Tables 18.3 in (1978AJ03, 1983AJ01). Upper limits for other transitions are not shown.

[b] $\Gamma_\pi/\Gamma = (3.0 \pm 0.6) \times 10^{-3}$ (1975SO05).

[c] δ is consistent with 0.

[d] $\Gamma_\pi/\Gamma \leq 2.3 \times 10^{-3}$.

[e] $\Gamma_\gamma/\Gamma = 0.561 \pm 0.013$ (1994ME02)

[f] $\Gamma_\alpha\Gamma_\gamma/\Gamma = 0.34$ eV.

[g] $\Gamma_\alpha\Gamma_\gamma/\Gamma = 0.89$ eV.

[h] $\Gamma_\alpha\Gamma_\gamma/\Gamma = 0.22$ eV.

Table 18.11: States of ^{18}O from ^{13}C(^{6}Li, p) [a]

E_x [a] (MeV ± keV)	σ_{tot} [a,b] (μb)	E_x [a] (MeV ± keV)	σ_{max} [a] (μb/sr)
0	6.1 ± 0.3	8.667 ± 13	20.8 ± 1.0
1.987 ± 8	39 ± 1	8.82 ± 20	13.0 ± 0.9
3.555 ± 10	56 ± 1	8.96 ± 20	16.3 ± 1.0
3.632 ± 15	13 ± 1	9.72 ± 30	26.3 ± 1.3
3.926 ± 6	36 ± 1	10.09 ± 30	30.6 ± 1.5
4.455 ± 8	46 ± 1	10.28 ± 30	100 ± 5
5.095 ± 11	74 ± 1	10.63 ± 30	31.3 ± 1.6
5.256 ± 9	44 ± 1	10.90 ± 30	42.7 ± 2.1
5.374 ± 8	35 ± 1	10.99 ± 20	84.8 ± 4.2
5.532 ± 8	45 ± 1	11.12 ± 20	17.7 ± 0.9
6.199 ± 8	37 ± 1	11.26 ± 20	33.9 ± 1.7
6.383 ± 11 [c]	131 ± 2	11.42 ± 30	46.6 ± 2.3
6.882 ± 19	5.3 ± 0.4	11.61 ± 30	34.1 ± 1.7
7.117 ± 5 [d]	208 ± 2	11.70 ± 30	75.4 ± 3.8
7.618 ± 10	33 ± 1	11.85 ± 30	81.9 ± 4.1
7.764 ± 14	37 ± 1	12.07 ± 30	34.2 ± 1.7
7.850 ± 13	101 ± 1	12.23 ± 30	32.1 ± 1.6
7.962 ± 12	84 ± 1	12.33 ± 30	50.4 ± 2.5
8.026 ± 14	19 ± 1	12.44 ± 30	96.0 ± 4.8
8.120 ± 12	140 ± 2	12.54 ± 30	90.2 ± 4.5
8.200 ± 17	48 ± 1	13.08 ± 30	48.4 ± 2.4
8.274 ± 15	103 ± 2	13.23 ± 30	99.3 ± 5.0
8.401 ± 12	45 ± 1	13.48 ± 30	24.6 ± 1.2
8.496 ± 15	75 ± 1	13.60 ± 30	29.0 ± 1.5
		13.81 ± 30	159 ± 8
		14.14 ± 30	92.7 ± 4.6
		15.80 ± 30	136 ± 7

[a] (1988SM01). The maximum value of the differential cross section results were compared with a Hauser-Feshbach calculation. The comparison suggests the the presence of an additional nonstatistical mechanism.
[b] See Table 18.5 in (1987AJ02), which shows a comparison with σ_{tot} from ^{12}C(^{7}Li, p) for $E_x \leq 8.3$ MeV.
[c] Unresolved doublet (1988SM01).
[d] See discussion of Γ_γ/Γ results from (1994ME02) under reaction 3 here.

Table 18.12: Resonances in ^{14}C(α, γ)^{18}O, ^{14}C(α, n)^{17}O and ^{14}C(α, α)^{14}C [a]

E_α (MeV $\pm$ keV)	$\Gamma_{\rm lab}$ (keV)	Particles out	$E_{\rm x}$(^{18}O) (MeV)	J^π
1.140 ± 2 [b]		γ	7.114	4^+
1.790 ± 2 [b]	< 3	γ	7.619 [h]	1^-
2.10 [b]		γ	7.86	5^-
2.330 ± 2 [b]	< 3	γ, α_0	8.039 [b, h]	1^-
2.440 ± 2 [b]		γ	8.125	5^-
2.554 ± 4 [b]	1.3 ± 1	γ, n, α_0	8.213	2^+
2.643 ± 3 [b]	10 ± 1	γ, n, α_0	8.282	3^-
2.800 ± 7	10 ± 7	n	8.404	
3.330 ± 12	90 ± 15	n, α_0	8.817	
3.508 ± 4	55 ± 3	n, α_0	8.955	
4.030 ± 15	35 ± 20	n, (α_0)	9.361	
4.07 ± 40	≈ 150	n, (α_0)	9.39	
4.17 ± 40	≈ 70	n, (α_0)	9.47	
4.434 ± 10	80 ± 40	n, (α_0)	9.675	
4.70 ± 40	≈ 200	n, (α_0)	9.88	
5.004 ± 10	21 ± 5	n, α_0	10.118	3^-
5.23 [c]	[d]	n, α_0	10.29	4^+
5.34	[d]	n, α_0	10.38	3^-
5.60	[e]	n, α_0	10.58	
5.90	[f]	n, α_0	10.82	
6.02	[f]	n, α_0	10.91	
6.13	[f]	n, α_0	10.99	
6.30	[e]	n, α_0	11.13	
6.64	[d]	n, α_0	11.39	(2^+)
6.67	[d]	n, α_0	11.41	(4^+)
6.93	[d]	n, α_0	11.62	5^-
7.03	[d]	n, α_0	11.69	6^+
7.19	[f]	n, α_0	11.82	(3^-)
7.47	[f]	n, α_0	12.04	(2^+)
7.75	[g]	n, α_0	12.25	$(0^+,\ 1^-)$
7.85	[d]	n, α_0	12.33	5^-
8.06	[d]	n, α_0	12.50	4^+
8.10	[d]	n, α_0	12.53	6^+

[a] See also Table 18.11. For references see Table 18.5 in (1978AJ03).
[b] (1987GA15): $\Gamma_\gamma = 0.095 \pm 0.020, 0.41 \pm 0.08, 0.043 \pm 0.009, 1.07 \pm 0.22, 0.27 \pm 0.05$, 0.41 ± 0.09, and 0.49 ± 0.13 eV, respectively for ^{18}O*(7.11, 7.62, 7.86, 8.04, 8.13, 8.21, 8.28 MeV).
[c] $\pm 10 - 20$ keV for this and all higher resonances (G.E. Mitchell, private communication).
[d] Γ_α, large; Γ_n, large.
[e] Γ_α, small; Γ_n, small.
[f] Γ_α, small; Γ_n, large.
[g] Γ_α, large; Γ_n, small.
[h] Recent ^{14}C(α, γ) measurements for these two 1^- states by (1994HA17) gave $E_x = 7.6159 \pm 0.0007$ and 8.0378 ± 0.0007 keV.

Resonances in the yield of capture γ-rays are observed at $E_\alpha = 1.14$, 1.79, 2.09, 2.33, 2.44, 2.55, and 2.64 MeV: see Tables 18.12 here and 18.5 in (1978AJ03). Gamma-ray angular distribution and correlation measurements lead to $J^\pi = 4^+$, 1^-, 1^-, and 5^- for ^{18}O*(7.11, 7.62, 8.04, 8.13), as well as to J^π assignments for lower states involved in the cascade decay. See also references in (1987AJ02) and see the cross section measurements of (1993DA17). The speculated presence of enhanced E1 γ de-excitation in ^{18}O (1983GA02) was followed by further experimental and theoretical investigations of collective band structure in ^{18}O (1989FU08, 1993RE03). See however (1986HA1J). See also (1989FU1H, 1989KAZH). The $4^+_2 \rightarrow 2^+_2$ $(7117 \rightarrow 5260)$ keV γ branching ratio of 0.30 ± 0.08% was measured by (1989GA01) and an E2 transition strength B(E2) $= 5.7 \pm 1.9$ W.u. was deduced. This result is conformed by the $(\Gamma_{\alpha X}\Gamma\gamma)/(\Gamma_\alpha + \Gamma_\gamma)$ and (7117 $\rightarrow$ 5260) keV γ branching (0.24 ± 0.08%) measurements of (1992GO14) and the $\Gamma_\gamma/\Gamma_\alpha$ measurement of (1994ME02).

The ^{14}C(α, γ) reaction is important in astrophysical processes and the details of the cross section are relevant to the process of heavy element formation in inhomogeneous big bang nucleosynthesis (1988AP1A, 1989FU06, 1990WIZP, 1992GA11, 1992GO14). See also (1988BU01, 1988MA1U, 1989KA1K, 1989NO1A, 1989TH1C) and the review of thermonuclear reaction rates in (1988CA26).

8. (a) ^{14}C(α, α')^{14}C $\qquad E_b = 6.227$
(b) ^{14}C(α, n)^{17}O $\qquad Q_m = -1.817$

Observed anomalies in the scattering [reaction (a)] for $E_\alpha = 2$ to 8.2 MeV and the resonances in the relative neutron yield [reaction (b)] for $E_\alpha = 2.3$ MeV are displayed in Table 18.12. See also (1978AJ03).

The α-cluster structure of ^{18}O has been investigated in theoretical work of (1989FU08, 1993RE03) based on ^{14}C(α, α) scattering, and the results do not support the existence of proposed negative-parity molecular dipole states. See (1989GA01).

9. (a) $^{14}C(^{6}Li, d)^{18}O$ $Q_m = 4.752$

(b) $^{14}C(^{6}Li, d\alpha)^{14}C$ $Q_m = -1.475$

Table 18.13: Gamma-ray branching ratios in $^{14}C(\alpha, \gamma)^{18}O$ [a]

E_i (MeV)	J_i^π	E_f (MeV)	J_f^π	Branching ratio (%)
7.620 ± 0.002	1^-	0	0^+	23 ± 2
		1.98	2^+	62 ± 3
		3.63	0^+	< 1
		3.92	2^+	< 3
		4.46	1^-	8 ± 2
		5.26	2^+	< 3
		5.34	0^+	6 ± 1
		5.53	2^-	< 5
		6.20	1^-	1 ± 1
7.859 ± 0.005	5^-	3.56	4^+	> 75
8.040 ± 0.002	1^-	0	0^+	17 ± 1
		1.98	2^+	71 ± 2
		3.63	0^+	9 ± 1
		3.92	2^+	< 1
		4.46	1^-	< 1.5
		5.10	3^-	< 1
		5.26	2^+	3.2 ± 0.9
		5.34	0^+	< 1
		5.53	2^-	< 2
		6.20	1^-	< 2
8.125 ± 0.002	5^-	3.55	4^+	99 ± 1
		5.10	3^-	1 ± 1
		7.12	4^+	< 2
8.214 ± 0.004	2^+	0	0^+	19 ± 4
		1.98	2^+	29 ± 3
		3.55	4^+	3 ± 1
		3.63	0^+	< 3

Table 18.13: Gamma-ray branching ratios in ^{14}C(α, γ)^{18}O [a] (continued)

$E_{\rm i}$ (MeV)	$J^{\pi}_{\rm i}$	$E_{\rm f}$ (MeV)	$J^{\pi}_{\rm f}$	Branching ratio (%)
		3.92	2^+	3 ± 1
		4.46	1^-	29 ± 3
		5.10	3^-	17 ± 1
		5.26	2^+	< 3
		$5.34 - 6.35$		< 1
8.283 ± 0.003	3^-	0	0^+	< 7
		1.98	2^+	< 3
		3.55	4^+	61 ± 3
		3.92	2^+	< 3
		4.46	1^-	3 ± 3
		5.10	3^-	< 8
		5.26	2^+	36 ± 3
		5.38	3^+	< 4
		5.53	2^-	< 8
		6.40	3^-	< 5

[a] (1987GA15). See also Table 18.12 for measured Γ_γ for these levels.

At E(^{6}Li) $= 34$ MeV angular distributions have been measured for the deuteron groups to many states of ^{18}O (1981CU07) [see also (1983AJ01)] including ^{18}O*(17.6 ± 0.2) (1982CU01). $J^\pi = 4^+, 2^+, 2^+, (4^+)$, and (4^+) are suggested for ^{18}O*(7.86, 8.9, 12.04, 14.6, 17.0) (1981CU07). The 2^+, 4^+, 6^+ and 8^+ members of the $K^\pi = 0^+_2$ rotational band based on ^{18}O*(3.62) are ^{18}O*(5.26, 7.12, 11.69, 17.6) (1982CU01).

Angular correlations have been measured at E(^{6}Li) $= 34$ MeV; these lead to the assignment of $J^\pi = 8^+$ to ^{18}O*(17.6) (1982CU01) and to the assignment of $J^\pi = 4^+, 5^-, 6^+, 7^-$ and 8^+ to sixteen states in ^{18}O with $11.4 \leq E_{\rm x} \leq 23.1$ MeV (1983CU03) [see (1983CU03) for assignment of ^{18}O states to bands]. At E(^{6}Li) $= 32$ MeV (1983AR11) find that the strongest groups are those to (unresolved) structures at $E_x = 17.05$ and 18.95 MeV [each $\Gamma \approx 0.35$ MeV] dominated by $J^\pi = 7^-$. ^{18}O*(11.6, 12.6) with $J^\pi = (6^+, 5^-)$ and 5^- are also observed (1983AR11) [see, however, the density of states]. See also (1987AJ02, 1990OS03).

10. ^{14}C(^{7}Li, t)^{18}O $\qquad Q_{\rm m} = 3.760$

At $E(^7\text{Li}) = 20.4$ MeV, triton groups are observed corresponding to a number of states of ^{18}O with $E_x < 12.6$ MeV. Angular distributions were obtained for some of these, including ^{18}O*(0, 1.98, 7.12, 11.69) with $J^\pi = 0^+, 2^+, 4^+, 6^+$. The latter two are the most strongly populated in this reaction: they appear to be part of the ground-state rotational band: see (1972AJ02). See also (1987AJ02).

In more recent work at $E(^7\text{Li}) = 15$ MeV, ^{18}O gamma de-excitation modes for all natural parity states up to the alpha-particle threshold at $E_x = 6.227$ MeV were studied (1991GA08). See Table 18.14.

Table 18.14: Gamma decay branching ratios for ^{18}O from ^{14}C(^{7}Li, tγ)^{18}O [a]

E_i (MeV)	J^π_i	E_f (MeV)	J^π_f	Branching ratio (%)
1.98	2^+_1	0.00	0^+	100
3.55	4^+_1	1.98	2^+	100
3.63	0^+_2	1.98	2^+	100
3.92	2^+_2	0.00	0^+	11.1 ± 1.0
		1.98	2^+	88.9 ± 1.0
4.45	1^-_1	0.00	0^+	< 0.2
		1.98	2^+	29.5 ± 1.0
		3.63	0^+_2	68.9 ± 1.0
		3.92	2^+_2	1.6 ± 0.2
5.10	3^-_1	1.98	2^+	76.5 ± 1.0
		3.55	4^+	5.6 ± 1.0
		3.92	2^+_2	17.9 ± 0.8
		4.45	1^-	< 0.14
5.26	2^+_3	0.00	0^+	30.3 ± 0.9
		1.98	2^+	55.9 ± 1.0
		3.55	4^+	1.1 ± 0.6
		3.63	0^+_2	1.0 ± 0.6
		3.92	2^+_2	8.7 ± 0.4
		4.45	1^-	3.0 ± 0.3
5.34	0^+_3	1.98	2^+	45.2 ± 5.0
		3.92	2^+_2	< 12.0
		4.45	1^-	54.8 ± 5.0
6.20	1^-_2	0.00	0^+	88.7 ± 0.9
		1.98	2^+	< 1.3

Table 18.14: Gamma decay branching ratios for ^{18}O from ^{14}C(^{7}Li, tγ)^{18}O [a] (continued)

E_i (MeV)	J_i^π	E_f (MeV)	J_f^π	Branching ratio (%)
		3.63	0_2^+	2.5 ± 0.3
		3.92	2_2^+	< 0.9
		4.45	1^-	4.1 ± 0.4
		5.09	3^-	< 0.7
		5.26	2_3^+	3.6 ± 0.4
		5.34	0_3^+	1.1 ± 0.3
6.40	3_2^-	1.98	2^+	68.1 ± 1.8
		3.55	4^+	7.4 ± 1.2
		3.92	2_2^+	6.3 ± 1.0
		4.45	1^-	2.8 ± 1.0
		5.09	3^-	9.8 ± 0.9
		5.26	2_3^+	5.6 ± 0.9
7.12	4_2^+	1.98	2^+	27.0 ± 0.5
		3.55	4^+	70.0 ± 1.0
		3.92	2_2^+	1.8 ± 0.4
		5.09	3^-	1.2 ± 0.3
		5.26	2_3^+	< 0.6
		6.40	3_2^-	< 0.2

[a] (1991GA08). See Table 1 of (1991GA08) for additional information including transition strengths. See also Table 18.10 here.

11. ^{14}C(^{14}C, ^{10}Be)^{18}O $\qquad Q_m = -5.785$

See (1985KO04).

12. ^{14}C(^{16}O, ^{12}C)^{18}O $\qquad Q_m = -0.935$

See (1978AJ03).

Table 18.15: States in ^{18}O from ^{16}O(t, p) [a]

E_x (keV)	L	J^π	E_x (keV)	E_x (keV)
0	0	0^+	7623 ± 18	9713 ± 7
1986 ± 4	2	2^+	7782 ± 6	9890 ± 11
3556 ± 2	4	4^+	7871 ± 2 [d]	10120 ± 40
3634 [b]	0	0^+	7983 ± 3 [d]	10300 ± 20
3915 ± 2	2	2^+	8046 ± 7	10400 ± 10
4458 ± 3	1	1^-	8140 ± 10	10610 ± 20
5105 ± 2	3	3^-	8233 ± 9	
5258 ± 6	2	2^+	8294 ± 5 [d]	
5340 ± 4	0	0^+	8430 ± 12	
5382 ± 4			8521 ± 3 [d]	
5530 ± 4			8660 ± 6	
6197 ± 3	1	1^-	9030 ± 15 [e]	
6356 ± 7	1, 2	$(1^-, 2^+)$ [c]	9362 ± 5 [d]	
6399 ± 3	3	3^-	9420 ± 20	
6885 ± 9			9480 ± 30	
7123 ± 7	4	4^+	9671 ± 8	

[a] (1981CO13): $E_t = 15$ MeV; DWBA analysis. See also Table 18.6 in (1978AJ03).

[b] Nominal energy.

[c] See, however, Table 18.18.

[d] Comparisons of E_x shown here with those displayed in Table 18.3 for ^{18}O*(3.92, 5.10, 6.40, 7.77) suggest that the uncertainty shown may be low: ±6 keV was arbitrarily used in calculating the best value for E_x for this state in Table 18.3 of (1987AJ02).

[e] This is the "average" of several unresolved levels. (1985FO11) states that the main components are at 8.96 and 9.03 MeV. [Comment: It is not clear whether these states are actually resolved (1987AJ02).]

13. ^{15}N(α, p)^{18}O $\qquad Q_m = -3.980$

Several states in ^{18}O at $E_x = 10$–25 MeV were observed in ^{15}N(α, p) experiments reported in (1987MIZY, 1988BRZY, 1989BR1J).

14. ^{15}N(^{13}C, ^{10}B)^{18}O $\qquad Q_m = -8.042$

See (1983AJ01).

15. ^{16}O(t, p)^{18}O $\qquad Q_m = 3.706$

Proton groups corresponding to states of ^{18}O are displayed in Table 18.15 here 1981CO13). See (1976LA13) for a general discussion of the properties of the states of ^{18}O. Lifetime measurements are reported in Table 18.4 of (1978AJ03). See also reaction 19 and (1982AN12, 1985AN17, 1985BA1A).

16. ^{16}O(α, 2p)^{18}O $\qquad Q_m = -16.108$

At $E_\alpha = 65$ MeV, the angular distribution to ^{18}O*(3.55) $[J^\pi = 4^+]$ has been studied. ^{18}O*(8.04, 9.15, 10.3) are also populated: see (1983AJ01).

17. (a) ^{16}O(^{10}B, ^{8}B)^{18}O $\qquad Q_m = -14.825$
(b) ^{16}O(^{13}C, ^{11}C)^{18}O $\qquad Q_m = -11.480$

At $E(^{10}\text{B}) = 100$ MeV, ^{18}O*(3.55) [first $(\text{d}_{5/2})^2_{4^+}$ state] is preferentially populated. ^{18}O*(1.98, 5.26, 7.12, 8.0, 8.3, 9.1) are also observed. The angular distribution to ^{18}O*(3.55) has been measured at $E(^{13}\text{C}) = 105$ MeV. See (1983AJ01, 1983OS07).

18. (a) ^{17}O(n, γ)^{18}O $\qquad Q_m = 8.044$
(b) ^{17}O(n, n$'$)^{17}O $\qquad E_b = 8.044$
(c) ^{17}O(n, α)^{14}C $\qquad Q_m = 1.817$

For reaction (a) see (1983AJ01). [The work reported there has not been published.] The scattering amplitude (bound) $a = 5.62 \pm 0.45$ fm, $\sigma_{\rm free} = 3.55 \pm 0.25$ b. The thermal cross section for reaction (c) is 235 ± 10 mb. See (1983AJ01) for references. See also (1988MCZT).

In more recent work, the cross section for ^{17}O(n, α) has been measured from $E_{\rm n} = 25 \times 10^{-3}$ eV to 1 MeV (1991KO31). An evaluation of the cross sections from $E_{\rm n} = 10^{-5}$ eV to 20 MeV has been carried out by (1991HI15). Results are given in tabular and graphical form. See also (1991KO1P).

19. ^{17}O(d, p)^{18}O $\qquad Q_{\rm m} = 5.820$

Table 18.16: States of ^{18}O from ^{17}O(d, p) [a]

$E_{\rm x}$ (MeV $\pm$ keV) [b]	$l_{\rm n}$ [b]	J^{π} [b]	S [b]
0	2	0^+	1.22
1.982 ± 10	$0 + 2$	2^+	$0.21 + 0.83$
3.552 ± 10	2	4^+	1.57
3.63	2	0^+	0.28
3.92	$0 + 2$	2^+	$0.35 + 0.66$
4.46	1	1^-	0.03
5.10	3	3^-	0.03
5.255 ± 10	0	2^+	0.35
5.34	2	0^+	0.16
5.375 ± 10	0	3^+	1.01
6.20	1	1^-	0.03
6.35	1	(2^-)	0.03
7.110 ± 15	2	4^+	
7.855 ± 20			
7.962 ± 20			
9.0 [c]			

[a] See references in Tables 18.7 of (1972AJ02, 1978AJ03).
[b] $E_{\rm x}$ values without uncertainties are nominal. J are consistent with $l_{\rm n}$ and are used to calculate S.
[c] (1985FO11). See text.

