Energy Levels of Light Nuclei
$A = 19$

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Abstract: Our evaluation of A = 18–19 was published in *Nuclear Physics* A595 (1995), p. 1. This version of A = 19 differs from the published version in that we have corrected some errors discovered after the article went to press. Figures and introductory tables have been omitted from this manuscript. Figures and the A = 18 evaluation are available elsewhere on this web site.

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^{19}He, ^{19}Li, ^{19}Be

(Not observed)

See (83ANZQ).

^{19}B

(Not illustrated)

^{19}B has been observed in the bombardment of Be by 12 MeV/A ^{56}Fe ions (84MU27) and in the fragmentation of 44 MeV/A ^{40}Ar (88GU1A) and 55 MeV/A ^{48}Ca (91MU19). See also (89DE1X). The mass excess adopted by (93AU05) is 59.360 ± 0.400 MeV.

Shell model predictions for low-lying levels are discussed in (92WA22). See also (89PO1K, 90LO11).

^{19}C

(Fig. 19.4)

^{19}C has been observed in the 0.8 GeV proton bombardment of thorium (86VI09, 88WO09) and in the fragmentation of 66 MeV/A argon ions (87GI05) and in 44 MeV/A ^{22}Ne on ^{181}Ta, and in 112 MeV/A ^{20}Ne on ^{12}C (94RA1P, 95OZ1A). The mass excess adopted by (93AU05) is 32.23 ± 0.11 MeV. See also (86VI09, 87GI05, 88WO09, 91OR01). ^{19}C is then stable with respect to decay into ^{18}C + n by 0.16 MeV and into ^{17}C + 2n by 4.35 MeV. The half-life was measured to be 30 ± 10 ms (88DU1C) and 45.5 ± 4.0 ms (94RA1P). The total reaction cross section for ^{19}C on Cu has been measured by (89SA10). See also (87DUZU) and the review of exotic light nuclei of (89DE1X).

Hartree-Fock calculations by (87SA15) predicted ground state properties and spectra of ^{19}C and other exotic light nuclei. A shell model study is presented in (92WA22). Microscopic predictions of β-decay half lives are discussed in (90ST08). The relative yields of carbon isotopes produced in the fragmentation of ^{84}Kr are calculated in (87SN1A). See also the study by (92LA13) of the influence of separation energy on the radius of neutron rich nuclei.

^{19}N

(Fig. 19.4)

^{19}N has been produced in a number of different multinucleon transfer reactions (83AJ01, 87AJ02), and these results lead to an adopted value (93AU05) of 15.860 ± 0.016 MeV for the mass excess. ^{19}N is then stable with respect to decay into ^{18}N + n by 5.33 MeV. The half-life has been measured to be 0.32 ± 0.10 sec (86DU07), $0.21^{+0.2}_{-0.1}$ sec (88MU08), 0.235 ± 0.032 sec (88SA04), 0.300 ± 0.080 sec (88DU1C), 0.329 ± 0.019 sec (91RE02). The neutron emission probability has been measured to be $P_n = 33^{+34}_{-11}$ %(88MU08) and $P_n = 62.4 \pm 2.6$ % (91RE02).

Excited states in ^{19}N observed in ^{18}O(^{18}O, ^{17}F)^{19}N have been reported by (89CA25) at $E_x = 1.11 \pm 0.02$, 1.65 ± 0.02, 2.54 ± 0.03, 3.47 ± 0.03, and 4.18 ± 0.02 MeV. See also (87AJ02, 88DU1C, 95OZ1A).

A discussion of self-consistent calculations for light neutron-rich nuclei is presented in (90LO11). Extensive shell model calculations for observables in exotic light nuclei are discussed in (93PO11). See also the shell model calculations and discussions in (92WA22).

^{19}O

(Figs. 19.1 and 19.4)

GENERAL: See Table 19.1.

1. ^{19}O(β^-)^{19}F $\qquad Q_m = 4.819$

The weighted mean of several half-lives is 26.96 ± 0.07 sec: see (72AJ02, 87AJ02). The decay is complex: see reaction 34 of ^{19}F and Tables 19.23 and 19.24.

2. ^{9}Be(^{18}O, ^{8}Be)^{19}O $\qquad Q_m = 2.293$

See (83AJ01).

3. ^{13}C(^{7}Li, p)^{19}O $\qquad Q_m = 7.412$

States of ^{19}O reported in this reaction are displayed in Table 19.4.

4. ^{17}O(t, p)^{19}O $\qquad Q_m = 3.520$

Proton groups corresponding to ^{19}O states with $E_x \leq 5.6$ MeV and E_γ measurements are displayed in Table 19.5.

5. (a) ^{18}O(n, γ)^{19}O $\qquad Q_m = 3.957$
   (b) ^{18}O(n, n$'$)^{18}O $\qquad E_b = 3.957$

Table 19.1
^{19}O – General

Reference	Description
	Nuclear Models
87CH1J	Nucl. struc. calcs. using mixed-config. shell model: effective & surface δ-interactions
88BR11	Semi-empirical effective interactions for the 1s-0d shell
88ET01	Analysis of magnetic dipole transitions between sd-shell states of some $A = 17$–39 nucl.
88WA17	Shell model predictions of energy spectra and wave functions for ^{19}N(β^-)^{19}O
89CA25	Multinucleon transfer rxns. at 117 MeV & shell model calc. of ^{17,19}N, ^{19,21}O levels
90SK04	$A = 18$ nuclei, effective interaction in the sd shell (also calc. $A = 19$ energy spectra)
91MA41	Finite nuclei calculations with realistic potential models
92JI04	Bonn potential used to evaluate energy spectra of some light sd-shell nuclei
92ZH15	Theoretical calculation of neutron induced data of ^{19}F and uncertainties of parameters
93PO11	Shell-model calcs. of several properties of exotic light nuclei
	Special States
87CH1J	Nucl. struc. calcs. using mixed-config. shell model: effective & surface δ-interactions
87LI1F	Double-δ & surface-δ interactions and spectra of oxygen isotopes in the sd shell
88WA17	Shell model predictions of energy spectra and wave functions for ^{19}N(β^-)^{19}O
89CA25	Multinucleon transfer rxns. at 117 MeV & shell model calcs. of ^{17,19}N, ^{19,21}O levels
89SA1H	Second class currents & neutrino mass in mirror transitions ($A = 19$)
90SK04	$A = 18$ nuclei, effective interaction in the sd shell (also calc. $A = 19$ energy spectra)
93NA08	Charge-symmetry-breaking nucleon-nucleon interaction in the 1s0d-shell nuclei
	Complex Reactions
Review:	
88JO1B	Heavy ion radioactivity
Other Articles:	
87BU07	Projectile-like fragments from ^{20}Ne + ^{197}Au – counting simultaneously emitted neutrons
87MI27	Measurement of total reaction cross sections of exotic neutron-rich nuclei
89BA2N	Evaluation of hypernucleus production cross-sections in relativistic heavy-ion collisions
89CA25	Multinucleon transfer rxns. at 117 MeV & shell model calc. of ^{17,19}N, ^{19,21}O levels
89SA10	Total cross sections of reactions induced by neutron-rich light nuclei

Table 19.2
Energy Levels of ^{19}O [a]

E_x (MeV ± keV)	J^π; T	τ or $\Gamma_{c.m.}$ [b]	Decay	Reactions
0	$\frac{5}{2}^+$; $\frac{3}{2}$	[$\tau_{1/2} = 26.91 \pm 0.08$ s]	β^-	1, 2, 3, 4, 5, 7, 8, 9, 10
0.0960 ± 0.5	$\frac{3}{2}^+$	$\tau_m = 2.00 \pm 0.07$ ns	γ	3, 4, 7, 8, 9, 10
		[g = -0.48 ± 0.06]		
1.4717 ± 0.4	$\frac{1}{2}^+$	$\tau_m = 1.27 \pm 0.17$ ps	γ	3, 4, 7, 8
2.3715 ± 1.0	$\frac{9}{2}^+$	$\tau_m > 3.5$ ps	γ	3, 4, 7
2.7790 ± 0.9	$\frac{7}{2}^+$	$\tau_m = 93 \pm 19$ fs	γ	3, 4, 7, 8
3.0674 ± 1.6	$(\frac{3}{2}^+)$ [d]	$\tau_m \geq 1$ ps	γ	3, 4, 7, 8
3.1535 ± 1.7	$\frac{5}{2}^+$	($\tau_m \geq 1$ ps)	γ	3, 4, 7, 8
3.2316 ± 2.3	$(\frac{1}{2}, \frac{3}{2}^-)$ [d]			3, 4, 7, 8
3.9449 ± 1.4 [c]	$\frac{3}{2}^-$		γ	3, 4, 7
4.1093 ± 1.9	$\frac{3}{2}^+$	$\Gamma < 15$ keV		3, 4, 7
4.3281 ± 2.4	$\frac{3}{2}, \frac{5}{2}$	$\Gamma < 15$ keV		3, 4, 7
4.4025 ± 2.7	$\frac{3}{2} \rightarrow \frac{7}{2}$	$\Gamma < 15$ keV		3, 4, 7
4.5820 ± 4.6	$\frac{3}{2}^-$	$\Gamma = 52 \pm 3$ keV	n	3, 4, 5, 7
4.7026 ± 2.7	$\frac{5}{2}^+$	$\Gamma < 15$ keV		3, 4, 7, 8
4.9683 ± 5.5	$\frac{5}{2}, \frac{7}{2}$			3
5.0070 ± 4.5	$\frac{3}{2}, \frac{5}{2}$	$\Gamma < 15$ keV		3, 4, 7
5.0820 ± 5.4	$\frac{1}{2}^-$	$\Gamma = 49 \pm 5$ keV	n	3, 5
5.1484 ± 3.2	$\geq \frac{5}{2}^+$	$\Gamma = 3.4 \pm 1.0$ keV	n	3, 4, 5, 7
5.3840 ± 2.8	$(\frac{9}{2} \rightarrow \frac{13}{2})$			3
5.5035 ± 3.1 [c]		$\Gamma < 15$ keV		3, 4, 7
5.54	$\frac{3}{2}^+$	$\Gamma \approx 490$ keV	n	5
5.7046 ± 4.3 [c]	$\frac{7}{2}^-$	$\Gamma = 7.8 \pm 1.4$ keV	n	3, 4, 5, 7, 8
6.1196 ± 3.2 [c]	$\frac{3}{2}^+$	$\Gamma \approx 110$ keV	n	3, 5
6.1916 ± 5.5				3
6.2693 ± 2.6	$\frac{7}{2}^-$	$\Gamma = 19.2 \pm 2.4$ keV	n	3, 4, 5, 7, 8
6.4058 ± 3.1 [c]				3
6.4662 ± 4.8	$(\frac{7}{2} \rightarrow \frac{11}{2})$		(n)	3, 5, 7
6.583 ± 6 [c]				3, 7
6.903 ± 8				3, 7
6.988 ± 9				3, 7
7.118 ± 10				3, 7
7.242 ± 8				3, 7
7.508 ± 10				3
8.048 ± 20				3
8.132 ± 20				3
8.247 ± 20				3
8.450 ± 20				3
8.561 ± 20				3

Table 19.2 (continued)
Energy Levels of ^{19}O [a])

E_x (MeV ± keV)	J^π; T	τ or $\Gamma_{c.m.}$ [b])	Decay	Reactions
8.591 ± 20				3
8.916 ± 20				3
8.923 ± 20				3
9.022 ± 20				3
9.064 ± 20				3
9.253 ± 20				3
9.324 ± 20				3
9.43				3
9.56				3
9.6	$\frac{7}{2}^-$		n	3, 5
9.9	$\frac{7}{2}^-$		n	3, 5
9.93				3
9.98				3
10.21	$\frac{7}{2}^-$		n	5
10.66	$\frac{7}{2}^-$		n	5
11.25 ± 50		$\Gamma = 240$ keV	n, α	6
11.58 ± 50		$\Gamma = 330$ keV	n, α	6

[a]) See also Tables 19.3 and 19.7.
[b]) See also reaction 1, and Table 19.2 in (78AJ03).
[c]) See footnotes to Table 19.4.
[d]) (87AJ02) gave $J^\pi = \frac{3}{2}^+$ for these levels. Assignments have been revised based on arguments presented in (88WA17).

Table 19.3
Radiative decays in ^{19}O [a])

E_i (MeV)	J^π_i	E_f (MeV)	Branch (%) [a])	δ
0.096	$\frac{3}{2}^+$	0	100	
1.47	$\frac{1}{2}^+$	0	2.0 ± 0.2	
		0.096	98.0 ± 0.2	
2.37	$\frac{9}{2}^+$	0	100	0.002 ± 0.05
2.78	$\frac{7}{2}^+$	0	100	0.8 ± 0.5
3.07	$\frac{3}{2}^+$	1.47	100	
3.16	$\frac{5}{2}^+$	0	8 ± 4	
		0.096	92 ± 4	$0.03 < \delta < 2.3$
3.94	$\frac{3}{2}^-$	0	33 ± 8	
		0.096	39 ± 8	
		1.47	28 ± 4	

[a]) For other values and for references see Table 19.5 in (78AJ03).

The thermal capture cross section is 0.16 ± 0.01 mb (81MUZQ). The scattering length $b = 5.84 \pm 0.07$ fm, $\sigma_{\text{free}} = 3.86 \pm 0.10$ b (79KO26). The total cross section has been measured for $E_n = 0.14$ to 2.47 MeV [see (78AJ03)] and at $E_n = 5$ to 7.5 MeV [G. Auchampaugh, quoted in (86KO10)]. A multi-level R-matrix analysis of these and additional $\sigma(\theta)$ data leads to the states shown in Table 19.6 and to some additional structures. The five $\frac{7}{2}^-$ states [^{19}O* (6.27, 9.64, 9.84, 10.21, 10.66)] (see, however, footnote (a) to Table 19.6) contain about 20–30% of the allowed $f_{7/2}$ single-particle strength. See also the compilation of neutron cross sections in (88MCZT). Isobaric analog assignments are presented (86KO10). See also (82RA1A) and see the astrophysical discussion in (88AP1A, 88MA1U).

6. ^{18}O(n, α)^{15}C $Q_m = -5.009$ $E_b = 3.957$

The total cross sections for the α_0 and α_1 groups have been measured for $E_n = 7.5$ to 8.6 MeV: resonance structure is reported at $E_n = 7.70 \pm 0.05$ and 8.05 ± 0.05 MeV with $\Gamma_{\text{lab}} = 0.25$ and 0.35 MeV, respectively [^{19}O* (11.25, 11.58)]: see (78AJ03).

7. ^{18}O(d, p)^{19}O $Q_m = 1.733$

Angular distributions have been measured at $E_d = 0.8$ to 15 MeV: see (78AJ03, 83AJ01). The l_n values and spectroscopic factors derived from these measurements are displayed in Table 19.5. Branching ratios are shown in Table 19.3. ^{19}O* (0.096) has $g = -0.48 \pm 0.06$; its configuration appears to be mainly $d^3_{5/2}$, and $B(\text{M1}) = 0.040 \pm$

Table 19.4
States in ^{19}O from ^{13}C(^{7}Li, p) [a]

E_x (MeV ± keV)	J [b]	E_x (MeV ± keV)	J [b]
0	$\frac{5}{2}$	6.4662 ± 4.8 [i]	
0.0944 ± 1.1	$\frac{3}{2}$	6.5827 ± 6.0 [j]	
1.4716 ± 1.8	$\frac{1}{2}$	6.903 ± 8	
2.3711 ± 1.9	$\frac{9}{2}$	6.988 ± 9	
2.7776 ± 1.9	$\frac{7}{2}$	7.118 ± 10	
3.0674 ± 1.6	$\frac{3}{2}$	7.242 ± 8	
3.1536 ± 2.8	$\frac{5}{2}$	7.508 ± 10	
3.2316 ± 2.3	$\frac{3}{2}$	8.048 ± 20	
3.9449 ± 1.4 [c]		8.132 ± 20	
4.1093 ± 1.9	$\frac{3}{2}$	8.247 ± 20	
4.3281 ± 2.4	$\frac{3}{2}, \frac{5}{2}$	8.450 ± 20	
4.4025 ± 2.7	$\frac{3}{2}, \frac{5}{2}, \frac{7}{2}$	8.561 ± 20	
4.5820 ± 4.6	$\frac{3}{2}$	8.591 ± 20	
4.7026 ± 2.7 [d]		8.916 ± 20	
4.9683 ± 5.5	$\frac{5}{2}, \frac{7}{2}$	8.923 ± 20	
5.0070 ± 4.5	$\frac{3}{2}, \frac{5}{2}$	9.022 ± 20	
5.0820 ± 5.4	$\frac{1}{2}$	9.064 ± 20	
5.1484 ± 3.2	$\frac{5}{2}$	9.253 ± 20	
5.3840 ± 2.8	$\frac{9}{2}, \frac{11}{2}, \frac{13}{2}$ [e]	9.324 ± 20	
5.5035 ± 3.1 [f]		9.43	
5.7046 ± 4.3 [g]		9.56	
6.1196 ± 3.2 [h]		9.77	
6.1916 ± 5.5	$\frac{1}{2}$	9.88	
6.2693 ± 2.6	$\frac{7}{2}$	9.93	
6.4058 ± 3.1 [h]		9.98	

[a] (77FO10); $E(^7\text{Li}) = 16.0$ MeV. Angular distributions have been reported to all states with $E_x < 6.8$ MeV. See also (78AJ03).
[b] Derived from total cross section and $2J + 1$ analysis.
[c] Corresponds to unresolved states. Assuming one of these to be a $\frac{3}{2}^-$ state (see Table 19.5), the other should have $J = \frac{7}{2} \rightarrow \frac{13}{2}$.
[d] May correspond to unresolved states.
[e] If this group corresponds to a single state, the analysis indicates $J^\pi = \frac{9}{2}^-, \frac{11}{2}^-$ or $\frac{13}{2}^+$ (77FO10).
[f] Narrow unresolved states: see discussion in (77FO10).
[g] Cross section is too large for the known state at this energy with $J^\pi = \frac{3}{2}^+$. If this group corresponds to a doublet, the other member should have $J = \frac{1}{2} \rightarrow \frac{5}{2}$.
[h] Sharp group; if due to a single state $J = \frac{11}{2} \rightarrow \frac{17}{2}$.
[i] $J = (\frac{7}{2}, \frac{9}{2}, \frac{11}{2})$.
[j] The total cross section to this state is very high implying unresolved states: if there are two states one must have $J > \frac{13}{2}$.

Table 19.5
Levels of ^{19}O from ^{17}O(t, p) and ^{18}O(d, p) [a]

E_x (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	l_n [b]	l_{2n} [c]	S [d]	J^π
0		2	0	0.57	$\frac{5}{2}^+$
0.0960 ± 0.5		2	2		$\frac{3}{2}^+$
1.4719 ± 0.5		0	2	1.00	$\frac{1}{2}^+$
2.3715 ± 1.0		2	$(2+4)$		$\frac{9}{2}^+$
2.7790 ± 0.9		(2)	2		$\frac{7}{2}^+$
3.0671 ± 2.6			$(2+4)$		$\frac{3}{2}^+$
3.1535 ± 2.4		2	$(0+2)$	(0.06)	$\frac{5}{2}^+$
3.237 ± 5					$\frac{3}{2}^+$
3.944 ± 3		1		0.11	$\frac{3}{2}^-$
4.118 ± 5	< 15	2	(2)	0.33	$\frac{3}{2}^+$
4.333 ± 12	< 15				
4.402 ± 12	< 15				
4.584 ± 12	75 ± 5	1		0.15	$\frac{3}{2}^-$
4.707 ± 12	< 15	2		0.02	$\frac{5}{2}^+$
4.998 ± 12	< 15				
5.150 ± 10	< 15	2		0.08	$\frac{5}{2}^+$
5.455 ± 10	320 ± 25	2	$(2+4)$	0.85	$\frac{3}{2}^+$
5.502 ± 12	< 15				
5.714 ± 12	< 15	2		0.17	$(\frac{3}{2}^+)$
6.280 ± 12	< 15	3		0.13	$\frac{7}{2}^-$
6.480 ± 15					
6.560 ± 15					
6.899 ± 15					
6.997 ± 15					
7.117 ± 15					
7.248 ± 15					

[a]) For references see Table 19.3 in (78AJ03). However, see note in Table 19.4 of (87AJ02) concerning errors in that table and subsequent corrections.
[b]) ^{18}O(d, p)^{19}O.
[c]) ^{17}O(t, p)^{19}O.
[d]) $E_d = 14.8$ MeV: polarization and differential cross section measurements. The spectroscopic factors for the states with $E_x > 4.1$ MeV have been calculated in the weakly bound approximation: see (78AJ03).

Table 19.6
Resonances in ^{18}O(n, n)^{18}O [a]

E_{res} (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	^{19}O* (MeV)	J^π
0.67	52 ± 3 [b]	4.59	$\frac{3}{2}^-$
1.18	49 ± 5 [b]	5.07	$\frac{1}{2}^-$
1.256 ± 10 [b]	3.4 ± 1.0 [b]	5.146	$\geq \frac{5}{2}^{(+)}$
1.42 [c]		5.30	$\frac{3}{2}^-$
1.67	490	5.54	$\frac{3}{2}^+$
1.840 ± 10 [b]	7.8 ± 1.4 [b]	5.699	$\frac{7}{2}^-, \frac{5}{2}$
2.22	110	6.06	$\frac{3}{2}^+$
2.45	19.2 ± 2.4 [b]	6.28	$\frac{7}{2}^-$
6.00		9.64	$\frac{7}{2}^-$
6.21		9.84	$\frac{7}{2}^-$
6.60		10.21	$\frac{7}{2}^-$
7.08 [d]		10.66	$\frac{7}{2}^-$

[a]) These data are from a multi-level R-matrix re-analysis by (86KO10) of the work displayed in Table 19.4 of (78AJ03), together with unpublished σ_t data by G.F. Auchampaugh, and $\sigma(\theta)$ for n_0 and n_1 for $5.0 < E_n < 7.5$ MeV. Uncertainties in E_x and Γ cannot be estimated. See also (86KO10) for other states and see footnote (a) in Table 19.5 of (87AJ02).
[b]) See Table 19.4 of (78AJ03).
[c]) See discussion in (86KO10).
[d]) May be a doublet, but at least one of the states has $J^\pi = \frac{7}{2}^-$ (86KO10).

Table 19.7
Levels of ^{19}O from ^{18}O(α, ^{3}He)^{19}O [a]

E_x (MeV)	l	J^π [b]	σ_{Int} [c] (mb)
0	2	$\frac{5}{2}^+$	2.60
0.1	2	$\frac{3}{2}^+$	0.19
1.47	0	$\frac{1}{2}^+$	0.08
3.07	2	$\frac{3}{2}^+$	0.03
3.15	2	$\frac{5}{2}^+$	0.06
3.24	2	$\frac{3}{2}^+$	0.05
4.70	2	$\frac{5}{2}^+$	0.09
5.33 [d]	2	$\frac{3}{2}^+$	0.18
5.70	3	$\frac{7}{2}^-$ [e]	0.14
6.27	3	$\frac{7}{2}^-$	0.31

[a] (92YA08) $E_\alpha = 65$ MeV; DWBA analysis.
[b] Cited from (87AJ02).
[c] Integrated cross section.
[d] See discussion of this level in (92YA08) and (74SE01). See also Table 19.6 here.
[e] Proposed in (92YA08).

0.015 μ_N^2. The ΔE value for the 1.47 → 0.096 transition is 1375.3 ± 0.5 keV. Assuming $E_f = 96.0 \pm 0.5$ keV (Table 19.2), $E_i = 1471.4 \pm 0.7$ keV. Angular correlations are consistent with $J^\pi = \frac{5}{2}^+$ for the ground state and unambiguously fix $J^\pi = \frac{3}{2}^+$ and $\frac{1}{2}^+$, respectively, for ^{19}O* (0.096, 1.47): see (78AJ03) for references. See also (86SE1B).

8. ^{18}O(α, ^{3}He)^{19}O $\quad Q_m = -16.620$

Differential cross sections were measured at $E_\alpha = 65$ MeV and analyzed with DWBA calculations (92YA08). See Table 19.7.

9. ^{19}N(β^-)^{19}O $\quad Q_m = 12.528$

Many measurements of the half-life have been reported (see ^{19}N) and a value of 0.304 ± 0.016 sec has been adopted. A neutron emission probability of 33^{+34}_{-11}% (88MU08) and 62.4 ± 2.6% (91RE02) has been measured. Shell model predictions for the ^{19}N(β^-)^{19}O decay are discussed in (88WA17), and a β^- delayed γ decay scheme for ^{19}O based on measurements of (86DU07) (E_γ = 96.0 ± 1.0, 709.2 ± 0.8, and 3137.8 ± 1.0 keV with relative intensities of 100 ± 10, 63 ± 21, and 76 ± 21) is proposed. Arguments for $J^\pi = (\frac{3}{2}^+)$ and $(\frac{1}{2}, \frac{3}{2}^-)$ for the 3067 and 3232 keV levels are given. Evidence on the formation and decay of the 3945 keV complex of levels is reviewed. These calculations predict a ^{19}N half life of 0.54 sec and a neutron emission probability $P_n = 0.87$. They also predict $J^\pi = \frac{1}{2}^-$ for the ^{19}N ground state and branching ratios for decay to ^{19}O levels.

10. ^{19}F(π^-, γ)^{19}O $\qquad Q_m = 134.749$

Transitions to ^{19}O* (0[u], 4.9, 6.3) have been observed in the radiative capture of stopped negative pions (83MA16).

11. ^{19}F(n, p)^{19}O $\qquad Q_m = -4.037$

See (86HEZW; $E_n = 200$ MeV).

12. ^{19}F(t, ^{3}He)^{19}O $\qquad Q_m = -4.800$

Differential cross sections for the ^{19}O ground state and $E_x = 0.1$ MeV state were measured at $E_t = 33$ MeV (91PI09). A DWBA analysis was carried out.

^{19}F

(Figs. 19.2 and 19.4)

GENERAL: See Table 19.8.

$$\langle r^2 \rangle^{1/2} = 2.885 \pm 0.015 \text{ fm [see (78AJ03)]}$$
$$\mu_{\text{g.s.}} = +2.628866 \text{ (8) n.m. (78LEZA)}$$
$$\mu_{0.197} = +3.607 \text{ (8) n.m. (78LEZA)}$$
$$Q_{0.197} = -0.12 \pm 0.02 \text{ b (78LEZA)}$$

1. ^{10}B(^{9}Be, X)

Mass distribution from the sequential decay of the compound nuclei formed from ^{10}B + ^{9}Be and ^{10}B + ^{10}B at $E_{\text{lab}}/A = 11$ MeV were measured by (93SZ02). It was determined that the hot composite systems as light as ^{19}F and ^{20}Ne can behave like liquid droplets with no remnant shell effects.

Table 19.8
^{19}F – General

Reference	Description

Shell Model

Reviews:	
88BR1P	Status of the nuclear shell model
88EL1B	Review of early attempts to describe the spectrum of ^{19}F using the shell model
Other articles:	
87BR30	Empirically optimum M1 operator for sd-shell nuclei
87LE15	A shell-model study of nuclear form factors for multi-nucleon transfer reactions
87RA36	Strong-absorption model analysis of elastic and inelastic ^{3}He scattering
88BR11	Semi-empirical effective interactions for the 1s-0d shell
89OR02	Empirical isospin nonconserving Hamiltonians for shell-model calculations
90GU10	Charge densities of sp- and sd-shell nuclei and occupation numbers of 2s states
90HA07	Neutrino nucleosynthesis in supernovae: shell model predictions
90SK04	$A = 18$ nuclei, effective interaction in the sd shell (also calc. $A = 19$ energy spectra)
91MA41	Finite nuclei calculations with realistic potential models
92FR01	Nuclear charge radii systematics in the sd shell from muonic atom measurements
92GU16	Root-mean square radii of sd-shell nuclei
92JI04	Bonn potential used to evaluate energy spectra of some sd-shell nuclei
92WA22	Effective interactions for the 0p1s0d nuclear shell-model space
93PO11	Shell-model calcs. of binding energies and magnetic moments of light nuclei
93VO01	Spin-Isospin SU(4) symmetry in sd- and fp-shell nuclei
94VE04	Exp. meas. & calc. of spectroscopic factors from one-proton stripping rxns on sd-shell nucl.

Cluster Models

88UT02	Quasi-free stripping rxns. – extended Serber model & cluster momentum distributions
90OS03	Cluster-stripping reactions in heavy-ion collisions (including ^{16}O(^{7}Li, α)^{19}F)
91LE07	Algebraic approach to α-cluster states in ^{19}F: predicted energy spectrum (SU(3) $\times$ U(2))
91LE08	Alg. approach to α-cluster states in ^{19}F: calc. EM & other properties comp. to exp. data
91OS04	Diff. cross-section of cluster transfer heavy-ion reactions in the whole angle region
92SA27	(t + ^{16}O) + (α + ^{15}N) cluster model study of electron scattering on ^{19}F: calc. form factors
93AB02	α-^{16}O and α-^{15}N optical potentials in the range between 0 and 150 MeV

Special States

Reviews:	
88BR1P	Status of the nuclear shell model
88GA1O	Nucleon-alpha reactions in nuclei
88HE1C	Symmetries and nuclei
Other articles:	
86AD1A	Parity and time-reversal violation in nuclei and atoms
88TA12	Coupled channel representation of phase anomaly observed in scattering of ^{19}F + ^{12}C
89HA22	Nucleon and nuclear anapole moments
89OR02	Empirical isospin nonconserving Hamiltonians for shell-model calculations
90KA1F	Theoretical aspects of nuclear parity violation
90SK04	$A = 18$ nuclei, effective interaction in the sd shell (also calc. $A = 19$ energy spectra)
91LE07	Algebraic approach to α-cluster states in ^{19}F: predicted energy spectru (SU(3) $\times$ U(2))
92RA1N	Mechanism of (n, γ) reaction at low neutron energies
93ZH17	Isospin selection rules and widths of highly-excited states of light nuclei

Table 19.8 (continued)
^{19}F – General

Reference	Description
	Electromagnetic
Reviews:	
88AR1I	Relativistic and quark effects in nuclear magnetic moments
88HE1E	Report on charge symmetry, charge independence, parity and time reversal invariance
92GO1Q	M4 excitations of p-shell nuclei
93EN03	Strengths of gamma-ray transitions in $A = 5$–44 Nuclei
Other articles:	
87BR30	Empirically optimum M1 operator for sd-shell nuclei
90PI1G	Coherent EM excitation & disintegration of relativistic nuclei passing through crystals
91LE08	Algebraic approach to α-cluster states in ^{19}F: calc. EM, etc. comp. to exp. data
	Astrophysics
Review:	
88AP1A	Neutrino diffusion, primordial nucleosynthesis and the r-process
89BA2P	Neutrino astrophysics
90AR10	Nuclear reactions in astrophysics
90TH1E	Summary of topics presented at Workshop on Primordial Nucleosynthesis
93HA1D	Core-collapse supernovae & other topics that combine nuclear, particle and astrophysics
Other articles:	
87DW1A	Cosmic-ray elemental abundances from 1 to 10 GeV per amu for boron through nickel
88CA1N	Analytic expressions for thermonuclear reaction rates involving $Z \leq 14$ nuclei
88HA1T	Neutrino preheating in supernovae, and the origin of fluorine (A)
88WO1C	Supernova neutrinos, neutral currents and the origin of fluorine
89JI1A	Nucleosynthesis inside thick accretion disks around massive black holes
90HA07	Neutrino nucleosynthesis in supernovae: shell model predictions
90MA1Z	Nuclear reaction uncertainties in standard & non-standard cosmologies
90SI1D	Spallation processes and nuclear interaction products of cosmic rays
90WE1I	Cosmic-ray source charge & isostopic abundances studied using fragmentation X-sects.
91RY1A	Detecting solar boron neutrinos with Cerenkov and scintillation detectors
92GA03	Direct processes in ^{7}Li + ^{12}C & ^{7}Li + ^{197}Au breakup rxns., extract astrophys. X-sects.
	Applications
87BH1A	Time differential perturbed angular distribution studies on ^{19}F implanted into diamond
87FR1F	Explanation of unexpected efg's in ^{19}F-time differential perturbed angular distrib. meas.
87KN01	Attenuations & atomic spin precessions of γ-angular correls. for Coulomb-excited ^{19}F
88AL1K	Analysis of "Desert Rose" (geological sample) using RBS and PIXE techniques (A)
88KO18	Experimental study on p-wave neutron strength functions for light nuclei
88UM1A	Quantitative H analysis; simultaneous detection of α's and recoil H's in ^{1}H(^{19}F, $\alpha\gamma$)^{16}O
89TA1N	Depth profiles of implanted ^{18}F, ^{79}Br & ^{132}Xe in Si in the energy range 85–600 keV
90ZI04	Study of fluorine in tin oxide films
90ZS01	Fluorine profiling after application of various anti-caries dental gels
91MC02	X-ray production in fluorine by highly charged boron, carbon, and oxygen ions
91PI12	Enhancement of role of low multipole transitions in Coulomb excit. of nucl. in crystals
92MO31	^{19}F & ^{31}P magic-angle spinning NMR of Sb(III)-doped fluorapatite phosphors
92ZS01	Test of new standard for F determination using p-induced γ-ray emission spectrometry
94TA1B	An investigation of range distribution parameters of implanted ^{19}F ions in Tantalum

Table 19.8 (continued)
^{19}F – General

Reference	Description
	Complex Reactions
Review:	
89NI1D	High energy gamma-ray production in nuclear reactions
Other articles:	
86MA13	Experimental search for nonfusion yield in heavy residues emitted from ^{11}B + ^{12}C
87BE1F	Target fragmentation at ultrarelativistic energies
87BU07	Projectile-like fragments from ^{20}Ne + ^{197}Au – counting simultaneously emitted neutrons
87HE1H	Search for anomalously heavy isotopes of low Z nuclei
87LY04	Fragmentation and the emission of particle stable and unstable complex nuclei
87PA1D	Recoil accelerator mass spectrometry of nuclear reaction products
87SH23	Dissipative phenomena & α-particle emission in reactions induced by ^{16}O + ^{27}Al
87YI1A	Deep inelastic collision induced by 93 MeV ^{14}N on $^{\rm nat}$Ca
88CA1G	Experimental indications of selective excitations in dissipative heavy ion collisions
88DI08	Molecular orbital theory of 2-cluster transfer process in heavy-ion scattering & rxns.
88SH03	^{28}Si + ^{14}N orbiting interaction
89BA1E	Production of hypernuclei in relativistic ion beams
89BA2N	Evaluation of hypernucleus production cross-sections in relativistic heavy-ion collisions
89BR1G	Fragmentation cross sections of ^{28}Si at 14.5 GeV/nucleon for $Z_{\rm f}$ = 6–13
89CA15	Fusion and binary reactions in the collision of ^{32}S on ^{26}Mg at E(lab) = 163.5 MeV
89GR13	Compound nucleus emission of intermediate mass fragments in ^{6}Li + Ag at 156 MeV
89GU1C	Peripheral collisions in Ar-induced rxns: energy dissip. study meas. via n multiplicities
89HA08	Complex-fragment emission in 12.6 MeV/nucleon ^{63}Cu + ^{12}C & ^{63}Cu + ^{27}Al rxns.
89MA45	Target excitation & angular momentum transfer in ^{28}Si + ^{181}Ta at $E/A = 11.9$ MeV
89PA06	Complete & incomplete fusion of 6 MeV/nucleon light heavy ions (incl. ^{19}F) on ^{51}V
89SA10	Total cross sections of reactions induced by neutron-rich light nuclei
89YO02	Quasi-elastic & deep inelastic transfer in ^{16}O + ^{197}Au for $E < 10$ MeV/u
89YO09	Energy damping feature in light heavy-ion reactions
89ZHZY	Mass measurement of Z = 7–19 neutron-rich nuclei using the TOFI spectrometer (A)
90AL40	The activation method in experiments searching for neutron nuclei
90BO04	3 paths for intermediate-mass fragment formation from 640-MeV ^{86}Kr + ^{63}Cu
90DE14	Reaction mechanisms and their interaction time from ^{19}F + ^{63}Cu at 100–108 MeV
90LE08	Statistical equilibrium in the ^{40}Ar + ^{12}C system at $E/A = 8$ MeV
90YE02	Intermediate mass fragment emission in the 161-MeV p + Ag reaction
94PI1A	In flight electromagnetic excitation of low-lying levels at energies up to a few GeV/A
	Muons and Neutrinos
90CH13	Muon capture rates in nuclei calculated & compared to experimental values
90HA07	Neutrino nucleosynthesis in supernovae: shell model predictions
91RY1A	Detection of solar neutrinos using Cerenkov and scintillation detectors
92DO11	Inelastic neutrino scattering by atomic electrons
93GO09	Measurement of hyperfine transition rates in muonic ^{19}F, ^{23}Na, ^{31}P and $^{\rm nat}$Cl

Table 19.8 (continued)
^{19}F – General

Reference	Description
	Pions & Hypernuclei
Review:	
88HE1G	Hadronic parity violation: a summary of theoretical discussion
94EJ01	Perspectives on the study of hypernuclear structure
Other articles:	
89BA1E	Production of hypernuclei in relativistic ion beams
89BA2N	Evaluation of hypernucleus production cross-sections in relativistic heavy-ion collisions
89GA09	Pionic distortion factors for radiative pion capture studies
89GE10	Threshold pion-nucleus amplitudes as predicted by current algebra
89KA37	Finite-range effects on strong-interaction level shifts & widths in pionic atoms
90CH12	Inclusive radiative pion capture in nuclei reanalyzed from a many-body point of view
91CI08	Momentum-space method for calc. of strong-interaction shifts & widths in pionic atoms
91CI11	Nuclear structure effects in light π-mesoatoms
93NI03	Pionic decay of Λ hypernuclei
	Antimatter
86KO1E	Search for $\bar{p}$-atomic X-rays at LEAR
87GR20	Widths of 4f antiprotonic levels in the oxygen region
87HA1J	Widths of 4f antiprotonic levels in the O region using realistic nucl. wavefunctions
90JO01	The strong-interaction fine and hyperfine structure of antiprotonic atoms
93PI10	Coulomb excitation of E1 & E2 transitions in ^{19}F of LiF crystals by p & $\bar{p}$
	Ground State Properties
Review	
89RA17	Compilation of exp. data on nuclear moments for ground & excited states of nucl.
92PY1A	Nuclear quadrupole moments for $Z = 1$–20: precise calcs. on atoms & small molecules
Other articles:	
87BR30	Empirically optimum M1 operator for sd-shell nuclei
88AR1I	Relativistic and quark contributions to nuclear magnetic moments
89AN12	A-dependence of the difference ($r_{el} - r_{mu}$), a dispersion effect in electron scattering
89GU25	Determin. of spectroscopic factors of several light nuclei from nuclear vertex constants
89SA10	Total cross sections of reactions induced by neutron-rich light nuclei
90GU10	Charge densities of sp- and sd-shell nuclei & occupation numbers of 2s states
90LO11	Self-consistent calcs. of bind. energies & various radii using density-functional method
92FR01	Nuclear charge radii systematics in the sd shell from muonic atom measurements

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

Table 19.9
Energy levels of ^{19}F [a])

E_x (MeV ± keV)	$J^\pi; T$	K^π	τ_m or $\Gamma_{c.m.}$	Decay	Reactions
0	$\frac{1}{2}^+; \frac{1}{2}$	$\frac{1}{2}^+$	stable		9, 11, 12, 15, 17, 18, 19, 21, 22, 23, 24, 25, 26, 31, 32, 33, 34, 39, 41, 42, 45, 46, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62
0.109894 ± 0.005	$\frac{1}{2}^-$	$\frac{1}{2}^-$	$\tau_m = 0.853 \pm 0.010$ ns	γ	9, 11, 15, 18, 19, 24, 26, 32, 34, 37, 38, 39, 41, 45, 49, 58, 60, 62
0.197143 ± 0.004	$\frac{5}{2}^+$	$\frac{1}{2}^+$	$\tau_m = 128.8 \pm 1.5$ ns [$\lvert g \rvert = 1.441 \pm 0.003$]	γ	8, 9, 12, 15, 17, 18, 19, 24, 25, 26, 32, 33, 34, 39, 41, 42, 45, 49, 51, 53, 58, 60
1.34567 ± 0.13	$\frac{5}{2}^-$	$\frac{1}{2}^-$	$\tau_m = 4.13 \pm 0.06$ ps [$\lvert g \rvert = 0.27 \pm 0.04$]	γ	9, 11, 12, 17, 18, 19, 24, 26, 32, 34, 39, 41, 42, 45, 49
1.4587 ± 0.3	$\frac{3}{2}^-$	$\frac{1}{2}^-$	$\tau_m = 90 \pm 20$ fs	γ	11, 12, 18, 19, 24, 32, 37, 39, 41, 42, 45, 49, 53, 60
1.554038 ± 0.009	$\frac{3}{2}^+$	$\frac{1}{2}^+$	$\tau_m = 5 \pm 3$ fs	γ	9, 17, 18, 19, 24, 25, 26, 31, 32, 33, 34, 39, 41, 42, 45, 49, 51, 53, 58, 60
2.779849 ± 0.034	$\frac{9}{2}^+$	$\frac{1}{2}^+$	$\tau_m = 280 \pm 30$ fs	γ	3, 4, 7, 9, 12, 14, 17, 18, 19, 22, 24, 25, 31, 32, 39, 41, 42, 49, 51, 53, 59, 60
3.90817 ± 0.20	$\frac{3}{2}^+$	$\frac{3}{2}^+$	$\tau_m = 9 \pm 5$ fs	γ	9, 18, 19, 24, 26, 32, 34, 37, 39, 42, 49, 60
3.9987 ± 0.7	$\frac{7}{2}^-$	$\frac{1}{2}^-$	$\tau_m = 19 \pm 7$ fs	γ	9, 18, 19, 24, 31, 32, 33, 39, 42, 49, 60
4.0325 ± 1.2	$\frac{9}{2}^-$	$\frac{1}{2}^-$	$\tau_m = 67 \pm 15$ fs	γ	9, 12, 17, 18, 19, 24, 31, 39, 42, 49, 60
4.377700 ± 0.042	$\frac{7}{2}^+$	$\frac{3}{2}^+$	$\tau_m < 11$ fs	γ	4, 9, 17, 18, 19, 24, 25, 26, 31, 32, 34, 39, 42, 49, 60
4.5499 ± 0.8	$\frac{5}{2}^+$	$\frac{3}{2}^+$	$\tau_m < 50$ fs	γ	9, 18, 19, 24, 26, 39, 42, 49, 60
4.5561 ± 0.5	$\frac{3}{2}^-$		$\tau_m = 17^{+10}_{-8}$ fs	γ	9, 18, 19, 26, 31, 32, 39, 42, 49, 60
4.648 ± 1	$\frac{13}{2}^+$	$\frac{1}{2}^+$	$\tau_m = 3.7 \pm 0.4$ ps	γ	4, 17, 18, 19, 24, 25, 26, 39, 49, 60
4.6825 ± 0.7	$\frac{5}{2}^-$		$\tau_m = 15.4 \pm 3.0$ fs	γ, α	4, 9, 18, 22, 24, 26, 31, 32, 39, 42, 49, 60
5.1066 ± 0.9	$\frac{5}{2}^+$		$\tau_m < 30$ fs	γ, α	4, 9, 18, 19, 24, 26, 31, 32, 39, 42, 49, 60
5.337 ± 2	$\frac{1}{2}^{(+)}$		$\tau_m \leq 0.1$ fs	γ, α	9, 18, 19, 24, 26, 32, 33, 39, 42, 49, 60

Table 19.9 (continued)
Energy levels of ^{19}F [a])