Table 18.17: Some states in ^{18}O from ^{17}O(α, ^{3}He) [a]

E_x (MeV) [b]	J^π [b]	σ_{int} (mb) [c]
0.0	0^+	0.22
1.98	2^+	0.64
3.55	4^+	1.59
5.38	3^+	0.12
7.12	4^+	0.09
7.86	5^-	0.14
8.12	5^-	0.06
8.82	(1^+)	0.04
11.06 [a]	(6^-) [a]	0.18
13.85	(6^-) [d]	0.02
14.17	(6^-) [d]	0.01

[a] (1992YA08); $E_\alpha = 65$ MeV.
[b] E_x and J^π values from Table (18.9).
[c] Integrated cross section. See Tables III and IV in (1992YA08) for spectroscopic factors.
[d] (1990SEZZ).

Observed proton groups are displayed in Table 18.16. A strong asymmetric peak is observed at $E_d = 12$ MeV corresponding to $E_x = 9.0$ MeV. On the basis of this work and the measurement of the cross section at a peak at about the same energy observed in the ^{16}O(t, p) reaction, (1985FO11) assign $J^\pi = 4^+$ and a (1d$_{5/2}$) (1d$_{3/2}$) configuration to ^{18}O*(9.0). Proton-γ coincidence measurements are shown in Table 18.10.

20. ^{17}O(α, ^{3}He)^{18}O $\qquad Q_m = -12.533$

Differential cross sections were measured at $E_\alpha = 65$ MeV (1992YA08) for ^{18}O states up to $E_x = 15$ MeV. DWBA analysis led to proposed spin parity and isospin assignments, and spectroscopic factors. See Table 18.17.

21. ^{17}O(^{12}C, ^{11}C)^{18}O $\qquad Q_m = -10.677$

Angular distributions involving ^{18}O*(0, 1.98, 3.55) have been studied at $E(^{12}C) = 115$ MeV: see (1983AJ01).

Table 18.18: Branching in ^{18}N(β^-)^{18}O [a]

Decay to ^{18}O* (keV)	Decay mode	J^π	Branch [b] (%)	log ft
1982.05 ± 0.09 [c]	γ	2^+	3.4 ± 1.3	6.79 ± 0.17
3554.13 ± 0.80	γ	4^+	< 0.5	> 7.3
3633.70 ± 0.11	γ	0^+	< 0.3	> 7.5
3920.42 ± 0.14	γ	2^+	< 0.4	> 7.4
4455.52 ± 0.10	γ	1^-	47.2 ± 0.9	5.167 ± 0.013
5097.60 ± 0.60	γ	3^-	< 0.4	> 7.1
5530.17 ± 0.32	γ	2^-	2.7 ± 0.3	6.16 ± 0.05
6198.22 ± 0.40	γ	1^-	1.2 ± 0.2	6.34 ± 0.08
6349.76 ± 1.0	γ	(2^-)	1.9 ± 0.2	6.10 ± 0.05
6880.45 ± 0.27	γ	0^- [d]	12.8 ± 0.7	5.13 ± 0.03
7620	α	1^-	6.8 ± 0.5	5.17 ± 0.04
7771.07 ± 0.50	γ	2^- [d]	4.3 ± 0.4	5.32 ± 0.05
8040	α	1^-	1.8 ± 0.2	5.61 ± 0.05
9000 [e]	α	(1^-)	$\geq 3.6 \pm 0.2$	≤ 5.0
(9090 ± 30)	n	$(0-2)^-$	0.16 ± 0.03	6.27 ± 0.09
9270 ± 20	n	$(0-2)^-$	0.39 ± 0.09	5.80 ± 0.11
9470 ± 20	n	$(0-2)^-$	0.47 ± 0.09	5.64 ± 0.09
9690 ± 20	n	$(0-2)^-$	0.14 ± 0.03	6.06 ± 0.10
9910 ± 20	n	$(0-2)^-$	0.17 ± 0.03	5.87 ± 0.08
10240 ± 30	n	$(0-2)^-$	0.16 ± 0.03	5.73 ± 0.09
10650 ± 30	n	$(0-2)^-$	0.43 ± 0.09	5.07 ± 0.10
10990 ± 30	n	$(0-2)^-$	0.13 ± 0.03	5.38 ± 0.11
11490 ± 30	n	$(0-2)^-$	0.19 ± 0.04	4.85 ± 0.10

[a] Branchings to γ-decaying levels (1982OL01), branchings to α-decaying levels (1989ZH04) and branchings to n-decaying levels (1994SC01).

[b] 12.2 ± 0.6% of the β-decay branching ratio has been measured to feed α-emitting states (1989ZH04). 14.3 ± 2.0% has been measured to feed n-decaying states (1991RE02). The branching ratio of γ-decaying states (1982OL01) have been renormalized to take these values into account. See reaction 22 of ^{18}O. Branchings in this table do not add up to 100% since n-decaying levels below 9.00 MeV were not measured by (1994SC01) and there is a missing 12.1% branching to n-decaying levels not listed.

[c] $E_\gamma = 1981.933 \pm 0.09$ keV is adopted by (1982OL01).

[d] See (1982OL01).

[e] Found as a broad bump at 3 MeV in β-delayed alpha spectrum. Could be several unresolved 1^- states or a new broad 1^- state in ^{18}O (1989ZH04).

22. ^{18}N(β^-)^{18}O $\qquad Q_\mathrm{m} = 13.899$

The transitions observed in the β^- decay are displayed in Table 18.18.

The γ-decaying states were measured by (1982OL01) and estimated 15 ± 6% branching to non-γ-decaying states in ^{18}O was assumed. At least 12.2 ± 0.6% of the β-decay branching ratio has been measured to feed 1^- alpha-particle emitting states (1989ZH04). See also the measurements of (1987GAZW, 1987ZHZV, 1988MI1G). A β-delayed neutron emission probability of 14.3 ± 2.0% has been measured (1991RE02). The β^- branchings to γ-emitting states of (1982OL01) has been renormalized to take in account the 26.5 ± 2.1% branches to particle emitting states. The γ-ray intensities of (1982OL01) also need to be renormalized by this factor, see Table 18.19. (1994SC01) has measured β decay branching ratios to 9 neutron emitting states in ^{18}O listed in Table 18.18 for a total of 2.2 ± 0.4%.

23. (a) ^{18}O(γ, n)^{17}O $\qquad Q_\mathrm{m} = -8.044$
(b) ^{18}O(γ, 2n)^{16}O $\qquad Q_\mathrm{m} = -12.187$
(c) ^{18}O(γ, p)^{17}N $\qquad Q_\mathrm{m} = -15.942$
(d) ^{18}O(γ, t)^{15}N $\qquad Q_\mathrm{m} = -15.834$
(e) ^{18}O(γ, pn + np)^{14}C $\qquad Q_\mathrm{m} = -34.522$
(f) ^{18}O(γ, α)^{14}C $\qquad Q_\mathrm{m} = -6.227$

The cross sections for the (γ, p), (γ, n), (γ, 2n) and (γ, tot) [tot $=$ total absorption] have been measured with monoenergetic photons to 42 MeV: observed resonances are displayed in Table 18.20. All three of the partial cross sections have substantial strength in the giant resonance region; the (γ, 2n) cross section is a significant fraction of σ(γ, tot) and is even larger than σ(γ, p). Above the GDR the partial cross sections decrease. The integrated σ(γ, tot) between 29 and 42 MeV is about one-third of the value integrated from threshold to 42 MeV. The relative strengths of partial cross sections leads to the T assignments shown in Table 18.20. The $T_<$ and $T_>$ components of the ^{18}O photo absorption cross section are also derived (1979WO04).

In a related, but more recent, experiment the cross section for reaction (e) was measured (1991MC01) and it was determined that the cross section rises to a maximum of 1.2 mb at 27.5 MeV, approximately one-tenth of the total (γ, n) cross section there. The cross section integrated to 43 MeV is only 11.8 mb $\cdot$ MeV, and as a result the isospin assignments of (1979WO04) are unaffected by neglect of this channel. A recent extensive study of isospin effects in the photodisintegration of light nuclei (1993MC02) used a collection of data on (γ, p), (γ, n), (γ, 2n) and (γ, n_0) cross sections and separated the $T_>$ and $T_<$ isospin components of the GDR in several light nuclei including ^{18}O. The relative strengths were extracted. See also the atlas of photoneutron cross sections with monoenergetic photons (1988DI02), and see (1988BE1T, 1989NO1C). Structures in the (γ, α_0) cross section are reported at $E_\mathrm{x} = 18.2$, 20.9, 22.1, and 24.2 MeV (1982BA03; $E_\mathrm{brems.}$). The decay of the GDR to ^{14}C, ^{15}N, ^{16}O, ^{17}N and ^{17}O states has been studied: see (1983AJ01). Less

Table 18.19: γ-ray intensities observed in ^{18}N(β^-)^{18}O [a]

E_γ (keV) [b]	E_i (keV)	E_f (keV)	I_γ [c]
535.24 ± 0.05	4456	3920	2.85 ± 0.14
821.71 ± 0.09	4456	3634	60.6 ± 1.8
1074.8 ± 0.6	5530	4456	0.80 ± 0.12
1177.3 ± 0.9	5098	3920	0.42 ± 0.13
1572.0 ± 0.8	3554	1982	0.64 ± 0.13
1609.6 ± 0.9	5530	3920	0.85 ± 0.34
1651.56 ± 0.07	3634	1982	60.5 ± 1.8
1893.9 ± 0.9	6350	4456	0.37 ± 0.06
1938.2 ± 0.2	3920	1982	4.49 ± 0.14
1981.93 ± 0.09	1982	0	98.0 ± 2.0
2424.8 ± 0.3	6880	4456	17.53 ± 0.70
2429.7 ± 0.8	6350	3920	1.41 ± 0.14
2473.0 ± 0.3	4456	1982	20.4 ± 1.0
2673.0 ± 0.5	7771	5098	1.63 ± 0.16
3114.5 ± 0.6	5098	1982	0.92 ± 0.14
3315.1 ± 0.9	7771	4456	0.63 ± 0.25
3547.7 ± 0.4	5530	1982	2.01 ± 0.14
3920.1 ± 0.9	3920	0	0.65 ± 0.07
4366.0 ± 0.8	6350	1982	0.84 ± 0.21
5788.5 ± 0.7	7771	1982	3.58 ± 0.32
6197.1 ± 0.4	6198	0	1.40 ± 0.14

[a] (1982OL01).

[b] γ-ray energies have not been corrected for nuclear recoil.

[c] γ-ray intensities are normalized such that the flux into the ground state is 100. To obtain γ-ray intensities per 100 parent decays multiply by 0.735 ± 0.021 (see reaction 22 under ^{18}O for discussion of this normalization).

than 20% of the decay of states with $14.5 < E_x < 20$ MeV goes via the n_0 channel (1987JU07). See (1978AJ03, 1987AJ02) for the earlier work.

24. ^{18}O(γ, γ)^{18}O

For ^{18}O*(6.20) $\Gamma_{\gamma_0} = 0.18 \pm 0.03$ eV, assuming $\Gamma_{\gamma_0}/\Gamma = 0.88$; $E_x = 6202.7 \pm 0.8$ keV: see (1978AJ03).

25. ^{18}O(e, e′)^{18}O

The ^{18}O charge radius, $\langle r^2 \rangle^{1/2} = 2.784 \pm 0.020$ fm, based on studies of the elastic charge form factors for $E_e = 70$ to 370 MeV, the resulting determinations of the difference in the ^{18}O and ^{16}O radii, and the rms radius of ^{16}O: see (1983AJ01).

Inelastic scattering has been reported to many states of ^{18}O: see (1983AJ01, 1987AJ02) and Table 18.21 here which also includes the recent work reported in (1995SE02). See also the comment (1987MI25) and reply (1987MA40) on the work reported in (1986MA48). Recent measurements are reported for 4^- and 6^- states at $E_e = 140$–275 MeV (1990SEZZ), and for 1^-, 3^-, 5^- states (1991MA14). Form factor measurements for the 2^+ level at $E_x = 8.21$ MeV and the (2^+) level at $E_x = 9.3$ MeV at momentum transfer $0.9 < \mathrm{q} < 2.1$ fm^{-1} (1990MA06) and for the 1^-, 3^- and 5^- levels at $0.6 < \mathrm{q} < 2.7$ fm^{-1} (1991MA14) are reported.

Several theoretical studies of inelastic electron scattering to states of ^{18}O have been carried out. A microscopic calculation for scattering to 2^+ states is reported in (1988HAZZ) and to 0^+ and 2^+ states in (1988KU17). See also the calculations of transition charge densities described in (1988GU03, 1988GU12, 1992GU11) and see (1987GU1D, 1988GU1B, 1989AJ1A).

26. (a) ^{18}O($\pi^{\pm}$, $\pi^{\pm\prime}$)^{18}O
(b) ^{18}O($\pi^{\pm}$, $\pi^{\pm}$p)^{17}N $\quad Q_m = -15.942$
(c) ^{18}O(π^-, π^-n)^{17}O $\quad Q_m = -8.044$

Angular distributions for the scattering to ^{18}O*(0, 1.98, 5.10) have been reported at $E_{\pi^\pm} = 29.2$ to 230 MeV [see (1983AJ01)] and at 50 MeV (1984TA1A; ^{18}O*(0, 1.98)) at 140, 180, and 220 MeV (1984SE1A; ^{18}O*(1.98)), at 164 MeV (1987CH14; ^{18}O*(0, 1.98, 4.46, 5.10)) and (1988SE04; ^{18}O*(1.98, 3.92, 5.26 MeV)). See also (1989GR1M, 1990WI1K). Measurements and analysis work reported in (1983AJ01) determine $\langle r_n^2 \rangle^{1/2} = 2.81 \pm 0.03$ fm, $\langle r_n^2 \rangle^{1/2} - \langle r_p^2 \rangle^{1/2} = 0.03 \pm 0.03$ fm. For a discussion of proton matter distribution in ^{18}O see (1985BA27). Total reaction cross sections at $E_\pi = 50$ MeV

Table 18.20: Resonances in $^{18}O + \gamma$

E_x (MeV) [a]				σ (mb)	Γ (MeV)
(γ, tot)	(γ, n)	(γ, 2n)	(γ, p)		
9.1	9.1			1.1 [b]	0.6
10.3	10.3			5.3 [b]	0.9
11.4	11.4			9.0 [b]	0.7
13.1	13.1	13.2		8.6 [b]	0.7
13.8	13.8	13.9		6.9 [b]	0.6
14.7	14.7	14.8		13.1 [b]	0.8
15.8	15.7	15.8		10.9 [b]	0.7
17.3 [c]	17.1		17.5	10.1 [b], 1.2 [e]	0.6
19.4 [c]		(19.1)	19.4	10.0 [b], 1.8 [e]	0.9
21.1 [d]		21.1	21.0	9.7 [b], 1.2 [e]	
22.6	(22.6)	22.7	22.7		
23.7 [d]	23.7	23.5	23.7	17.7 [b], 6.1 [e]	1.6
27 [c]	27		27 − 28		
30 [f]	30				
36 [f]					

[a] (1979WO04). See also (1987JU07, 1993MC02) and Table 18.9 in (1983AJ01).
[b] $\sigma(\gamma,\ n) + 2\sigma(\gamma,\ 2n)$.
[c] $T = 2$: see (1979WO04).
[d] $T = 1$: see (1979WO04).
[e] $\sigma(\gamma,\ p)$.
[f] Weak and broad resonances: may indicate the presence of particle-hole states at these high energies.

Table 18.21: Some states of ^{18}O from ^{18}O(e, e′) [a]

E_x (MeV)	Γ (keV)	$J^\pi; T$	Mult.	Transition probability (in $e^2 \cdot \mathrm{fm}^{2\lambda}$)
1.98 [b]		$2^+; 1$	C2	44.8 ± 1.3
3.55 [b]		$4^+; 1$	C4	$(9.04 \pm 0.90) \times 10^2$
3.92 [b]		$2^+; 1$	C2	22.2 ± 1.0
4.46 [c]		1^-		
5.10 [c]		3^-	C3	1301 ± 39
5.26 [b]		$2^+; 1$	C2	28.3 ± 1.5
5.53 ± 0.01 [e]	< 50	$2^-; 1$		
6.20 [c]		1^-		
6.35 ± 0.01 [e]	< 50	$(2^-); 1$		
6.40 [c]		3^-	C3	40 ± 9
7.12 [b]		$4^+; 1$	C4	$(1.31 \pm 0.06) \times 10^4$
7.62 [c]		1^-		
7.77 ± 0.01 [e]	< 50	$2^-; 1$		
7.86 [c]		5^-	C5	$(3.54 \pm 0.64) \times 10^4$
8.04 [c]		1^-		
8.13 [c]		5^-	C5	$(1.88 \pm 0.35) \times 10^4$
8.21 [d]		2^+; (1)	C2	7.3 ± 4.2
8.29 [c]		3^-	C3	≤ 19
8.41 ± 0.01 [e]	< 50	$(2^-); 1$		
8.52 ± 0.01 [e]	< 50	$(4^-); 1$		
8.82 ± 0.01 [e]	70 ± 12	$(1^+); 1$		
8.96 ± 0.01 [e]	43 ± 3	$(4^+); 1$		
9.36 ± 0.01 [d, e]	≤ 20	$(2^+); 1$		
9.71 ± 0.01 [e]	< 50	$(5^-); 1$		
10.31 ± 0.02 [e]	< 50	$(4^+); 1$		
10.43 ± 0.04 [e]	< 50	$(2^-); 1$		
10.67 ± 0.02 [e]	< 50	$(2^-); 1$		
10.99 ± 0.02 [e]	< 50	$(2^-); 1$		
11.52 ± 0.05 [e]	< 50	$(2^-); 1$		
11.67 ± 0.02 [e]	112 ± 7	$(3^-); 1$		

Table 18.21: Some states of ^{18}O from ^{18}O(e, e′) [a] (continued)

E_x (MeV ± keV)	Γ (keV)	$J^\pi; T$	Mult.	Transition probability (in $e^2 \cdot \text{fm}^{2\lambda}$)
11.90 ± 0.03 [e]	< 50	$(2^-); 1$		
12.09 ± 0.02 [e]	< 50	$(1^-, 2^+); 1$		
12.41 ± 0.02 [e]	143 ± 24	$(3^-); 1$		
12.52 ± 0.02 [e]	< 50			
12.66 ± 0.02 [e]	< 50	$(2^-); 1$		
12.99 ± 0.02 [e]	68 ± 18	$(4^-); 1$		
13.40 ± 0.02 [e]	108 ± 26	$(2^-); 1$		
13.85 ± 0.13 [e]	≈ 200	$(6^-); 1$		
14.17 ± 0.04 [e]	140 ± 50	$(6^-); 1$		
14.45 ± 0.05 [e]	≈ 1070			
15.23 ± 0.04 [e]	≈ 300			
15.95 ± 0.03 [e]	< 50			
16.210 ± 0.01 [f, g]		$1^{(-)}$		
16.315 ± 0.01 [f, g]		$(3, 2)^-$		
16.399 ± 0.005 [f, h]	< 20	$2^-; 2$ [i]	M2	$(64 \pm 8) \times 10^{-2}$
16.40 ± 0.02 [e]	< 50	$(2^-); 2$		
16.88 ± 0.03 [e]	< 50	$(4^-, 2^-; 1)$		
16.948 ± 0.01 [f, g]		$(3, 2)^-$		
17.025 ± 0.01 [e, f, g, h]	20 ± 6	$(3^-); 2$		
17.398 ± 0.01 [f, g]		$(2, 1, 3)^-$		
17.450 ± 0.01 [f, g]		$(2, 1, 3)^-$		
17.46 ± 0.03 [e]	≈ 600	$(4^-); 1$		
17.5 [f]	≈ 150			
17.502 ± 0.01 [f, g]		$(1, 2, 3)^-$		
17.635 ± 0.01 [f, g]				
18.049 ± 0.01 [f, g]		[d]		
18.2 [f]	≈ 150			
18.45 ± 0.02 [e]	75 ± 27	$(3^-; 1)$		
18.5 [f]	≈ 4300			
18.68 ± 0.02 [e, h]	< 50	$(4^-; 2)$		63 ± 8 [h]

Table 18.21: Some states of ^{18}O from ^{18}O(e, e′) [a] (continued)

E_x (MeV ± keV)	Γ (keV)	$J^\pi; T$	Mult.	Transition probability (in $e^2 \cdot \text{fm}^{2\lambda}$)
18.871 ± 0.005 [f]		$1^+; 2$	M1	$(3.1 \pm 0.4) \times 10^{-2}$
18.927 [f, g]		$1\ (2^+)$		
19.027 ± 0.01 [f, g]		$(1, 3)^-$		
19.150 ± 0.01 [f, g]		$1^-\ (2^+, 3^-)$		
19.22 ± 0.02 [e]	< 50	$(3^-; 2)$		
19.7 [f]	≈ 200			
20.2 [f]	≈ 180			
20.36 ± 0.02 [e, h]	< 20	$(4^-); 2$	M4	66 ± 6
20.86 ± 0.02 [e]	97 ± 41			
21.0 [f]	≈ 150			
21.42 ± 0.02 [e, h]	49 ± 37	$(4^-; 2)$		
22.40 ± 0.02 [e, f, h]	91 ± 8 [e]	$4^-; 2$ [e]	M4	400 ± 32
23.10 ± 0.02 [e]	49 ± 24			
23.8 [f]	≈ 1300			

[a] Additional states have been excited: see reaction 28 in (1983AJ01). For ground state see reaction 25 here.
[b] (1982NO04).
[c] (1991MA14).
[d] (1990MA06).
[e] (1995SE02).
[f] (1983BE36).
[g] Weakly excited.
[h] (1986MA48).
[i] See Fig. 5 for missing $T = 2$ strength.

have been determined by (1987ME12). At $E = 165$ MeV, the cross section for reaction (c) is larger for ^{18}O than for ^{16}O while reaction (b) has a lower cross section (1982PI06). For the (π^+, 2p), (π^+, pn) and (π^-, pn) reactions at $E_\pi = 165$ MeV see (1984AL20, 1986AL22).

Results of Glauber model calculations of pion scattering from ^{18}O at energies above the Δ_{33} resonance are presented in (1991OS01). A microscopic study of inelastic scattering to the 2^+ states in ^{18}O is reported in (1988HAZZ). See also the review of pion-nucleus physics in (1991MO13).

27. ^{18}O(n, n′)^{18}O

Angular distributions have been measured for $E_{\rm n} = 2.9$ to 24 MeV [see (1972AJ02, 1983AJ01)] and at $E_{\rm n} = 5.0$ to 7.5 MeV (1986KO10; $\rm n_0$, $\rm n_1$).