E_x (MeV ± keV)	$J^\pi; T$	K^π	τ_m or $\Gamma_{c.m.}$	Decay	Reactions
5.418 ± 1	$\frac{7}{2}^-$		$\Gamma = (2.6 \pm 0.7) \times 10^{-3}$ keV	γ, α	4, 9, 18, 24, 26, 32, 33, 39, 42, 49
5.4635 ± 1.5	$\frac{7}{2}^+$	$\frac{1}{2}^+$	$\tau_m \leq 0.26$ fs	γ, α	4, 9, 12, 17, 18, 19, 24, 25, 26, 39, 42, 49
5.5007 ± 1.7	$\frac{3}{2}^+$		$\Gamma = 4 \pm 1$ keV	γ, α	9, 10, 19, 24, 26, 33, 39, 42, 49
5.535 ± 2	$\frac{5}{2}^+$			γ, α	9, 24, 26, 33, 39, 42, 49, 60
5.621 ± 1	$\frac{5}{2}^-$		$\tau_m < 1.3$ fs	γ, α	9, 24, 26, 31, 32, 39, 42, 49, 59, 60
5.938 ± 1	$\frac{1}{2}^+$			γ, α	9, 26, 31, 32, 33, 39, 42, 60
6.070 ± 1	$\frac{7}{2}^+$		$\Gamma = 1.2$ keV	γ, α	4, 9, 24, 39, 42
6.088 ± 1	$\frac{3}{2}^-$		$\Gamma = 4$ keV	γ, α	9, 12, 18, 19, 24, 26, 39, 42, 60
6.100 ± 2	$\frac{9}{2}^-$			γ	4, 26, 39
6.1606 ± 0.9	$\frac{7}{2}^-$		$\Gamma = (3.7 \pm 1.0) \times 10^{-3}$ keV	γ, α	4, 9, 26, 33, 39, 42, 60
6.255 ± 1	$\frac{1}{2}^+$		$\Gamma = 8$ keV	α	10, 24, 26, 31, 32, 33, 39, 42, 60
6.282 ± 2	$\frac{5}{2}^+$		$\Gamma = 2.4$ keV	γ, α	9, 10, 17, 24, 26, 31, 33, 39, 42
6.330 ± 2	$\frac{7}{2}^+$		$\Gamma = 2.4$ keV	γ, α	4, 7, 10, 12, 24, 39, 42
6.429 ± 8	$\frac{1}{2}^-$		$\Gamma = 280$ keV	α	10, 39
6.4967 ± 1.4	$\frac{3}{2}^+$			γ, α	9, 19, 25, 26, 32, 33, 39
6.5000 ± 0.9	$\frac{11}{2}^+$	$\frac{3}{2}^+$	$\Gamma > 2.4 \times 10^{-3}$ keV	γ, α	4, 9, 19, 24, 26, 39
6.5275 ± 1.4	$\frac{3}{2}^+$		$\Gamma = 4$ keV	γ, α	9, 17, 19, 24, 26, 39
6.554 ± 2	$\frac{7}{2}^{(+)}$		$\Gamma = 1.6$ keV	γ, α	9, 24, 39
6.592 ± 2	$\frac{9}{2}^+$	$\frac{3}{2}^+$	$\Gamma = (7.6 \pm 1.8) \times 10^{-3}$ keV	γ, α	4, 9, 17, 24, 26, 32, 39
6.787 ± 2	$\frac{3}{2}^-$		$\Gamma = (6.9 \pm 1.1) \times 10^{-3}$ keV	γ, α	9, 10, 24, 26, 32, 39
6.8384 ± 0.9	$\frac{5}{2}^+$		$\Gamma = 1.2$ keV	γ, α	9, 10, 24, 26, 27
6.891 ± 4	$\frac{3}{2}^-$		$\Gamma = 28$ keV	γ, α	9, 10, 24, 39
6.9265 ± 1.7	$\frac{7}{2}^-$		$\Gamma = 2.4$ keV	γ, α	4, 9, 10, 12, 17, 18, 24, 26, 32, 33, 39
6.989 ± 3	$\frac{1}{2}^-$		$\Gamma = 51$ keV	α	10, 26, 39
7.114 ± 6	$\frac{7}{2}^+$		$\Gamma = 32$ keV	α	10, 32, 39
7.1662 ± 0.7	$\frac{11}{2}^-$		$\Gamma = (6.9 \pm 1.1) \times 10^{-3}$ keV	γ, α	4, 9, 26, 39
7.262 ± 2	$\frac{3}{2}^+$		$\Gamma < 6$ keV	α	10, 17, 18, 19, 26, 31, 32, 39, 51
7.364 ± 4	$\frac{1}{2}^+$			α	19, 26, 31, 32, 33, 39

Table 19.9 (continued)
Energy levels of ^{19}F [a])

E_x (MeV ± keV)	$J^\pi; T$	K^π	τ_m or $\Gamma_{c.m.}$	Decay	Reactions
7.5396 ± 0.9	$\frac{5}{2}^+; \frac{3}{2}$		$\Gamma = 0.16 \pm 0.05$ keV [c])	γ, α	9, 10, 12, 17, 26, 32, 33, 39
7.56 ± 10	$\frac{7}{2}^+$		$\Gamma < 90$ keV	α	10
7.587	$(\frac{5}{2}^-)$			γ	39
7.6606 ± 0.9	$\frac{3}{2}^+; \frac{3}{2}$		$\Gamma = 0.0022 \pm 0.0007$ keV	γ, α	9, 10, 26, 32, 33, 37, 39, 61
7.702 ± 5	$\frac{1}{2}^-$		$\Gamma < 30$ keV	α	10, 17, 26, 32, 39
7.74 ± 40	$(\frac{5}{2}, \frac{7}{2})^-$		$\Gamma < 6$ keV		39, 51
(7.90)			$\Gamma < 200$ keV	α	10
7.929 ± 3	$\frac{7}{2}^+, \frac{9}{2}$			γ, α	9, 17, 19
7.937 ± 3	$\frac{11}{2}^+$			γ, α	9, 25
8.0140 ± 1.0	$\frac{5}{2}^+$			p	32, 33
8.084 ± 3			$\Gamma \leq 3$ keV	p, α	10, 30, 32
8.1377 ± 1.2	$\frac{1}{2}^+$		$\Gamma \leq 0.3$ keV	γ, p, α	10, 26, 30, 31, 32
(8.16)			$\Gamma < 50$ keV	α	10
8.1990 ± 1.0	$(\frac{5}{2}^+)$		$\Gamma < 0.8$ keV	γ, p, α	10, 26, 30, 32
8.2543 ± 2.6	$(\frac{5}{2}, \frac{7}{2})^-$		$\Gamma \leq 1.5$ keV	γ, p	26, 32, 51
8.288 ± 2	$\frac{13}{2}^-$	$(\frac{1}{2}^-)$	$\Gamma < 1$ keV [c])	γ, α	4, 9, 10, 11, 12, 13, 14, 17, 18
8.3100 ± 1.2	$\frac{5}{2}^+$		$\Gamma = 0.047 \pm 0.019$ keV	γ, p, α	9, 26, 30, 32
8.370 ± 4	$\frac{7}{2}, \frac{5}{2}^+$		$\Gamma = 7.5 \pm 1.5$ keV	γ, α	9
8.5835 ± 1.6	$\frac{5}{2}^+$		$\Gamma \leq 0.5$ keV	γ, p, α	9, 26
8.5919 ± 1.0	$\frac{3}{2}^-$		$\Gamma = 2.0 \pm 0.1$ keV	γ, p, α	9, 17, 26, 28, 30, 32
8.629 ± 4	$\frac{7}{2}^-$		$\Gamma < 1$ keV [c])	γ, α	4, 9, 10, 51
8.65	$\frac{1}{2}^+$		$\Gamma \sim 300$ keV	γ, p, α	26, 28, 30
8.7932 ± 1.5	$\frac{1}{2}^+; \frac{3}{2}$		$\Gamma = 46 \pm 2$ keV	γ, p	26, 28, 30, 32, 33
8.864 ± 4	$< \frac{9}{2}$		$\Gamma \approx 1$ keV	γ, α	9
8.9267 ± 2.8	$\frac{3}{2}^-$		$\Gamma = 3.6 \pm 0.2$ keV	γ, p, α	17, 18, 26, 28, 30
8.953 ± 3	$\frac{11}{2}^-$	$\frac{1}{2}^-$ [d])	$\Gamma =\approx 1$ keV [c])	γ, α	4, 9, 10, 11, 12, 13, 14
9.030 ± 5	$\frac{5}{2}, \frac{7}{2}$		$\Gamma = 4.2 \pm 1$ keV	γ, α	9
9.0997 ± 0.7	$\frac{7}{2}^-$		$\Gamma = 0.57 \pm 0.03$ keV	γ, p, α	9, 26, 28, 30
9.101 ± 4	$\frac{7}{2}^+, \frac{9}{2}^+$		$\Gamma \approx 1$ keV	γ, α	4, 9, 32
9.167 ± 1.4	$\frac{1}{2}^+$		$\Gamma = 6.2 \pm 0.5$ keV	γ, p, α	9, 28, 30, 32
9.204 ± 7	$\frac{3}{2}$		$\Gamma = 10.2 \pm 1.5$ keV	γ, α	9
9.267 ± 4	$\frac{11}{2}^+, \frac{9}{2}^+$		$\Gamma = 2 \pm 1$ keV	γ, α	9
9.280 ± 5	$(\frac{7}{2}, \frac{9}{2})^+$		$\Gamma < 1.5$ keV	γ, α	9, 51
9.318 ± 2	$\frac{3}{2}^+$		$\Gamma = 3.4 \pm 0.7$ keV	γ, p, α	9, 17, 26
9.321 ± 1.1	$\frac{1}{2}^+$		$\Gamma = 5.0 \pm 0.2$ keV	γ, p, α	28, 30

Table 19.9 (continued)
Energy levels of ^{19}F [a])

E_x (MeV ± keV)	$J^\pi; T$	K^π	τ_m or $\Gamma_{c.m.}$	Decay	Reactions
9.329 ± 4	$< \frac{5}{2}$		$\Gamma \approx 6$ keV	γ, α	9
9.509 ± 4	$\frac{5}{2}^+, \frac{7}{2}^+$ [c])		$\Gamma < 1$ keV [c])	γ, α	9, 10
9.527 ± 6	$(\frac{5}{2})$		$\Gamma = 28$ keV	p, α	28, 30
9.5364 ± 2.0	$\frac{5}{2}^+$		$\Gamma = 6.3 \pm 1.5$ keV	γ, p, α	9, 26
9.566 ± 3	$\frac{3}{2}^-$		$\Gamma = 26 \pm 3$ keV	γ, p	26
9.575 ± 4	$\frac{3}{2}^-$		$\Gamma = 67 \pm 3$ keV	γ, p, α	26, 28, 30
9.586 ± 3	$\frac{7}{2}$		$\Gamma = 8.9 \pm 1.2$ keV	γ, p, α	9, 26, 32
9.642 ± 6	$\frac{3}{2}, \frac{5}{2}$		$\Gamma \approx 8$ keV	γ, α	9
9.654 ± 6	$\frac{3}{2}, \frac{5}{2}$		$\Gamma \approx 6$ keV	γ, α	9
9.6675 ± 1.5	$\frac{3}{2}^+$		$\Gamma = 3.6 \pm 0.4$ keV	γ, p, α	9, 26, 28, 30, 32
9.710 ± 4	$\frac{9}{2}^+, \frac{11}{2}^-$ [c])		$\Gamma < 1$ keV [c])	γ, α	4, 9, 10, 17
9.820 ± 1.0	$\frac{5}{2}^-$		$\Gamma = 0.3 \pm 0.05$ keV	γ, p, α	9, 26, 28, 30
9.834 ± 3	$\frac{11}{2} \rightarrow \frac{15}{2}$		$\Gamma < 1$ keV [c])	γ, α	4, 9, 10
9.8740 ± 1.8	$\frac{11}{2}^-$		$\Gamma = (2.6 \pm 0.6) \times 10^{-3}$ keV	γ, p, α	4, 9, 10, 17, 18, 26
9.887 ± 3	$\frac{1}{2}^+$		$\Gamma = 25 \pm 2$ keV	γ, p, α	26, 28, 30
9.895 ± 5				γ	4
9.926 ± 3	$\frac{9}{2}^+; \frac{3}{2}$ [c])		$\Gamma \approx 1$ keV [c])	γ, α	4, 9, 10
10.088 ± 5	$\frac{5}{2}^-, \frac{7}{2}^-$ [c])		$\Gamma < 1.5$ keV [c])	γ, α	9, 10, 12
10.137 ± 0.8	$\frac{3}{2}^-$		$\Gamma = 4.3 \pm 0.6$ keV	γ, p, α	9, 26, 30
10.162 ± 3	$\frac{1}{2}^+$		$\Gamma = 31$ keV	p, α	28, 30
10.232 ± 3	$\frac{1}{2}^+$		$\Gamma < 1$ keV	p, α	10, 28, 30
10.254 ± 3	$\frac{1}{2}^+$		$\Gamma = 22$ keV	p, α	28, 30
10.308 ± 4	$\frac{3}{2}^+$		$\Gamma = 9.2$ keV	p, α	10, 19, 28, 30
10.365 ± 4	$\frac{7}{2} \rightarrow \frac{11}{2}$		$\Gamma = 3 \pm 1.5$ keV	γ, α	4, 9, 32
10.411 ± 3	$\frac{13}{2}^+$	$\frac{3}{2}^+$	$\Gamma < 1.5$ keV [c])	γ, α	4, 9, 10, 12, 17, 18, 19, 26, 59
10.469 ± 4			$\Gamma = 11.0 \pm 1.2$ keV	p, α	10
10.488 ± 4			$\Gamma = 4.8 \pm 0.8$ keV	p, α	10
10.4963 ± 1.3	$\frac{3}{2}^+$		$\Gamma = 5.7 \pm 0.6$ keV	n, p, α	10, 27, 28, 30
10.521 ± 4			$\Gamma = 14 \pm 2$ keV	p, α	10, 32
10.5423 ± 1.1			$\Gamma = 2.5 \pm 0.2$ keV	n, p, α	10, 27
10.555 ± 3	$\frac{3}{2}^+; (\frac{3}{2})$		$\Gamma = 4.0 \pm 1.2$ keV	p, α	10, 28, 30
10.5647 ± 2.0			$\Gamma = 4.6 \pm 0.7$ keV	n, p, α	10, 27
10.581 ± 4	$(\frac{5}{2}^+)$		$\Gamma = 22 \pm 3$ keV	p, α	28, 30
10.6143 ± 1.6	$\frac{5}{2}^+; \frac{3}{2}$		$\Gamma = 4.7 \pm 0.5$ keV	n, p, α	27, 28, 30
10.7633 ± 2.5	$\frac{1}{2}^-$		$\Gamma = 6 \pm 3$ keV	n, p, α	17, 27, 28, 30

Table 19.9 (continued)
Energy levels of ^{19}F [a])

E_x (MeV ± keV)	$J^\pi; T$	K^π	τ_m or $\Gamma_{c.m.}$	Decay	Reactions
10.8597 ± 1.9	$\frac{5}{2}^+$		$\Gamma = 240 \pm 1.5$ keV	n, p, α	27, 28, 30
10.927 ± 8				γ	4
10.9750 ± 2.5	$(\frac{3}{2}, \frac{5}{2})^+$		$\Gamma = 14 \pm 2$ keV	n, p, α	27, 28, 30
10.989 ± 2.5			$\Gamma = 7 \pm 2$ keV	n, p	27
11.072 ± 2.7	$\frac{1}{2}^+$		$\Gamma = 35 \pm 4$ keV	n, p, α	27, 28, 30
11.188 ± 4	$(\frac{1}{2}^-)$		$\Gamma = 17 \pm 4$ keV	n, p, α	27, 28, 30
11.273 ± 3			$\Gamma = 7 \pm 2$ keV	n, p	27
11.286 ± 7	$\frac{5}{2}^+$		$\Gamma = 22 \pm 5$ keV	n, p, α	27, 28, 30
11.35 ± 25	$\frac{1}{2}^+$		$\Gamma = 272 \pm 31$ keV	p	28
11.450 ± 3.5	$\frac{1}{2}^-$		$\Gamma = 38 \pm 7$ keV	n, p, (α)	17, 27, 28, 30
11.478 ± 5			$\Gamma = 7 \pm 3$ keV	n, p	27
11.502 ± 5	$(\frac{3}{2}^-)$		$\Gamma = 4 \pm 2$ keV	n, p, α	27, 28, 30
11.540 ± 7	$\frac{5}{2}^+$		$\Gamma = 22 \pm 5$ keV	n, p, α	27, 28, 30
11.569 ± 7	$(T = \frac{3}{2})$		$\Gamma = 15 \pm 10$ keV	n, p	27
11.603 ± 12	$\frac{3}{2}^-$		$\Gamma = 63 \pm 7$ keV	n, p	27, 28
11.653 ± 4	$\frac{3}{2}^+; (\frac{3}{2})$		$\Gamma = 33 \pm 6$ keV	n, p, (α)	12, 17, 27, 28, 30
11.84 ± 10			$\Gamma < 50$ keV	n, p	27
11.93 ± 10			$\Gamma = 90$ keV	n, p	27
12.04 ± 20	$\frac{1}{2}^-$		$\Gamma = 71 \pm 24$ keV	p, α	12, 28, 30
12.136 ± 8	$\frac{3}{2}^-; \frac{3}{2}$		$\Gamma = 105 \pm 14$ keV	n, p, (α)	27, 28, 30
12.222 ± 12	$\frac{3}{2}^+$		$\Gamma = 74 \pm 1$ keV	n, p, α	27, 28, 30
12.522 ± 7	$\frac{1}{2}^-$		$\Gamma = 15 \pm 4$ keV	p	28
12.577 ± 10	$\frac{5}{2}^+$		$\Gamma = 48 \pm 10$ keV	p, α	28, 30
12.58 ± 25	$\frac{1}{2}^-; \frac{3}{2}$		$\Gamma = 285 \pm 48$ keV	p	28
12.78 ± 10	$\frac{5}{2}^+; \frac{3}{2}$		$\Gamma = 95 \pm 38$ keV	n, p, (α)	17, 27, 28, 30
12.86 ± 30	$\frac{3}{2}^+; \frac{3}{2}$		$\Gamma = 276 \pm 38$ keV	p	28
12.94 ± 25	$\frac{5}{2}^+$		$\Gamma = 71 \pm 24$ keV	p, α	28, 30
12.98 ± 50	$\frac{1}{2}^-$		$\Gamma = 124 \pm 38$ keV	p	28
13.068 ± 4	$\frac{1}{2}^+$		$\Gamma \leq 10$ keV	n, p, t	15, 27
13.09 ± 75	$\frac{3}{2}^-$		$\Gamma = 285 \pm 71$ keV	p	28
13.17 ± 15			$\Gamma = 70$ keV	n, p	27
13.245 ± 10	$\frac{1}{2}^-$		$\Gamma = 7$ keV	t	15
13.270 ± 10	$\frac{1}{2}^+$		$\Gamma = 4.5$ keV	t	15
13.317 ± 8	$\frac{7}{2}^-; (\frac{3}{2})$		$\Gamma = 28 \pm 6$ keV	n, p, α	27, 28, 30, 33
13.36 ± 25	$\frac{3}{2}^-$		$\Gamma = 38 \pm 19$ keV	p	28
13.532 ± 10	$\frac{1}{2}^+$		$\Gamma = 22$ keV	t	15
13.732 ± 11	$\frac{7}{2}^-; \frac{3}{2}$		$\Gamma = 52 \pm 10$ keV	n, p, (α)	18, 27, 28, 30, 33
13.878 ± 15	$\frac{1}{2}^+$		$\Gamma = 101$ keV	t	15
14.04 ± 20	$\frac{5}{2}^+$		$\Gamma = 141 \pm 28$ keV	p	28

Table 19.9 (continued)
Energy levels of ^{19}F [a])

E_x (MeV ± keV)	J^π; T	K^π	τ_m or $\Gamma_{c.m.}$	Decay	Reactions
14.10 ± 21	$\frac{3}{2}^-$		$\Gamma = 84 \pm 28$ keV	p	12, 18, 28
14.147 ± 20	$\frac{1}{2}^+$		$\Gamma = 21$ keV	t	15
14.24 ± 15			$\Gamma = 350$ keV	n, p	27
14.255 ± 15	$\frac{3}{2}^+$		$\Gamma = 51$ keV	t	15
14.33 ± 20	$\frac{3}{2}^-$		$\Gamma = 76 \pm 28$ keV	p	28
14.352 ± 10	$\frac{1}{2}^+$		$\Gamma = 154$ keV	t	15
14.46 ± 25	$\frac{3}{2}^+$		$\Gamma = 179$ keV	t	15
14.46 ± 25	$\frac{5}{2}^+$		$\Gamma = 46$ keV	t	15
14.70 ± 20	$\frac{3}{2}^-$		$\Gamma = 124 \pm 38$ keV	p	28
14.72 ± 70	$\frac{1}{2}^-$		$\Gamma = 257 \pm 67$ keV	α	30
14.74 ± 50	$\frac{1}{2}^+$		$\Gamma = 361 \pm 67$ keV	p, α	28, 30
14.78 ± 20	$\frac{5}{2}^+$			n, p	27, 28
14.92 ± 30	$\frac{7}{2}^-$			p	12, 18, 28
15.00 ± 20				n, p	27
15.36 ± 20	$\frac{1}{2}^-$			p	28
15.40 ± 30	$\frac{5}{2}^+$			p	28
15.56 ± 30					18
15.77 ± 21	$\frac{3}{2}^-$		$\Gamma = 150$ keV	n, p	27
16.09 ± 50					12
16.20 ± 40	$\frac{3}{2}^+$			p	28
16.23 ± 30	$\frac{7}{2}^-$			p	28
16.28 ± 20	$\frac{3}{2}^-$		$\Gamma = 200$ keV	n, p	27, 28
16.45 ± 50					12
16.80 ± 30				n, p	27
17.05 ± 40	$\frac{3}{2}^-$		$\Gamma = 331 \pm 67$ keV	p	28
17.16 ± 40	$\frac{7}{2}^-$		$\Gamma = 323 \pm 67$ keV	p	28
17.45 ± 30	$\frac{3}{2}^-$		$\Gamma = 32 \pm 19$ keV	p	12, 28
17.65 ± 60	$\frac{7}{2}^-$		$\Gamma = 95 \pm 57$ keV	p	28
17.93 ± 40	$\frac{3}{2}^-$		$\Gamma = 255 \pm 57$ keV	p	28
18.03 ± 60	$\frac{7}{2}^-$		$\Gamma = 365 \pm 57$ keV	p	12, 28
18.92 ± 30					12
19.07 ± 60	$\frac{3}{2}^-$		$\Gamma = 555 \pm 143$ keV	p	28
19.83 ± 150	$\frac{5}{2}^-$		$\Gamma = 369 \pm 57$ keV	p	28
19.89 ± 30	$\frac{3}{2}^-$		$\Gamma = 473 \pm 57$ keV	p	12, 28
20.81 ± 50	$\frac{1}{2}^-$		$\Gamma = 412 \pm 57$ keV	p	28
20.93 ± 50	$\frac{3}{2}^-$		$\Gamma = 317 \pm 48$ keV	p	28
21.05 ± 40 [b])	$\frac{7}{2}^-$		$\Gamma = 448 \pm 29$ keV	p	28

[a]) See also Tables 19.10 and 19.11.
[b]) For evidence of additional states see reaction 36.
[c]) See Table 19.14.
[d]) See (89PR01).