28. ^{18}O(p, p′)^{18}O

Angular distributions have been measured for $E_{\rm p} = 0.84$ to 135 MeV [see (1978AJ03, 1983AJ01)], at $E_{\rm p} = 135$ MeV (1986KE05; $\rm p_1$) and at $E_{\rm p} = 800$ MeV (1982GL08; p to ^{18}O*(0, 1.98, 7.12).) At $E_{\rm p} = 24.5$ MeV (1974ES02) have studied the angular distributions of the proton groups to ^{18}O*(1.98, 3.55, 3.63, 3.92, 4.46, 5.10, 5.26, 5.53, 7.12): a modified DWBA analysis leads to $J^\pi = 2^+$, 4^+, 0^+, 2^+, 1^-, 3^-, 2^+, 2^- and 4^+ for these states. A coupled-channels calculation suggests $\beta_2 = 0.37 \pm 0.03$, 0.56 ± 0.06 and 0.18 ± 0.04 for ^{18}O*(1.98, 5.10, 7.12). Such calculations also support evidence for a rotational band involving ^{18}O*(0, 1.98, 7.12). The 3^- state at 5.10 MeV is strongly excited and collective in nature: B(E3) $= 1120\ e^2 \cdot {\rm fm}^6$. For ^{18}O*(1.98, 3.92, 5.26), B(E2) $= 45$, 8.3 and 24 $e^2 \cdot {\rm fm}^4$ (1974ES02). The 800 MeV data indicates that ^{18}O*(7.12) can be described only if a large hexadecapole deformation is assumed (1982GL08). At $E_{\rm p} = 201$ MeV, $\sigma(\theta)$ at forward angles has been measured to ^{18}O*(8.21, 8.82, 16.40): it is proposed that ^{18}O*(8.82) has $J^\pi = 1^+$ and that additional 1^+ strength is located in a group centered at $E_{\rm x} \approx 10.1$ MeV as well as in the region $E_{\rm x} = 12.4$ to 15 MeV. The 1^+; $T = 2$ state ^{18}O*(18.87), reported in (e, e′), is not observed (1987DJ01). See also (1988CR1B).

^{18}O*(1.98) has $|{\rm g}| = 0.287 \pm 0.015$ [$\tau_{\rm m} = 2.99 \pm 0.12$ ps]. ^{18}O*(3.55) has $|{\rm g}| = 0.62 \pm 0.10$ suggesting a mainly $({\rm d}_{5/2})^2$ configuration for this state: see (1983AJ01). See also ^{19}F and (1987AJ02).

A Dirac optical model analysis of ^{18}O(p, p) cross section and analyzing power at 800 MeV is described in (1990PH02). A coupled-channels analysis was presented in (1988DE31). The intrinsic radial sensitivity of nucleon inelastic scattering was studied by (1988KE01) and a comparison of electromagnetic and hadronic probes of nuclear structures is described in (1986KE1C).

29. ^{18}O($\bar{\rm p}$, $\bar{\rm p}'$)^{18}O

Angular distributions are reported with 178.4 MeV antiprotons to ^{18}O*(0, 1.98) (1986BR04, 1986LE13). For atomic effects see (1986KO22). See also (1987AJ02).

Differential cross sections for elastic and inelastic scattering of 180 MeV antiprotons by ^{18}O were calculated in the eikonal and Glauber approaches by (1992TA08).

30. ^{18}O(d, d)^{18}O

Angular distributions have been reported at $E_{\rm d} = 7.0$ to 15.0 MeV: see (1972AJ02, 1983AJ01). See also ^{20}F.

31. ^{18}O(t, t′)^{18}O

See (1972AJ02).

32. ^{18}O(^{3}He, ^{3}He′)^{18}O

The elastic scattering has been studied at $E(^3\text{He}) = 11.0$ to 41 MeV [see (1972AJ02, 1983AJ01)] and at 14 MeV (1982AB04), at 25 MeV (1982VE13) [the matter radius, $\langle r^2 \rangle_{\text{m}}^{1/2} = 2.59 \pm 0.12$ fm] and at 33 MeV (1983LE03; also A_γ; and also to ^{18}O*(1.98)). A strong-absorption model analysis of angular distributions at 2.5 and 41 MeV is described in (1987RA36). See also (1985HA11, 1987CO07).

33. ^{18}O(α, α')^{18}O

Recent elastic scattering cross sections at $\text{E}_\alpha = 44.8$ MeV were reported by (1992AR18). Angular distributions of many α-groups have been measured in the range $E_\alpha = 21$ to 40.5 MeV [see (1978AJ03)], at 23.5 MeV (1984SA28; to ^{18}O*(1.98, $3.56 + 3.63$, 3.92, 4.45, 5.1–5.53)) and at 54.1 MeV (1987AB03; g.s.). The transitions to ^{18}O*(4.46, 5.10) are $L = 1$ and 3, respectively, fixing $J^\pi = 1^-$ and 3^- for these states. Measurements of α-groups near $180°$ for $E_\alpha = 20.0$ to 23.4 MeV confirm assignments of natural parity for ^{18}O*(1.98, 3.55, 3.63, 3.92, 4.46, 5.10, 5.26, 5.34, 6.20, 6.40, 7.12, 7.62, 7.86, 8.22, 8.29, 8.82, 8.96, 9.03, 9.10, 9.36, 9.41, 9.67, 9.72 ± 0.03, 9.88, 10.12, 10.30, 10.40, 11.62, 11.69). [See, however, Table 18.9.] Levels at $E_{\text{x}} = 5.38$, 8.48 and 8.64 MeV were not observed, and those at 5.53, 6.35 and 6.88 MeV were populated weakly indicating unnatural parity; $J^\pi = 3^+$ and 2^- respectively for ^{18}O*(5.38, 5.53).

Alpha-gamma correlation measurements involving ^{18}O states below $E_{\text{x}} = 6.4$ MeV [see Table 18.10] lead to $J^\pi = 1^-$ and 3^- for ^{18}O*(6.20, 6.40). Other J^π values agree with previous assignments. The transitions $3.92 \rightarrow 1.98$ and $5.26 \rightarrow 1.98$ are almost pure M1. For τ_{m} measurements, see Table 18.4 in (1978AJ03). For references see (1983AJ01, 1987AJ02). A microscopic investigation of the $\alpha + {}^{18}$O system in a three-cluster model is discussed in (1988DE37).

34. (a) ^{18}O(^{6}Li, ^{6}Li′)^{18}O
(b) ^{18}O(^{7}Li, ^{7}Li′)^{18}O

See (1972AJ02, 1983AJ01).

35. (a) ^{18}O(^{9}Be, ^{9}Be′)^{18}O
(b) ^{18}O(^{9}Be, π^-n)X (not observed)

A recent search for a bound system of π^- and neutrons in the fragmentation region of ^{18}O+^{9}Be collisions at 100 $A \cdot$ MeV is reported in (1993SU08). Upper limits were obtained.

See also (1972AJ02, 1987AJ02).

36. (a) ^{18}O(^{10}B, ^{10}B′)^{18}O
(b) ^{18}O(^{11}B, ^{11}B′)^{18}O

An elastic angular distribution has been reported at $E(^{11}\text{B}) = 115$ MeV: see (1983AJ01). For reaction (a) see (1974AJ01).

A recent measurement of ^{18}O on ^{10,11}B targets at $E_{\text{lab}} \approx 55$ MeV is described in (1993AN08) and evidence for fusion-fission rather than orbiting is reported. See also (1990SZ1C).

37. (a) ^{18}O(^{12}C, ^{12}C′)^{18}O
(b) ^{18}O(^{13}C, ^{13}C′)^{18}O
(c) ^{18}O(^{14}C, ^{14}C′)^{18}O
(d) ^{18}O(^{12}C, α^{12}C′)^{14}C $\qquad Q_{\text{m}} = -6.227$

Elastic angular distributions have been studied at $E(^{18}\text{O}) = 32.3$ to 57.5 MeV for reaction (a) [as well as at $E(^{18}\text{O}) = 70$, 100, and 140 MeV (1982HE07)] and at $E(^{18}\text{O}) = 31$ MeV for reaction (b). Yields and fusion cross sections are reported by (1982BA49, 1982HE07, 1985BE40, 1985CA01, 1986GA13). For reaction (c) see (1986STZY). See also (1983AJ01, 1987AJ02).

Angular correlations (reaction (d)) have been studied at $E(^{18}\text{O}) = 82$ MeV. ^{18}O*(7.10, 7.62, 7.86, 8.04, 8.22, 10.30, 11.59, 12.55) are observed: the first seven of these have $J^\pi = 4^+, 1^-, 5^-, 1^-, 2^+, 4^+, 5^-$ (1984BH01, 1984RA07). In addition ^{18}O*(9.33, 9.65) are also populated [$\Gamma \approx 0.3$ MeV]: a possible interpretation of the data is that these two are 3^- states and that there is in addition a very wide (> 1 MeV) 2^+ state at ≈ 9.5 MeV (1984RA17). See also (1987AJ02).

Giant dipole decays in nuclei excited by $^{18}\text{O} + {}^{12}\text{C}$ collisions were discussed in (1989BEZC, 1990SN1A). Competition between p2n, dn and t emissions in the $^{12}\text{C} + {}^{18}\text{O}$ reaction was studied in an experiment reported in (1990XE01).

Predictions of possible resonant behavior in medium-mass colliding systems are discussed in (1989CI1C). Molecular single particle effects for $^{12}\text{C} + {}^{18}\text{O}$ are explored in calculations described in (1987MO27).

38. ^{18}O(^{15}N, ^{15}N′)^{18}O

See (1983DU13).

39. ^{18}O(^{16}O, ^{16}O$'$)^{18}O

Angular distributions have been measured at many energies for $E(^{16}\text{O}) = 24$ to 54.5 MeV and $E(^{18}\text{O}) = 25$ to 52 MeV, involving besides $^{18}\text{O}_{\text{g.s.}}$, ^{18}O*(1.98, $3.55 + 3.63$, 3.92, 4.46, 5.10, 7.12). At $E(^{18}\text{O}) = 126$ MeV ^{18}O*(9.0) is relatively strongly populated. See (1983AJ01). For yields and fusion cross sections, including the effect of ^{18}O*(1.98), see (1985TH03, 1985WU03, 1986GA13, 1986TH01). See also (1987AJ02). Competition between p2n, dn and t emissions in $^{18}\text{O} + ^{16}\text{O}$ reactions was studied in an experiment reported in (1990XE01).

A unified description of sub-barrier interactions of oxygen isotopes is discussed in (1987PO11); see the coupled-channels calculations reported in (1992LI1K). See also the review of sub-barrier fusion in (1988BE1W). A semi-classical analysis of two particle transfer in $^{16}\text{O} + ^{18}\text{O}$ reactions is discussed in (1987MA22).

40. (a) ^{18}O(^{17}O, ^{17}O$'$)^{18}O
(b) ^{18}O(^{18}O, ^{18}O$'$)^{18}O

Angular distributions involving ^{18}O*(0, 1.98) are reported at $E(^{17}\text{O}) = 36$ MeV. Angular distributions [reaction (b)] have been studied at $E(^{18}\text{O}) = 20$ to 52 MeV. ^{18}O*($3.55+3.63$, 4.46, 5.10, 7.12) are also populated; see (1978AJ03, 1983AJ01). See also (1987AJ02) and see (1990XE01) reporting on p2n, dn and t emissions in $^{18}\text{O} + ^{18}\text{O}$ reactions.

The effect of high spin states on fusion in $^{18}\text{O} + ^{18}\text{O}$ systems has been studied in the framework of a statistical theory (1987RA28).

41. ^{18}O(^{19}F, ^{19}F$'$)^{18}O

The elastic scattering has been studied at $E(^{19}\text{F}) = 27$, 30, and 33 MeV: see (1983AJ01). See also (1987AJ02). An experiment reported in (1990XE01) studied p2n, dn and t emission in $^{18}\text{O} + ^{19}\text{F}$ reactions.

42. (a) ^{18}O(^{24}Mg, ^{24}Mg$'$)^{18}O
(b) ^{18}O(^{26}Mg, ^{26}Mg$'$)^{18}O

Angular distributions are reported for reaction (a) at $E(^{18}\text{O}) = 29$ and 35 MeV to ^{18}O*(0, 1.98). See (1987AJ02).

43. ^{18}O(^{27}Al, ^{27}Al$'$)^{18}O

The elastic angular distribution has been studied at $E(^{18}\text{O}) = 100$ MeV (1981ME13). See also (1983AJ01, 1987AJ02).

44. $^{18}\text{O}(^{28}\text{Si}, ^{28}\text{Si}')^{18}\text{O}$

Elastic angular distributions are reported at $E(^{18}\text{O}) = 36$ to 56 MeV [see (1983AJ01)] and at 351.7 MeV (1984BUZX, 1988BU15; also to $^{18}\text{O}^*(1.98)$). See also (1987AJ02).

Ambiguities in optical-model potentials for describing $^{18}\text{O} + ^{28}\text{Si}$ and other heavy-ion reactions are discussed in (1987HO18). See also (1989NA1M).

45. (a) $^{18}\text{O}(^{40}\text{Ca}, ^{40}\text{Ca}')^{18}\text{O}$
(b) $^{18}\text{O}(^{44}\text{Ca}, ^{44}\text{Ca}')^{18}\text{O}$
(c) $^{18}\text{O}(^{48}\text{Ca}, ^{48}\text{Ca}')^{18}\text{O}$

Angular distributions have been measured at $E(^{18}\text{O}) = 62.1$ MeV [reaction (a)] for the transitions to $^{18}\text{O}^*(0, 1.98, 5.10)$ (1982RE14). For a fusion study [reaction (b)] see (1984DE38). See also (1987AJ02, 1987SC34).

46. $^{18}\text{F}(\beta^+)^{18}\text{O}$ $\quad Q_\text{m} = 1.655$

See ^{18}F.

47. $^{19}\text{F}(\gamma, \text{p})^{18}\text{O}$ $\quad Q_\text{m} = -7.994$

(1985KE03) have measured the yields of proton groups to $^{18}\text{O}^*(0, 1.98)$ [and to unresolved states] for E_bs in the GDR range. See also (1978AJ03) and ^{19}F.

48. $^{19}\text{F}(\text{n}, \text{d})^{18}\text{O}$ $\quad Q_\text{m} = -5.770$

Angular distributions have been measured at $E_\text{n} = 14$ to 14.4 MeV: see (1972AJ02). See also (1978AJ03) and ^{20}F. Nuclear model calculations for $E_\text{n} = 2$–20 MeV are described in (1992ZH15).

Table 18.22: ^{18}O states from ^{19}F(t, $\alpha\gamma$) [a]

E_x (keV)	J^π	E_x (keV)	J^π
1982.16 ± 0.20		5530.5 ± 0.6	1, 2
3555.07 ± 0.45		6196.3 ± 1.2	1
3634.50 ± 0.40		6351.3 ± 0.6	1, 2
3920.6 ± 0.4		6404.4 ± 1.2	
4456.1 ± 0.5		6881.6 ± 1.2	0, (1)
5098.5 ± 1.2		7116.9 ± 1.2	
5260.4 ± 1.2		7750	1, 2, 3, 4
5336.4 ± 0.6		7980	1, 2, 3, 4, 5
5377.8 ± 1.2		[b]	

[a] (1973OL02): See Table 18.10 for branching ratios and Table 18.9 for τ_m. See also Table 18.10 in (1983AJ01).
[b] Alpha groups are also reported to ^{18}O states with $E_x = 7.60$, 7.75, 7.84, 7.96, 8.02, 8.11, 8.19, 8.26, 8.39, 8.48, 8.64 MeV (± 20 keV) (1962HI06).

49. ^{19}F(p, pp)^{18}O $\qquad Q_m = -7.994$

Experimental and theoretical studies of knockout reactions are reviewed in (1987VD1A).

50. ^{19}F(d, ^{3}He)^{18}O $\qquad Q_m = -2.500$

Many states of ^{18}O ($E_x < 14.6$ MeV) have been populated in this reaction: see Table 18.8 in (1978AJ03). [Comment: Note, however, density of states.] Analyzing powers for the ground-state transition are reported at $E_d = 12.4$ MeV (1983EN02). See also (1983KI13).

51. ^{19}F(t, α)^{18}O $\qquad Q_m = 11.820$

See Table 18.22.

52. ^{22}Ne(d, ^{6}Li)^{18}O $\qquad Q_m = -8.192$

At $E_{\rm d} = 80$ MeV angular distributions have been measured for the ^{6}Li groups to the ground state of ^{18}O and to excited states at 1.98, 3.57, 5.10, 6.30, 7.8, 9.4 $[\pm 0.04]$ MeV (1984OE02) [see also for $S_{\rm rel.}$]. For the earlier work see (1983AJ01).

^{18}F
(Figs. 3 and 5)

GENERAL: See Table 18.23.

$$\mu_{1.12} = +2.86 \pm 0.03 \text{ nm [see (1983AJ01)]}$$
$$Q_{1.12} = 0.13 \pm 0.03 \text{ b [see (1983AJ01)].}$$

1. ^{18}F(β^+)^{18}O $\qquad Q_m = 1.655$

The positron decay is entirely to the ground state of ^{18}O [$J^\pi = 0^+$, $T = 1$]; the half-life is 109.77 ± 0.05 min [see Table 18.11 in (1972AJ02)]; $\log ft = 3.554$. The fact that the β^+ transition to ^{18}O$_{\text{g.s.}}$ is allowed fixes $J^\pi = 1^+$ for ^{18}F$_{\text{g.s.}}$.

The ratio $\epsilon_K/\beta^+ = 0.030 \pm 0.002$: see (1978AJ03, 1987AJ02). See also (1989SA1P, 1989KA1S).

The influence of meson exchange currents of the second kind is discussed in (1988SA12) and in (1989SA1H) which also considers the effects of neutrino mass. Charged-current (ν_e, e$^-$) reactions on ^{18}O and the predicted effects on a proposed neutrino elastic scattering measurement of the Weinberg angle is discussed in (1988HA22).

2. (a) ^{10}B(^{9}Be, n)^{18}F $\qquad Q_m = 14.455$
(b) ^{11}B(^{9}Be, 2n)^{18}F $\qquad Q_m = 3.001$

See (1986CU02) for production cross sections of 0.94 MeV γ-rays.

3. (a) ^{12}C(^{6}Li, d)^{16}O $\qquad Q_m = 5.687$ $\qquad E_b = 13.213$
(b) ^{12}C(^{6}Li, α)^{14}N $\qquad Q_m = 8.798$
(c) ^{12}C(^{6}Li, ^{6}Li)^{12}C

Cross sections for these and other charged particle channels have been measured for $E(^6\text{Li}) = 1.9$ to 36 MeV [see (1978AJ03, 1983AJ01)]. More recently, measurements of cross sections at $E(^6\text{Li}) = 210$ MeV are reported in (1988NA02). Vector analyzing power measurements have been made at $E(^6\text{Li}) = 150$ MeV (1987TA21, 1988TA08) and at $E(^6\text{Li}) = 30$ MeV (1994RE01). for elastic scattering and at $E(^6\text{Li}) = 30$ MeV (1988VAZY, 1989VA04) for inelastic scattering to ^{12}C*(4.43). Neutron yields from ^{6}Li + ^{12}C at $E(^6\text{Li}) = 40$ MeV have been measured by (1987SC11).

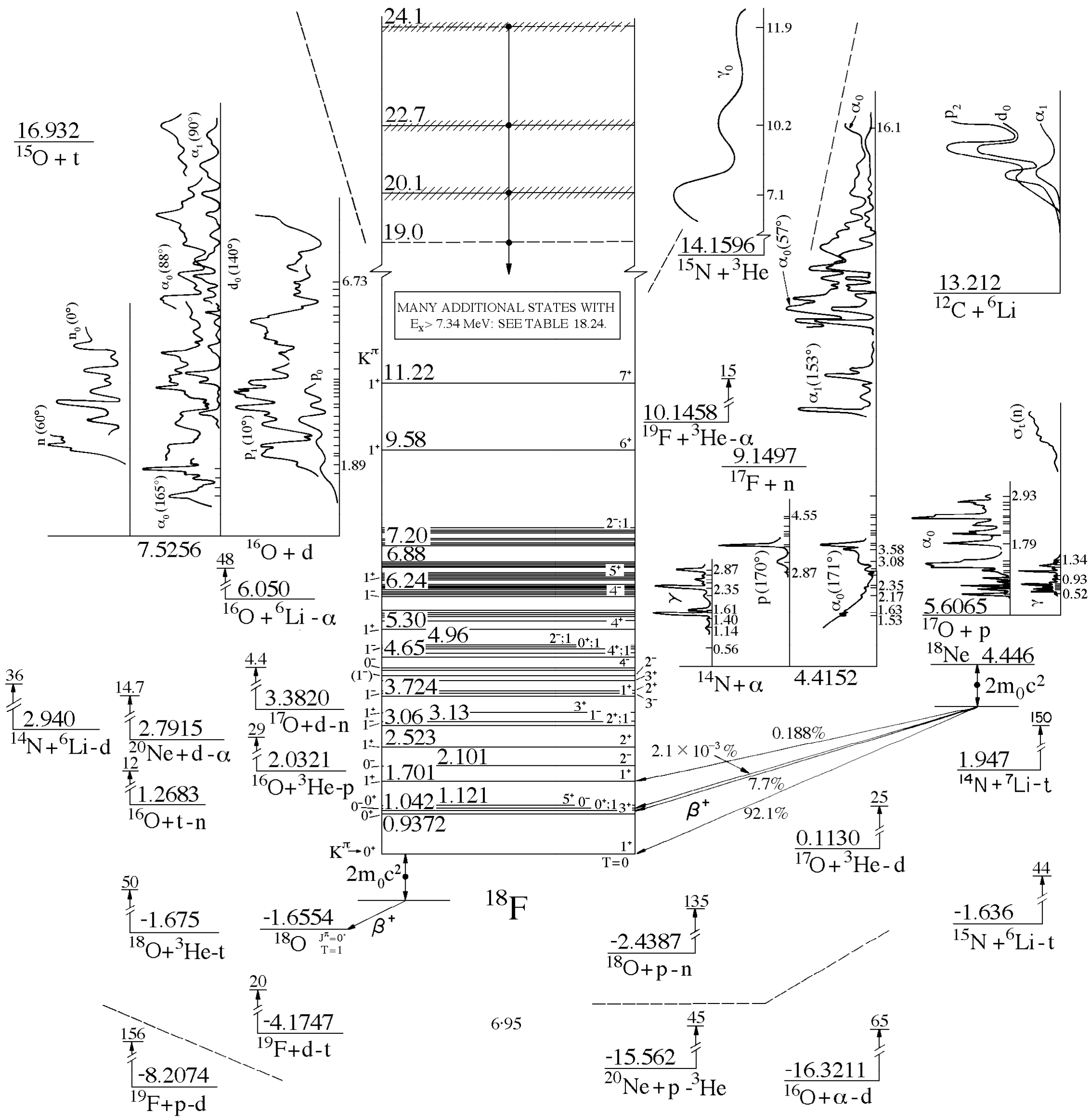

Fig. 3: Energy levels of ^{18}F. For notation see Fig. 2.

Table 18.23: ^{18}F – General

Reference	Description

Model Calculations

1987LE1L	Low-lying non-normal parity states of ^{18}O & ^{18}F calculated in shell model + tensor force
1987SH1O	Validity of M-3Y force equivalent G-matrix element for s-d shell nucl. struc. calcs.
1988BR11	Semi-empirical effective interactions for the 1s-0d shell
1989HJ03	Effective interactions through 3rd order for $A = 18$ nuclei with the Paris potential
1989TR18	2-nucleon and 4-nucleon clusters in light & heavy nuclei
1989ZH05	Evidence for unnatural parity-pairing correlations in some light nuclei
1990HJ03	Choice of single-particle potential & the convergence of the effective interaction
1990SK04	Study of $A = 18$ nuclei and the effective interaction in the sd shell
1990SK07	Effective interaction derived from the BAGEL approach
1992HJ01	Folded-diagram effective interactions with the Bonn meson-exchange potential model
1992JI04	Bonn potential used to evaluate energy spectra of some light sd-shell nuclei
1992WA22	Effective interactions for the 0p1s0d nuclear shell-model space

Special States

Review:

1989RA17	Compilation of exp. data on nuclear moments for ground & excited states of nucl.

Other Articles:

1987LE1L	Non-normal parity states of ^{18}O & ^{18}F calculated in shell model + tensor force
1987MU16	Relativistic effects in the low-energy spectra of 1s0d-shell nuclei
1987SH1O	Validity of M-3Y force equivalent G-matrix element for s-d shell nucl. struc. calcs.
1988ET01	Analysis of magnetic dipole transitions between sd-shell states
1989HJ03	Effective interactions through 3rd order for $A = 18$ nuclei with the Paris potential
1989ZH05	Evidence for unnatural parity-pairing correlations in some light nuclei
1990HJ01	3rd order number-conserving sets & effective interactions calc. with Bonn-Jülich potential
1990HJ03	Choice of single-particle potential & the convergence of the effective interaction
1990SK04	Study of $A = 18$ nuclei and the effective interaction in the sd shell

Electromagnetic

Reviews:

1988HE1E	Report on charge symmetry, charge independence, parity and time reversal invariance

Table 18.23: ^{18}F – General – cont.

Reference	Description
	Electromagnetic – cont.
1989MC1C	Nuclear tests of fundamental interactions
1989RA17	Compilation of exp. data on nuclear moments for ground & excited states of nucl.
Other articles:	
1988ET01	Analysis of magnetic dipole transitions between sd-shell states
1988KA1U	Evaluation of the weak pion-nucleon vertex; predicts γ-asymmetry in ^{18}F
1993EN03	Strengths of γ-ray transitions in $A = 5$–44 nuclei
	Astrophysical
Reviews:	
1987RA1D	Nuclear processes & accelerated particles in solar flares
1989WH1B	Abundance ratios as a function of metallicity
1990AR10	Nuclear reactions in astrophysics
Other articles:	
1987GOZX	Measurement of ^{21}Ne(p, α)^{18}F & its astrophysical implications (A)
1988CA26	Analytic expressions for thermonuclear reaction rates involving $Z \leq 14$ nuclei
1989JI1A	Nucleosynthesis inside thick accretion disks around massive black holes
1990TH1C	Explosive nucleosynthesis in SN 1987A: composition, radioactivities, neutron star mass
	Applications
Review:	
1989WO1B	Biomedical applications of particle accelerators (A)
Other articles:	
1988HI1F	Design & uses of positron emission tomography target systems (A)
1988VO1D	Radionuclide production for positron emission tomography: accelerator choices (A)
1988VO1E	Water targetry for ^{18}F prod. (calc. & exp. verification of beam heating & heat removal) (A)
1989AR1J	Production and acceleration of radioactive ion beams at Louvain-la-Neuve

Table 18.23: ^{18}F – General – cont.

Reference	Description
	Complex Reactions
1987BU07	Projectile-like fragments from ^{20}Ne + ^{197}Au: counting simultaneously emitted neutrons
1987FE04	Single-nucleon transfer reactions induced by 376-MeV ^{17}O on ^{208}Pb (DWBA analysis)
1987HI05	Energy & linear-momentum dissipation in the fusion reaction ^{165}Ho + ^{20}Ne at 30 MeV/A
1989SA10	Total cross sections of reactions induced by neutron-rich light nuclei
1990GL01	Structure phenomena in the orbiting ^{12}C + ^{24}Mg system
	Hypernuclei
1988MA1Q	Identification of one Glue-like mechanism of the Λ-Hyperon in hypernuclei
1989BA92	Evaluation of hypernucleus production cross-sections in relativistic heavy-ion collisions
1989TA32	Schmidt diagrams & configuration mixing effects on hypernuclear magnetic moments
	Symmetries and Fundamental Interactions
1986ADZT	Parity and time-reversal violation in nuclei and atoms
1986HA1I	Fundamental interaction studies in nuclei
1988HE1C	Studies of symmetries and symmetry breaking using nuclei
1988HE1E	Status report on charge symmetry & charge independence
1989MC1C	Nuclear tests of fundamental interactions
	Other Topics
Review	
1989AJ1A	Summary of recent work involving light nuclei (Sec. 4.2 covers $A = 18$)
Other articles:	
1987MU16	Relativistic effects in the low-energy spectra of 1s0d-shell nuclei
1988KA1U	Evaluation of the weak pion-nucleon vertex; predicts γ-asymmetry in ^{18}F

Table 18.23: ^{18}F – General – cont.

Reference	Description
	Other Topics – cont.
1988TR02	Interacting boson scheme for light nuclei
1989GE10	Threshold pion-nucleus amplitudes as predicted by current algebra
1989ZH05	Evidence for unnatural parity-pairing correlations in some light nuclei
1990HJ01	3rd order number-conserving sets & effective interactions calc. with Bonn-Jülich potential
1990KA1F	Theoretical aspects of nuclear parity violation
1990SK04	Study of $A = 18$ nuclei and the effective interaction in the sd shell
1990SK07	Effective interaction derived from the BAGEL approach
	Ground State Properties
Review:	
1989RA17	Compilation of exp. data on nuclear moments for ground & excited states of nucl.
Other articles:	
1989SA10	Total cross sections of reactions induced by neutron-rich light nuclei
1989TR18	2-nucleon and 4-nucleon clusters in light & heavy nuclei
1991UE01	Unitary pole approx. for Coulomb+Yamaguchi potential used for 3-body bound-state calc.

(A) denotes that only an abstract is available for this reference.

The cross section for the isospin-forbidden α_1 group [to ^{14}N*(2.31), 0^+, $T = 1$] is 1 to 2% of the cross section of the allowed α_0 and α_2 groups for $E(^6\text{Li}) = 3.2$ to 6 MeV while for 9 to 14 MeV it varies from 0.4 to 1.8%. At 20 MeV, the α_1 yield is 0.02% of the allowed yield. Structures are reported at $E(^6\text{Li}) = 11.0$ and 13.0 MeV in the α_0 yield, at 11.5 and 13.0 MeV in the α_1 yield and at ≈ 11.7 and 12.8 MeV in the α_2 yield. A resonance is also reported in the α_1 yield at $E(^6\text{Li}) = 4.2$ MeV: $E_x = 15.99 \pm 0.02$ MeV, $\Gamma_{\text{c.m.}} = 290 \pm 30$ keV, $J^\pi = 2^+$ (one-level BW fit). It is suggested that this resonance is due to 2^+ states with $T = 0$ and 1 which are unresolved. Cross sections for populating ^{16}O*(8.87, 10.36, 11.08, 11.10) are reported by (1981GL02).

The excitation functions for the ^{6}Li ions to ^{12}C*(0, 4.43) show a single isolated structure at $E(^6\text{Li}) = 22.8$ MeV, in the range 20–36 MeV, with $\Gamma \approx 0.8$ MeV. It is unlikely to be due to an isolated state in ^{18}F. Analyzing power measurements are reported for many deuteron and α groups and for elastically scattered ^{6}Li ions at $E(^6\text{Li}) = 20$ MeV. VAP measurements for elastic scattering are also reported at $E_d = 9.0$ and 19.2 MeV (1983RU09) and at 150 MeV (1986KA1C, 1986TA1B).

For fusion studies see (1982DE30, 1987PA12). For references to earlier work and for additional comments see (1978AJ03, 1983AJ01, 1987AJ02), ^{12}C in (1985AJ01), ^{14}N in (1986AJ01), and ^{16}O in (1986AJ04, 1993TI07).

Table 18.24: Energy levels of ^{18}F [a]

E_x (MeV ± keV)	$J^\pi; T$	K^π	τ or $\Gamma_{c.m.}$	Decay	Reactions
0	$1^+; 0$	0^+	$\tau_{1/2} = 109.77 \pm 0.05$ min	β^+	1, 4, 5, 6, 9, 10, 12, 13, 15, 21, 23, 24, 25, 29, 31, 34, 35, 36, 37, 38, 40, 41, 42, 43, 44
0.93720 ± 0.06	$3^+; 0$	0^+	$\tau_m = 67.6 \pm 2.5$ ps (g $= +0.56 \pm 0.05$)	γ	2, 6, 9, 10, 13, 21, 23, 25, 30, 31, 35, 36, 38, 40, 41, 42, 44
1.04155 ± 0.08	$0^+; 1$		$\tau_m = 2.55 \pm 0.45$ fs	γ	6, 9, 21, 25, 30, 31, 34, 35, 37, 38, 40, 42, 43
1.08054 ± 0.12	$0^-; 0$	0^-	$\tau_m = 27.5 \pm 1.9$ fs	γ	6, 9, 10, 21, 25, 35, 37, 38, 40, 41, 42, 44
1.12136 ± 0.15	$5^+; 0$	0^+	$\tau_m = 234 \pm 10$ ns ($\mu = +2.86 \pm 0.03$ nm) ($Q = 0.13 \pm 0.036$ b)	γ	5, 6, 9, 10, 13, 14, 21, 22, 25, 30, 31, 32, 35, 37, 40, 42, 44
1.70081 ± 0.18	$1^+; 0$	1^+	$\tau_m = 955 \pm 27$ fs	γ	6, 10, 21, 25, 34, 35, 40, 42, 43, 44
2.10061 ± 0.10	$2^-; 0$	0^-	$\tau_m = 5.1 \pm 0.5$ ps	γ	6, 10, 13, 21, 23, 25, 35, 40, 42, 44
2.52335 ± 0.18	$2^+; 0$	1^+	$\tau_m = 590 \pm 24$ fs	γ	6, 10, 21, 25, 30, 31, 40, 42
3.06184 ± 0.18	$2^+; 1$		$\tau_m < 1.2$ fs	γ	6, 21, 25, 30, 31, 35, 38, 40, 42, 43
3.13387 ± 0.15	$1^-; 0$	1^-	$\tau_m = 0.39 \pm 0.02$ ps	γ	6, 10, 21, 25, 35, 38, 40, 42
3.3582 ± 1.0	$3^+; 0$	1^+	$\tau_m = 0.44 \pm 0.03$ ps	γ	6, 10, 21, 35, 40, 42, 44
3.72419 ± 0.22	$1^+; 0$		$\tau_m = 2.7^{+4.1}_{-2.7}$ fs	γ	6, 10, 21, 23, 25, 31, 34, 35, 40, 42, 44
3.79149 ± 0.22	$3^-; 0$	1^-	$\tau_m = 1.91 \pm 0.13$ ps	γ	5, 10, 21, 23, 25, 35, 40, 42, 44
3.83917 ± 0.22	$2^+; 0$		$\tau_m = 19.0 \pm 2.7$ fs	γ	6, 10, 21, 23, 25, 30, 35, 40, 42, 44
4.11590 ± 0.25	$3^+; 0$		$\tau_m = 91 \pm 22$ fs	γ	6, 10, 21, 23, 25, 30, 31, 35, 40, 42, 44
4.2258 ± 0.7	$2^-; 0$	(1^-)	$\tau_m = 110 \pm 15$ fs	γ	6, 10, 21, 23, 35, 40, 42, 44
4.36015 ± 0.26	$1^+; 0$		$\tau_m = 27 \pm 10$ fs	γ	10, 21, 25, 34, 35, 40, 42, 44
4.3981 ± 0.7	$4^-; 0$	0^-	$\tau_m = 58 \pm 12$ fs	γ	6, 10, 13, 14, 21, 35, 40, 42, 44
4.652 ± 2	$4^+; 1$		$\tau_m < 10$ fs	γ	6, 21, 24, 30, 31, 35, 40, 42
4.753 ± 3	$0^+; 1$			γ	21, 35, 38, 40, 42, 44
4.8483 ± 0.5	$5^-; 0$	1^-	$\tau_m = 5.2 \pm 0.9$ ps	γ	5, 23
4.860 ± 2	$1^-; 0$		$\tau_m = 66 \pm 18$ fs	γ, α	6, 21, 40, 42, 44
4.9636 ± 0.8	$2^+; 1$		$\tau_m < 4$ fs	γ	6, 21, 30, 40, 42
5.2976 ± 1.5	$4^+; 0$	1^+	$\tau_m = 30 \pm 5$ fs	γ, α	6, 9, 10, 11, 21, 40, 42

Table 18.24: Energy levels of ^{18}F [a] (continued)

E_x (MeV ± keV)	$J^\pi; T$	K^π	τ or $\Gamma_{c.m.}$	Decay	Reactions
5.502 ± 2	$3^{(-)}; 0$		$\tau_m = 63 \pm 25$ fs	γ, α	6, 10, 21, 40, 42
5.60338 ± 0.27	1^+		$\Gamma = 43.3 \pm 1.6$ eV	γ, α	6, 8, 25, 40, 42, 44
5.60486 ± 0.28	$1^-; 0+1$		$\Gamma < 1.2$ keV	γ, α	6, 8, 10, 21, 25, 40, 42, 44
5.67257 ± 0.32 [d]	$1^-; 0+1$		$\Gamma < 0.8$ keV	γ, α	6, 8, 10, 21, 25, 40, 42, 44
5.786 ± 2.4	$2^-; 0$		$\tau_m = 15 \pm 10$ fs	γ, α	6, 21, 40, 42, 44
6.0964 ± 1.1	$4^-; 0$	1^-	$\Gamma = 0.24 \pm 0.03$ keV	γ, p, α	6, 10, 21, 25, 29, 40, 42, 44
6.108 ± 3	$(1^+); 0$		$\Gamma = 0.034 \pm 0.003$ keV	γ, p, α	6, 8, 21, 23, 29, 42, 44
6.13647 ± 0.33	$0^+; 1$		$\Gamma \leq 1$ keV	γ, p	21, 25, 27, 42, 44
6.1632 ± 0.9	$3^+; 1$		$\Gamma = 14 \pm 0.5$ keV	γ, p, α	21, 25, 27, 42, 44
6.2404 ± 0.8	$3^-; 0+1$		$\Gamma = 0.19 \pm 0.03$ keV	γ, p, α	6, 21, 25, 27, 29, 42
6.242 ± 3	$3^-; 0+1$		$\Gamma = 0.18 \pm 0.04$ keV	γ, p, α	6, 8, 21, 25, 29, 42
6.262 ± 2.5	$1^+; 0$		$\Gamma = 0.60 \pm 0.12$ keV	γ, p, α	6, 8, 10, 21, 29, 34, 42
6.2832 ± 0.9	$2^+; 1$		$\Gamma = 10.0 \pm 0.5$ keV	γ, p, α	21, 25, 27, 29
6.3105 ± 0.8	$3^+; 0$		$\Gamma = 0.95 \pm 0.14$ keV	γ, p, α	6, 21, 25, 27, 29, 44
6.3855 ± 1.7	$2^+; 0+1$		$\Gamma = 0.49 \pm 0.09$ keV	γ, p, α	6, 21, 25, 29, 42
6.4849 ± 1.5	$3^+; 0$		$\Gamma = 0.40 \pm 0.10$ keV	γ, p, α	6, 21, 25, 29, 42, 44
6.5670 ± 1.5	$5^+; 0$	1^+	$\Gamma = 0.56 \pm 0.13$ keV	γ, p, α	6, 8, 9, 10, 11, 21, 29, 42
6.633 ± 10	1		$\Gamma = 80 \pm 2$ keV	p, α	29, 42
6.6437 ± 0.8	$2^-; 1$		$\Gamma = 0.60 \pm 0.07$ keV	γ, p, α	6, 7, 21, 25, 29
6.647 ± 4	1^-		$\Gamma = 91 \pm 4$ keV	p, α	8, 10, 29
6.777 ± 1.4	$4^+; 0$		$\Gamma = 9.2 \pm 1.0$ keV	γ, p, α	21, 25, 27, 29, 42
6.8031 ± 1.5	$1^+, 2, 3^+; 0$		$\Gamma \leq 2$ keV	γ, p	10, 21, 25, 27, 42
6.809 ± 5	2^-		$\Gamma = 88 \pm 2$ keV	p, α	7, 8, 29
6.811	(2^+)		$\Gamma = 3.0 \pm 0.5$ keV	p, α	29
6.857 ± 10	(3^-)		$\Gamma = 5.0 \pm 1.0$ keV	p, α	29, 42
6.8774 ± 1.7	$3, 4^-; 0$		$\Gamma \leq 2$ keV	γ, p, α	21, 25, 29
7.201 ± 2	$(4^+); 0$		$\Gamma = 6.5$ keV	p, α	8, 20, 42
7.247 ± 2	$(1^+); 0$		$\Gamma = 46.5$ keV	p, α	8, 29
7.291 ± 2	3^-		$\Gamma = 38$ keV	p, α	7, 8, 27, 29
7.315 ± 4	$(3^-; 0)$		$\Gamma = 52$ keV	p, α	29, 40
7.336 ± 2	$1^-; 1$		$\Gamma = 16 \pm 2$ keV	γ, p	25, 27
7.406 ± 2	1^+		$\Gamma = 14.6 \pm 1.4$ keV	p	27
7.447 ± 10			$\Gamma = 140$ keV	p, α	29, 31
7.454 ± 2	1^-		$\Gamma = 6$ keV	p	27
7.478 ± 2	(2)		$\Gamma = 12 \pm 3$ keV	γ, p, α	25, 27, 29
(7.485 ± 2)	(1^-)		$\Gamma = 32$ keV	p	27

Table 18.24: Energy levels of ^{18}F [a] (continued)

E_x (MeV $\pm$ keV)	$J^\pi; T$	K^π	τ or $\Gamma_{c.m.}$	Decay	Reactions
7.506 ± 2	4^-		$\Gamma = 12 \pm 2$ keV	p, α	27, 29
7.513 ± 2			$\Gamma < 4$ keV	γ, p	25
7.528 ± 2	$2^-; 1$		$\Gamma = 16.5 \pm 3.0$ keV	γ, p, α	25, 27, 29
7.532 ± 5			$\Gamma = 75$ keV	p, α	27, 29
7.555 ± 2	(1^-)		$\Gamma = 30$ keV	p	27
7.584 ± 2			$\Gamma = 9 \pm 2$ keV	γ, p, α	25, 27, 29
7.685 ± 2	$3^+, 4^+$		$\Gamma = 36 \pm 4$ keV	p, α	27, 29
7.729 ± 4	≥ 1		$\Gamma = 66 \pm 5$ keV	p, α	27, 29
7.763 ± 4			$\Gamma = 70$ keV	p	27
7.878 ± 3	≥ 2		$\Gamma = 20$ keV	p, α	27, 29
7.899 ± 2	(2^-)		$\Gamma = 38$ keV	p, α	7, 8, 29
7.941 ± 12	(1^+)		$\Gamma = 112$ keV	p, α	7, 8, 29
8.064 ± 6	≥ 4		$\Gamma = 60$ keV	p, α	27, 29
8.115 ± 8			$\Gamma = 96$ keV	p	27
8.209 ± 2	2^-		$\Gamma = 52$ keV	p, α	27, 29
8.238 ± 2	4^+		$\Gamma = 20$ keV	p	27
9.02	$(5^-; 1)$				31
9.207 ± 15 [b]	$3, 4^-; 0$			p, d, α	16, 17, 18
9.50	$2, 3^+; 0$			n, d, α	16, 18
9.58 ± 20 [c]	6^+	1^+		d, α	9, 10, 11, 22, 31
10.58 ± 50					11
11.22 ± 30	7^+	1^+		d, α	9, 10, 11
12.75	$(6^-; 1)$				31
13.83	$4^-, 5^+$		$\Gamma = 60$ keV	d, α	18
14.02	$4^-, 5^+$		$\Gamma = 60$ keV	d, α	18
14.10	$4^-, 5^+$		$\Gamma = 60$ keV	d, α	18
14.18 ± 40	(8^+)	(1^+)		d, α	9, 10, 11
14.65	(7^+)				31
15.09	$4^-, 5^+$			d, α	18
15.34	$5^+, 6^-$			d, α	18
15.79 ± 100	$(6^-; 1)$				11, 31
16.07	$4^-, 5^+$		$\Gamma = 220$ keV	d, α	18
16.72	$4^-, 5^+$		$\Gamma = 60$ keV	d, α	18
17.43	$4^-, 5^+, 6^-$		$\Gamma = 70$ keV	d, α	18
18.62 ± 120					11
(19.00 ± 150)			$\Gamma = (500 \pm 150)$ keV	γ, ^{3}He	12

Table 18.24: Energy levels of ^{18}F [a] (continued)

E_x (MeV ± keV)	$J^\pi; T$	K^π	τ or $\Gamma_{c.m.}$	Decay	Reactions
20.1 ± 200	$(2^-; 1)$		$\Gamma = 1600 \pm 100$ keV	γ, ^{3}He	12
22.7 ± 200	$(2^-; 1)$		$\Gamma = 1200 \pm 100$ keV	γ, ^{3}He	12
(24.1 ± 200)			$\Gamma = (1400 \pm 300)$ keV	γ, ^{3}He	12

[a] See also Table 18.25 for radiative transitions and 18.26 for τ_m.
[b] Uncertainty estimated by evaluators.
[c] For other states with $E_x < 9.6$ MeV see footnote [e] in Table 18.17 of (1978AJ03) and Table 18.27 here. For other states with $10.0 < E_x < 19.6$ MeV see Table 18.27 here, and Tables 18.14 and 18.16 in (1978AJ03). These two tables in (1978AJ03) display the states deduced from the yields of the isospin-forbidden α_1 groups in ^{14}N$+\alpha$ and ^{16}O$+$d, respectively. (1976CH24) reports 151 isospin-mixed natural-parity states with $10.4 < E_x < 17.5$ MeV [^{14}N(α, α_1)] and (1973JO13) reports 138 such states with $9.2 < E_x < 19.4$ MeV [^{16}O(d, α_1)] of which 16 have $E_x > 17.5$ MeV. In the region $10.4 < E_x < 20.8$ MeV some 167 states with mixed isospin and natural parity have been reported. See also reaction 29.
[d] (1989BO01).