Table 19.10

Radiative transitions in ^{19}F [a])

$E_{\rm i}$ (MeV)	$J^{\pi}_{\rm i}$	$E_{\rm f}$ (MeV)	Branching ratio (%)	δ
0.110	$\frac{1}{2}^-$	0	100	
0.197	$\frac{5}{2}^+$	0	100	
		0.110	< 0.06	
1.35	$\frac{5}{2}^-$	0.110	96.8 ± 1	0.0 ± 0.7 [b])
		0.197	3.2 ± 1	
1.46	$\frac{3}{2}^-$	0	20.5 ± 0.7	0.01 ± 0.03
		0.110	68.8 ± 0.9	0.248 ± 0.020
		0.197	10.7 ± 0.5	
		1.35	< 0.2 [h])	
1.55	$\frac{3}{2}^+$	0	2.55 ± 0.10	
		0.110	4.85 ± 0.12	
		0.197	92.6 ± 0.2	
		1.35	< 0.011 [h])	
		1.46	< 0.14 [h])	
2.78	$\frac{9}{2}^+$	0.197	100	
3.91	$\frac{3}{2}^+$	0	48 ± 2	
		0.110	17 ± 2	
		0.197	14 ± 2	
		1.55	21 ± 3	
4.00	$\frac{7}{2}^-$	0.197	18 ± 4	
		1.35	70 ± 4	
		1.46	12 ± 6	
4.03	$\frac{9}{2}^-$	1.35	100	
4.38 [c])	$\frac{7}{2}^+$	0	< 5	
		0.110	< 2	
		0.197	80.5 ± 2.0	0.155 ± 0.22
		2.78	19.5 ± 1.0	-0.16 ± 0.07
4.55 [d])	$\frac{5}{2}^+$	0.197	69 ± 7	
		1.35	5 ± 3	
		1.46	8 ± 3	
		1.55	18 ± 4	
4.56	$\frac{3}{2}^-$	0	36 ± 4	
		0.110	45 ± 5	
		0.197	9 ± 3	
		1.35	4 ± 3	
		1.46	< 4	
		1.55	6 ± 3	
4.65	$\frac{13}{2}^+$	2.78	100	$\lvert M\rvert^2 = 3.1 \pm 0.3$ W.u.
4.68	$\frac{5}{2}^-$	0.197	5.6 ± 0.9	$0 < \delta < 2.0$
		1.35	63.1 ± 3.8	$-0.22^{+0.14}_{-0.24}$

Table 19.10 (continued)
Radiative transitions in ^{19}F [a])

$E_{\rm i}$ (MeV)	$J^{\pi}_{\rm i}$	$E_{\rm f}$ (MeV)	Branching ratio (%)	δ
5.11 [i])	$\frac{5}{2}^+$	[j])	79.7 ± 3.7	$\Gamma_\gamma/\Gamma = 0.83 \pm 0.10$
		1.46	31.3 ± 2.2	0.0 ± 0.24 or $2.0^{+1.5}_{-0.6}$
		1.35	< 1.6	
		1.46	10.4 ± 2.7	$\lvert\delta\rvert < 1.4$
		1.55	1.8 ± 1.8	
		2.78	0.7 ± 0.6	
		3.91	5.4 ± 0.9	$\delta = 0.0 \pm 0.3$
		4.38	2.0 ± 0.5	
5.34	$\frac{1}{2}^{(+)}$	0	37 ± 4	
		0.110	42 ± 4	
		1.46	20 ± 2	
5.42	$\frac{7}{2}^-$	1.35	70	
		1.46	13	
		4.00	10	
		4.03	6	
5.46	$\frac{7}{2}^+$	0.197	4	
		1.35	32	
		1.55	5	
		2.78	59	
5.50	$\frac{3}{2}^+$	0.110	25	
		0.197	49	
		1.35	16	
		1.55	11	
5.54	$\frac{5}{2}^+$	0	7	
		0.197	47	
		1.46	45	
5.62	$\frac{3}{2}^-$	0.197	39 ± 4	
		1.35	61 ± 4	
5.94	$\frac{1}{2}^+$	0	7 ± 4	
		0.110	20 ± 6	
		0.197	2 ± 1	
		1.46	63 ± 6	0.25 ± 0.02
		1.55	< 2	
		3.91	8 ± 3	0.28 ± 0.09
6.07	$\frac{7}{2}^+$	0.197	54 ± 5	-0.26 ± 0.02
		1.35	19 ± 2	
		1.55	$1^{+1}_{-0.5}$	0.035 ± 0.023
		2.78	23 ± 3	0.06 ± 0.08
		4.38	4 ± 1	
6.09	$\frac{3}{2}^-$	0	25 ± 4	-0.021 ± 0.014

Table 19.10 (continued)
Radiative transitions in ^{19}F [a])

E_i (MeV)	J_i^π	E_f (MeV)	Branching ratio (%)	δ
		0.110	61 ± 5	0.045 ± 0.021
		0.197	14 ± 3	0.014 ± 0.043
6.16	$\frac{7}{2}^-$	0.197	31 ± 3	-0.045 ± 0.025
		1.35	65 ± 4	0.077 ± 0.007
		1.46	1.3 ± 0.6	
		4.00	1.6 ± 0.6	
		4.03	2.3 ± 0.3	
6.28	$\frac{5}{2}^+$	0	14 ± 2	-0.05 ± 0.07
		0.197	4.2 ± 1.0	
		1.35	36 ± 2	-0.01 ± 0.09
		1.46	26 ± 2	-0.02 ± 0.04
		1.55	20 ± 2	0.11 ± 0.06
6.33	$\frac{7}{2}^+$	0.197	56 ± 3	-0.27 ± 0.24
		1.35	17 ± 2	-0.02 ± 0.03
		1.55	8.5 ± 1.5	0.00 ± 0.14
		4.38	18 ± 2	0.04 ± 0.20
6.497	$\frac{3}{2}^+$	0	38 ± 2	-0.06 ± 0.04 or 2.00 ± 0.17
		0.110	14 ± 2	0.00 ± 0.03
		0.197	9 ± 2	$0.3 \rightarrow 1.8$
		1.35	14 ± 2	-0.11 ± 0.09
		1.46	25 ± 2	0.00 ± 0.07
6.500	$\frac{11}{2}^+$	2.78	55	
		4.65	45	
6.53	$\frac{3}{2}^+$	0	29 ± 2	0.32 ± 0.04 or 0.90 ± 0.06
		0.110	59 ± 3	0.00 ± 0.02
		4.55	12 ± 2	-0.23 ± 0.13
6.55	$\frac{7}{2}^{(+)}$	0.197	19 ± 2	0.03 ± 0.05
		1.35	55 ± 4	0.01 ± 0.030
		2.78	26 ± 3	0.05 ± 0.07
6.59	$\frac{9}{2}^+$	0.197	13 ± 2	-0.13 ± 0.13
		2.78	63 ± 3	-0.20 ± 0.20
		4.38	24 ± 2	0.02 ± 0.07
6.79	$\frac{3}{2}^-$	0	15 ± 2	-0.08 ± 0.03
		0.110	39 ± 2	0.11 ± 0.02
		0.197	13 ± 2	0.05 ± 0.06
		1.35	5.3 ± 0.8	
		1.46	25 ± 2	-0.13 ± 0.08
		3.91	2.6 ± 1.0	
6.84	$\frac{5}{2}^+$	0	9 ± 5	
		0.110	9 ± 5	

Table 19.10 (continued)
Radiative transitions in ^{19}F [a])

E_i (MeV)	J_i^π	E_f (MeV)	Branching ratio (%)	δ
		0.197	27 ± 6	-0.5 ± 0.5
		1.35	10 ± 7	
		1.46	45 ± 8	-0.02 ± 0.11
6.89	$\frac{3}{2}^-$	0	9 ± 2	
		1.35	61 ± 5	$0.22 \rightarrow 2.2$
		1.46	30 ± 5	0.15 ± 0.12
6.93	$\frac{7}{2}^-$	0.197	73 ± 3	-0.01 ± 0.03
		1.35	22 ± 2	0.01 ± 0.02
		2.78	2.4 ± 0.5	0.00 ± 0.16
		4.00	1.3 ± 0.5	
		4.03	1.3 ± 0.5	
7.17 [e])	$\frac{11}{2}^-$	4.00	5.6 ± 0.7	$\Gamma_\gamma/\Gamma = 0.025 \pm 0.003$
		4.03	90.9 ± 0.8	
		4.65	3.5 ± 0.5	
7.54	$\frac{5}{2}^+; T = \frac{3}{2}$	0.197	29 ± 3	0.09 ± 0.04
		1.35	1.2 ± 0.4	
		1.55	41 ± 3	0.017 ± 0.015
		4.38	27 ± 3	0.042 ± 0.030
		5.11	1.7 ± 0.4	
7.66 [f])	$\frac{3}{2}^+; T = \frac{3}{2}$	0	38 ± 4	0.06 ± 0.02
		0.197	13 ± 2	0.06 ± 0.07 or 3.5 ± 1.1
		1.55	36 ± 2	0.06 ± 0.04
		3.91	(3^{+3}_{-2})	
		4.55	5.1 ± 0.3	-0.11 ± 0.13
		5.11	5.9 ± 0.5	-0.04 ± 0.16
7.93	$\frac{7}{2}^+, \frac{9}{2}$	0.197	4	
		2.78	96	
7.94	$\frac{11}{2}^+$	2.78	10	
		4.65	90	
8.14	$\frac{1}{2}^+$	0	8 ± 1	
		0.110	24 ± 2	
		0.197	8 ± 1	
		1.55	2 ± 1	
		3.91	54 ± 2	$\Gamma_\gamma(\text{tot}) = 1.3$ eV
		5.94	10 ± 0.5	
		6.26	3 ± 1	
8.25	$(\frac{5}{2}, \frac{7}{2})^-$	0.197	18 ± 7	
		1.35	33 ± 10	
		1.46	24 ± 8	
		3.91	25 ± 8	

Table 19.10 (continued)
Radiative transitions in ^{19}F [a])

E_i (MeV)	J_i^π	E_f (MeV)	Branching ratio (%)	δ
8.29 [g])	$\frac{13}{2}^-$	4.03	93 ± 4	$\Gamma_\gamma(\text{tot}) = 72 \pm 8$ meV
		4.65	7 ± 4	
8.31	$\frac{5}{2}^+$	0	12 ± 1	$\Gamma_\gamma(\text{tot}) = 0.71 \pm 0.17$ eV
		1.55	48 ± 2	$\delta = 0.02 \pm 0.05$ or 2.2 ± 0.6
		4.38	40 ± 2	$\delta = -0.14 \pm 0.07$
8.37 [g])	$\frac{7}{2}, \frac{5}{2}^+$	0.197	13 ± 2	
		1.35	39 ± 3	
		2.78	30 ± 3	
		4.00	18 ± 3	
8.58	$\frac{5}{2}^+$	0	4 ± 1	
		0.197	38 ± 5	
		1.35	23 ± 3	
		1.55	20 ± 3	
		4.00	$(4 \pm 1$ [g]))	
		4.55	2.0 ± 0.7	
		5.42	4 ± 1	
		5.46	2.0 ± 0.5	
		5.62	2.2 ± 0.5	
		5.94	1.8 ± 0.5	
		6.16	2.5 ± 0.5	
		6.93	0.5 ± 0.3	
8.59	$\frac{3}{2}^-$	0	5 ± 2	$\Gamma_\gamma(\text{tot}) = 0.85 \pm 0.17$ eV
		0.110	3 ± 1	
		0.197	42 ± 2	
		1.35	7 ± 1	
		1.55	28 ± 3	
		3.91	8 ± 1	
		4.55	3.6 ± 0.6	
		5.11	1.0 ± 0.5	
		5.50	1.5 ± 0.5	
		6.28	0.6 ± 0.2	
		6.79	0.3 ± 0.1	
8.63 [g])	$\frac{7}{2}^-$	0.197	34 ± 2	
		1.35	6 ± 1	
		1.46	6 ± 1	
		2.78	38 ± 2	
		4.00	13 ± 1	
		4.03	3 ± 1	
8.65	$\frac{1}{2}^+$	0.110	53 ± 6	
		1.46	23 ± 6	

Table 19.10 (continued)
Radiative transitions in ^{19}F [a])

E_i (MeV)	J_i^π	E_f (MeV)	Branching ratio (%)	δ
		3.91	24 ± 6	
8.79	$\frac{1}{2}^+; T = \frac{3}{2}$	0	1.2 ± 0.4	
		0.110	30 ± 1	
		0.197	0.3 ± 0.2	
		1.46	22 ± 1	
		1.55	8 ± 1	
		3.91	22 ± 1	
		5.34	0.5 ± 0.1	
		5.94	1.8 ± 0.2	
		6.09	1.7 ± 0.2	
		6.26	0.2 ± 0.1	
		6.49	6 ± 1	
		6.53	2.1 ± 0.2	
		6.79	1.2 ± 0.3	
		6.99	0.5 ± 0.1	
		7.26	1.7 ± 0.2	
		7.36	0.6 ± 0.1	
		7.66	0.2 ± 0.1	
8.86 [g])	$< \frac{9}{2}$	1.35	100	
8.92	$\frac{3}{2}^-$	0	5 ± 2	0.1 ± 0.3 or 1.7 ± 0.9
		0.110	10 ± 2	0.20 ± 0.04 or 2.9 ± 0.4
		0.197	24 ± 7	1.0 ± 0.8
		1.46	25 ± 7	3.0 ± 2.5
		1.55	23 ± 7	0.30 ± 0.06 or ∞
		3.91	13 ± 7	
8.95 [g])	$\frac{11}{2}^-$	2.78	50 ± 2	$\Gamma_\gamma(\mathrm{tot}) = 230 \pm 30$ meV
		4.00	26 ± 2	
		4.03	9 ± 1	
		4.65	10 ± 2	
		5.42	5 ± 1	
9.03 [g])	$\frac{5}{2}, \frac{7}{2}$	0.197	44 ± 5	
		4.38	30 ± 5	
		6.07	26 ± 4	
9.100	$\frac{7}{2}^-$	0.197	2.0 ± 0.3	$\delta = 0.0 \pm 0.2$ or 2.5 ± 0.6
		1.35	2.7 ± 0.3	-0.1 ± 0.3 or ∞
		2.78	47 ± 2	-0.09 ± 0.10
		4.00	2.5 ± 0.3	0.3 ± 0.3 or -2.2 ± 0.9
		4.03	7.0 ± 0.5	-0.08 ± 0.01 or ∞
		4.68	2.0 ± 0.3	-0.09 ± 0.34 or ∞
		5.11	1.2 ± 0.2	0.0 ± 0.2 or 3.0 ± 1.6

Table 19.10 (continued)
Radiative transitions in ^{19}F [a]

E_i (MeV)	J_i^π	E_f (MeV)	Branching ratio (%)	δ
		5.42	19 ± 2	0.25 ± 0.10 or -6.0 ± 5.5
		5.54	1.3 ± 0.7	0.1 ± 0.3
		5.62	3.3 ± 0.3	0.17 ± 0.10
		6.10	12 ± 1	0.0 ± 0.3
9.101 [g]	$\frac{7}{2}^+, \frac{9}{2}^+$	2.78	11 ± 2	
		4.00	24 ± 2	
		4.38	24 ± 2	
		6.07	15 ± 2	
		6.33	10 ± 2	
9.17 [g]	$\frac{1}{2}^+$	0.197	51 ± 2	
		1.55	30 ± 2	
		4.56	19 ± 2	
9.20 [g]	$\frac{3}{2}$	0	18 ± 2	
		0.110	46 ± 3	
		0.197	10 ± 4	
		1.35	26 ± 3	
9.27 [g]	$\frac{11}{2}^+, \frac{9}{2}^+$	2.78	27 ± 2	
		4.38	18 ± 2	
		4.65	55 ± 3	
9.28 [g]	$(\frac{7}{2}, \frac{9}{2})^+$	4.00	58 ± 3	
		4.03	42 ± 3	
9.32	$\frac{1}{2}^+$	0	30 ± 1	0.10 ± 0.08 or 1.4 ± 0.3
		0.197	12 ± 1	0.1 ± 0.4 or ≥ 0.6
		1.46	28 ± 1	0.1 ± 0.2
		1.55	17 ± 1	-0.2 ± 0.3 or ≤ 0.9
		3.91	3.0 ± 0.3	0.40 ± 0.05 or ≥ 2.3
		4.56	3.2 ± 0.3	0.2 ± 0.3
		4.68	6.8 ± 0.5	0.1 ± 0.2
9.33 [g]	$< \frac{5}{2}$	1.55	100	
9.51 [g]	$\frac{5}{2}^+, \frac{7}{2}^+$	1.35	14 ± 2	
		1.55	14 ± 2	
		2.78	72 ± 3	
9.54	$\frac{5}{2}^+$	1.35	26 ± 2	0.3 ± 1.1
		4.56	15 ± 1	0.7 ± 0.4
		4.68	12 ± 1	0.3 ± 0.3
		5.11	29 ± 2	0.3 ± 0.2
		7.54	10 ± 1	0.7 ± 0.3
		7.66	6 ± 1	0.4 ± 0.3 or $1.0 \rightarrow 0.4$
		8.02	2 ± 1	
9.566	$\frac{3}{2}^-$	0.197	77 ± 10	

Table 19.10 (continued)
Radiative transitions in ^{19}F [a])

E_i (MeV)	J_i^π	E_f (MeV)	Branching ratio (%)	δ
		6.26	23 ± 6	
9.575	$\frac{7}{2}^+$	1.46	26 ± 2	-0.1 ± 0.2
		3.91	4 ± 1	-6 ± 7
		4.55	17 ± 2	
		6.09	38 ± 2	1.8 ± 1.0
		7.54	11 ± 2	-0.3 ± 0.8
		7.66	4 ± 1	-0.1 ± 1.3
9.59	$\frac{7}{2}$	1.35	32 ± 4	0.0 ± 0.5 or 3.7 ± 2.5
		2.78	30 ± 2	0.1 ± 0.2 or 11 ± 5
		4.00	17 ± 2	-0.7 ± 1.1
		4.55	21 ± 2	
9.64 [g])	$\frac{3}{2}, \frac{5}{2}$	0.197	13 ± 3	
		1.35	61 ± 7	
		4.55	26 ± 6	
9.65 [g])	$\frac{3}{2}, \frac{5}{2}$	1.35	41 ± 9	
		1.55	59 ± 9	
9.67	$\frac{3}{2}^+$	0	22 ± 2	-0.72 ± 0.04 or -10 ± 4
		0.110	20 ± 2	0.00 ± 0.05
		0.197	9 ± 1	0.30 ± 0.03 or 1.7 ± 0.3
		1.35	9 ± 1	0.00 ± 0.03
		1.46	5 ± 1	0.00 ± 0.07
		1.55	10 ± 1	0.00 ± 0.06 or -4.2 ± 1.3
		3.91	5.5 ± 0.5	0.12 ± 0.03 or -7.5 ± 2.0
		4.38	0.5 ± 0.2	
		4.55	8 ± 1	0.00 ± 0.03 or 4.7 ± 0.5
		5.11	1.5 ± 0.3	0.00 ± 0.05
		5.34	1.0 ± 0.2	-0.22 ± 0.03 or 3.3 ± 0.2
		6.84	1.0 ± 0.3	0.05 ± 0.02 or 3.3 ± 0.2
		7.54	4.0 ± 0.3	0.02 ± 0.03
		7.66	3.5 ± 0.3	0.14 ± 0.04
9.71 [g])	$\frac{9}{2}^+, \frac{11}{2}^-$	2.78	19 ± 3	
		4.03	80 ± 4	
		4.65	1 ± 1	
9.82	$\frac{5}{2}^-$	0.110	0.7 ± 0.2	
		0.197	41 ± 2	0.00 ± 0.05
		1.35	2.4 ± 0.5	-0.6 ± 0.2
		1.46	8 ± 1	-0.07 ± 0.05 or 2.7 ± 0.7
		1.55	30 ± 2	0.01 ± 0.04
		4.00	1.0 ± 0.2	0.0 ± 0.2 or ∞
		4.55	0.5 ± 0.1	0.30 ± 0.15

Table 19.10 (continued)
Radiative transitions in ^{19}F [a])

E_i (MeV)	J_i^π	E_f (MeV)	Branching ratio (%)	δ
		4.68	4.8 ± 0.3	0.0 ± 0.1 or -1.7 ± 0.4
		5.11	0.3 ± 0.2	0.4 ± 0.5 or ∞
		5.42	10 ± 1	-0.04 ± 0.05 or ∞
		5.54	0.6 ± 0.2	0.0 ± 0.2
		5.62	0.7 ± 0.2	0.33 ± 0.15 or -3.4 ± 1.2
9.83 [g])	$\frac{11}{2} \rightarrow \frac{15}{2}$	4.65	100	
9.87	$\frac{11}{2}^-$	2.78	63 ± 3	0.0 ± 0.2
		4.00	4.2 ± 1.0	
		4.03	24 ± 2	-0.43 ± 0.05 or 2.2 ± 0.2
		4.65	2.1 ± 0.8	
		6.10	3.8 ± 0.8	0.2 ± 0.1 or 2.7 ± 1.0
		6.50	1.9 ± 0.7	-0.4 ± 0.7
		8.29	1.0 ± 0.3	
9.89	$\frac{1}{2}^+$	0.197	15 ± 8	
		1.46	15 ± 5	
		3.91	32 ± 2	
		5.94	4 ± 1	
		6.09	13 ± 3	
		6.53	16 ± 2	
		7.66	5 ± 1	
9.93 [g])	$\frac{9}{2}^+$	0.197	1 ± 1	
		2.78	19 ± 1	
		5.46	10 ± 1	
		6.07	7 ± 1	
		6.33	8 ± 1	
		6.50	54 ± 2	
10.09 [g])	$\frac{5}{2}^-, \frac{7}{2}^-$	0.197	10 ± 1	
		1.35	35 ± 2	
		4.00	19 ± 2	
		5.42	26 ± 2	
		6.07	10 ± 1	
10.14 [g])	$\frac{3}{2}^-$	1.35	29 ± 4	
		1.46	71 ± 4	
10.37 [g])	$\frac{7}{2} \rightarrow \frac{11}{2}$	4.03	100	
10.41 [g])	$\frac{13}{2}^+$	2.78	3 ± 1	
		4.68	88 ± 1	
		6.50	9 ± 1	

[a]) For references and other information see Tables 19.7 in (78AJ03, 83AJ01) and (82OL02). See also Tables 19.11, 19.12 and 19.15 here. See also Table 2 here and (87FO03) for B(E2).
[b]) $|M|^2 = 21.4 \pm 0.3$ W.u.