4. ^{12}C(^{9}Be, t)^{18}F $\qquad Q_m = -4.475$

Angular distributions are reported at $E(^9\text{Be}) = 12$ to 27 MeV to ^{18}F$_{g.s.}$ and to the unresolved states at 1 MeV: see (1983AJ01). For excitation functions see (1982HU06, 1983JA09).

5. ^{12}C(^{11}B, αn)^{18}F $\qquad Q_m = -2.701$

For ^{18}F*(4.85) [5^-; $T = 0$] $\tau_m = 5.2 \pm 0.9$ ps. The E1 strength is $(3.4 \pm 0.6) \times 10^{-6}$ W.u. for the transition to ^{18}F*(1.12) [5^+; $T = 0$] and the E2 strength is 14.8 ± 2.6 W.u. for that to ^{18}F*(3.79) [3^-; 0]. The latter strength, which is that of a highly collective transition, corresponds to a quadrupole moment $Q_0 = 395 \pm 35$ mb and suggests that ^{18}F*(4.85) is the 5^- state of a (strongly decoupled) $K^\pi = 1^-$ band (1982KO24). See also Tables 18.14 and 18.15.

6. ^{14}N(α, γ)^{18}F $\qquad Q_m = 4.415$

The non-resonant S-factor for this reaction is $S \approx 0.7$ MeV $\cdot$ b: see (1978AJ03). A number of resonances have been observed for $E_\alpha < 3$ MeV: see Table 18.27. Studies of these, principally by the Toronto and Queen's groups [see references in (1978AJ03, 1983AJ01)] in conjunction with work on ^{14}N(α, α), ^{16}O(^{3}He, p), ^{17}O(p, γ) and ^{17}O(p, α) [see Tables 18.29, 18.30, 18.31] have led to the determination of branching ratios, mixing ratios and widths (Table 18.25), lifetimes (Table 18.26) and the E_x, J^π and K^π assignments for ^{18}F states with $E_x < 6.9$ MeV. The reader is referred to the series of papers by the Toronto group for the most complete and definitive arguments on the parameters of the low-lying states of ^{18}F.

A recent measurement reported in (1989BO01) determines a value $E_x = 5672.57 \pm 0.32$ keV for the first ^{18}F level above the proton threshold. This level is important for calculating the rate of ^{17}O destruction during hydrogen burning in stars.

No evidence is seen for the excitation of the (forbidden) state at $E_x = 4.753$ MeV [$J^\pi = 0^+$, $T = 1$] (1981LE1A, 1983LE08). See also (1987AJ02), and see the tables of reaction rates (1988CA26) and the reviews of (1989KA24, 1989WH1B, 1989TH1C).

7. ^{14}N(α, p)^{17}O $\qquad Q_m = -1.192 \qquad E_b = 4.415$

Table 18.25: Radiative decays in ^{18}F [a]

E_i (MeV)	J^π_i	E_f (MeV)	Branch (%)	Widths and mixing ratios
0.94	$3^+; 0$	0	100	
1.04	$0^+; 1$	0	100	
1.08	$0^-; 0$	0	100	
1.12	$5^+; 0$	0.94	100	
1.70	$1^+; 0$	0	29.8 ± 1.3	
		1.04	70.2 ± 1.3	
2.10	$2^-; 0$	0	38 ± 1	$\Gamma_\gamma = (4.6 \pm 2.2) \times 10^{-5}$ eV
		0.94	31 ± 1	$\Gamma_\gamma = (4.0 \pm 1.9) \times 10^{-5}$ eV
		1.08	31 ± 1	
2.52	$2^+; 0$	0	74.9 ± 1.8	$\delta = 3.0 \pm 1.0$
		0.94	21.5 ± 1.2	$\delta = -(1.5 \pm 0.6)$
		1.70	3.9 ± 0.6	$\delta = 0.94 \pm 0.4$
3.06	$2^+; 1$	0	23.2 ± 0.8	
		0.94	76.7 ± 0.8	
		1.04	0.11 ± 0.03	
3.13	$1^-; 0$	0	39 ± 2	$\delta = +(0.07 \pm 0.05)$
				$\Gamma_\gamma = (5.7 \pm 2) \times 10^{-4}$ eV

Table 18.25: Radiative decays in ^{18}F [a] (continued)

E_i (MeV)	J^{π}_i	E_f (MeV)	Branch (%)	Widths and mixing ratios
		1.04	34 ± 2	$\Gamma_\gamma = (7.3 \pm 2.7) \times 10^{-4}$ eV
		1.08	25 ± 2	$\Gamma_\gamma = (4.8 \pm 1.8) \times 10^{-4}$ eV
		1.70	2.0 ± 0.5	$\delta = +(0.22 \pm 0.15)$
3.36	3^+; 0	0	45 ± 5	
		0.94	9 ± 3	
		1.70	40 ± 4	
		2.10	< 3	
		2.52	6 ± 3	$\delta = -0.4^{+0.3}_{-0.5}$
3.72	1^+; 0	0	5 ± 2	
		1.04	91 ± 2	$\Gamma_\gamma = (1.3 \pm 0.2) \times 10^{-3}$ eV [c]
		3.06	4 ± 2	
3.79	3^-; 0	2.10	68 ± 4	$\delta = -(0.22 \pm 0.06)$
		2.52	2.2 ± 1.1	
		3.06	30 ± 3	$\delta = -(0.09 \pm 0.09)$
3.84	2^+; 0	0	38 ± 2	$\delta = -(1.8 \pm 0.5)$
		0.94	8.9 ± 1.4	$\delta = -(0.3 \pm 0.3)$
		1.70	3.0 ± 1.0	
		3.06	50 ± 3	$\delta = -(0.1 \pm 0.3)$
4.12	3^+; 0	0	5 ± 3	
		3.06	95 ± 3	$\delta = +0.06 \pm 0.07$
4.23	2^-; 0	0	23 ± 2	$\delta = 0.15 \pm 0.15$
		0.94	49 ± 3	$\delta = 0.0 \pm 0.2$
		1.08	3.2 ± 1.0	
		1.70	9.3 ± 1.2	
		2.10	15 ± 5	
		3.13	0.9 ± 0.6	
4.36	1^+	3.06	100	
4.40	4^-; 0	0.94	13 ± 4	$\delta = -(0.2 \pm 0.3)$
		1.12	60 ± 6	$\delta = -(0.2 \pm 0.2)$
		2.10	27 ± 3	
4.65	4^+; 1	0.94	17 ± 3	

Table 18.25: Radiative decays in ^{18}F [a] (continued)

$E_{\rm i}$ (MeV)	$J^{\pi}_{\rm i}$	$E_{\rm f}$ (MeV)	Branch (%)	Widths and mixing ratios
		1.12	83 ± 3	$\delta = 0.15 \pm 0.15$
4.75	0^+; 1	0	92 ± 4	
		1.70	8 ± 4	
4.85 [b]	5^-; 0	1.12	65 ± 4	
		3.79	35 ± 4	
4.86	1^-; 0	1.04	65 ± 11	
		1.08	8 ± 6	
		3.06	23 ± 7	$\delta = -(0.4 \pm 0.4)$
		3.13	4 ± 3	
4.96	2^+; 1	0	100	$\delta = 1.2 \pm 0.7$
5.30	4^+; 0	0.94	9 ± 2	$\delta = -(0.3 \pm 0.1)$
		1.12	7 ± 2	$\delta = -(1.1 \pm 0.5)$
		2.52	78 ± 3	$\Gamma_\gamma = 1.2 \pm 0.4 \times 10^{-2}$ eV [c]
		3.36	5 ± 1	$\delta = 2.5 \pm 0.8$
		4.65	1.3 ± 0.3	
5.50	$3^{(-)}$; 0	3.06	100	$\Gamma_\gamma = 2.1 \pm 0.7 \times 10^{-3}$ eV [c]
5.603	1^+	0	16.7 ± 2.3	$\Gamma_\gamma = 0.485 \pm 0.046$ eV [c]
		1.04	3.8 ± 1.2	
		3.06	79.5 ± 5.9	
5.605	1^-; $0+1$	0	6.7 ± 1.2	
		1.04	4.2 ± 0.8	
		1.08	54.3 ± 3.1	$\Gamma_\gamma = 0.87 \pm 0.07$ eV [c]
		3.06	2.6 ± 1.4	
		3.13	32.2 ± 2.5	$\delta = -0.05 \pm 0.02$
5.67	1^-; $0+1$	0	6.2 ± 0.4	$\delta = -0.01 \pm 0.04$
		1.04	8.1 ± 0.7	
		1.08	52 ± 3	$\Gamma_\gamma = 0.46 \pm 0.06$ eV [c]
		1.70	0.8 ± 0.3	
		2.10	0.4 ± 0.2	
		3.06	4.0 ± 0.4	$\delta = 0.04 \pm 0.06$
		3.13	28.5 ± 2.0	$\delta = +0.10 \pm 0.03$

Table 18.25: Radiative decays in ^{18}F [a] (continued)

E_i (MeV)	J_i^π	E_f (MeV)	Branch (%)	Widths and mixing ratios
5.79	2^-; 0	0.94	40 ± 8	
		1.08	60 ± 8	
6.10	4^-; 0	0.94	4.9 ± 0.9	$\Gamma_\gamma = 5.1 \pm 1.0 \times 10^{-2}$ eV [c]
		1.12	55 ± 3	
		2.10	27 ± 2	
		3.79	1.4 ± 0.3	
		4.12	1.8 ± 0.3	
		4.40	0.7 ± 0.3	
		4.65	8.7 ± 0.7	
6.10	(1^+); 0	0	24 ± 3	
		0.94	11 ± 3	
		2.10	20 ± 6	
		3.06	45 ± 5	
6.14	0^+; 1	0	50 ± 3	$\Gamma_\gamma > 1.6$ eV
		1.70	12 ± 2	
		3.72	36 ± 3	
		4.36	2.1 ± 0.4	
		5.603	0.19 ± 0.02	
6.16	3^+; 1	0	0.2 ± 0.2	$\Gamma_\gamma = 0.96 \pm 0.26$ eV [c]
		0.94	51 ± 3	
		1.12	1.0 ± 0.1	
		2.52	5.5 ± 0.4	
		3.06	1.3 ± 0.3	
		3.79	11.6 ± 1.3	
		3.84	25.0 ± 1.6	
		4.12	1.5 ± 0.3	
		4.23	0.9 ± 0.3	
		4.40	2.0 ± 0.2	
6.240	3^-; $0 + 1$	0.94	4.6 ± 0.3	
		2.10	71.5 ± 3.0	$\Gamma_\gamma = 0.8 \pm 0.11$ eV [c]
		3.36	1.1 ± 0.4	

Table 18.25: Radiative decays in ^{18}F [a] (continued)

$E_{\rm i}$ (MeV)	$J^{\pi}_{\rm i}$	$E_{\rm f}$ (MeV)	Branch (%)	Widths and mixing ratios
		3.79	10.6 ± 0.5	
		3.84	1.0 ± 0.2	
		4.12	0.5 ± 0.2	
		4.23	7.8 ± 0.4	
		4.40	2.9 ± 0.3	
6.242	$3^-; 0+1$	0.94	4.1 ± 0.3	
		2.10	71.2 ± 3.0	$\Gamma_\gamma = 0.73 \pm 0.11$ eV [c]
		3.36	0.8 ± 0.3	
		3.79	11.6 ± 0.6	
		3.84	0.9 ± 0.2	
		4.12	1.1 ± 0.4	
		4.23	8.2 ± 0.4	
		4.40	2.1 ± 0.3	
6.26	1^+; 0	0	(100)	
6.28	2^+; 1	0	0.3 ± 0.1	$\Gamma_\gamma = 1.8 \pm 0.5$ eV [c]
		0.94	67 ± 3	
		1.04	1.3 ± 0.1	
		1.70	5.7 ± 0.6	
		2.10	1.2 ± 0.3	
		2.52	0.3 ± 0.2	
		3.13	0.7 ± 0.3	
		3.36	2.3 ± 0.3	
		3.72	1.4 ± 0.5	
		3.84	15.8 ± 1.4	
		4.12	3.9 ± 0.2	
		4.36	0.5 ± 0.4	
6.31	3^+; 0	0	4.0 ± 0.7	$\Gamma_\gamma = 0.17 \pm 0.04$ eV [c]
		0.94	10.6 ± 1.0	
		1.70	3.0 ± 0.8	
		2.52	4.0 ± 0.5	
		3.06	57 ± 3	$\delta = -(0.03 \pm 0.10)$

Table 18.25: Radiative decays in ^{18}F [a] (continued)

E_i (MeV)	J^{π}_i	E_f (MeV)	Branch (%)	Widths and mixing ratios
		3.72	1.4 ± 0.7	
		3.84	4.6 ± 1.0	
		4.12	2.4 ± 1.7	
		4.96	13.0 ± 1.5	$\delta = -(0.01 \pm 0.14)$
6.39	$2^+; 0+1$	0	1.5 ± 0.5	$\Gamma_\gamma = 0.44 \pm 0.18$ eV [c]
		0.94	75 ± 3	$\delta = -(0.25 \pm 0.10)$
		1.70	6.8 ± 1.7	
		3.84	14.1 ± 1.6	$\delta = 0.1 \pm 0.2$
		4.12	2.3 ± 0.5	
6.48	$3^+; 0$	0	13 ± 2	$\Gamma_\gamma = 74 \pm 21$ meV [c]
		0.94	33 ± 2	
		1.12	10 ± 2	
		1.70	4 ± 2	
		2.52	4 ± 2	
		3.06	21 ± 3	
		3.79	4 ± 2	
		3.84	9 ± 2	
		4.96	2 ± 2	
6.57	$5^+; 0$	0.94	15.2 ± 1.6	
		3.36	83 ± 3	$\Gamma_\gamma = 2.6 \pm 0.5 \times 10^{-2}$ eV [c,d]
		5.30	2.3 ± 0.6	
6.64	$2^-; 1$	0.94	8.9 ± 0.6	$\Gamma_\gamma = 1.4 \pm 0.4$ eV [c]
		2.10	58 ± 3	
		3.13	22.0 ± 1.3	
		3.72	0.9 ± 0.2	
		3.79	2.4 ± 0.2	
		4.12	1.0 ± 0.3	
		4.86	2.6 ± 0.2	
		5.50	4.0 ± 0.3	
6.78	$4^+; 0$	0.94	12.6 ± 0.9	$\Gamma_\gamma = 0.31 \pm 0.08$ eV [c]
				$\delta = -(0.35 \pm 0.18)$

Table 18.25: Radiative decays in ^{18}F [a] (continued)

E_i (MeV)	J_i^π	E_f (MeV)	Branch (%)	Widths and mixing ratios
		1.12	25.2 ± 1.3	$\delta = -(1.4 \pm 1.1)$
		4.65	62 ± 2	$\delta = 0.13 \pm 0.13$
6.80	1^+, 2^+, 3^+; (0)	0	20 ± 2	
		0.94	20 ± 2	
		3.06	50 ± 3	
		3.84	3.0 ± 1.6	
		4.96	7.0 ± 1.7	
6.88	3, 4^-; 0	2.10	9 ± 2	
		4.65	91 ± 2	
7.34	1^-; 1	0	4 ± 0.5	
		1.08	54 ± 2	
		2.10	18 ± 1	
		3.06	1 ± 0.5	
		3.13	8 ± 0.5	
		4.23	15 ± 0.6	
7.48	(2)	0.94	100	
7.52		0.94	5 ± 4	
		2.10	7 ± 5	
		3.79	33 ± 5	
		4.40	55 ± 7	
7.53	2^-	0	10 ± 3	
		0.94	14 ± 6	
		2.10	50 ± 9	
		3.79	26 ± 7	
7.59		0	18 ± 7	
		0.94	14 ± 12	
		1.12	9 ± 7	
		4.65	59 ± 16	

[a] For earlier references see Tables 18.11 in (1978AJ03) and 18.12 in (1983AJ01). See these tables also for upper limits for transitions to other states.
[b] (1982FR15): see reactions 6 and 23.
[c] Γ_γ = total radiative width for this state.
[d] $\Gamma_\alpha = \Gamma \approx 560$ eV, $\Gamma_p < 4.5$ eV.
[d] See Table 18.27.

Observed resonances are displayed in Table 18.27. See also ^{17}O in (1986AJ04, 1993TI07).

8. (a) $^{14}N(\alpha, \alpha')^{14}N$ $\qquad E_b = 4.415$
(b) $^{14}N(\alpha, 2\alpha)^{10}B$ $\qquad Q_m = -11.613$
(c) $^{14}N(\alpha, {}^6Li)^{12}C$ $\qquad Q_m = -8.798$

Table 18.26: Lifetime measurements of some ^{18}F states

^{18}F* (MeV)	$J^\pi; T$	τ_m	References
0.94	$3^+; 0$	67.6 ± 2.5 ps	mean [a]
1.04	$0^+; 1$	2.7 ± 0.4 fs	[b]
		2.2 ± 0.6 fs	(1983CA21)
		2.55 ± 0.45 fs	(1983CA21) [c]
1.08	$0^-; 0$	27.5 ± 1.9 ps	mean [a]
1.12	$5^+; 0$	234 ± 10 ns	mean [b]
1.70	$1^+; 0$	0.971 ± 0.30 ps	(1982BA40)
		0.897 ± 0.057 ps	(1983MO16) [d]
		0.955 ± 0.027 ps	mean
2.10	$2^-; 0$	5.12 ± 0.56 ps	(1982BA40)
		4.93 ± 0.78 ps	(1983MO16)
		5.06 ± 0.46 ps	mean
2.52	$2^+; 0$	0.605 ± 0.029 ps	(1982BA40)
		0.554 ± 0.045 ps	(1983MO16)
		0.590 ± 0.024 ps	mean
3.06	$2^+; 1$	< 1.2 fs	(1982BA40) [a,e]
3.13	$1^-; 0$	0.403 ± 0.018 ps	(1982BA40)
		0.343 ± 0.022 ps	(1983MO16)

Table 18.26: Lifetime measurements of some ^{18}F states (continued)

^{18}F* (MeV)	$J^\pi; T$	τ_m	References
		0.39 ± 0.02 ps [A]	
3.36	$3^+; 0$	0.435 ± 0.041 ps	(1982BA40)
		0.451 ± 0.034 ps	(1983MO16)
		0.44 ± 0.03 ps [A]	
3.72	$1^+; 0$	4 ± 2 fs	(1973RO04)
		$2.7^{+4.1}_{-2.7}$ fs [A]	(1982BA40) [c]
3.79	$3^-; 0$	1.91 ± 0.17 ps	(1982BA40)
		1.90 ± 0.20 ps	(1983MO16)
		1.91 ± 0.13 ps	mean
3.84	$2^+; 0$	17.4 ± 3.6 fs	(1982BA40)
		21 ± 4 fs	(1983MO16)
		19.0 ± 2.7 fs	mean
4.12	$3^+; 0$	91 ± 22 fs	(1973RO06)
4.23	$2^-; 0$	110 ± 15 fs	(1973RO06)
4.36	$1^+; 0$	27 ± 10 fs	(1973RO06)
4.40	$4^-; 0$	58 ± 12 fs	(1973RO06)
4.65	$4^+; 1$	< 10 fs	(1973RO06)
4.85	$5^-; 0$	5.2 ± 0.9 ps	(1973RO06)
4.86	$1^-; 0$	66 ± 18 fs	(1973RO06)
4.96	$2^+; 1$	< 4 fs	(1973RO06)
5.30	$4^+; 0$	30 ± 5 fs	(1973RO06)
5.50	$3^{(-)}; 0$	63 ± 25 fs	(1973RO06)
5.79	$2^-; 0$	15 ± 10 fs	(1973RO06)

A = adopted.

[a] See Table 18.12 in (1978AJ03).

[b] See Table 18.13 in (1983AJ01).

[c] See also (1985KE1C).

[d] See also (1982MO09).

[e] See also (1983MO16).

Table 18.27: Resonances in ^{14}N $+ \alpha$ below $E_\alpha = 5$ MeV [a]

E_α (MeV $\pm$ keV)	Particles out	$\Gamma_{\rm c.m.}$ (keV)	$(2J+1)\Gamma_\gamma\Gamma_\alpha/\Gamma$ (eV)	J^π; T	$E_{\rm x}$ (MeV)
			$< 2 \times 10^{-5}$		4.657
0.559	γ		$(2.8 \pm 0.5) \times 10^{-4}$	1; 0	4.850
0.698			$< 0.5 \times 10^{-4}$	2^+; 1	4.958
1.136 ± 3	γ		0.084 ± 0.004	4^+; 0	5.299
1.398 ± 3	γ		0.022 ± 0.003	$3^{(-)}$; 0	5.502
1.527	γ, α_0		1.44 ± 0.14	1^+	5.603 [e]
1.529 ± 2	γ, α_0	< 1.2	2.60 ± 0.21	1^-; $0+1$	5.604 [f]
1.618 ± 2	γ, α_0	< 0.8	1.4 ± 0.2 [b]	1^-; $0+1$	5.673 [g]
1.765 ± 4	γ		0.047 ± 0.018	2^-; 0	5.788
2.160 ± 4	γ		0.20 ± 0.04	4^-; 0	6.095
2.166 ± 7	γ, α_0		0.08 ± 0.03	1, 2, $3^{(-)}$; 0	6.100
			[c]		
2.348 ± 3	γ, α_0	< 0.8		3^-; $0+1$	6.241 [h]
2.372 ± 3	γ, α_0	< 3		1^+; (0)	6.260 [i]
			[d]		
2.438 ± 4	γ		0.52 ± 0.12	3^+; 0	6.311
2.532 ± 4	γ		1.6 ± 0.4	2^+; $0+1$	6.384
	γ		0.16 ± 0.06	3^+; (0)	6.480
2.767 ± 4	γ, α_0	(< 0.8)	0.29 ± 0.06	5^+; 0	6.567
2.870 ± 4	γ, p_0	< 1.6	2.7 ± 0.5	2^-; 1	6.647
2.870 ± 6	α_0	93 ± 5	$\Gamma_\alpha/\Gamma = 0.85$	1^-	6.647
			0.12 ± 0.07	4^+; 0	6.78
			< 0.2	1^+, 2^+, 3^+; (0)	6.803
3.080 ± 6	p_0, α_0	101 ± 5		2^-	6.810
3.576 ± 4	α_0	< 4		(4^+)	7.196
3.67	α_0	45 ± 10		(1^+)	7.27
3.72	p_0, α_0	53 ± 6		(3^-)	7.31
4.00	p_0, α_0	35		(3^-)	7.53
4.05	p_0, α_0	60			7.57
4.11	p_0, α_0	40			7.61

Table 18.27: Resonances in $^{14}N + \alpha$ below $E_\alpha = 5$ MeV [a] (continued)

E_α (MeV ± keV)	Particles out	$\Gamma_{c.m.}$ (keV)	$(2J+1)\Gamma_\gamma\Gamma_\alpha/\Gamma$ (eV)	$J^\pi; T$	E_x (MeV)
4.28	p_0, α_0	120			7.74
4.50	p_0, α_0	30		(2^-)	7.92
4.55	p_0, α_0	70		(1^+)	7.95

[a] References are displayed in Tables 18.13 of (1972AJ02, 1978AJ03). Higher resonances observed in ^{14}N(α, α_1) are listed in Table 18.14 of (1978AJ03).
[b] $\omega\gamma = 0.45 \pm 0.02$ (1982BE29).
[c] ≤ 0.07 for ^{18}F*(6.11, 6.16 MeV) (1973RO03).
[d] ≤ 0.03 for ^{18}F*(6.28 MeV) (1973RO03).
[e] $\Gamma_\alpha = 42.8 \pm 1.6$ eV, $\Gamma_\gamma = 0.485 \pm 0.046$ eV, $l_\alpha = 0$ (1980MA26). See also Table 18.30.
[f] $\Gamma_\alpha = 32.0 \pm 2.1$ eV, $\Gamma_\gamma = 0.891 \pm 0.074$ eV, $l_\alpha = 1$. ΔE_x for ^{18}F*(5.603, 5.605 MeV) is 1.84 ± 0.04 keV (1980MA26). See also Table 18.30.
[g] $\Gamma_\alpha = 130 \pm 5$ eV, $\Gamma_\gamma = 1.4 \pm 0.3$ eV, $l_\alpha = 1$ (1980MA26). More recently, an accurate energy measurement for this level by (1989BO01) gave $E_x = 5672.57 \pm 0.32$ keV.
[h] This resonance corresponds to two states at $E_x = 6240$ and 6242 keV. The lower member of the doublet (both of which have $J^\pi = 3^-$ and mixed isospin) has $\Gamma_\alpha = 133 \pm 4$ eV, $\Gamma_\gamma = 0.80 \pm 0.11$ eV; the higher has $\Gamma_\alpha = 137 \pm 0.4$ eV, $\Gamma_\gamma = 0.73 \pm 0.11$ eV (1979KI12).
[i] $\Gamma_\alpha = 580 \pm 12$ eV, $\Gamma_p = 25^{+35}_{-25}$ eV (1979KI12).

Observed anomalies in the elastic scattering [reaction (a)] are exhibited in Table 18.27. Resonances in the α_1 isospin-forbidden yield are displayed in Table 18.14 of (1978AJ03). In the α_1 study, carried out for $E_\alpha = 7.6$–16.9 MeV, a partial-wave analysis involving a method of removing ambiguities and parametrizing S-matrix elements gives the level parameters of 151 isospin mixed, natural-parity states in ^{18}F with $10.4 < E_x < 17.5$ MeV. Many of these states have also been reported in the ^{16}O(d, α_1) reaction [Table 18.16 of (1978AJ03)]. The agreement is best for low-lying 2^+ or 4^+ states, and is quite good for 3^- and 5^- states, while for high-J states the greater centrifugal barrier for ^{16}O + d at the same E_x leads to a relative suppression of high-J states in the ^{16}O + d work. A study of the energy dependence of averaged intensities of the partial waves shows some indication that the lower partial waves conserve isospin as E_x increases.

The total cross sections for formation of ^{10}B and ^{6}Li have been studied for $E_\alpha = 21$ to 42 MeV [see (1978AJ03)], as has the cross section for production of 1.64 and 2.31 MeV γ-rays from threshold to $E_\alpha = 26$ MeV (1985DY05). See also (1987AJ02), and see (1987BU27, 1989BE1R, 1990WE14, 1991LE33).

9. (a) ^{14}N(^{6}Li, d)^{18}F $\qquad Q_m = 2.940$
(b) ^{14}N(^{6}Li, dα)^{14}N $\qquad Q_m = -1.475$

Angular distributions have been measured for the deuteron groups to ^{18}F*(5.34 $[4^+]$, 6.56 $[5^+]$, 9.58, 11.2, 14.1) at $E(^6\text{Li}) = 36$ MeV. Angular correlations lead to $J^\pi = 6^+$ and 8^+ for ^{18}F*(9.58, 14.1) and the data are consistent with $J^\pi = 7^+$ for ^{18}F*(11.2) (1983ET02). For the earlier work see (1978AJ03).

10. ^{14}N(^{7}Li, t)^{18}F $\qquad Q_m = 1.948$

At $E(^7\text{Li}) = 36$ MeV the $K^\pi = 1^+$ band appears to be selectively populated. States at $E_x = 9.58 \pm 0.02$, 11.22 ± 0.03 and 14.18 ± 0.04 MeV are strongly populated. It is suggested that the first two are the 6^+ and 7^+ members of that band: see reaction 8. [Angular distributions are reported for ^{18}F*(1.70, 2.10, 2.52, 3.36, 4.40, 5.30, 6.57, 9.58, 11.22, 14.18).] See (1978AJ03, 1987AJ02) for the earlier work.

11. (a) ^{14}N(^{11}B, ^{7}Li)^{18}F $\qquad Q_m = -4.250$

(b) ^{14}N(^{13}C, ^{9}Be)^{18}F $\qquad Q_m = -6.233$

These reactions have been studied at $E(^{11}\text{B}) = 115$ MeV and $E(^{13}\text{C}) = 105$ MeV. Differential cross sections at three angles are reported for the transitions to ^{18}F*(9.58, 10.57 ± 0.07, 11.2) in reaction (a) and to ^{18}F*(5.30, 6.57, 9.58, 10.60 ± 0.08, 11.2) in reaction (b). In addition to these states ^{18}F*(14.18) is strongly excited in both reactions, and transitions to ^{18}F*(15.79 ± 0.10, 18.62 ± 0.12) are also reported: see (1983AJ01).

12. (a) ^{15}N(^{3}He, γ)^{18}F $\qquad Q_m = 14.156$

(b) ^{15}N(^{3}He, α)^{14}N $\qquad Q_m = 9.745 \qquad E_b = 14.160$

Excitation functions have been measured for $E(^3\text{He}) = 2.5$ to 16 MeV for the γ_0 and $\gamma_{1\to4}$ yields. Resonances are observed corresponding to $E_x = (19.00 \pm 0.15)$ $[\gamma_{1\to4}]$, (20.1 ± 0.2) $[\gamma_0,\ \gamma_{1\to4}]$, (22.7 ± 0.2) $[\gamma_0,\ \gamma_{1\to4}]$ and (24.1 ± 0.2) MeV $[\gamma_{1\to4}]$, with $\Gamma_{\text{c.m.}} = (0.5 \pm 0.15)$, (1.6 ± 0.1), (1.2 ± 0.1) and (1.4 ± 0.3) MeV, respectively. The γ_0 yield is dominated by ^{18}F*(20.10) [(1983WA05): see for $(2J+1)\Gamma_{^3\text{He}}\Gamma_\gamma$ values]. It is suggested that structures decaying by γ_0 have $J^\pi = 2^-$ (and possibly $T = 1$) (1983WA05). For analyzing power measurements at $E(^3\text{He}) = 33$ MeV see (1986DR03).

13. ^{15}N(^{6}Li, t)^{18}F $\qquad Q_m = -1.635$

At $E(^6\text{Li}) = 30$ MeV preferential excitation of odd-parity states of ^{18}F below $E_x = 5$ MeV is reported. Angular distributions of the tritons to ^{18}F*(0, 0.94, 2.10, 4.40) [$J^\pi = 1^+, 3^+, 2^-, 4^-$] are all strongly forward peaked: see (1978AJ03).

14. (a) ^{15}N(^{11}B, ^{8}Li)^{18}F $\quad Q_m = -13.048$
    (b) ^{15}N(^{12}C, ^{9}Be)^{18}F $\quad Q_m = -12.119$

These reactions have been studied with $E(^{11}\text{B}) = E(^{12}\text{C}) = 115$ MeV. Reaction (a) is dominated by the transitions to ^{18}F*(1.12) [presumably $J^\pi = 5^+$ state, although the group is unresolved] and to ^{18}F*(7.15, 9.45) [$J^\pi = (7^-)$ and (6^-)]. No single state is strongly preferentially populated in reaction (b). Differential cross sections for ^{18}F*(4.40, 6.10, 7.15, 9.45) [$J^\pi = 4^-, (5^-), (7^-), (6^-)$], are fitted by FRDWBA: see (1983AJ01).

15. ^{16}O(d, γ)^{18}F $\quad Q_m = 7.526$

The capture cross section rises from 0.1 μb at $E_d = 0.4$ MeV to 25 μb at 3.5 MeV: Γ_γ over this range is ≈ 2 eV: see (1972AJ02).

16. (a) ^{16}O(d, n)^{17}F $\quad Q_m = -1.624 \quad E_b = 7.526$
    (b) ^{16}O(d, p)^{17}O $\quad Q_m = 1.919$

Excitation functions and polarization studies have been carried out to $E_d = 17$ MeV [see (1978AJ03, 1983AJ01)] and at $E_d \approx 5.6$ to 8.3 MeV (1985GR1B; p_0, p_3, p_4). Structures attributed to states in ^{18}F are displayed in Table 18.28. See also ^{17}O and ^{17}F in (1986AJ04, 1993TI07), (1987AJ02), and see (1992LA08) for applications.

17. ^{16}O(d, d′)^{16}O $\quad E_b = 7.526$

The yields and polarized observables of elastically scattered deuterons have been reported for $E_d = 0.65$ to 56 MeV: see (1978AJ03, 1983AJ01). More recent measurements are those by (1985GR1B) [excitation functions for $E_d \approx 5.6$ to 8.3 MeV] and the polarization studies at $E_d = 20.5$ MeV (1984FR14; TAP), 56 MeV (1986MA32, VAP, TAP) and 200, 400 and 700 MeV (1987NG01; VAP, TAP). An analysis for $E_d = 400$ MeV in terms of the folding model is discussed in (1987GR16). Virtual breakup effects in (d, d) elastic scattering have been studied (1988IS02). For references to earlier work see (1987AJ02), and see the ^{16}O sections of (1986AJ04, 1993TI07).

18. ^{16}O(d, α)^{14}N $\qquad Q_m = 3.111 \qquad E_b = 7.526$

The yields of various groups of α-particles have been measured for $E_d \leq 20$ MeV: see (1978AJ03, 1983AJ01). The yield curves have been fitted in terms of a large number of states in ^{18}F: see Table 18.28 here, and 18.16 in (1978AJ03).

Table 18.28: Maxima in the yields of ^{16}O + d [a]

E_d (MeV ± keV)	Particles out	$\Gamma_{c.m.}$ (keV)	$J^\pi; T$	E_x (MeV)
0.895	p_1, α_0	210 ± 25		(8.320)
1.048	p_1, d_0, α_0	88 ± 10	1^+	8.456
1.199	α_0	230 ± 30		(8.590)
1.298	p_1, d_0, α_0	13 ± 3		(8.678)
1.325	d_0, α_0			(8.702)
1.482	α_0	40 ± 5		(8.842)
1.563	d_0, α_0	121 ± 15		(8.914)
1.616	α_0	19 ± 15		(8.961)
1.765	d_0, α_0	141 ± 10		(9.093)
1.885	p_0, p_1, d_0, α_0	108 ± 12	$3, 4^-; 0$	9.200
2.22	n_0, α_0		$2, 3^+; 0$	9.50
2.28	α_0		$2, 3^+; 0$	(9.55)
2.34	n_0, p_1			(9.60)
2.55	p_1			(9.79)
2.92	n_0, p_0, p_1			10.12
3.05	α_0		$3, 4^-; 0$	10.24
3.13	n, p_1, α_0, α_1		$\geq 2; 0$	10.31
3.37	n_0, p_0, p_1, α_1			10.52
3.47	α_0		$4, 5^+; 0$	10.61
3.68	n_0, p_0, p_1, α_1		2^+	10.79
3.80	p_0, α_0		$\geq 2^+; 0$	10.90
3.94	n, p_1, α_1			11.03
3.95	p_1, α_0	$\simeq 35$	$3, 4^-; 0$	11.03
4.07	n, p_1			11.14
4.38	p_1, α_0		$4, 5^+; 0$	11.42

Table 18.28: Maxima in the yields of $^{16}O + d$ [a] (continued)

E_d (MeV ± keV)	Particles out	$\Gamma_{c.m.}$ (keV)	$J^\pi; T$	E_x (MeV)
4.57	α_0		5, 6^-; 0	11.58
4.80	d_0, α_0		≥ 3; 0	11.79
4.93	α_0		5, 6^-; 0	11.90
5.05 ± 15	α_4	40		12.01
5.11	α_0, α_2, α_4	60	4, 5^+; 0	12.06
5.17	α_0	55	$T = 0$	12.12
5.32	α_0	70		12.25
5.34	α_0, α_2	170		12.27
5.40	α_0, α_4	130		12.32
5.47	α_4	80		12.38
5.49	α_2, α_3, α_4	120		12.40
5.59	α_0, α_2	120		12.49
5.65	α_0, α_2	140		12.54
5.77	α_0	180	2^+	12.65
5.80	α_0, α_2, α_4	160		12.68
5.81	α_3, α_4	80	5^-	12.69
5.91	α_2	160		12.77
6.00	α_0	120		12.85
6.11	α_0, α_4	120		12.95
6.19	α_2, α_3	200	≥ 4; 0	13.02
6.25	α_0, α_4	150	$T = 0$	13.08
6.30	α_0, α_2	160		13.12
6.34	α_0, α_3	160	5, 6^-; 0	13.16
6.38	α_0, α_3	145	$T = 0$	13.19
6.43	α_0, α_2	120		13.24
6.46	α_0, α_4	100		13.26
6.54	α_0, α_2	135		13.33
6.61	α_2, α_3, α_4	120		13.40
6.64	α_0, α_2	200		13.42
6.66	α_0	100		13.44

Table 18.28: Maxima in the yields of $^{16}O + d$ [a] (continued)

E_d (MeV ± keV)	Particles out	$\Gamma_{c.m.}$ (keV)	$J^\pi; T$	E_x (MeV)
6.72	α_2	100		13.49
6.73	α_2	100		13.50
6.80	α_2, α_3	140		13.56
6.84	$\alpha_0, \alpha_2, \alpha_4$	150		13.60
6.94	α_0, α_3	90		13.69
7.10	α_3, α_4	60	$4^-, 5^+$	13.83
7.27	α_3	150		13.98
7.31	α_2	60	$4^-, 5^+$	14.02
7.34	$\alpha_0, \alpha_3, \alpha_4$	200		14.04
7.38	α_0, α_3	210		14.08
7.41	α_3	60	$4^-, 5^+$	14.10
7.49	α_0	220		14.18
7.58	α_0	200	$\geq 4; 0$	14.26
7.62	α_4	85		14.29
7.66	$\alpha_0, \alpha_2, \alpha_4$	130	$T = 0$	14.33
7.67	$\alpha_0, \alpha_2, \alpha_3, \alpha_4$	250	$T = 0$	14.34
7.74	α_3	200	$3^+, 4^-$	14.40
7.80	α_0, α_4	70		14.45
7.82	α_0, α_2	225		14.47
7.99	α_4	200		14.62
8.02	α_0	150		14.65
8.03	α_3	310		14.66
8.07	α_0	120		14.69
8.08	α_3, α_4	310		14.70
8.21	α_2	250		14.82
8.25	α_4	380		14.85
8.30	$\alpha_0, \alpha_2, \alpha_3$	210		14.90
8.34	α_4	115		14.93
8.37	α_0	130		14.96
8.37	α_0, α_3	250		14.96

Table 18.28: Maxima in the yields of $^{16}O + d$ [a] (continued)

E_d (MeV ± keV)	Particles out	$\Gamma_{c.m.}$ (keV)	$J^\pi; T$	E_x (MeV)
8.40	α_0	310		14.99
8.43	α_4	120		15.01
8.52	α_3, α_4	160	4^-, 5^+	15.09
8.52	α_2	150		15.09
8.56	α_2	220		15.13
8.58	α_4	180		15.15
8.61	α_0, α_3	200		15.17
8.65	α_0, α_2	135		15.21
8.72	α_2, α_4	120		15.27
8.76	α_2	160		15.30
8.79	α_0	200		15.33
8.80	α_0, α_3, α_4	200	5^+, 6^-	15.34
8.89	α_3	110		15.42
8.93	α_3, α_4	190		15.46
8.97	α_2, α_4	210		15.49
9.00	α_0, α_2	190		15.52
9.62	α_3	220	4^-, 5^+	16.07
10.35	α_3	60	4^-, 5^+	16.72
11.15	α_3	70	4^-, 5^+, 6^-	17.43

[a] For references see Table 18.15 in (1978AJ03). This table does not include the structures in α_1 leading to isospin-mixed states in ^{18}F: for the latter see Table 18.16 in (1978AJ03).

A detailed study by (1973JO13) of the isospin-forbidden α_1 yield, analyzed by S-matrix theory, identifies a large number of isospin-mixed states in ^{18}F, possibly as many as 138 with $9.2 < E_x < 19.4$ MeV. The reaction mechanism appears to be almost entirely compound nuclear. The isospin impurity, averaged over 1 MeV intervals, is 3–10% for the above E_x range. The average coherence width increases from ≈ 100 keV at $E_x = 14$ MeV to ≈ 500 keV at $E_x = 20$ MeV. The level densities appear to be consistent with predictions of the Fermi-gas model (1973JO13). See also (1985JOZZ). [For mixed isospin states observed in ^{14}N(α, α_1) see Table 18.14 in (1978AJ03).] Polarized beam measurements are reported for $E_d = 6.8$ to 16 MeV: see (1978AJ03, 1983AJ01).

19. ^{16}O(d, ^{6}Li)^{12}C $Q_{\rm m} = -5.687$ $E_{\rm b} = 7.526$

Vector and tensor polarized beam measurements are reported for the transitions to ^{12}C*(0, 4.4) at $E_{\rm d} = 18$ and 22 MeV (1987TA07; VAP, TAP) and 51.7 MeV (1986YA12; VAP; also to ^{12}C*(14.1)).

20. ^{16}O(t, n)^{18}F $Q_{\rm m} = 1.269$

Recent measurement of neutron yields for $E_{\rm x} = 20$ MeV are discussed in (1993DR03, 1993DR04). Applications are discussed in (1987BO16, 1990BA1S). For earlier work see (1983AJ01, 1987AJ02).

21. ^{16}O(^{3}He, p)^{18}F $Q_{\rm m} = 2.032$

Excitation energies derived from measurements of γ-rays are displayed in Table 18.29 together with l-assignments obtained from distorted-wave analyses, and J^{π}, T and K^{π} assignments from branching ratios, radiative widths, linear polarization, γ-ray angular distributions and $\tau_{\rm m}$ measurements [see also Tables 18.25 and 18.26]. Studies of this reaction, together with the work on ^{14}N(α, γ) and ^{17}O(p, γ), have defined the low-lying states of ^{18}F.

The g-factor of ^{18}F*(0.94) [$J^{\pi} = 3^{+}$] is $(+0.56 \pm 0.05)$: see (1983AJ01). The circular polarization of the 1.08 MeV $\rightarrow$ g.s. γ-ray, $P_{\gamma} = (-10 \pm 18) \times 10^{-4}$ (1982AH07), $(2.7 \pm 5.7) \times 10^{-4}$ (1985BI03, 1988BI07), $(1.6 \pm 5.6) \times 10^{-4}$ (1985EV03), $(1.7 \pm 5.8) \times 10^{-4}$ (1987PA07). The weak pion-nucleon coupling constant deduced from the weighted average of all recent P_{γ} measurements $[(1.2 \pm 3.9) \times 10^{-4}]$ is $(0.3^{+1.0}_{-0.3}) \times 10^{-7}$. Together with PNC matrix elements in other experiments this suggests that the isovector weak NN interaction may be strongly suppressed compared with the isoscalar weak NN interaction (1985EV03, 1987PA07). For a measurement of the ICC of the 0.94, 1.02, 1.04, and 1.08 MeV γ-rays see (1986KR04). See also (1978AJ03, 1983AJ01, 1987AJ02) and ^{19}Ne.

A discussion of nuclear tests of fundamental interactions is presented in (1989MC1C). For recent work on the use of this reaction for oxygen analysis, see (1991BA62, 1992CO08). For applications related to ^{18}F production see (1991GU05, 1991SU17).

22. ^{16}O(α, d)^{18}F $Q_{\rm m} = -16.321$

Angular distributions of the deuteron groups to ^{18}F*(1.12) [$J^{\pi} = 5^{+}$] have been studied at $E_{\alpha} = 28.0$ to 33.6 MeV: see (1983AJ01). At $E_{\alpha} = 65.3$ MeV a number of angular distributions are reported to ^{18}F states with $E_{\rm x} \leq 11.4$ MeV: ^{18}F*(9.49, 10.54) are suggested to have $J^{\pi} = 6^{-}$ and 7^{+} respectively (1986KA36). See, however, reactions 9 and 10. The use of this reaction in ^{18}F production is discussed in (1991GU05).

23. $^{16}O(^{6}Li, \alpha)^{18}F$ $Q_m = 6.051$

Angular distributions have been measured at $E(^{6}Li) = 5.5$ to 34 MeV [see (1983AJ01)] and at $E(^{6}Li) = 48$ MeV (1984CO05; α_0, α_1, α_4). (1982FR15) report the excitation of a state at $E_x = 4848 \pm 0.5$ keV which decays (35 ± 4)% to $^{18}F^*(3.79)$ [$E_\gamma = 1056.8 \pm 0.4$ keV] and (65 ± 4)% to $^{18}F^*(1.12)$. Alpha-gamma angular correlations are consistent with $J^\pi = 5^-$, and $T = 0$ (1982FR15). See also (1986GL02) and (1986IC01).

24. (a) $^{16}O(^{11}B, ^{9}Be)^{18}F$ $Q_m = -8.290$

(b) $^{16}O(^{13}C, ^{11}B)^{18}F$ $Q_m = -11.153$

(c) $^{16}O(^{14}N, ^{12}C)^{18}F$ $Q_m = -2.747$

See (1983AJ01).