[c]) $\Gamma_\gamma/\Gamma = 0.91 \pm 0.05$.
[d]) $\Gamma_\gamma/\Gamma = 0.76 \pm 0.15$ for $4.55 \rightarrow 0.20$ transition.
[e]) (85DI16).
[f]) $\Gamma_\gamma = 4.7$ eV, $\Gamma_\gamma/\Gamma = 0.65 \pm 0.10$.
[g]) Branching ratios are the relative intensities at $\theta = 55°$.
[h]) (82VE05).
[i]) (80VE1A) and private communication to Fay Ajzenberg-Selove (1986).
[j]) g.s. + 0.110 + 0.197.

2. ^{12}C(^{7}Li, ^{7}Li′)^{12}C $E_b = 16.395$

Vector analyzing power measurements for the elastic scattering have been reported at $E(^7\text{Li}) = 21.1$ MeV (84MO06). Fusion cross sections have been measured by (82DE30). For other channels in the interaction of ^{12}C + ^{7}Li see (78AJ03, 83AJ01, 87AJ02) for earlier work. More recently, neutron yield spectra for 40 MeV ^{7}Li on ^{12}C were measured by (87SC11). The ^{12}C(^{7}Li, ^{7}Be)^{12}B reaction was studied at projectile energies of 14, 21, and 26 MeV/A by (90NA24). Measurements and analysis of elastic breakup of 54 MeV ^{7}Li on ^{12}C are discussed in (92GA03). See also the coupled-channels investigation of the effects of projectile breakup and target excitations in the scattering of polarized ^{7}Li by ^{12}C at $E_{\text{lab}} = 21$ MeV by (88SA10). An evaluation of hypernuclear production cross-section by projectile fragmentation in ^{7}Li + ^{12}C at 3.0 GeV/A is presented in (89BA2N).

3. ^{12}C(^{9}Be, d)^{19}F $Q_m = -0.301$

For excitation curves and angular distributions involving unresolved states and ^{19}F* (2.78) see (83AJ01, 87AJ02).

4. (a) ^{12}C(^{11}B, α)^{19}F $Q_m = 7.730$
(b) ^{12}C(^{12}C, αp)^{19}F $Q_m = -8.227$
(c) ^{12}C(^{14}N, ^{7}Be)^{19}F $Q_m = 11.420$

States in ^{19}F with $4.3 < E_x < 11.0$ MeV were observed in reaction (a) by (89PR01) and are displayed in Table 19.12.

For reaction (b) see (83AJ01, 87AJ02). See also (88MA07).

Table 19.11
Lifetimes of some ^{19}F states

^{19}F* (MeV)	J^π	τ_m	Refs.
0.110	$\frac{1}{2}^-$	0.853 ± 0.010 ns	mean: see (72AJ02)
0.197	$\frac{5}{2}^+$	128.8 ± 1.5 ns	mean: see (78AJ03)
1.35	$\frac{5}{2}^-$	4.17 ± 0.06 ps [a])	(83BI03)
1.46	$\frac{3}{2}^-$	90 ± 20 fs	[c])
1.55	$\frac{3}{2}^+$	5 ± 3 fs	[c])
2.78	$\frac{9}{2}^+$	280 ± 30 fs	[c])
3.91	$\frac{3}{2}^+$	9 ± 5 fs	[c])
4.00	$\frac{7}{2}^-$	19 ± 7 fs	[c])
4.03	$\frac{9}{2}^-$	67 ± 5 fs	[c])
4.38	$\frac{7}{2}^+$	< 11 fs	[c])
4.55	$\frac{5}{2}^+$	< 50 fs	[c])
4.56	$\frac{3}{2}^-$	17^{+10}_{-8} fs	[c])
4.65	$\frac{13}{2}^+$	3.68 ± 0.38 ps [b])	(83BI03)
4.68	$\frac{5}{2}^-$	15.4 ± 3.0 fs	[c])
5.11	$\frac{5}{2}^+$	< 30 fs	[c])
5.34	$\frac{1}{2}^{(+)}$	≤ 0.1 fs	[c])
5.42	$\frac{7}{2}^-$	≤ 0.9 fs	[c])
5.46	$\frac{7}{2}^+$	< 0.26 fs	[c])
5.62	$\frac{5}{2}^-$	≤ 1.3 fs	[c])

[a]) $|M|^2 = 21.4 \pm 0.3$ W.u. (83BI03) for the E2 transition [$1.35 \to 0.11$]. See also (85KE1C) and Table 19.8 in (83AJ01).
[b]) $|M|^2 = 3.1 \pm 0.3$ W.u. (83BI03). See also (83AJ01).
[c]) See Table 19.8 in (83AJ01) and Table 19.12 here.

Table 19.12
States in ^{19}F from ^{12}C(^{11}B, α) [a]

^{19}F* (MeV) [b]	J^{π} [b]	Γ_{γ}/Γ	Γ_{α} (eV) [c]	Γ (eV) [d]
4.378	$\frac{7}{2}^+$	> 0.96		$> 6 \times 10^{-2}$
4.648	$\frac{13}{2}^+$	> 0.96		$(3.0 \pm 0.4) \times 10^{-4}$
4.683	$\frac{5}{2}^-$	> 0.85	$(2.0 \pm 0.3) \times 10^{-3}$	$(4.3 \pm 0.8) \times 10^{-2}$
5.107	$\frac{5}{2}^+$	0.97 ± 0.03	$(4.5 \pm 2.7) \times 10^{-3}$	$> 2 \times 10^{-2}$
5.418	$\frac{7}{2}^-$	0.040 ± 0.007	2.6 ± 0.7	
5.464	$\frac{7}{2}^+$	< 0.028	> 18	
6.070	$\frac{7}{2}^+$	< 0.025	1200	1200
6.100	$\frac{9}{2}^-$	< 0.038		
6.161	$\frac{7}{2}^-$	0.206 ± 0.017	2.9 ± 0.8	
6.330	$\frac{7}{2}^+$	< 0.017	2400	2400
6.500	$\frac{11}{2}^+$	> 0.18 [e]	≥ 2.4	
6.592	$\frac{9}{2}^+$	0.044 ± 0.006	7.3 ± 1.7	
6.927	$\frac{7}{2}^-$	< 0.008	2400	2400
7.166	$\frac{11}{2}^-$	0.025 ± 0.003	6.7 ± 1.1	
8.288	$\frac{13}{2}^-$	[e]	900 ± 140	900 ± 140
8.629	$\frac{7}{2}^-$	< 0.006	66 ± 24	66 ± 24
8.953	$\frac{11}{2}^-$	< 0.002	3570 ± 50	3570 ± 50
9.100		[e]		
9.710	$\frac{11}{2}^-$	< 0.007	124 ± 30	124 ± 30
9.834	$\frac{11}{2}, \frac{13}{2}$	0.045 ± 0.009	1.7 ± 0.5	< 200
9.873	$\frac{11}{2}^-$	0.43 ± 0.04	1.4 ± 0.3	< 500
9.895 [f]		< 0.01		
10.365	$\frac{7}{2}$–$\frac{11}{2}$	< 0.002	$(3.0 \pm 1.5) \times 10^3$	$(3.0 \pm 1.5) \times 10^3$
10.411	$\frac{13}{2}^+$	0.010 ± 0.002	246 ± 57	310 ± 110
10.927 [f]		0.051 ± 0.004		

[a]) (89PR01).
[b]) Cited from (87AJ02).
[c]) See Table 2 of (89PR01).
[d]) See Table 1 of (89PR01) for references.
[e]) Unresolved doublet.
[f]) New level observed in (89PR01). The uncertainties in the excitation energies are ± 5 keV and ± 8 keV for the 9.895 MeV and 10.927 MeV levels respectively.

5. (a) ^{13}C(^{6}Li, t)^{16}O $Q_{\rm m} = 6.998$ $E_{\rm b} = 18.698$
(b) ^{13}C(^{6}Li, α)^{15}N $Q_{\rm m} = 14.684$
(c) ^{13}C(^{6}Li, ^{6}Li$'$)^{13}C
(d) ^{13}C(^{6}Li, p)^{18}O $Q_{\rm m} = 10.704$

Uncorrelated structures have been observed in the excitation functions for reactions (a) and (b). Angular distributions have been measured for reaction (d) at $E(^{6}{\rm Li}) = 28$ MeV (88SM01). See also ^{18}O in the present review and see ^{13}C and ^{15}N in (91AJ01). Fusion cross sections have also been measured.

6. ^{13}C(^{10}B, α)^{19}F $Q_{\rm m} = 14.238$

Cross sections were measured for $E(^{10}{\rm B}) = 17.16$–31.32 MeV at $\theta_{\rm lab} = 14.3°$–$41.6°$ (88MA07). Several excited states in ^{19}F were studied. A fluctuation and resonance analysis was carried out.

7. ^{13}C(^{9}Be, t)^{19}F $Q_{\rm m} = 1.010$

See (83AJ01).

8. (a) ^{14}N(^{7}Li, d)^{19}F $Q_{\rm m} = 6.122$
(b) ^{14}N(^{12}C,^{7}Be)^{19}F $Q_{\rm m} = -11.420$
(c) ^{14}N(^{14}N, 2αp)^{19}F $Q_{\rm m} = -4.926$

See (87AJ02).

9. ^{15}N(α, γ)^{19}F $Q_{\rm m} = 4.014$

Resonances in the yield of γ-rays are observed below $E_\alpha = 8.1$ MeV ($E_{\rm x} = 10.4$ MeV): the parameters for these are displayed in Table 19.13. Branching ratios are shown in Table 19.10 and $\tau_{\rm m}$ measurements in Table 19.11. The J^π values shown in Table 19.13 are based on correlation and angular distribution measurements and on branching ratio determinations. In work reported since the previous review (87AJ02), measurements were made by (87MA31) for the resonance at $E_{\rm x} = 4.550$ or 4.556 MeV. Widths of nine states between $E_{\rm x} = 8.288$ and 10.411 MeV were measured by (88HE03). These new results are included in Table 19.13. See also the study by (89GA06) of the $T = 3/2$ levels at $E_{\rm x} = 7.538$, 7.660, 9.927 MeV.

Table 19.13
Resonances in ^{15}N(α, γ)^{19}F [a])

E_α (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	$\omega\gamma$ (eV)	J^π	E_x (MeV ± keV)
0.679 [k])	[$\Gamma_\alpha = (3.2 \pm 0.7) \times 10^{-5}$ eV]	$(9.7 \pm 2.0) \times 10^{-5}$	$\frac{5}{2}^+$	4.550
0.687 [k])	[$\Gamma_\alpha < 5 \times 10^{-6}$ eV]	$< 1 \times 10^{-5}$	$\frac{3}{2}^-$	4.556
0.85	$(42.8 \pm 8.5) \times 10^{-6}$ [b])	$(6.0 \pm 1.0) \times 10^{-3}$	$\frac{5}{2}^-$	4.681 ± 1
1.385 ± 3		$(13 \pm 8) \times 10^{-3}$ [c])	$\frac{5}{2}^+$	5.105 ± 2
1.678 ± 3	[i])	1.64 ± 0.16	$\frac{1}{2}^{(+)}$	5.337 ± 2
1.790		0.42 ± 0.09 [c])	$\frac{7}{2}^-$	5.427
1.839 ± 2	< 1	2.5 ± 0.4 [c])	$\frac{7}{2}^+$	5.465
1.883 ± 3	4 ± 1	4.2 ± 1.1 [c])	$\frac{3}{2}^+$	5.500
1.930		0.48 ± 0.11 [c])	$\frac{5}{2}^+$	5.54
2.035 ± 4		0.37 ± 0.09	$\frac{3}{2}^-$	5.620
2.441 ± 4		0.53 ± 0.13	$\frac{1}{2}^+$	5.938 ± 3
2.608 ± 2		2.70 ± 0.54	$\frac{7}{2}^+$	6.070 ± 1
2.631 ± 4		4.50 ± 0.90	$\frac{3}{2}^-$	6.088 ± 3
2.722 ± 2		2.40 ± 0.60	$\frac{7}{2}^-$	6.160 ± 1
2.873 ± 3		1.0 ± 0.2	$\frac{5}{2}^+$	6.282 ± 2
2.935 ± 3		0.76 ± 0.15	$\frac{7}{2}^+$	6.330 ± 2
3.1468 ± 1.5		1.7 ± 0.3	$\frac{3}{2}^+$	6.4976 ± 1.5
3.1498 ± 1.5		2.3 ± 0.4	$\frac{11}{2}^+$	6.5000 ± 1.5
3.183 ± 2		2.4 ± 0.4	$\frac{3}{2}^+$	6.526 ± 2
3.218 ± 2		0.63 ± 0.13	$\frac{7}{2}$	6.554 ± 2
3.267 ± 2		1.6 ± 0.3	$\frac{9}{2}^+$	6.592 ± 2
3.511 ± 3		10.9 ± 1.5	$\frac{3}{2}^-$	6.785 ± 2
3.576 ± 3		1.0 ± 0.2	$\frac{5}{2}$	6.836 ± 2
3.645 ± 5		6.1 ± 1.3	$\frac{3}{2}^-$	6.891 ± 4
3.688 ± 3		9.7 ± 1.4	$\frac{7}{2}$	6.925 ± 2
3.993 ± 2		1.00 ± 0.12 [j])	$\frac{11}{2}^-$	7.1662 ± 0.7
4.465		17.0 ± 2.7	$\frac{5}{2}^+; T = \frac{3}{2}$	7.538 ± 2
4.618		3.7 ± 0.9	$\frac{3}{2}^+; T = \frac{3}{2}$	7.659 ± 2
4.96 ± 3		2.3 ± 0.4	$\frac{7}{2}^+, \frac{9}{2}$	7.929
4.97 ± 3		3.1 ± 0.5	$\frac{11}{2}^+$	7.937
5.413 ± 5	< 1	0.53 ± 0.08	$\frac{13}{2}^-$	8.288 ± 2
5.438 [e])	< 1	2.1 ± 0.5 [d])	$\frac{5}{2}^+$	8.306 ± 4
5.519 [e])	7.5 ± 1.5	0.54 ± 0.2 [d])	$\frac{7}{2}, \frac{5}{2}^+$	8.370 ± 4
5.784	≈ 1	5.1 ± 1.3 [d])	$\frac{5}{2}$	8.579 ± 4
5.794		1.6 ± 0.35 [d,f])	$\frac{3}{2}$	8.587 ± 3
5.847 [e])	< 1	2.5 ± 0.4 [d])	$\frac{7}{2}^-$	8.629 ± 4
6.145	< 1	0.2 ± 0.05 [d])	$< \frac{9}{2}$	8.864 ± 4
6.259 [e])	≈ 1	0.85 ± 0.2 [d])	$\frac{11}{2}^+, (\frac{9}{2}^+)$	8.953 ± 3
6.356	4.2 ± 1	0.53 ± 0.26 [d])	$\frac{5}{2}, \frac{7}{2}$	9.030 ± 5

Table 19.13 (continued)
Resonances in ^{15}N(α, γ)^{19}F [a])

E_α (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	$\omega\gamma$ (eV)	J^π	E_x (MeV ± keV)
6.442		0.48 ± 0.15 [d,g])	$\frac{7}{2}^+$	9.098 ± 4
6.445	≈ 1	0.40 ± 0.1 [d])	$\frac{7}{2}, \frac{9}{2}$	9.101 ± 4
6.526	9.9 ± 1.5	1.4 ± 1 [d])	$\frac{1}{2}, \frac{3}{2}$	9.165 ± 5
6.576	10 ± 1.5	1.5 [d])	$\frac{3}{2}$	9.204 ± 7
6.656	2 ± 1	0.15 ± 0.04 [d])	$\frac{11}{2}^+, \frac{9}{2}^+$	9.267 ± 4
6.672	< 1.5	0.38 ± 0.09 [d])	$\frac{7}{2}, \frac{9}{2}$	9.280 ± 5
6.723 [e])	3.4 ± 1	3.4 ± 1.7 [d])	$\frac{1}{2}^+$	9.320 ± 4
6.735	≈ 6		$< \frac{5}{2}$	9.329 ± 4
6.963	< 1	0.7 ± 0.2 [d])	$\frac{5}{2}^+, \frac{7}{2}^+$	9.509 ± 4
6.993	6.3 ± 1.5	0.5 [d])	$\frac{3}{2} \rightarrow \frac{7}{2}$	9.533 ± 6
7.057	9.6 ± 1.5	5.2 ± 3 [d])	$\frac{7}{2}$	9.584 ± 4
7.131	≈ 8	≈ 1 [d])	$\frac{3}{2}, \frac{5}{2}$	9.642 ± 6
7.146	≈ 6	≈ 2 [d])	$\frac{3}{2}, \frac{5}{2}$	9.654 ± 6
7.179	≈ 4	≈ 1 [d])	$\frac{1}{2}, \frac{3}{2}$	9.680 ± 6
7.217	< 1	4 ± 0.7 [d])	$\frac{9}{2}^+, \frac{11}{2}$	9.710 ± 4
7.349	< 1.5	3.5 ± 0.8 [d,h])	$\frac{5}{2}^+$	9.814 ± 4
7.375 [e])	< 0.2	0.51 ± 0.1 [d])	$\frac{11}{2} \rightarrow \frac{15}{2}$	9.834 ± 3
7.422	≈ 1.5	3.6 ± 0.6 [d])	$\frac{9}{2}^+, \frac{11}{2}^-$	9.872 ± 3
7.491	≈ 1	19.3 ± 3.0 [d])	$\frac{9}{2}^+$	9.926 ± 3
7.696	1.15 ± 0.14	2.37 ± 0.5 [d])	$\frac{5}{2}, \frac{7}{2}$	10.088 ± 5
7.749	3.2 ± 1	1.3 ± 0.4 [d])	$\frac{3}{2}, \frac{5}{2}$	10.130 ± 6
8.047	3 ± 1.5	0.9 ± 0.4 [d])	$\frac{7}{2} \rightarrow \frac{11}{2}$	10.365 ± 4
8.105	< 1.5	15.0 ± 3.0 [d])	$\frac{11}{2}^+, \frac{13}{2}^+$	10.411 ± 3

[a]) For references see Tables 19.8 in (78AJ03) and 19.9 in (83AJ01). For branching ratios see Table 19.10 here. $\omega\gamma = (\Gamma_\alpha \Gamma_\gamma / \Gamma)\frac{1}{2}(2J+1)$.
[b]) $\Gamma_\alpha = 2.1 \pm 0.7$ meV, $\Gamma_\gamma = 40.7 \pm 8.1$ meV.
[c]) See also Table 19.7 in (72AJ02).
[d]) $\omega\gamma$ measured at (55°) by (78SY01) are uncorrected for angular distribution effects.
[e]) Value recalculated by reviewer (87AJ02) from E_x.
[f]) $\Gamma_\alpha/\Gamma_p = 0.026 \pm 0.008$.
[g]) $\Gamma_\alpha/\Gamma_p = 0.1 \pm 0.04$. Using $\Gamma = 0.57 \pm 0.03$ keV (Table 19.18), $\Gamma_\alpha = 0.052 \pm 0.03$ keV, $\Gamma_p = 0.52 \pm 0.03$ keV.
[h]) $\Gamma_\alpha/\Gamma_p = 0.55 \pm 0.16$.
[i]) See (82KR05).
[j]) See also (85DI16).
[k]) See (87MA31).

The discussion in (87AJ02) notes that the ^{19}F levels involved in cascade decay are at E_x = 3999.6 ± 1.2, 4031.9 ± 0.4, 4377 ± 1 and 4548 ± 2 keV. The $K^\pi = \frac{1}{2}^-$ band involves ^{19}F* (0.110[$\frac{1}{2}^-$], 1.46[$\frac{3}{2}^-$], 1.35[$\frac{5}{2}^-$], 4.00[$\frac{7}{2}^-$], 4.03[$\frac{9}{2}^-$], 7.16[$\frac{11}{2}^-$]) and possibly ^{19}F* (8.29)[$\frac{13}{2}^-$] [J^π in brackets]. See, however, reaction 11. See (72AJ02) for a discussion of the evidence for other assignments of J^π and K^π. ^{19}F* (10.41) is likely to be the second $\frac{13}{2}^+$ (2s, 1d)^3 state in ^{19}F. For references see (83AJ01). See also the comment (85DI16) and reply (85MO20) on negative-parity alpha cluster states in ^{19}F.

10. (a) ^{15}N(α, p)^{18}O $\qquad Q_m = -3.980 \qquad E_b = 4.014$

(b) ^{15}N(α, α')^{15}N

Resonances observed in the (α, $\alpha'\gamma$) and (α, pγ) reactions and in the elastic scattering are displayed in Table 19.14. See also (85OH04).

In work reported since the previous review (87AJ02), nine states in ^{19}F between E_x = 8.288 and 10.411 MeV were studied by (88HE03). Alpha widths were measured. $T = \frac{3}{2}$ levels at E_x = 7.538, 7.660 and 9.927 MeV were studied by (89GA06). These results are included in Table 19.14.

In related work, optical potentials for ^{15}N + α were extracted for E_α = 0–150 MeV (93AB02) and alpha particle strength functions were obtained from resonance parameters by (88LE05). See also the tables of thermonuclear reaction rates (85CA41, 88CA1N). Cross sections for α scattering on light nuclei for ion beam analysis are presented in (91LE33).