Table 18.29: States in ^{18}F from $^{16}O(^{3}He, p\gamma)^{18}F$ [a]

E_x (keV) [b]	l [a]	$J^\pi; T$ [c]	K^π [c]
0	0	$1^+; 0$	0^+
937.1 ± 0.4	2	$3^+; 0$	0^+
1040.9 ± 0.5	0	$0^+; 1$	
1080.1 ± 0.5		$0^-; 0$	0^-
1119.0 ± 0.6	4	$5^+; 0$	0^+
1701.4 ± 0.7	0	$1^+; 0$	1^+
2099.9 ± 0.6		$2^-; 0$	0^-
2523.4 ± 0.7	2	$2^+; 0$	1^+
3061.2 ± 0.5	2	$2^+; 1$	
3132.8 ± 0.6		$1^-; 0$	1^-
3358.2 ± 1.0		$3^+; 0$	1^+
3725.4 ± 0.8		$1^+; 0$	
3790 ± 0.9		$3^-; 0$	1^-
3838.4 ± 0.7	2	$2^+; 0$	
4114.5 ± 0.9		$3^+; 0$	
4225.8 ± 0.7		$2^{(-)}; 0$	(1^-)
4361.0 ± 0.7		$1^{(+)}$	
4398.1 ± 0.7		$3^-, 4^-; 0$ [d]	(0^-)

Table 18.29: States in ^{18}F from ^{16}O(^{3}He, pγ)^{18}F [a] (continued)

E_x (keV) [b]	l [a]	$J^\pi; T$ [c]	K^π [c]
4652 ± 2	4	$4^+; 1$	
4753 ± 3		$(0^+; 1)$	
4860 ± 2		$1^{(-)}; 0$	
4963.6 ± 0.8		$2^+; 1$	
5297.6 ± 1.5		4^+	1^+
5502 ± 2		$3^{(-)}; 0$	
5603 ± 2		$1^-; 0 + 1$	
5669 ± 2		$1^-; 0 + 1$	
5785 ± 3		$2^-; 0$	
6097.4 ± 1.4		$4^-; 0$	1^-
6108 ± 3		$1, 2, 3^{(-)}; 0$	
6138.3 ± 1.0		$0^+; 1$	
6164.0 ± 1.0		$3^+; 1$	
6241.2 ± 1.0		$3^-; 1$	
6263 ± 3		1^+	
6284.0 ± 1.0		$2^+; 0 + 1$	
6310.5 ± 0.8		$3^+; 0$	
6383 ± 3		$2^+; 0 + 1$	
6480 ± 2		$3^+; (0)$	
6567.0 ± 1.5		5^+	1^+
6643.0 ± 1.5		$2^-; 1$	
6777 ± 2 [c]		4^+	
6803.0 ± 1.5		$1^+, 2, 3^+; (0)$	
6878 ± 2 [c]		$3^{(-)}, 4^-; (0)$	

[a] For earlier results derived from measurements of proton spectra and of γ-rays, see Table 18.18 in (1972AJ02). See also Tables 18.25 and 18.26 here.
[b] (1973RO03): γ-ray measurements.
[c] See Table 18.17 in (1978AJ03).
[d] See p. 179 of (1979KI12).

Table 18.30: Excited states of ^{18}F from ^{17}O(p, γ)^{18}F [a]

E_x (keV)	E_x (keV)
937.18 ± 0.06	3724.19 ± 0.22
1041.55 ± 0.08	3791.49 ± 0.22
1080.54 ± 0.12	3839.17 ± 0.22
1121.36 ± 0.15	4115.90 ± 0.25
1700.81 ± 0.18	4360.15 ± 0.26
2100.61 ± 0.10	5603.38 ± 0.27
2523.35 ± 0.18	5604.86 ± 0.28
3061.84 ± 0.18	5668 ± 2
3133.87 ± 0.15	6136.47 ± 0.33

[a] See also Table 18.31 here, and Table 18.17 in (1983AJ01).

25. ^{17}O(p, γ)^{18}F $\qquad Q_m = 5.607$

Gamma-ray measurements lead to the very accurate E_x determinations for ^{18}F states below 6.2 MeV: see Table 18.30. Observed resonances are displayed in Table 18.31; branching ratios, radiative widths and multipole mixing ratios are shown in Table 18.25; and τ_m in Table 18.26.

The direct capture cross section has been studied for $E_p = 0.3$ to 1.9 MeV: ^{18}F*(5.603, 5.605, 5.668, 5.786 MeV) have $J^\pi = 1^+, 1^-, 1^-$ and 2^-. The 1^- states have mixed isospin. For astrophysical work, see the thermonuclear reaction rate tables in (1985CA41) and the analytical expression presented in (1988CA26). See also (1978AJ03, 1983AJ01, 1987AJ02).

26. ^{17}O(p, n)^{17}F $\qquad Q_m = -3.543 \qquad E_b = 5.607$

Observed resonances are displayed in Table 18.31. Analyzing power measurements are reported at $E_p = 135$ MeV (1983PUZZ; n_0).

For astrophysics-related work see the thermonuclear reaction rate tables of (1985CA41) and the analytical expressions of (1988CA26).

27. ^{17}O(p, p$'$)^{17}O $\qquad E_b = 5.607$

The elastic scattering has been studied for $E_p = 0.5$ to 13 MeV [see (1978AJ03, 1983AJ01)]: observed anomalies are displayed in Table 18.31. Analyzing powers have been measured at $E_p = 89.7$ MeV (1985VO12).

28. ^{17}O(p, t)^{15}O $\qquad Q_m = -11.325 \qquad E_b = 5.607$

Analyzing powers have been reported at $E_p = 89.7$ MeV for the triton groups to a number of ^{15}O states (1985VO12).

29. ^{17}O(p, α)^{14}N $\qquad Q_m = 1.192 \qquad E_b = 5.607$

The yield of α_0 shows a number of resonances for $E_p = 0.49$ to 3.0 MeV: see Table 18.31. The R-matrix fit of (1979KI13), obtained using data from $E_p = 400$ to 1400 keV, confirms the earlier result [see, e.g., reaction 31 in (1978AJ03)] that a significant quantity of ^{17}O is burned up in the (p, γ) rather than in the (p, α) reaction for a wide range of stellar temperatures (1979KI13). See also (1987AJ02, 1987AS05).

Table 18.31: Resonances in ^{17}O + p [a]

E_p (keV)	Particles out	$\Gamma_{c.m.}$ (keV)	$(2J+1)\Gamma_\gamma\Gamma_p/\Gamma$ (eV)	$J^\pi; T$	E_x (MeV ± keV)
517.0 ± 1.0	γ, α_0	0.24 ± 0.03	0.26 ± 0.05	4^-; 0	6.095
525	α_0	0.034 ± 0.003		(1^+)	6.102
561.2 ± 1.0	γ	≤ 1	2.2 ± 0.6	0^+; 1	6.136
587.1 ± 1.0	γ, p_0, α_0	14 ± 0.5	6.7 ± 1.8	3^+; 1	6.161
670.5 ± 1.0	γ, p_0, α_0	0.19 ± 0.03	[c]	$3^-; 0+1$	6.239
673.0	γ, α_0	0.18 ± 0.04	[c]	$3^-; 0+1$	6.242
690 ± 4	α_0	0.60 ± 0.12	≤ 0.02	1^+; 0	6.258
714.2 ± 1.0	γ, p_0, α_0	10.0 ± 0.5	9.1 ± 2.3	2^+; 1	6.281
741 ± 2	γ, p_0, α_0	0.95 ± 0.14	0.64 ± 0.17	3^+; 0	6.306
826 ± 2	γ, α_0	0.40 ± 0.09	0.60 ± 0.18	$2^+; 0+1$	6.386
926 ± 2	γ, α_0	0.40 ± 0.10	0.36 ± 0.15	3^+; 0	6.481
1015	α_0	0.56 ± 0.13	≤ 0.0023	5^+; 0	6.565
1090	α_0	80 ± 2		1	6.635
1098.4 ± 0.4	γ, α	0.60 ± 0.07	4.3 ± 1.2	2^-; 1	6.6439
1101 ± 4	α_0	89 ± 5			6.646
1240 ± 2 [b]	γ, p_0, α_0	9.2 ± 1.0	2.8 ± 0.7	4^+; 0	6.777
1270	γ, p_0	≤ 2	0.54 ± 0.20	$1^+, 2, 3^+$; 0	6.8031 ± 1.5
1274 ± 5	α_0	88 ± 2		2^-	6.809

Table 18.31: Resonances in $^{17}O + p$ [a] (continued)

E_p (keV)	Particles out	$\Gamma_{c.m.}$ (keV)	$(2J+1)\Gamma_\gamma\Gamma_p/\Gamma$ (eV)	$J^\pi; T$	E_x (MeV ± keV)
1276	α_0	3.0 ± 0.5		(2^+)	6.811
1338	α_0	5.0 ± 1.0		(3^-)	6.870
1345 ± 3	γ, α_0	≤ 2	1.0 ± 0.4	3, 4^-; 0	6.876
1687.5 ± 1	α_0	6.5	3.9	(4^+); 0	7.199
1738 ± 2	α_0	46.5	8.8	(1^+); 0	7.247
1784 ± 2	p_0, α_0	38	47	3^-	7.291
1810 ± 4	α_0	52	8.5	$(3^-; 0)$	7.315
1832.5 ± 1	γ, p_0, p_1	16 ± 2	[d]	1^-; 1	7.336
1906 ± 2	p_0, p_1	14.6 ± 1.4		1^+	7.406
1950 ± 10	α_0	140	5.6		7.447
1957 ± 2	p_0	6		1^-	7.454
1983 ± 2	γ, p_1, α_0	12 ± 3	1.5	(2)	7.478
(1990 ± 2)	p_0	32		(1^-)	(7.485)
2012 ± 2	p_0, α_0	12 ± 2	7.2	4^-	7.506
2020 ± 2	γ	≤ 4			7.513
2036 ± 2	$\gamma, p_0, p_1, \alpha_0$	16.5 ± 3.0	5.5 [e]	2^-; 1	7.528
2040 ± 5	p_1, α_0	75			7.532
2064 ± 2	p_0	30		(1^-)	7.555
2095 ± 2	$\gamma, p_0, p_1, \alpha_0$	9 ± 2	3.7 [f]	[g]	7.584
2202 ± 2	p_0, p_1, α_0	36 ± 4	25.1	$3^+, 4^+$ [g]	7.685
2248 ± 4	p_1, α_0	66 ± 5	28.2	≥ 1	7.729
2284 ± 4	p_1	70			7.763
2406 ± 3	p_1, α_0	20	24.4	≥ 2	7.878
2429 ± 2	α_0	38	42	(2^-)	7.899
2473 ± 12	α_0	112	80	(1^+)	7.941
2603 ± 6	p_1, α_0	60	11	≥ 4	8.064
2657 ± 8	p_1	96			8.115
2757 ± 2	p_0, α_0	52	63	2^-	8.209
2788 ± 2	p_0	20		4^+	8.238
2828	α_0	$\simeq 50$			8.370

Table 18.31: Resonances in ^{17}O + p [a] (continued)

$E_{\rm p}$ (keV)	Particles out	$\Gamma_{\rm c.m.}$ (keV)	$(2J+1)\Gamma_\gamma\Gamma_{\rm p}/\Gamma$ (eV)	$J^\pi; T$	$E_{\rm x}$ (MeV ± keV)
3915 ± 20	n	95			9.302
(4163 ± 20)	n	19			(9.536)
4235 ± 10	n	33			9.604
4330 ± 10	n	33			9.694
4490 ± 20	n	$\simeq 100$			9.845
(4790 ± 10)	n	28			(10.128)
4900 ± 20	n	$\simeq 140$			10.232

[a] For references see Tables 18.18 in (1978AJ03, 1983AJ01).
[b] See footnote [d] in Table 18.18 (1978AJ03).
[c] This corresponds to a doublet of 3^-, mixed isospin states, separated by 2.09 ± 0.04 keV. $\omega\gamma_{\rm p,\gamma} = 2.04 \pm 0.45$ eV for the lower resonance and 1.16 ± 0.26 eV for the higher one.
[d] $\Gamma_\gamma = 3.5 \pm 1.0$ eV.
[e] $\Gamma_\gamma = 0.44 \pm 0.10$ eV.
[f] $\Gamma_\gamma = 0.11 \pm 0.03$ eV.
[g] Assumed to be unresolved.

Measurements (1989BO01; see ^{14}N(α, γ)^{18}F reaction) of the first level $(J^\pi = 1^-)$ of ^{18}F above the proton threshold determined $E_{\rm x} = 5672.57 \pm 0.32$ keV. This result and a new value for the proton width of this level deduced from ^{17}O(^{3}He, d)^{18}F measurements (1989LA19) lead to substantial changes in the stellar reaction rate for ^{17}O(p, α)^{14}N. [See discussion in (1989LA19).] A direct search for the $E_{\rm x} = 70$ keV resonance ($E_{\rm p} = 5672.57 \pm 0.32$ keV) was carried out and an upper limit for the resonance strength ($\omega\gamma \leq 8 \times 10^{-10}$ eV) was reported in (1992BE21).

30. ^{17}O(^{3}He, d)^{18}F $\qquad Q_{\rm m} = 0.113$

At $E(^3{\rm He}) = 15$ MeV DWBA analysis of angular distributions of deuteron groups corresponding to states of ^{18}F with $E_{\rm x} < 5$ MeV have led to J^π values and spectroscopic information: see (1972AJ02). Proton widhts of states near the proton threshold were measured by (1989LA19). See also (1987ER05).

31. ^{17}O(α, t)^{18}F $\qquad Q_{\rm m} = -14.207$

Table 18.32: Some states in ^{18}F from ^{17}O(α, t) [a]

E_x (MeV) [b]	J^π [b]	σ_{int} (mb) [c]
0.0	1^+	0.26
0.94	3^+	0.41
1.04	$0^+, T = 1$	
1.12	5^+	1.92
2.52	2^+	0.02
3.06	$2^+, T = 1$	0.32
3.72	1^+	0.15
4.12	3^+	0.43
4.65	$4^+, T = 1$	0.61
7.44	(5^-) [d]	0.09
9.02	$(5^-, T = 1)$ [d]	0.09
9.58	(6^-) [d]	0.19
12.75	$(6^-, T = 1)$	0.03
14.65	(7^+) [d]	0.07
15.8	$(6^-, T = 1)$ [d]	0.03

[a] (1992YA08); $E_\alpha = 65$ MeV.

[b] E_x and J^π values from (1987AJ02).

[c] Integrated cross section. See Tables III and IV in (1992YA08) for spectroscopic factors.

[d] J^π value assumed in analysis by (1992YA08).

Measurements and DWBA analysis of differential cross sections at $E_\alpha = 65$ MeV are reported in (1992YA08). Measured level energies and spectroscopic information are included in Table 18.32.

32. ^{17}O(^{12}C, ^{11}B)^{18}F $\qquad Q_{\rm m} = -10.350$

See (1983AJ01).

33. ^{18}O(π^+, π^0)^{18}F $\qquad Q_{\rm m} = 2.939$

See (1983AS01, 1984AS05, 1989LE1L).

34. ^{18}O(p, n)^{18}F $\qquad Q_{\rm m} = -2.437$

(1983AN05) have studied the distribution of Gamow-Teller (GT) strength. At $E_{\rm p} = 135$ MeV angular distributions have been studied to the 0^+ state at 1.04 MeV and to the 1^+ states ^{18}F*(0, 1.70, 3.72, 4.36, 6.26 MeV) as well as to possible 1^+; $T = 1$ groups at $E_{\rm x} = 9.9$, 10.9 and 11.9 MeV. 82% of the observed strength lies in the ground state group and 5.5% in the $T = 1$ states. The observed GT strength is $\approx \frac{2}{3}$ of that expected from the simple sum rule (1983AN05). Multipole decomposition of data from measurements at $E_{\rm p} = 494$ MeV is reported in (1994ME07). See also (1978AJ03, 1987AJ02).

More recently the (p, n) reaction as a probe of beta decay strength is discussed in (1987GO1V, 1987TA13, 1988MA53). See also (1989RA1G). Studies of stretched state excitation are described in (1986AN1E) and measurement of spin observables at $E_{\rm p} = 135$ MeV are discussed in (1989WAZZ, 1990WAZT). Total cross sections for ^{18}O production from ^{18}O(p, n) were measured by (1990WA10). See (1988HI1F, 1991GU05) for related applications.

35. ^{18}O(^{3}He, t)^{18}F $\qquad Q_{\rm m} = -1.674$

At $E(^3{\rm He}) = 16$ MeV, the triton spectrum is dominated by strong groups to ^{18}F*(0, 0.94) and to the 0^+ and 2^+, $T = 1$ states ^{18}F*(1.04, 3.06). Angular distributions have been studied to these and many other states at this energy and at $E(^3{\rm He}) = 17.3$ MeV. $A_{\rm y}$ measurements for $\rm t_0$ have been reported at $E(^3{\rm He}) = 33$ MeV. See (1983AJ01) for references.

36. ^{18}O(^{6}Li, ^{6}He)^{18}F $\qquad Q_{\rm m} = -5.163$

Table 18.33: Branching in ^{18}Ne(β^+)^{18}F [a]

Decay to ^{18}F* (MeV)	$J^\pi; T$	E_{γ_0} (keV)	Branch [b] (%)	$\log f_0t$ [c]
0	$1^+; 0$		92.11 ± 0.21	3.096 ± 0.004
1.04 [d]	$0^+; 1$	1041.5 ± 0.3	7.70 ± 0.21	3.473 ± 0.013
1.08 [d]	$0^-; 0$	1080.76 ± 0.13 [b]	$(2.07 \pm 0.28) \times 10^{-3}$	7.012 ± 0.059
1.70	$1^+; 0$	1699.9 ± 0.3 [e]	0.188 ± 0.006	4.477 ± 0.015

[a] For the earlier work see Tables 18.19 in (1983AJ01) and 18.20 in (1978AJ03).
[b] (1983AD03). See also (1982HE04).
[c] Based on $\tau_{1/2} = 1672 \pm 8$ ms: see (1983AD03).
[d] The splitting of the 0^+ and 0^- states is 39.20 ± 0.11 keV (1983AD03).
[e] And 659.2 ± 0.3 keV for the γ-ray to ^{18}F*(1.04) (1982HE04).

The reaction was studied at $E(^6\text{Li}) = 156$ MeV by (1990MO13). Evaluated cross sections for Gamow-Teller transitions at $0°$ and strengths for analogous beta decays were compared.

37. ^{18}Ne(β^+)^{18}F $\qquad Q_{\text{m}} = 4.446$

The half-life of ^{18}Ne is 1672 ± 8 ms [see ^{18}Ne]. The decay is to ^{18}F*(0, 1.04, 1.08, 1.70 MeV): see Table 18.33 and reaction 1 under ^{18}Ne.

38. ^{19}F(γ, n)^{18}F $\qquad Q_{\text{m}} = -10.431$

Cross sections have been reported to 30 MeV for the transitions to ^{18}F*(0.94, 1.04, 1.08, 3.06, 3.13, 4.75 MeV): see (1983AJ01).

Cross sections for the (γ, n_0) photoneutron reaction were measured between $48°$ and $139°$ for $E_\gamma = 15$–25 MeV by (1989KU10). The E1 absorption strength was deduced.

39. ^{19}F(n, 2n)^{18}F $\qquad Q_{\text{m}} = -10.431$

Cross sections have been measured at $E_{\text{n}} = 18$, 21, 23, 25, and 27 MeV (1991HA17).

40. ^{19}F(p, d)^{18}F $\qquad Q_{\text{m}} = -8.207$

Table 18.34: γ-ray intensities in ^{18}Ne(β^+)^{18}F [a]

E_γ (keV)	E_i (keV)	E_f (keV)	I_γ [b]
659.0 ± 0.2	1701	1042	0.135 ± 0.005
1041.55 ± 0.08	1042	0	7.83 ± 0.21
1080.76 ± 0.13	1081	0	0.00226 ± 0.00021
1700.81 ± 0.18	1701	0	0.0538 ± 0.0018

[a] (1983AD03).

[b] γ-ray intensities are per 100 parent decays.

Angular distributions have been reported to many states of ^{18}F with $E_x \leq 6$ MeV: see Table 18.20 in (1983AJ01). See also (1987AJ02). Spectroscopic factors derived from measurements of $E_p = 18.6$ MeV are discussed in (1987VA28). See also (1989VAZM).

41. ^{19}F(d, t)^{18}F $\qquad Q_m = -4.174$

See (1972AJ02, 1978AJ03), and see (1989VAZM) for cross section measurements and deduced level energies and spectroscopic factors. A recent measurement of total cross sections at $E_d = 5$–12 MeV (1993AB18) detected eight resonances with widths $\Gamma \approx 200$–400 keV.

42. ^{19}F(^{3}He, α)^{18}F $\qquad Q_m = 10.146$

See (1978AJ03, 1987VA1I, 1988GOZB), and see (1989VAZM) for cross section measurements and deduced level energies and spectroscopic factors.

43. ^{20}Ne(p, ^{3}He)^{18}F $\qquad Q_m = -15.557$

See (1978AJ03).

44. ^{20}Ne(d, α)^{18}F $\qquad Q_m = 2.796$

At $E_d = 11$ MeV α-groups are observed to many states of ^{18}F with $E_x < 7$ MeV. Weak or absent (each $\leq 0.3\%$ of the total yield at $30°$) are the groups corresponding to ^{18}F*(1.04, 3.06, 4.66, 4.74, 4.96 MeV): $T = 1$. Measurements of the TAP for $E_{\rm d} = 10.25$ to 12.0 MeV leads to assignments of 2^-, 1^+, 0^+, 1^-, 1^+, 3^+, 3^+ to ^{18}F*(4.23, 4.36, 4.75, 4.86, 5.603, 6.16, 6.48 MeV). See (1972AJ02, 1978AJ03, 1983AJ01) for references and for other results and (1987HI1B) for applications. Use of this reaction for ^{18}F production is discussed in (1991GU05).

45. ^{21}Ne(p, α)^{18}F $\qquad Q_{\rm m} = -1.741$

See (1987GOZX).

46. ^{23}Na(p, X)^{18}F

The ^{18}F yield from protons on ^{23}Na at $E_{\rm p} = 20$–67.5 MeV was measured (1992LA25) and cross sections were deduced.

47. ^{23}Na(d, ^{7}Li)^{18}F $\qquad Q_{\rm m} = -12.175$

See (1984NE1A).

^{27}Al(^{16}O, ^{25}Mg)^{18}F $\qquad Q_{\rm m} = -9.616$

Cross sections have been measured for $E(^{16}{\rm O}) = 13.6$ GeV/nucleon by (1993CU05).

^{18}Ne
(Figs. 4 and 5)

GENERAL: See Table 18.35.
For B(E2) of ^{18}Ne* (1.89) and other parameters see (1987RA01) and Table 2 here.

1. ^{18}Ne(β^+)^{18}F $\qquad Q_{\rm m} = 4.446$

The half-life of ^{18}Ne is 1672 ± 8 ms: see (1978AJ03) and (1983AD03). The decay is primarily to ^{18}F*(0, 1.04, 1.70 MeV). In addition there is an extremely weak branch [$(2.07 \pm 0.28) \times 10^{-3}$%] to ^{18}F* (1.08 MeV) [$J^\pi = 0^-$; $T = 0$] (1983AD03): see Table 18.33 for the parameters of the decay. The parity mixing in the ^{18}F*(1.04, 1.08) 0^+–0^- doublet has been studied by (1983AD03). It has been proposed as a probe of T-odd nuclear forces (1992HE12). See also (1982HE04). For the earlier work see (1983AJ01, 1987AJ02).

2. ^{12}C(^{12}C, ^{6}He)^{18}Ne $\qquad Q_{\rm m} = -22.913$

This reaction was studied at ^{6}He angles from $0°$ to $10°$ with a magnetic spectrometer (1992HAZZ). New levels at $E_{\rm x} > 6$ MeV, including ^{18}Ne(6.15, 7.35 MeV), were found. Astrophysical implications are discussed.