11. ^{15}N(^{6}Li, d)^{19}F $\qquad Q_m = 2.539$

At $E(^6\text{Li})$ = 22 MeV angular distributions are reported to ^{19}F* (0.11, 1.35[u], 1.46, 4.0[u], 8.29[u]). Comparisons are made with the results from the ^{16}O(^{6}Li, d)^{20}Ne reaction, in an attempt to determine whether ^{19}F* (8.95) is the $\frac{11}{2}^-$ member of the $K^\pi = \frac{1}{2}^-$ band, of which ^{19}F* (8.29) is the $\frac{13}{2}^-$ member (84MO08, 85DI16, 85MO20). Configuration mixing appears to be involved in the $\frac{11}{2}^-$ states [^{19}F* (7.17, 8.95, 9.87)] and in the $\frac{7}{2}^-$ states [^{19}F*(4.00, 5.42)] to which they decay (87FO03).

12. ^{15}N(^{7}Li, t)^{19}F $\qquad Q_m = 1.547$

This reaction has been studied at $E(^7\text{Li})$ = 40 MeV: see Table 19.11 in (83AJ01).

13. ^{15}N(^{11}B, ^{7}Li)^{19}F $\qquad Q_m = -4.651$

See (83AJ01).

Table 19.14
Levels of ^{19}F from ^{15}N(α, p) and ^{15}N(α, α) [a]

E_α (MeV $\pm$ keV) [b]	$\Gamma_{\rm lab}$ (keV)	J^π	$E_{\rm x}$ (MeV $\pm$ keV)
1.878 ± 10	4	$\frac{3}{2}^+$	5.496
2.614 ± 10	1.5	$\frac{5}{2}^+$	6.077
2.635 ± 10	5	$\frac{5}{2}^-$	6.094
2.833 ± 10	10	$\frac{1}{2}^+$	6.250
2.883 ± 10	3	$\frac{5}{2}^+$	6.289
2.944 ± 10	3	$\frac{7}{2}^+$	6.338
3.060 ± 10	360	$\frac{1}{2}^-$	6.429 ± 8
3.194 ± 10	5	$\frac{1}{2}^+$	6.535
3.229 ± 10	2	$\frac{5}{2}^+$	6.563
3.525 ± 10	3	$\frac{3}{2}^-$	6.796
3.587 ± 10	1.5	$(\frac{5}{2}, \frac{3}{2})^+$	6.845
3.648 ± 10	35	$\frac{5}{2}^-$	6.893
3.705 ± 10	3	$(\frac{9}{2}, \frac{7}{2})^+$	6.938
3.770 ± 10	64	$\frac{1}{2}^-$	6.989 ± 8
3.930 ± 10	40	$\frac{7}{2}^+$	7.116 ± 8
4.127	< 8		7.271
4.23	< 82	$\frac{7}{2}^+$	7.35
4.465 [f]	0.16 ± 0.05	$\frac{5}{2}^+; T = \frac{3}{2}$	7.538
4.49	< 110	$\frac{7}{2}^+$	7.56
4.53	< 50	$\frac{5}{2}^+$	7.59
4.619 [f]	0.0028 ± 0.0008	$\frac{3}{2}^+; T = \frac{3}{2}$	7.660
4.710	< 40	$\frac{1}{2}^-$	7.731
4.780	< 8		7.787
4.93	< 260		7.90 [e]
(5.005)	(< 8)		(7.964)
(5.018)	(< 5)		(7.974)
5.116	< 8		8.052
5.203	< 8		8.120
5.232	< 6		8.143
5.25	< 65		8.16
5.284	< 10		8.184
5.415 [c]	0.90 ± 0.10	$\frac{13}{2}^-$	8.288
5.481	< 10		8.340
5.847 [c]	0.066 ± 0.024	$\frac{7}{2}^{(-)}$	8.629
6.259 [c]	3.57 ± 0.05	$\frac{11}{2}^-$	8.954
6.963 [c]	0.46 ± 0.05	$\frac{7}{2}^+$	9.509
7.216 [c]	0.12 ± 0.03	$\frac{11}{2}^-$	9.709
7.373 [c]	< 0.2	$(\frac{11}{2}$–$\frac{15}{2})$	9.833
7.430 [c]	< 0.5	$\frac{11}{2}^-$	9.878

Table 19.14 (continued)
Levels of ^{19}F from ^{15}N(α, p) and ^{15}N(α, α) [a])

E_α (MeV $\pm$ keV) [b])	Γ_{lab} (keV)	J^π	E_x (MeV $\pm$ keV)
7.491 [f])	0.61 ± 0.09	$\frac{9}{2}^+; T = \frac{3}{2}$	9.926
7.695 [c])	1.15 ± 0.14	$\frac{5}{2}^-$	10.087
7.877 [d])	< 1	$\frac{1}{2}^+$	10.231 ± 4
7.977 [d])		$\frac{3}{2}^+$	10.308 ± 4
8.104 [c])	0.31 ± 0.11	$\frac{13}{2}^+$	10.410
8.179 [d])	13.8 ± 1.5		10.469 ± 4
8.205 [d])	6.0 ± 1.0		10.488 ± 4
8.220	5.4 ± 1.0	$\frac{3}{2}^+$	10.501 ± 4
8.245	18 ± 2		10.521 ± 4
8.277	2.5 ± 1		10.546 ± 4
8.287 [d])	5.0 ± 1.5	$\frac{3}{2}^+$	10.554 ± 4
8.307 [d])	3.7 ± 1		10.560 ± 4

[a]) For references see Tables 19.9 in (78AJ03) and 19.10 in (83AJ01). See also footnote (c).
[b]) Resonances below $E_\alpha = 5.5$ MeV are observed in (α, α_0); resonances above that energy are observed in (α, pγ) and (α, $\alpha'\gamma$), except those labelled (c).
[c]) ^{15}N(α, α_0) (88HE03). The total width shown is in the c.m. system and assumes $\Gamma_{\text{tot}} = \Gamma_{\alpha_0}$.
[d]) Value recalculated by reviewer (87AJ02) from E_x.
[e]) See, however, reaction 32.
[f]) (89GA06). The total width is in the c.m. system and assumes $\Gamma_{\text{tot}} = \Gamma_{\alpha_0}$

Table 19.15
Resonances in ^{16}O(t, t) [a]

$E_{\rm c.m.}$ (MeV)	$E_{\rm x}$ (MeV ± keV)	J^π	$\Gamma_{\rm c.m.}$ (keV)
1.368	13.068 ± 4	$\frac{1}{2}^+$	< 10
1.545	13.245 ± 10	$\frac{1}{2}^-$	7
1.570	13.270 ± 10	$\frac{1}{2}^+$	4.5
1.832	13.532 ± 10	$\frac{1}{2}^+$	22
2.018	13.718 ± 20	$\frac{3}{2}^-$	128
2.178	13.878 ± 15	$\frac{1}{2}^+$	101
2.447	14.147 ± 20	$\frac{1}{2}^+$	21
2.555	14.255 ± 15	$\frac{3}{2}^+$	51
2.652	14.352 ± 10	$\frac{1}{2}^+$	154
2.759	14.459 ± 25	$\frac{3}{2}^+$	179
2.763	14.463 ± 25	$\frac{5}{2}^+$	46

[a]) For references see (78AJ03).

14. ^{15}N(^{13}C, ^{9}Be)^{19}F $\quad Q_{\rm m} = -6.634$

Groups are reported at $E(^{13}{\rm C}) = 105$ MeV leading to states which are generally unresolved; J^π assignments are suggested: see (83AJ01).

15. (a) ^{16}O(t, γ)^{19}F $\quad Q_{\rm m} = 11.700$
(b) ^{16}O(t, n)^{18}F $\quad Q_{\rm m} = 1.269$ $\quad E_{\rm b} = 11.700$
(c) ^{16}O(t, p)^{18}O $\quad Q_{\rm m} = 3.706$
(d) ^{16}O(t, t′)^{16}O
(e) ^{16}O(t, α)^{15}N $\quad Q_{\rm m} = 7.686$

For reaction (a) see (78AJ03). The excitation function for reaction (b) has been measured for $E_{\rm t} = 0.3$ to 3.7 MeV: there is evidence for a maximum at $E_{\rm t} = 2.5$ MeV. For resonances in the yields of p_0, p_1, α_0, α_{1+2} see (78AJ03). The elastic yield [reaction (d)] shows a large number of resonances; their parameters are displayed in Table 19.15. See also (87AJ02).

More recently, double differential neutron yields for reaction (b) at $E_{\rm x} = 20$ MeV were reported in (93DR03, 93DR04). An analysis of reaction (d) by a quasi-resonating-group method is described in (87ZH13). A study of the isospin dependence of the $A = 3$ isospin potential using reaction (d) for $E_{\rm x} = 33$ MeV is discussed in (87EN06). See also (86HA1H).

16. (a) ^{16}O(^{3}He, p)^{18}F $\quad Q_{\rm m} = 2.032$
(b) ^{16}O(^{3}He, α)^{15}O $\quad Q_{\rm m} = 4.914$

The use of reaction (a) in an ^{18}F production technique with natural water is described in (91SU17). An ion beam technique for oxygen analysis using reaction (b) is discussed in (92CO08).

17. ^{16}O(α, p)^{19}F $\qquad Q_m = -8.114$

Angular distributions have been measured at $E_\alpha = 20.1$ to 40 MeV: see (78AJ03, 83AJ01, 87AJ02). States observed in this reaction are displayed in Table 19.12 of (78AJ03). See also the shell-model study of nuclear form factors in (87LE15). An application of a perturbed angular correlation measurement to the study of high temperature superconducting oxides is described in (90KOZG).

18. ^{16}O(^{6}Li, ^{3}He)^{19}F $\qquad Q_m = -4.095$

This reaction (and its mirror reaction ^{16}O(^{6}Li, t)^{19}Ne [see ^{19}Ne, reaction 5]) have been studied at $E(^6\text{Li}) = 24$ and 46 MeV: see (78AJ03, 83AJ01). Members of the $K^\pi = \frac{1}{2}^+$ and $\frac{1}{2}^-$ rotational bands have been identified: see Table 19.16. Other groups, mainly to unresolved states, have also been observed. A recent measurement to determine the structure of ^{19}F between $E_x = 5.5$–7.5 MeV was reported in (92ROZZ).

19. ^{16}O(^{7}Li, α)^{19}F $\qquad Q_m = 9.233$

Many states have been populated in this reaction: see Table 19.14 in (78AJ03) and (84MO28; $E(^7\text{Li}) = 20$ MeV). Angular distributions in the latter work have been analyzed via Hauser-Feshbach compound nucleus calculations and FRDWBA. The $K^\pi = \frac{1}{2}^+$ and $\frac{1}{2}^-$ states [see Table 19.16] are discussed in (84MO28).

More recently a discussion of the theory of cluster-stripping reactions was presented in (90OS03). Differential cross sections were calculated with the exact finite-range distorted wave Born approximation (91OS04).

20. ^{16}O(^{10}B, ^{7}Be)^{19}F $\qquad Q_m = -6.969$

See reaction 6 in ^{19}Ne. See also (83AJ01).

21. ^{16}O(^{11}B, ^{8}Be)^{19}F $\qquad Q_m = 0.477$

See (78AJ03).

Table 19.16
Levels of ^{19}F and ^{19}Ne from ^{16}O(^{6}Li, ^{3}He) and ^{16}O(^{6}Li, t) [a]

J^π [b]	E_x in ^{19}F (MeV)			E_x in ^{19}Ne (MeV)		
	$K^\pi = \frac{1}{2}^+$	$K^\pi = \frac{1}{2}^-$	other	$K^\pi = \frac{1}{2}^+$	$K^\pi = \frac{1}{2}^-$	other
$\frac{1}{2}^+$	0			0.0		
$\frac{3}{2}^+$	1.56			1.54 [d]		
$\frac{5}{2}^+$	0.20			0.24		
$\frac{7}{2}^+$	5.47			5.42		
$\frac{9}{2}^+$	2.78			2.79 [d]		
$\frac{11}{2}^+$	(6.50) [c]					
$\frac{13}{2}^+$	4.65			4.64		
$\frac{1}{2}^-$		0.11			0.28	
$\frac{3}{2}^-$		1.46			1.62 [d]	
$\frac{5}{2}^-$		1.35			1.51 [d]	
$\frac{7}{2}^-$		4.00			4.20 [f]	
$\frac{9}{2}^-$		4.03			4.14 [f]	
$\frac{3}{2}^+$			3.91			4.03
$\frac{7}{2}^+$			4.38			4.38
$\frac{5}{2}^{(+)}$			4.55			4.55 [d]
$\frac{3}{2}^-, (\frac{1}{2}^-)$			4.56			4.593 ± 0.006
$\frac{5}{2}^-$			4.68			4.71
$\frac{5}{2}^{(-)}$			5.11			5.09 [e]
$\frac{5}{2}^+$			5.34			
$\frac{7}{2}^-$			5.43			

[a] For references see Table 19.13 in (83AJ01). E_x values shown are nominal.
[b] J^π assignments based on similarities in angular distributions, and on known spin of one of the analog states.
[c] Not strongly populated at $E(^6\text{Li}) = 24$ MeV.
[d] J^π assignments based on similarities in σ_{max} in both reactions, and on known spin of analog state.
[e] $J^\pi = (\frac{5}{2}^-; \frac{7}{2}^-)$; at 4.78 MeV is also reported.
[f] See, however, reaction 5 in ^{19}Ne.

22. (a) ^{16}O(^{12}C, ^{9}B)^{19}F $Q_{\rm m} = -15.666$
(b) ^{16}O(^{13}C, ^{10}B)^{19}F $Q_{\rm m} = -12.176$

See (83AJ01, 87AJ02).

23. ^{17}O(d, t)^{16}O $Q_{\rm m} = 2.114$ $E_{\rm b} = 13.814$

For early polarization measurements see (83AJ01). More recently differential cross sections and analyzing powers were measured for $E_{\rm d} = 89$ MeV (90SA27). See ^{16}O, reaction 67 in (93TI07). For other channels see (78AJ03).

24. ^{17}O(^{3}He, p)^{19}F $Q_{\rm m} = 8.320$

States studied in this reaction at $E(^{3}\text{He}) = 18$ MeV are displayed in Table 19.14 of (83AJ01). A study involving states with $E_{\rm x} \leq 7$ MeV was reported by (86SE1C).

25. ^{17}O(α, d)^{19}F $Q_{\rm m} = -10.033$

At $E_\alpha = 47.5$ MeV angular distributions have been studied for deuterons leading to the $\frac{1}{2}^+$, $\frac{5}{2}^+$, $\frac{3}{2}^+$, $\frac{9}{2}^+$, $\frac{13}{2}^+$ and $\frac{7}{2}^+$ members of the $K = \frac{1}{2}^+$ band [^{19}F* (0, 0.197, 1.55, 2.78, 4.65, 5.47)], to two $\frac{11}{2}^+$ states ^{19}F* (6.49, 7.94) [both of which are strongly populated] and to the $\frac{7}{2}^+$ state at 4.38 MeV. The reaction populates strongly only those positive-parity states that are predominantly (sd)^3: see (83AJ01).

26. ^{18}O(p, γ)^{19}F $Q_{\rm m} = 7.994$

This reaction was studied for $E_{\rm p} = 80$ to 2200 keV by (80WI17). A large number of resonances have been investigated and $E_{\rm res}$, total and partial widths, branching and mixing ratios and $\omega\gamma$ values are reported. Transition strength arguments as well as analyses of γ-ray angular distribution data lead to J^π assignments: see Tables 19.10, 19.17, and 19.18 for a display of the results. More recently measurements were made for $E_{\rm p} < 0.22$ MeV by (90VO06), and the results are included in Table 19.18.

Absolute cross sections measured for direct capture lead to C^2S values for a number of states of ^{19}F. Reduced widths and J^π determinations led (80WI17) to postulate ^{19}F* (3.91, 4.55, 4.38, 6.59, 6.50, 10.43) as the $J^\pi = \frac{3}{2}^+$, $\frac{5}{2}^+$, $\frac{7}{2}^+$, $\frac{9}{2}^+$, $\frac{11}{2}^+$, $\frac{13}{2}^+$ states of the $K^\pi = \frac{3}{2}^+$ rotational band; ^{19}F* (7.70 or 7.26, 6.09, 9.82, 6.93, 9.87) as the $J^\pi = \frac{1}{2}^-$, $\frac{3}{2}^-$, $\frac{5}{2}^-$, $\frac{7}{2}^-$ and $\frac{11}{2}^-$ members of the excited $K^\pi = \frac{1}{2}^-$ rotational band; and ^{19}F* (4.56, 4.68,

Table 19.17
Some bound states of ^{19}F involved in the capture γ-rays from ^{18}O + p [a]

E_x (keV)	E_x (keV)	E_x (keV)
4648 ± 1	6088 ± 1	6839 ± 1
5107 ± 1	6100 ± 2 [c]	6930 ± 3
5338 ± 4	6163 ± 2	6989 ± 3
5418 ± 1	6255 ± 1	7262 ± 2 [d]
5462 ± 2	6283 ± 3	7364 ± 4 [e]
5501 ± 2	6493 ± 3	7540 ± 1
5535 ± 2	6500 ± 1	7661 ± 1
5621 ± 1 [b]	6529 ± 2	
5938 ± 1	6789 ± 2	

[a] (80WI17). See also Tables 19.10 and 19.18.
[b] $J^\pi = \frac{5}{2}^-$.
[c] $J^\pi = \frac{9}{2}^-$.
[d] $J^\pi = \frac{1}{2}^-, \frac{3}{2}$.
[e] $J^\pi = \frac{1}{2}^+$.

5.42, 6.10, 7.17) as the $J^\pi = \frac{3}{2}^-, \frac{5}{2}^-, \frac{7}{2}^-, \frac{9}{2}^-$ and $\frac{11}{2}^-$ members of the $K^\pi = \frac{3}{2}^-$ rotational band. Evidence suggesting the presence of isospin mixing in the $\frac{5}{2}^+$, first $T = \frac{3}{2}$ state in ^{19}F at 7.54 MeV has been pointed out (80WI17). See also Table 19.9.

Stellar reaction rates have also been calculated: the data cover $T_9 = 0.01$–5.0. The consequences for the final termination of the CNO tri-cycle are discussed by (80WI17). See also (87AJ02). See also the more recent tables of thermonuclear reaction rates in (83HA1B, 85CA41, 88CA1N).

27. ^{18}O(p, n)^{18}F $\qquad Q_m = -2.437 \qquad E_b = 7.994$

Yield measurements are reported from $E_p = 2.5$ to 13.5 MeV [see (78AJ03) for the references]. The observed resonances are displayed in Table 19.19. Measurements of spin observables for this reaction with polarized protons at $E_p = 135$ MeV were reported by (89WAZZ). Total cross sections for production of ^{18}F for $E_p < 30$ MeV were measured by (90WA10). A cryogenic ^{18}O target technique is discussed in (93FI08). See also (86HA1H).

28. ^{18}O(p, p$'$)^{18}O $\qquad E_b = 7.994$

Scattering studies have been carried out for $E_p = 0.6$ to 16.3 MeV and for $E_p = 6.1$ to 16.6 MeV: see (78AJ03, 83AJ01, 87AJ02). Pronounced resonant structure is evident up to

Table 19.18
Resonances in ^{18}O(p, γ)^{19}F [a]

E_p (keV)	Γ_{lab} (keV)	$\omega\gamma$ (eV)	J^π	E_x (keV)
50–120 [k]		$< (0.02 \pm 0.02) \times 10^{-6}$ [k]		< 8.108 [k]
150.5 ± 0.5 [k]	< 0.5 [k]	$(0.92 \pm 0.06) \times 10^{-3}$ [k]	$\frac{1}{2}^+$ [k]	8.1367 [e]
214.7 ± 0.5 [k]	< 0.8 [k]	$(5.0 \pm 1.0) \times 10^{-6}$ [k]		8.199 [k]
274 ± 3	< 1.5	$(3.7 \pm 0.5) \times 10^{-5}$	$< \frac{7}{2}$	8.254
334 ± 2	< 1	$(0.95 \pm 0.08) \times 10^{-3}$	$\frac{5}{2}^+$	8.310 [f]
622 ± 2	< 0.5	$(10 \pm 2) \times 10^{-3}$	$\frac{5}{2}^+$	8.583
629.6 ± 0.3	2.0 ± 0.3	0.10 ± 0.02	$\frac{3}{2}^-$	8.5904 [g]
~ 680	300		$\frac{3}{2}$	8.638
841 ± 2	48 ± 2	1.4 ± 0.2	$\frac{1}{2}^+$ [b]	8.791 [h]
			$[T = \frac{3}{2}]$	
977 ± 2	10 ± 2	$(1.5 \pm 0.2) \times 10^{-2}$	$\frac{3}{2}$	8.919
1166.5 ± 0.4		0.29 ± 0.03 [j]	$\frac{7}{2}^-$	9.0988 [i]
1398 ± 2	3.6 ± 0.8	0.08 ± 0.01	$\frac{3}{2}^+$	9.318
1630 ± 2 [c]	7 ± 2	0.025 ± 0.005	$\frac{5}{2}^+$	9.538
1660 ± 3	27 ± 3	0.041 ± 0.010	$\frac{3}{2}^-$	9.566
1670 ± 4	70 ± 3	0.06 ± 0.01	$\frac{3}{2}^-$	9.576
1684 ± 4	8 ± 2	0.025 ± 0.004	$\frac{7}{2}$	9.589
1768 ± 1.4	3.8 ± 0.4	1.2 ± 0.2	$\frac{3}{2}^+$	9.668
1928.4 ± 0.6 [d]	0.3 ± 0.05	2.8 ± 0.7	$\frac{5}{2}$	9.820
1986 ± 2	< 1.5	0.13 ± 0.04	$\frac{11}{2}^-$	9.875
1996 ± 4	26 ± 2	0.14 ± 0.05	$\frac{1}{2}^+$	9.884
2263.0 ± 0.7	5.0 ± 1.0		$\frac{3}{2}^-$	10.137
> 2300 [d]				

[a] Mostly from (80WI17). See Tables 19.15 in (78AJ03) and 19.16 in (83AJ01) for other early references. See also Tables 19.10 and 19.17.
[b] Supported by direct capture into this state with a $\sin^2\theta$ distribution of the d.c. γ-rays and by interference patterns near the resonance.
[c] Decays partly (see Table 19.10) via a state at 8015 ± 2 keV with $J^\pi = \frac{5}{2}^+$.
[d] See Table 19.15 in (78AJ03).
[e] $\Gamma_p = 0.17$ eV, $\Gamma_\alpha = 220$ eV, $\Gamma_\gamma = 1.3$ eV.
[f] $\Gamma_\gamma = 0.71 \pm 0.17$ eV, $\Gamma_p = 0.019 \pm 0.009$ eV, $\Gamma_\alpha = 46 \pm 19$ eV, $\Gamma_{total} = 47 \pm 19$ eV.
[g] $\Gamma_\gamma = 0.85 \pm 0.17$ eV, $\Gamma_p = 224 \pm 43$ eV, $\Gamma_\alpha = 3410 \pm 1220$ eV.
[h] The strength of the transition to ^{19}F* (7.62) [see Table 19.20] limits J to $\frac{1}{2}$ or $\frac{3}{2}$ for that state.
[i] The angular distribution of the γ-ray from this state to ^{19}F* (5.62) and branching ratio arguments lead to $J = \frac{5}{2}$ for that state.
[j] (82BE29).
[k] (90VO06).