3. ^{14}O(α, γ)^{18}Ne $\qquad Q_{\rm m} = 5.112$

The thermonuclear reaction rates for this reaction have been estimated (1987WI11) using information from the isobaric analog ^{18}O. A new ^{18}Ne level at $E_{\rm x} = 6.15$ MeV (see ^{16}O(^{3}He, n)) has been observed (1990GAZW) which may play a role in ^{14}O + α burning. See also (1988CA26).

4. ^{14}O(α, p)^{17}F $\qquad Q_{\rm m} = 1.190$

This reaction is considered important in the generation of Z ≥ 10 nuclei from products in the hot CNO cycle. Microscopic multichannel calculations for this reaction are discussed in (1988FU02, 1989FU01).

5. ^{16}O(^{3}He, n)^{18}Ne $\qquad Q_{\rm m} = -3.196$

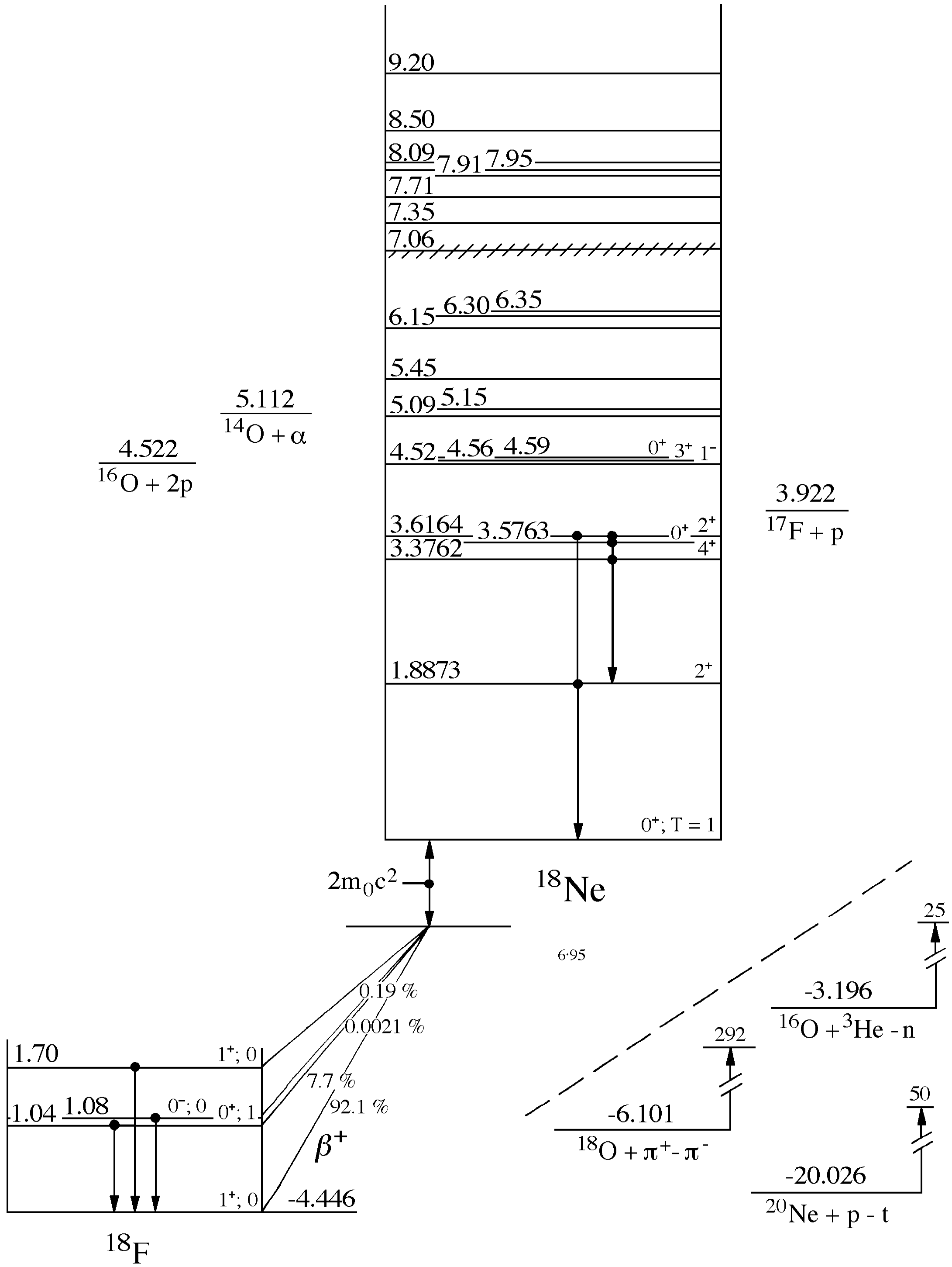

Fig. 4: Energy levels of ^{18}Ne. For notation see Fig. 2.

Table 18.35: ^{18}Ne – General

Reference	Description
Reviews:	
1987LE1B	Strong interaction studies via meson-nucleus reactions
1987RA1D	Nuclear processes and accelerated particles in solar flares
1993EN03	Strengths of γ-ray transitions in $A = 5$–44 nuclei
Other articles:	
1987BE1I	Search for a nucleon-participant multiplicity effect on anomalous fragment production
1987BU12	An ISOL/post-accelerator facility for nuclear astrophysics at TRIUMF
1987CO31	Simple parametrization for low energy octupole modes of s-d shell nuclei
1987KA39	Delta-hole approach to pion double charge exchange (DCX) reactions
1987PA1H	Anomalous behavior of low energy analog double charge exchange
1988MA1Q	Identification of one glue-like mechanism of the Λ-hyperon in hypernuclei
1988YU04	Contribution of the 2nd kind of meson exchange current to ^{18}O(π^+, π^-)^{18}Ne(g.s.)
1989BA92	Strangeness production in relativistic heavy-ion collisions
1989CH1P	1s-0d effective interactions of isospin triplet & ^{18}Ne-^{18}O Coulomb displacement energies
1989RA16	Predxns. from systematics & tabulation of B(E2; $0_1^+ \to 2_1^+$) values for even-even nucl.
1989TR18	2-nucleon and 4-nucleon clusters in light & heavy nuclei
1990BR13	Empir. p-n interactions: global trends, configuration sensitivity & $N = Z$ enhancements
1990BR26	Shell-model calcs. of isospin-forbidden β-delayed proton emission of isobaric analog state
1990LO11	Self-consistent calculations of light nuclei
1990MAZW	Hybrid quark hadron model of DCX in the delta resonance region (A)
1990PO04	New method of determining masses & quantum characteristics of light nuclei
1992AV03	The proton-neutron interaction & mass calcs. for nuclei with $Z > N$
1994CI02	Specific heat and shape transitions in light sd nuclei

(A) denotes that only an abstract was available for this reference.

Table 18.36: Energy levels of ^{18}Ne [a]

E_x (MeV ± keV)	$J^\pi; T$	τ or $\Gamma_{c.m.}$	Decay	Reactions
0	$0^+; 1$	$\tau_{1/2} = 1672 \pm 8$ ms	β^+	1, 5, 9, 10
1.8873 ± 0.2	2^+	$\tau_m = 0.67 \pm 0.06$ ps	γ	5, 9, 10
3.3762 ± 0.4	4^+	$\tau_m = 4.4 \pm 0.6$ ps	γ	5, 7, 8, 10
3.5763 ± 2.0	0^+	$\tau_m = 4 \pm 2$ ps	γ	5, 10
3.6164 ± 0.6	2^+	$\tau_m = 63^{+30}_{-20}$ fs	γ	5, 10
4.519 ± 8	1^-	$\Gamma \leq 20$ keV	(p)	5, 10
4.561 ± 9	3^+			5
4.590 ± 8	0^+	$\Gamma \leq 20$ keV	(p)	5, 10
5.090 ± 8	$(2^+, 3^-)$	$\Gamma = 40 \pm 20$ keV	(p)	5, 10
5.146 ± 7	$(2^+, 3^-)$	$\Gamma = 25 \pm 15$ keV		5, 10
5.453 ± 10		$\Gamma \leq 50$ keV		10
6.15 [b, c]	(1^-)			2, 3
6.297 ± 10	(4^+)	$\Gamma \leq 60$ keV		5, 10
6.353 ± 10		$\Gamma \leq 60$ keV		10
7.059 ± 10	$(1^-, 2^+)$	$\Gamma = 180 \pm 50$ keV		5
7.35 [c]				2
7.713 ± 10		$\Gamma \leq 50$ keV		5, 10
7.910 ± 10	$(1^-, 2^+)$	$\Gamma \leq 50$ keV		5
7.950 ± 10		$\Gamma \leq 60$ keV		10
8.086 ± 10		$\Gamma \leq 50$ keV		5
8.500 ± 30		$\Gamma \leq 120$ keV		5
9.201 ± 9		$\Gamma \leq 50$ keV		10

[a] See also Table 18.37.
[b] (1990GAZW).
[c] (1992HAZZ). This work reports the observation of several new levels in the region $E_x > 6$ MeV.

See Table 18.38. See also (1983AJ01).

Recent work reported in (1991GA03) found that the 3^+ level in ^{18}Ne predicted by (1988WI08) occurs at $E_x = 4.561 \pm 0.009$ MeV. Astrophysical consequences are discussed. New levels in ^{18}Ne at $E_x \geq 6$ MeV observed in ^{16}O(^{3}He, n) were reported in (1990GAZW). [See discussion under ^{14}O(α, γ)^{18}Ne.] See also (1989GAZW, 1990GAZR). For applied work related to this reaction see (1991GU05, 1992DI04).

6. ^{16}O(α, nn)^{18}Ne $\quad Q_m = -23.773$

See (1991GU05) for measurements at $E_\alpha = 40$ MeV.

Table 18.37: Branching ratios and lifetimes of ^{18}Ne states [a]

E_i (MeV)	J_i^π	E_f (MeV)	Branch (%)	τ_m (ps)
1.89	2^+	0	100	0.67 ± 0.06
3.38	4^+	1.89	100 [b]	4.4 ± 0.6
3.58	0^+	1.89	100 [c]	4 ± 2
3.62	2^+	0	9 ± 2	
		1.89	91 ± 2 [d]	$0.063^{+0.030}_{-0.020}$

[a] For references see Table 18.24 in (1978AJ03).
[b] Ground state decay is < 1%.
[c] Ground state decay is < 5%.
[d] The mixing ratio, δ, is consistent with 0.

7. ^{16}O(^{10}B, ^{8}Li)^{18}Ne $\quad Q_m = -18.951$

At $E(^{10}\text{B}) = 100$ MeV, the angular distribution to ^{18}Ne*(3.38) [$(\text{d}_{5/2})^2_{4^+}$ state], which is preferentially populated, has been studied. ^{18}Ne*(1.89) is also observed (see (1983AJ01). See also (1983OS07).

8. ^{16}O(^{12}C, ^{10}Be)^{18}Ne $\quad Q_m = -22.663$

Measurements at $E(^{12}\text{C}) = 480$ MeV are reported in (1988KR11, 1988ME10). The 4^+ level at $E_x = 3.38$ MeV is observed.

Table 18.38: States in ^{18}Ne from ^{16}O(^{3}He, n) and ^{20}Ne(p, t) [a]

E_x (MeV ± keV)		$\Gamma_{c.m.}$ [b]	J^π [a, b]
A	B	(keV)	
0			0^+
1.8873 ± 0.2	1.886 ± 10		2^+
3.3762 ± 0.4	3.375 ± 10		4^+
3.5763 ± 2.0	3.580 ± 10		0^+
3.6164 ± 0.6	3.612 ± 10		2^+
4.513 ± 13	4.522 ± 10	≤ 20	1^-
4.561 ± 9 [c]		25 [c]	3^+ [c]
4.587 ± 13	4.592 ± 10	≤ 20	0^+
5.075 ± 13	5.099 ± 10	40 ± 20	$(2^+, 3^-)$
5.141 ± 10	5.151 ± 10	25 ± 15	$(2^+, 3^-)$
	5.453 ± 10	≤ 50	
6.291 ± 30 [d]	6.297 ± 10	≤ 60	(4^+)
	6.353 ± 10	≤ 60	
7.062 ± 12 [a]		180 ± 50	$(1^-, 2^+)$
7.712 ± 20	7.713 ± 10	≤ 50	
7.915 ± 12 [a]		≤ 50	$(1^-, 2^+)$
	7.949 ± 10	≤ 60	
8.100 ± 14 [a]		≤ 50	
8.50 ± 30		≤ 120	
	9.198 ± 10	≤ 50	

A: ^{16}O(^{3}He, n)^{18}Ne: for references see Table 18.23 (1978AJ03) and (1981NE09).
B: ^{20}Ne(p, t)^{18}Ne: (1981NE09).
[a] See also Table 18.23 in (1978AJ03).
[b] (1981NE09).
[c] (1991GA03). The width $\Gamma = 25$ keV is estimated from a Woods Saxon calculation.
[d] $\Gamma = 180 \pm 60$ keV.

9. ^{18}O(π^+, π^-)^{18}Ne $\qquad Q_m = -6.101$

Angular distributions have been studied at $E(\pi^+) = 164$ and 292 MeV [see (1983AJ01)] and at 48.3 MeV (1985AL15; to ^{18}Ne$_{g.s.}$) and 100 to 292 MeV (1985SE08; to ^{18}Ne$_{g.s.}$). The excitation functions for production of ^{18}Ne*(0, 1.89) have been measured for $E(\pi^+) = 80$ to 292 MeV: see (1983AJ01, 1985SE08). See also (1987AJ02).

The behavior of double charge exchange (DCX) cross sections at low energies (50 ± 30 MeV) was reviewed in (1987PA1H, 1988SE1A, 1989BA1R). See also the review of (1989ST1H). Measurements at energies of 300–500 MeV above the Δ(1232) resonance were reported in (1989WI02). More recently a search for an η bound state in this reaction is described in (1992JOZZ, 1993JO03).

The contribution of the two-nucleon pion absorption emission mechanism is discussed in (1990CH14). See also (1989CH1O, 1990CH1U) and see (1989YU1A). A quark-antiquark annihilation mechanism is proposed in (1989CH21). A two-amplitude model for the DCX energy dependence is described in (1989FO02). In other recent work, the contribution of sequential charge exchange and delta-nucleon charge exchange is examined in (1993GI03). Absorption contributions near $T_\pi = 50$ MeV are evaluated by (1992OS05). High energy DCX and isovector renormalization is calculated and compared with data in (1993OS01). See also (1992MA46) for a discussion of dibaryon effects.

10. ^{20}Ne(p, t)^{18}Ne $\qquad Q_m = -20.022$

Observed triton groups are displayed in Table 18.38 as are J^π derived from DWBA analysis of angular distributions: The 0_3^+ state, identified at $E_x = 4.59$ MeV, appears to have a largely $s_{1/2}^2$ configuration based on its large downward shift with respect to the analog state in ^{18}O (1981NE09).

11. ^{20}Ne(^{3}He, nα)^{18}Ne $\qquad Q_m = -7.926$

See (1991GU05).

^{18}Na

(Not observed)

^{18}Na has not been observed; its atomic mass excess has been estimated to be 25.32 MeV (1993AU05); it is then unbound with respect to proton emission by 1.6 MeV: see (1978AJ03). See also (1986AN07) and (1983ANZQ).

^{18}Mg, etc.

(Not observed)

See (1986AN07) and (1983ANZQ). See also the results of calculations of β^+/electron capture half lives for neutron deficient nuclei in (1993HI08).

Table 18.39: Isospin triplet components ($T = 1$) in $A = 18$ nuclei [a]

^{18}O		^{18}F			^{18}Ne		
E_x (MeV)	J^π	E_x (MeV)	$J^\pi; T$	ΔE_x (MeV) [b]	E_x (MeV)	J^π	ΔE_x (MeV) [c]
0	0^+	1.04	$0^+; 1$	–	0	0^+	–
1.98	2^+	3.06	$2^+; 1$	$+0.04$	1.88	2^+	-0.09
3.55	4^+	4.65	$4^+; 1$	$+0.06$	3.38	4^+	-0.18
3.63	0^+	4.75	$0^+; 1$	$+0.08$	3.57	0^+	-0.06
3.92	2^+	4.96	$2^+; 1$	$+0.002$	3.62	2^+	-0.30
4.46	1^-	{ 5.60	$1^-; 0+1$	$+0.11$	4.52	1^-	$+0.06$
		5.67	$1^-; 0+1$	$+0.18$			
5.10	3^-	{ 6.240	$3^-; 0+1$	$+0.10$	5.09	$(2^+, 3^-)$	-0.01
		6.242	$3^-; 0+1$	$+0.10$	5.15	$(2^+, 3^-)$	$+0.05$
5.25	2^+	{ 6.28	$2^+; 1$	-0.01			
		6.39	$2^+; 1$	$+0.09$			
5.34	0^+	6.14	$0^+; 1$	-0.24	4.59	0^+	-0.75
5.38	3^+	6.16	$3^+; 1$	-0.26			
5.53	2^-	6.64	$2^-; 1$	$+0.07$			
6.19	1^-	7.34	$1^-; 1$	$+0.10$			

[a] As taken from Tables 18.9, 18.24 and 18.36.

[b] Defined as $E_x(^{18}\mathrm{F}) - E_x(^{18}\mathrm{O}) - 1.04$ MeV.

[c] Defined as $E_x(^{18}\mathrm{Ne}) - E_x(^{18}\mathrm{O})$.

Table 18.40: ($T = 2$) states in ^{18}N and ^{18}O [a]

^{18}N		^{18}O	
E_x (MeV)	J^π	E_x (MeV)	$J^\pi; T$
0	1^- [b]		
0.11	(2^-) [b, c]	16.4	2^-; 2
0.59	(2^-) [b]		
0.75	(3^-) [b, c]	17.03	(3^-); 2
		17.4	1^-; (2)
		18.7	(4^-); 2
		18.9	1^+; 2
		19.24	(> 2); 2
		19.4	1^-; (2)
		20.36	(4^-); 2
		21.42	(4^-); (2)
		22.40	4^-; 2
		27	1^-; (2)

[a] As taken from Tables 18.4 and 18.9.

[b] Coulomb-shift computations (R. Sherr, private communication) for these four levels suggest that the analogs of the ^{18}N 1^- and (2^-) levels at $E_x = 0$ and 0.59 MeV are the ^{18}O $1^{(-)}$ and (3, 2)$^-$ levels at $E_x = 16.21$ and 16.95 MeV respectively.

[c] It is noted (A.H. Wapstra, private communication) that the combined evidence on these two levels and their analogs in ^{18}O is an argument for assignments of 2^- and (3^-) in both nuclei, and in ^{18}O they should lie above an unobserved 1^-; 2 state near 16.3 MeV.

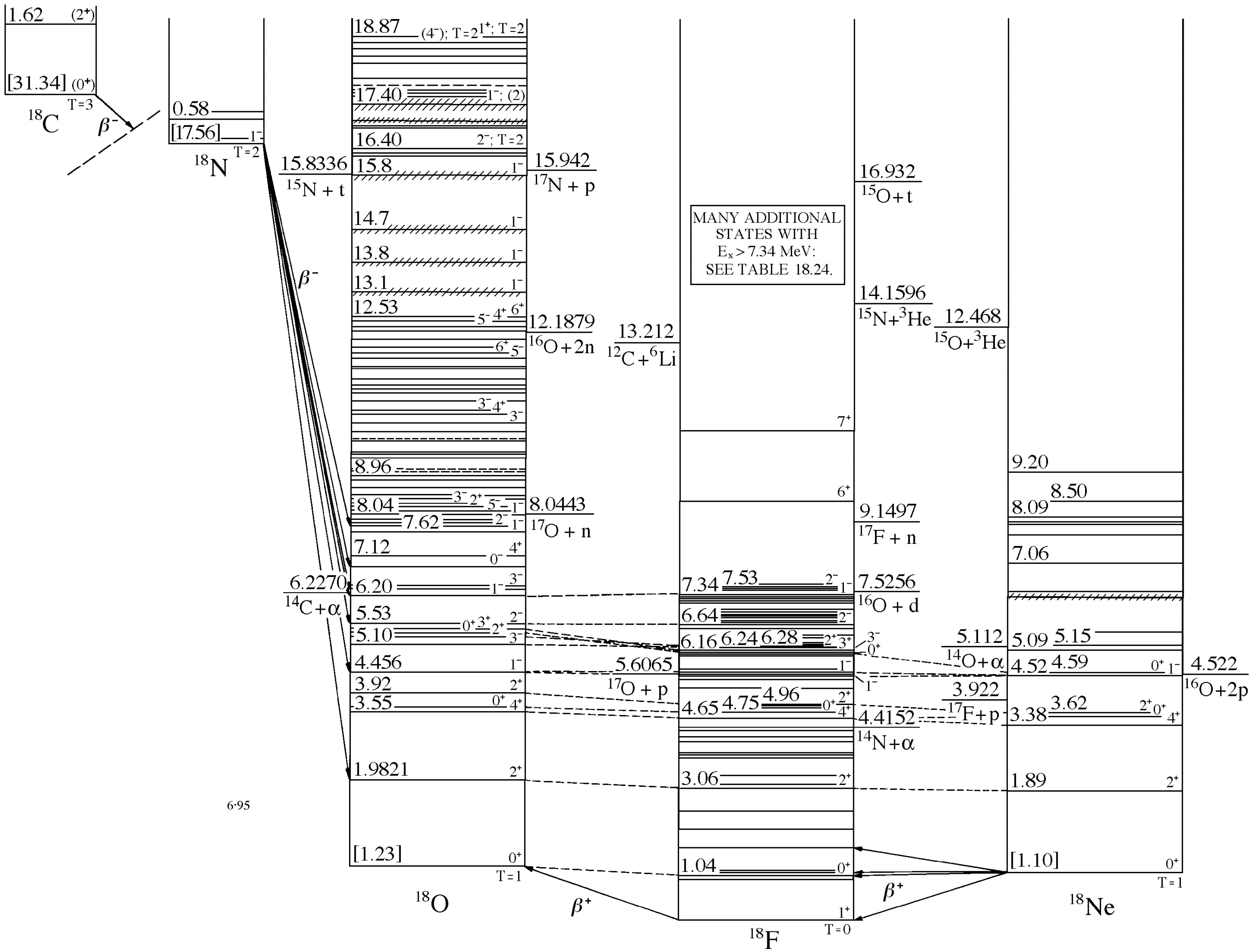

Fig. 5: Isobar diagram, $A = 17$. The diagrams for individual isobars have been shifted vertically to eliminate the neutron-proton mass difference and the Coulomb energy, taken as $E_{\rm C} = 0.60Z(Z-1)/A^{1/3}$. Energies in square brackets represent the (approximate) nuclear energy, $E_{\rm N} = M(Z,A) - ZM({\rm H}) - NM({\rm n}) - E_{\rm C}$, minus the corresponding quantity for ^{18}F: here M represents the atomic mass excess in MeV. Levels which are presumed to be isospin multiplets are connected by dashed lines.

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