Table 19.19
Resonances in $^{18}O(p, n)^{18}F$ [a])

E_p (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Res. in yield of [b])	J^π	E_x in ^{19}F (MeV)
2.643 ± 1.0	6.2 ± 0.5	n	$(\frac{3}{2})$	10.497
2.691 ± 1.0	2.5 ± 0.2	n		10.542
2.717 ± 1.5	5.2 ± 0.5	n		10.567
2.767 ± 1.5	4.7 ± 0.5	n	$\frac{5}{2}^{(+)}$	10.614
2.923 ± 4	6 ± 3	n		10.762
3.025 ± 2.0	24.0 ± 15	n	$\frac{3}{2}$	10.859
(3.08 ± 20)	≈ 60	n		(10.91)
3.148 ± 3	14 ± 2	n		10.975
3.164 ± 2.5	7 ± 2	n		10.990
3.250 ± 2.5	35 ± 4	n	$\frac{3}{2}$	11.072
3.370 ± 4	17 ± 4	n		11.185
3.463 ± 3	7 ± 2	n		11.273
3.470 ± 15	70 ± 20	n		11.280
3.653 ± 4	40 ± 10	n, n_1		11.453
3.680 ± 5	7 ± 3	n		11.479
3.705 ± 5	4 ± 2	n, n_1		11.502
3.748 ± 15	50 ± 15	n		11.543
3.775 ± 7	15 ± 10	n, n_2	$(T = \frac{3}{2})$	11.569
(3.79 ± 20)	60 ± 20	n		(11.58)
3.863 ± 4	45 ± 10	n, n_1		11.652
4.00		n_1, n_3		(11.78)
4.06 ± 10 [c])	< 50	n, n_1		11.84
4.11		n_1		(11.89)
4.16 ± 10	90	n, n_1		11.93
4.33		n_1, n_3		(12.09)
4.37 ± 10	100	n, n_1, n_2		12.13
4.47	50	n, n_1, n_2, n_3		12.23
4.58 ± 10 [d])		n_1		(12.33)
4.70		n_3		(12.44)
4.83		n_1, n_2, n_3		(12.57)
4.90		n_2		(12.63)
5.05 ± 10	200	n, n_1, n_2		12.78
5.10		n_1, n_2		(12.82)
5.20		n_2, n_3		(12.92)
5.35		n, n_1, n_2, n_3		13.06
5.47 ± 15	70	n, n_1		13.17
5.622 ± 15	30	n, n_1, n_2	$(T = \frac{3}{2})$	13.317
5.76		n_1, n_3		(13.45)
6.061 ± 15	50	n, n_1, n_2	$(T = \frac{3}{2})$	13.73

Table 19.19 (continued)
Resonances in $^{18}O(p, n)^{18}F$ [a])

E_p (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Res. in yield of [b])	J^π	E_x in ^{19}F (MeV)
6.60 ± 15	350	n		14.24
(6.70 ± 15)		n		(14.34)
7.17 ± 20	300	n		14.78
7.40 ± 20		n		15.00
(7.8)		n		(15.4)
(7.98)		n		(15.55)
8.19 ± 25	150	n		15.75
8.74 ± 25	200	n		16.27
9.30 ± 30		n		16.80

[a]) See Table 19.16 in (78AJ03) for the references.
[b]) n without subscript refers to total neutron yield.
[c]) Errors here and below are estimated from published data of (64BA16) by H.B. Willard, private communication to Fay Ajzenberg-Selove.
[d]) See also (82DI11).

14 MeV. Observed resonances are shown in Table 19.20. For polarization measurements see (82GL08; E_p = 800 MeV). See also (87AJ02) and (89PLZV).

Coupled-channel analyses of cross section and analyzing power data for E_p = 398–697 MeV were carried out by (88DE31). A Dirac optical model analysis for E_p = 800 MeV was reported by (90PH02).

29. $^{18}O(p, t)^{16}O$ $Q_m = -3.706$ $E_b = 7.994$

For polarization measurements at E_p = 90 MeV see (86VO10) and see (78AJ03). See also the tables of astrophysical reaction rates (83HA1B, 85CA41) and a study of the effect of electron screening on low energy fusion cross sections (87AS05).

30. $^{18}O(p, \alpha)^{15}N$ $Q_m = 3.980$ $E_b = 7.994$

Yield measurements have been studied for E_p = 72 keV to 14 MeV: see (72AJ02, 83AJ01, 87AJ02): observed resonances are displayed in Table 19.20. Use of the resonance at E_p = 150 keV for ^{18}O depth profiling is discussed in (91BA54).

31. $^{18}O(d, n)^{19}F$ $Q_m = 5.770$

Table 19.20

Energy levels of ^{19}F from ^{18}O(p, p)^{18}O and ^{18}O(p, α)^{15}N [a])

E_p (MeV ± keV)	Γ_{lab} (keV)	Particles out	Γ_p [b]) (keV)	Γ_α [b]) (keV)	J^π	E_x (MeV)
0.095 ± 3 [c])	≤ 3	α_0				8.084
0.152 ± 1 [c])	≤ 0.5	α_0				8.138
0.216 ± 1 [c])	≤ 1	α_0				8.199
0.334 ± 1 [c])	≤ 1	α_0				8.310
0.6326 ± 0.4 [c])	2.1 ± 0.1	p_0, α_0	0.065 ± 0.006	2.0 ± 0.2	$\frac{3}{2}^-$	8.5933
≈ 0.695 [c])	≈ 340	p_0, α_0	5 [d])	95 [d])	$\frac{1}{2}^+$	8.65
0.846 ± 1.5 [c,g])	47 ± 1	p_0, α_0	26 ± 1.5	21 ± 1	$\frac{1}{2}^+$; $T = \frac{3}{2}$	8.795
0.9870 ± 0.7	3.8 ± 0.2	p_0, α_0	0.080 ± 0.007	3.7 ± 0.3	$\frac{3}{2}^-$	8.929
(1.135)	140					(9.069)
1.1685 ± 0.5	0.60 ± 0.03	p_0, α_0	0.005 ± 0.0006	0.595 ± 0.08	$\frac{7}{2}^+$	9.1007
1.2390 ± 1	6.1 ± 0.3	p_0, (α_0)	0.40 ± 0.03	5.7 ± 0.4	$\frac{1}{2}^+$	9.167
1.4025 ± 1	5.2 ± 0.2	p_0, α_0	0.23 ± 0.02	5.0 ± 0.4	$\frac{1}{2}^+$	9.322
1.620 ± 6	30	p_0, α_0			$(\frac{5}{2})$	9.528
1.668 ± 6	27	p_0, α_0			$\frac{3}{2}$	9.574
1.766 ± 3	3.6	p_0, α_0	2.1	1.5	$\frac{3}{2}^+$	9.666
1.928 ± 3	0.16	p_0, α_0	0.09	0.07	$(\frac{5}{2}, \frac{7}{2})^-$	9.820
2.001 ± 4	31	p_0, α_0	12	19	$\frac{1}{2}^+$	9.889
2.2630 ± 0.7	5.0 ± 1.0	α_0, α_1, α_2	≈ 5	0.004 [c])	$\frac{3}{2}^-$	10.137
2.289 ± 3	33	p_0, α_0	2.3	(1.0)	$\frac{1}{2}^+$	10.162
2.363 ± 3	4.5	p_0, α_0	2.8	1.7	$\frac{1}{2}^+$	10.232
2.387 ± 3	24	p_0, α_0	11	13	$\frac{3}{2}^+$	10.254
2.443 ± 4	9.7	p_0, α_0	5.2	4.5	$\frac{3}{2}^+$	10.308
2.644 ± 3	4.6	p_0, p_1, α_0, α_{1+2}	2.4	(1.0)	$\frac{3}{2}^+$	10.498
2.705 ± 3	8 ± 2	p_1, α_0			$\frac{3}{2}^{(+)}$; ($T = \frac{3}{2}$)	10.556
2.732 ± 4	23 ± 3	p_1, α_0			$(\frac{5}{2}^+)$	10.581
2.768 ± 3	4.0	p_0, p_1, α_0, α_{1+2}	0.7	(1.0)	$\frac{5}{2}^+$; $T = \frac{3}{2}$ [a])	10.615
2.925 ± 3	5.7	p_0, p_1, α_0, α_{1+2}	4.5	1.2	$\frac{1}{2}^-$	10.764
3.029 ± 4	19.5	p_0, p_1, α_0, α_{1+2}	13.0		$\frac{5}{2}^+$	10.862
(3.06)		α_0				(10.89)
3.148 ± 4	(14)	p_0, p_1, α_0, α_{1+2}	(4.5)	(4.5)	$(\frac{3}{2}, \frac{5}{2})^+$	10.975
3.266 ± 9	35	p_0, p_1, α_0, α_{1+2}			$\frac{1}{2}^+$	11.087
3.386 ± 9	20	p_0, p_1, α_0, α_{1+2}			$(\frac{1}{2}^-)$	11.200
3.479 ± 8	23 ± 5	p_0, p_1, α_0, α_{1+2}	4.3 ± 1		$\frac{5}{2}^+$	11.288
3.547 ± 25	286 ± 33	p_0	241 ± 2		$\frac{1}{2}^+$	11.35
3.643 ± 9	40 ± 7	p_0, (α_{1+2})	17 ± 3		$\frac{1}{2}^-$	11.444
3.694 ± 9	29 ± 6	p_0, p_1, α_0, (α_{1+2})	12 ± 2		$\frac{3}{2}^-$	11.492
3.744 ± 8	23 ± 5	p_0, p_1, α_0	3.7 ± 1		$\frac{5}{2}^+$	11.539
3.811 ± 12	66 ± 7	p_0	30 ± 12		$\frac{3}{2}^-$	11.603
3.869 ± 8	28 ± 7	p_0, p_1, (α_{1+2})	12 ± 2		$\frac{3}{2}^+$; ($T = \frac{3}{2}$)	11.658
4.290 ± 30	75 ± 25	p_0, α_0, α_{1+2}	10 ± 3		$\frac{1}{2}^-$	12.06

Table 19.20 (continued)
Energy levels of ^{19}F from ^{18}O(p, p)^{18}O and ^{18}O(p, α)^{15}N [a]

E_p (MeV ± keV)	Γ_{lab} (keV)	Particles out	Γ_p [b] (keV)	Γ_α [b] (keV)	J^π	E_x (MeV)
4.390 ± 15	110 ± 15	p_0, p_1, (α_0, α_{1+2})	60 ± 10		$\frac{3}{2}^-$; $T = \frac{3}{2}$	12.151
4.465 ± 12 [c]	78 ± 1	p_0, p_1, α_0, α_{1+2}	48 ± 6		$\frac{3}{2}^+$	12.222
4.782 ± 7 [e]	16 ± 4	p_0, p_1	2.4 ± 1		$\frac{1}{2}^-$	12.522
4.840 ± 10	50 ± 10	p_0, p_1, α_{1+2}	6.4 ± 2		$\frac{5}{2}^+$	12.577
4.848 ± 25	300 ± 15	p_0	80 ± 25		$\frac{1}{2}^-$; $T = \frac{3}{2}$	12.58
5.074 ± 30	100 ± 40	p_0, p_1, $\alpha_{(0)}$	13 ± 5		$\frac{5}{2}^+$; $T = \frac{3}{2}$	12.80
5.135 ± 30	290 ± 40	p_0, p_1	114 ± 17		$\frac{3}{2}^+$; $T = \frac{3}{2}$	12.86
5.225 ± 25	75 ± 25	p_0, p_1, α_{1+2}	3 ± 1.5		$\frac{5}{2}^+$	12.94
5.27 ± 50	130 ± 40	p_0	20 ± 8		$\frac{1}{2}^-$	12.98
5.38 ± 75	300 ± 75	p_0	75 ± 25		$\frac{3}{2}^-$	13.09
5.622 ± 8 [e]	30 ± 6	p_0, p_1, α_0, α_{1+2}	10 ± 3		$\frac{7}{2}^-$	13.317
5.670 ± 25	40 ± 20	p_0	2 ± 2		$\frac{3}{2}^-$	13.36
6.060 ± 11	55 ± 10	p_0, p_1, (α_{1+2})	13 ± 3		$\frac{7}{2}^-$; $T = \frac{3}{2}$	13.732
6.390 ± 20 [f]	148 ± 30	p_0	12 ± 3		$\frac{5}{2}^+$	14.04
6.428 ± 30	88 ± 30	p_0	8 ± 3		$\frac{3}{2}^-$	14.08
6.687 ± 20	80 ± 30	p_0	9 ± 3		$\frac{3}{2}^-$	14.33
7.080 ± 20	130 ± 40	p_0	21 ± 5		$\frac{3}{2}^-$	14.70
7.10 ± 70	270 ± 70	α_0			$\frac{1}{2}^-$	14.72
7.125 ± 50	380 ± 70	p_0, α_0	100 ± 25		$\frac{1}{2}^+$	14.74
7.167 ± 40	210 ± 50	p_0	21 ± 6		$\frac{5}{2}^+$	14.78
7.337 ± 40	208 ± 30	p_0	20 ± 4		$\frac{7}{2}^-$	14.94
7.775 ± 20	70 ± 10	p_0	6 ± 2		$\frac{1}{2}^-$	15.36
7.820 ± 30	84 ± 25	p_0	7 ± 2		$\frac{5}{2}^+$	15.40
8.282 ± 40	102 ± 25	p_0	8 ± 3		$\frac{3}{2}^-$	15.83
8.670 ± 40	180 ± 30	p_0	16 ± 4		$\frac{3}{2}^+$	16.20
8.695 ± 30	234 ± 40	p_0	13 ± 4		$\frac{7}{2}^-$	16.23
8.747 ± 30	176 ± 30	p_0	13 ± 4		$\frac{3}{2}^-$	16.28
9.563 ± 40	348 ± 70	p_0	39 ± 8		$\frac{3}{2}^-$	17.05
9.679 ± 40	340 ± 70	p_0	30 ± 8		$\frac{7}{2}^-$	17.16
9.986 ± 30	34 ± 20	p_0	3 ± 2		$\frac{3}{2}^-$	17.45
10.200 ± 60	100 ± 60	p_0	5 ± 3		$\frac{7}{2}^-$	17.65
10.496 ± 40	268 ± 60	p_0	23 ± 5		$\frac{3}{2}^-$	17.93
10.596 ± 60	384 ± 60	p_0	32 ± 7		$\frac{7}{2}^-$	18.03
11.698 ± 60	584 ± 150	p_0	22 ± 7		$\frac{3}{2}^-$	19.07
12.499 ± 150	388 ± 60	p_0	13 ± 6		$\frac{5}{2}^-$	19.83
12.547 ± 40	498 ± 60	p_0	39 ± 8		$\frac{3}{2}^-$	19.87
13.542 ± 50	434 ± 60	p_0	32 ± 5		$\frac{1}{2}^-$	20.81
13.662 ± 50	334 ± 50	p_0	12 ± 4		$\frac{3}{2}^-$	20.93
13.791 ± 40	472 ± 30	p_0	25 ± 5		$\frac{7}{2}^-$	21.05

Table 19.20 (continued)
Energy levels of ^{19}F from ^{18}O(p, p)^{18}O and ^{18}O(p, α)^{15}N [a])

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[a]) See also Tables 19.14 in (72AJ02) and 19.17 in (78AJ03) for the earlier work and references.
[b]) See also Table 19.18.
[c]) (p, α) resonance strengths from (79LO01) are as follows (E_p (MeV±keV): Resonance strength (eV)): (0.095±3: $(1.6 \pm 0.5) \times 10^{-7}$), (0.152 ± 1: 0.17 ± 0.02), (0.216 ± 1: $(2.3 \pm 0.6) \times 10^{-3}$), (0.334 ± 1: 0.057 ± 0.010), (0.629 ± 2: 420 ± 80), (≈ 0.695: $\approx 1.22 \times 10^5$), (0.846 ± 1.5: $4.1 \pm 1.0) \times 10^4$).
[d]) Widths not in accord with Γ measured by (79LO01).
[e]) See (82DI11). A resonance at $E_p = 4.58$ MeV in the p channel is also reported. It is suggested that the states corresponding to $E_x = 12.33$, 12.52, and 13.32 MeV have $T = \frac{3}{2}$ and $J^\pi = (\frac{3}{2}^+)$, $\frac{5}{2}^{(+)}$ and $\frac{3}{2}^-$, respectively.
[f]) The parameters of this resonance and most of the ones below are from a phase-shift analysis by (79MU05) of the elastic scattering for $E_p = 6.1$ to 16.6 MeV. Other structures have also been observed but parameters for those have not been obtained.
[g]) See also (86CO1F).

Angular distributions of neutron groups corresponding to ^{19}F states with $E_x < 8.2$ MeV have been measured at $E_d = 3$ and 4 MeV: see Table 19.18 in (78AJ03) and Table 19.21 here. See also the $E_d = 25$ MeV measurements of (92TEZY).

32. ^{18}O(^{3}He, d)^{19}F　　　　$Q_m = 2.500$

Angular distributions of the deuterons corresponding to many states of ^{19}F have been analyzed by DWBA: the results are shown in Table 19.21. Spectroscopic factors for population of $J^\pi = \frac{1}{2}^+, \frac{5}{2}^+, \frac{3}{2}^+$ levels at $E_x = 0$, 0.199, 1.554 MeV by (^{3}He, d) at E(^{3}He = 25 MeV have been deduced by (94VE04). The spectroscopic factors obtained for ^{19}F* (7.54, 8.80), the $T = \frac{3}{2}$, $J^\pi = \frac{5}{2}^+$ and $\frac{1}{2}^+$ analogs of ^{19}O* (0, 1.47) are in good agreement with those obtained for the ^{19}O states in the ^{18}O(d, p)^{19}O reaction: see (78AJ03). A search for a state at $E_x = 7.90$ MeV [just below the ^{18}O + p threshold, and of astrophysical interest] has been unsuccessful: $\theta_p^2 < 5 \times 10^{-5}$ (86CH29). See also (87AJ02).

33. ^{18}O(α, t)^{19}F　　　　$Q_m = -11.820$

Cross sections were measured at $E_\alpha = 65$ MeV and analyzed with DWBA (92YA08). Spin-parity and isospin assignments were proposed. Spectroscopic factors were obtained and compared with shell-model calculations. See Table 19.22.

34. ^{19}O($\beta-$)^{19}F　　　　$Q_m = 4.819$

Table 19.21
Energy levels of ^{19}F from ^{18}O(d, n)^{19}F and ^{18}O(^{3}He, d)^{19}F [a]

E_x [b]	l [b]	$C^2S(2J_f+1)$ [b]	J^π [b]
0	0	0.42 [a,f]	$\frac{1}{2}^+$
0.112 ± 3	1	0.224	$\frac{1}{2}^-$
0.199 ± 3	2	2.45 [a,f]	$\frac{5}{2}^+$
1.347 ± 5			
1.460 ± 5	1	0.098	$\frac{3}{2}^-$
1.5544 ± 0.6 [c]	2	1.01 [f]	$\frac{3}{2}^+$
2.784 ± 5	4	0.027	$\frac{9}{2}^+$
3.912 ± 5			
3.999 ± 1 [c]	(3)	(0.019)	$(\frac{7}{2}^-)$
4.036 ± 10			
4.3761 ± 0.8 [c]	(4)	(0.048)	$(\frac{7}{2}^+)$
4.5557 ± 0.5 [c]	2	0.31	[a]
4.684 ± 1 [c]			
5.113 ± 5 [a]	(2, 3)		$\frac{5}{2}^-, \frac{7}{2}^-$ [a]
5.34 ± 5	(2, 3)	0.0065	$\frac{5}{2}^+$
5.428 ± 8	(2, 3)	(0.042)	$(\frac{3}{2}^+)$
5.492 ± 5 [d]			
5.54 ± 5	3	0.14	$\frac{7}{2}^-$
5.625 ± 4			
5.943 ± 5	0	0.014	$\frac{1}{2}^+$
6.095 ± 5	1	0.12	$\frac{1}{2}^-$
6.167 ± 5			
6.255 ± 8	(0)	0.19 [a]	$\frac{1}{2}^+$ [a]
6.503 ± 5	2	0.133	$\frac{3}{2}^+$
6.595 ± 10			
6.792 ± 5	1	0.29 [a]	$\frac{3}{2}^-$
6.93 ± 5	(2, 3)		$(\frac{5}{2}^+, \frac{7}{2}^-)$
7.112 ± 8	2	0.087	$\frac{5}{2}^+$
7.26 ± 5			
7.364 ± 5	0	0.091	$\frac{1}{2}^+$
7.540 ± 3	2	0.665	$\frac{5}{2}^+; T=\frac{3}{2}$
7.665 ± 5	(2)	0.035 [a]	$(\frac{3}{2}^+)$
7.702 ± 5	(0, 1)	(0.052)	$(\frac{3}{2}^-)$
8.0140 ± 1.0 [e]	2	0.26	$\frac{5}{2}^+$
8.086 ± 5	(2, 3)	0.097	$(\frac{5}{2}^+)$
8.135 ± 5	(0, 1)	0.156	$\frac{1}{2}^+$ [a]
8.198 ± 5	(2, 3)	0.035	$(\frac{5}{2}^+)$
8.255 ± 5	(2)	0.035	$(\frac{5}{2}^+)$
8.31 ± 5 [e]	2		$\frac{5}{2}^+$

Table 19.21 (continued)
Energy levels of ^{19}F from ^{18}O(d, n)^{19}F and ^{18}O(^{3}He, d)^{19}F [a])

E_x [b])	l [b])	$C^2S(2J_f+1)$ [b])	J^π [b])
8.592 ± 10	(2, 3)		
8.795 ± 15	0	(0.13)	$\frac{1}{2}^+; T = \frac{3}{2}$
9.113 ± 10			
9.18 ± 15			
9.596 ± 10			
9.682 ± 15			
10.275 ± 15			
10.33 ± 15			
10.525 ± 15			

[a]) See also Table 19.18 in (78AJ03), in which column 3 should refer to footnote [c]).
[b]) ^{18}O(^{3}He, d): $E(^3\text{He}) = 16$ MeV, except where footnote is shown.
[c]) ^{18}O(d, nγ).
[d]) Many of the states with $E_x \geq 4.5$ MeV are unresolved: compare with Table 19.9.
[e]) ^{18}O(^{3}He, d): $E(^3\text{He}) = 26.4$ MeV (86CH29) (and A.E. Champagne, private communication to Fay Ajzenberg-Selove). $\theta_p^2 = 1.3 \times 10^{-2}$ and 7.4×10^{-4}, respectively for ^{19}F* (8.01, 8.31).
[f]) Spectroscopic factors for population of these levels by (^{3}He, d) at $E(^3\text{He}) = 25$ MeV were also determined by (94VE04).

Table 19.22
Energy levels of ^{19}F from ^{18}O(α, t)^{19}F [a]

E_x (MeV) [b]	J^π [b]	σ_{INT} (mb)
0	$\frac{1}{2}^+$	0.13
0.20	$\frac{5}{2}^+$	4.84
1.55	$\frac{3}{2}^+$	1.22
4.00	$\frac{7}{2}^-$	0.2
5.34	$\frac{1}{2}^{(+)}$ [a]	0.05
5.42	$\frac{7}{2}^-$	0.18
5.5	$\frac{3}{2}^+$	0.17
5.53	$\frac{5}{2}^+$	0.27
5.94	$\frac{1}{2}^+$	0.03
6.16	$\frac{7}{2}^-$	0.23
6.26	$\frac{1}{2}^+$	0.03
6.28	$\frac{5}{2}^+$	0.09
6.5	$\frac{3}{2}^+$	0.11
6.93	$\frac{7}{2}^-$	0.56
7.36	$\frac{1}{2}^+$	0.03
7.54	$\frac{5}{2}^+; T = \frac{3}{2}$	0.64
7.66	$\frac{3}{2}^+; T = \frac{3}{2}$	0.09
8.02	$\frac{5}{2}^+$	0.13
8.79	$\frac{1}{2}^+; T = \frac{3}{2}$	0.02
13.32	$\frac{7}{2}^-; T = \frac{3}{2}$ [a]	0.04
13.73	$\frac{7}{2}^-; T = \frac{3}{2}$	0.06

[a]) See Table II of (92YA08) for more complete information including experimental and calculated spectroscopic factors.
[b]) Cited from (87AJ02) except where noted.

Table 19.23
Branching in ^{19}O(β^-)^{19}F [a]

Decay to ^{19}F* (keV) [b]	J^π	Branch (%) [c]	log ft
0	$\frac{1}{2}^+$	≤ 4	≥ 6.5
110	$\frac{1}{2}^-$	$0.055^{+0.013}_{-0.038}$	$8.34^{+0.30}_{-0.10}$
197.143 ± 0.004	$\frac{5}{2}^+$	45.4 ± 1.5	5.384 ± 0.014
1346	$\frac{5}{2}^-$	0.017 ± 0.002	8.25 ± 0.05
1459	$\frac{3}{2}^-$	< 0.010	> 8.4
1554.038 ± 0.009	$\frac{3}{2}^+$	54.4 ± 1.2	4.625 ± 0.010
2779.849 ± 0.034	$\frac{9}{2}^+$	< 0.002	> 8.2
3908.17 ± 0.20	$\frac{3}{2}^+$	0.0081 ± 0.0005	6.133 ± 0.027
3999	$\frac{7}{2}^-$	< 0.001	> 6.9
4033	$\frac{9}{2}^-$	< 0.001	> 6.8
4377.700 ± 0.042	$\frac{7}{2}^+$	0.0984 ± 0.0030	3.859 ± 0.017
4550	$\frac{5}{2}^+$	< 0.001	> 5.1

[a]) (82OL02). See Table 19.19 in (78AJ03) for the earlier work.
[b]) For γ-ray branchings see Table 19.24.
[c]) β-branches and log ft's are calculated assuming 0% for the ^{19}O(β^-)^{19}F ground-state transition.

The decay is primarily by allowed transitions to ^{19}F* (0.197, 1.55), $J^\pi = \frac{5}{2}^+, \frac{3}{2}^+$. Very weak branches are also observed to ^{19}F* (0.11, 1.35, 3.91, 4.39), $J^\pi = \frac{1}{2}^-, \frac{5}{2}^-, \frac{3}{2}^+, \frac{7}{2}^+$: see Table 19.23. The half-life is 26.96 ± 0.07 sec: see reaction 1 in ^{19}O. The character of the allowed decay to the $\frac{5}{2}^+$ and $\frac{3}{2}^+$ states and the forbiddenness of the decay to the ground state of ^{19}F are consistent with $J^\pi = \frac{5}{2}^+$ for the ground state of ^{19}O, and with $(\frac{7}{2}^+)$ for ^{19}F* (4.39). Gamma-ray branching ratios are displayed in Table 19.24. See also (83AJ01, 85BR29).

35. ^{19}F(γ, n)^{18}F $\qquad Q_m = -10.431$

The cross section for (γ, Tn) has been measured for $E_\gamma = 10.5$ to 28 MeV: it shows a clear resonance at $E_\gamma \approx 12$ MeV and unresolved structures at higher energies: see (78AJ03). More recently, photoneutron angular distributions were measured by (89KU10) for $E_\gamma = 15$–25 MeV. E1 absorption strengths were deduced. An atlas of photoneutron cross sections is presented in (88DI02). See also (72AJ02, 87AJ02). A model for describing relative (γ, n) and (γ, p) yields is discussed in (86IS09).

36. (a) ^{19}F(γ, p)^{18}O $\qquad Q_m = -7.994$
(b) ^{19}F(γ, t)^{16}O $\qquad Q_m = -11.700$

Table 19.24
γ-ray intensities in $^{19}O(\beta^-)^{19}F$ [a])

E_γ (keV)	E_i (keV)	E_f (keV)	I_γ [b])
109.894 ± 0.005	110	0	2.54 ± 0.10
197.142 ± 0.004	197	0	95.9 ± 2.1
1149	1346	197	0.0005 [c])
1236	1346	110	0.017 ± 0.002
1356.843 ± 0.008	1554	197	50.4 ± 1.1
1444.085 ± 0.010	1554	110	2.64 ± 0.06
1553.970 ± 0.008	1554	0	1.39 ± 0.03
1597.780 ± 0.025	4378	2780	$(1.92 \pm 0.05) \times 10^{-2}$
2353.98 ± 0.26	3908	1554	$(1.81 \pm 0.23) \times 10^{-3}$
2582.517 ± 0.033	2780	197	$(1.89 \pm 0.05) \times 10^{-2}$
3710.64 ± 0.20	3908	197	$(1.10 \pm 0.15) \times 10^{-3}$
3797.87 ± 0.20	3908	110	$(1.33 \pm 0.14) \times 10^{-3}$
3907.74 ± 0.20	3908	0	$(3.84 \pm 0.17) \times 10^{-3}$
4180.063 ± 0.041	4378	197	$(7.92 \pm 0.17) \times 10^{-2}$

[a]) (82OL02).
[b]) γ-ray intensities are per 100 parent decays assuming 0% β-branch to the ground state.
[c]) Calculated assuming previously measured branching ratios.

(84KE04) have measured absolute differential cross sections for the p_0 and p_1 channels at 7 angles for $E_\gamma = 13.4$ to 25.8 MeV. Angle integrated cross sections for (γ, p_0) show pronounced structures at $E_\gamma = 15.45$, 16.70, 17.35, and 18.55 MeV as well as a broad bump at ≈ 20.5 MeV. Additional minor structures may exist at $E_\gamma = 13.65$, 14.35, 15.85, 17.90, 19.5, 21.3, 22.2, and 23.5 MeV. In the (γ, p_1) reaction broad bumps appear at $\approx$ (17.0) and 21.5 MeV. The E2 cross section [from (γ, p_0) angular distribution coefficients] is estimated to be ≈ 0.37 of the E2 EWSR (84KE04). The (γ, p_{tot}) cross section to 26 MeV has been derived by (85KE03). See also (78AJ03). A model for describing relative (γ, p) and (γ, n) yields is discussed in (86IS09).

In reaction (b) the (γ, t_0) reaction has been studied for $E_\gamma = 18$ to 23 MeV: two peaks are observed at $E_\gamma = 18.8$ and 20.1 MeV. It is suggested that $J^\pi = \frac{1}{2}^-$ or $\frac{3}{2}^-$, $T = \frac{1}{2}$. The (γ, t_0) process contributes ≈ 1 % to the total GDR strength: see (78AJ03).

37. $^{19}F(\gamma, \gamma)^{19}F$

The energy of the first excited state is 109.894 ± 0.005 keV; its width is $(5.1 \pm 0.7) \times 10^{-7}$ eV. $^{19}F^*$ (1.46, 3.91, 7.66) are also excited. The scattering cross section is relatively small and structureless for $E_\gamma = 14$ to 30 MeV: see (78AJ03).

38. ^{19}F(μ^-, ν)

The time spectrum of gamma rays following muonic capture reactions on the ^{19}F muonic atom was measured by (93GO09). The hyperfine transition rates of muonic ^{19}F atoms were determined from these measurements. The hyperfine dependence of muon capture is related to the weak axial and pseudoscalar coupling in the nuclear medium.

39. ^{19}F(e, e$'$)^{19}F

With $E_{\mathrm{e}} = 78$ to 340 MeV, most states of ^{19}F below $E_{\mathrm{x}} = 7.7$ MeV have been observed with an energy resolution of 25–50 keV. Longitudinal and transverse form factors have been derived and compared with shell-model calculations. The spectrum of positive-parity longitudinal excitations is dominated at higher momentum transfer by the $\frac{1}{2}^+$, $\frac{3}{2}^+$, $\frac{5}{2}^+$, $\frac{7}{2}^+$ and $\frac{9}{2}^+$ members of the ground state $K^\pi = \frac{1}{2}^+$ band. The C2 strength is concentrated at $E_{\mathrm{x}} < 1.5$ MeV with a small secondary concentration for $5.5 < E_{\mathrm{x}} < 6.5$ MeV. The C4 strength is spread from 3 to 6 MeV, predominantly in ^{19}F* (2.78) [$J^\pi = \frac{9}{2}^+$]. The spectra of longitudinal excitations of negative parity states are dominated by ^{19}F* (1.35) [$J^\pi = \frac{5}{2}^-$] and ^{19}F* (5.5) [$\frac{5}{2}^- + \frac{7}{2}^-$]. In the transverse mode ^{19}F* (0.11, 6.79) [$J^\pi = \frac{1}{2}^-$, $\frac{3}{2}^-$, respectively] are prominent. Agreement with theory is good for $\frac{5}{2}^-$ and $\frac{7}{2}^-$ but poorer for $\frac{1}{2}^-$ and $\frac{3}{2}^-$ states. The parity of ^{19}F* (5.34) is uncertain while that of ^{19}F* (6.55) is probably positive. States are reported at 7.587 and 7.753 MeV with $J^\pi = (\frac{5}{2}^-)$ and $(\frac{7}{2}^-)$, respectively (85BR15). The form factors for ^{19}F* (0, 0.11, 2.78) have also been studied by (86DO10) for $q = 0.4$–2.8 fm^{-1}. Cross section measurements for ^{19}F states with $E_{\mathrm{x}} \leq 4.4$ MeV performed with $E_{\mathrm{e}} = 500$ MeV and momentum transfer $q = 1.4$–2.6 fm^{-1} were reported by (87DO10). Form factors were compared with shell model calculations. For electromagnetic transition rates see Table 19.25. For the earlier work see (78AJ03, 83AJ01, 87AJ02). See also (88BR1D).

40. ^{19}F(n, γ)^{20}F $\qquad Q_{\mathrm{m}} = 6.601$

Capture gamma rays were measured from broad neutron resonances in ^{19}F (91IG1A). Strong primary M1 transitions to low-lying ^{20}F states were observed.

41. (a) ^{19}F(n, n$'$)^{19}F
(b) ^{19}F(n, 2n)^{18}F $\qquad Q_{\mathrm{m}} = -10.431$
(c) ^{19}F(n, p)^{19}O $\qquad Q_{\mathrm{m}} = -4.037$
(d) ^{19}F(n, np)^{18}O $\qquad Q_{\mathrm{m}} = -7.994$
(e) ^{19}F(n, d)^{18}O $\qquad Q_{\mathrm{m}} = -5.770$
(f) ^{19}F(n, α)^{16}N $\qquad Q_{\mathrm{m}} = -1.523$

Table 19.25
Electromagnetic transition rates from ^{19}F(e, e′) [a]

E_x in ^{19}F (MeV)	J^π	Multipole	$\|M\|^2$ [b]
0.110	$\frac{1}{2}^-$	C1	$(5.5 \pm 0.6) \times 10^{-4}$
0.197	$\frac{5}{2}^+$	C2	62.8 ± 0.7
1.46	$\frac{3}{2}^-$	C1	$(9 \pm 2) \times 10^{-4}$
1.55	$\frac{3}{2}^+$	M1	0.15 ± 0.09
3.91	$\frac{3}{2}^+$	M1	0.43 ± 0.25
4.56	$\frac{3}{2}^-$	C1	$(2.8 \pm 2.3) \times 10^{-4}$
5.34	$\frac{1}{2}^+$	M1	0.34 ± 0.05
	$\frac{1}{2}^-$	C1	$(3.8 \pm 0.5) \times 10^{-3}$
5.50	$\frac{3}{2}^+$	M1	0.025
6.09	$\frac{3}{2}^-$	C1	$(4.7 \pm 1.3) \times 10^{-3}$
6.28	$\frac{5}{2}^+$	C2	17 ± 6
6.79	$\frac{3}{2}^-$	C1	$(5.0 \pm 1.3) \times 10^{-3}$
		M2	87 ± 42
7.66	$\frac{3}{2}^+; T = \frac{3}{2}$	M1	0.26 ± 0.08

[a]) (85BR15). See Table 19.20 in (78AJ03) for the earlier work. P.M. Endt (private communication to Fay Ajzenberg-Selove) adopts $|M|^2 = 8.9 \pm 0.5$ (C3), 6.9 ± 0.5 (C2) and 6.1 ± 2.4 W.u. (M5) for the ground state transitions of ^{19}F* (1.35, 1.55, 2.78). See (93EN03).
[b]) B(C1) in units of $e^2 \cdot \mathrm{fm}^2$, B(M1) in units of μ_N^2, B(C2) in units of $e^2 \cdot \mathrm{fm}^4$ and B(M2) in units of $\mu_N^2 \cdot \mathrm{fm}^2$. These are for transitions from the ground state.

Angular distributions of neutron groups from elastic and inelastic scattering have been reported at $E_n = 2.6$, 14.1 and 14.2 MeV: see (72AJ02). Neutron activation cross sections for reactions (b, c, d, f) were measured for $E_n = 13.4$–14.9 MeV by (92KA1G). Reaction (e) is included in a review of (n, d) reactions for $E_n = 14$–15 MeV by (93AT04). Nuclear model codes are used to calculate neutron induced reactions on ^{19}F for $E_n = 2$–20 MeV by (92ZH15). See also (89HO1H).

42. (a) ^{19}F(p, p′)^{19}F
(b) ^{19}F(p, X)

Table 19.21 in (78AJ03) displays energy levels of ^{19}F derived from inelastic proton scattering. Angular distributions of various proton groups have been measured from $E_p =$ 4.3 to 35.2 MeV [see (78AJ03, 83AJ01)] and at $E_p = 2.76$ and 2.97 MeV (86OU01). The ground-state rotational band is characterized by $\beta_2 = 0.44 \pm 0.04$, $\beta_4 = 0.14 \pm 0.04$. The gyromagnetic ratio of ^{19}F* (0.197) is $g = 1.442 \pm 0.003$ (69BL18), 1.438 ± 0.005 (84AS03). The mixing ratio for the $1.46 \rightarrow 0.11$ transition ($\frac{3}{2}^- \rightarrow \frac{1}{2}^-$; $K = \frac{1}{2}^-$ band) δ(E2/M1) $= 0.248 \pm 0.020$. The E2 strength is 18.7 ± 1.9 W.u. The $1.46 \rightarrow 0$ transition is pure E1 ($\delta = 0.01 \pm 0.03$). For references see (83AJ01). See also ^{20}Ne in (87AJ02). A study of Coulomb excitation by protons and antiprotons is discussed in (93PI10). A discussion of the need for (p, p) cross-section data in thin-film analyses by Rutherford backscattering is presented in (93BO40).

Experimental and theoretical studies of nucleon and cluster knockout by $E_p = 30$–150 MeV protons are reviewed in (87VD1A). See also (88BA83). The reactions ^{19}F(p, p′γ) and ^{19}F(p, $\alpha\gamma$) were used in a study of proton-induced gamma ray emission spectroscopy to determine flourine concentration in materials by (92ZS01).

43. ^{19}F(p, $\alpha\gamma$)^{16}O $\qquad Q_m = 8.114$

This reaction is discussed in detail under ^{20}Ne in (87AJ02); resonances are displayed in Tables 20.24, 20.25, and 20.27. A recent measurement of the excitation function for $E_p = 0.3$–3.0 MeV is reported in (93DA1L). The absolute yield, angular distribution, and resonance width of photons from the 340.5 keV resonance was measured by (91CR06). Tests of a new standard for flourine determination utilizing this reaction are described in (92ZS01). See also the related work of (94TA1B). An accelerator calibration procedure utilizing ^{19}F(p, $\alpha\gamma$) is discussed in (93LA1E). See also (94BA1V). A DWBA analysis for energies below the Coulomb barrier is presented in (91HE16).

44. ^{19}F(d, p)^{20}F $\qquad Q_m = 4.377$

This reaction is discussed under ^{20}F in (87AJ02). A recent measurement of the ^{20}F half life utilizing this reaction was reported in (92WA04).

45. ^{19}F(d, d$'$)^{19}F

Angular distributions have been measured for $E_{\rm d}$ = 2.0 to 15 MeV: see (72AJ02, 78AJ03).

46. ^{19}F(t, t$'$)^{19}F

Elastic angular distributions have been studied for $E_{\rm t} = 2$ and 7.2 MeV: see (72AJ02). More recently, differential cross sections were measured at $E_{\rm t} = 33$ MeV and analyzed with a phenomenological optical model (87EN06).

47. ^{19}F(t, ^{3}He)^{19}O $\qquad$ $Q_{\rm m} = -4.800$

See reaction 12 of ^{19}O.

48. ^{19}F(^{3}He, ^{3}He$'$)^{19}F

Elastic angular distributions have been measured for $E(^{3}{\rm He})$ = 4.0 to 29 MeV [see (72AJ02, 78AJ03)] and at 25 MeV (82VE13). $\langle r^2\rangle^{1/2}_{\rm matter} = 2.72 \pm 0.12$ fm (82VE13). A strong-absorption model analysis for $E(^{3}{\rm He}) = 25$ and 41 MeV is presented in (87RA36).

49. ^{19}F(α, α')^{19}F

Elastic angular distributions have been studied at E_α = 19.9 to 23.3 MeV and at 38 MeV: see (72AJ02) and more recently at 50 MeV (91FR02). Many inelastic groups have also been studied: see Table 19.22 in (78AJ03). Differential cross sections for ^{19}F levels at $E_{\rm x} = 0.20$, 1.55, and 2.78 MeV were measured at $E_\alpha = 50$ MeV by (91FR02) and analyzed in a coupled-channels approach. See also (88LE05) in which the alpha-particle strength function distribution for targets with $12 \leq A \leq 40$ is discussed.

The energy of the γ-ray from the 1.35 $\rightarrow$ 0.11 transition is 1235.8 ± 0.2 keV; $E_{\rm x}$ is then 1345.7 ± 0.2 keV. $|g| = 0.269 \pm 0.043$ (83BI03). See also Table 19.10. For $\tau_{\rm m}$ see Table 19.11. ^{19}F* (4.65) decays to the $\frac{9}{2}^+$ state ^{19}F* (2.78): the angular distribution of the cascade γ-rays and $\tau_{\rm m}$ for ^{19}F* (4.65) indicate $J^\pi = \frac{13}{2}^+$. See also (83AJ01, 87AJ02).

50. (a) ^{19}F(^{6}Li, ^{6}Li$'$)^{19}F
(b) ^{19}F(^{7}Li, ^{7}Li$'$)^{19}F

See (78AJ03).

51. (a) ^{19}F(^{12}C, ^{12}C$'$)^{19}F
(b) ^{19}F(^{12}C, ^{12}C$'$)^{19}F* $\rightarrow \alpha +$ ^{15}N $\qquad Q_m = -4.014$

Angular distributions (reaction (a)) have been studied at $E(^{12}$C) = 40.6 MeV [see (83AJ01)] and at 30.0 to 60.1 MeV [as well as at $E(^{19}$F) = 63.8 MeV] (84TA08, 86TAZO; to ^{19}F* (0, 0.197, 1.55, 2.78)) and at $E(^{19}$F) = 46.5 to 57.1 MeV (84MA32; to ^{19}F* (0, 0.197)) [see (84MA32, 86VO12) for yield measurements] and at $E(^{12}$C = 30, 40, 50, 60 MeV (88TA12) to ^{19}F* (0.197, 1.554, 2.780 MeV). Measurements of evaporation residues at $E(^{19}$F) = 32–72 MeV were reported in (90AN14). See also (90XE01).

Angular correlations involving the α-decay to ^{15}N$_{\rm g.s.}$ of twenty ^{19}F states have been measured at $E(^{19}$F) = 78.5, 82 and 144 MeV and analyzed with DWBA and strong absorption model calculations. Two new states with $J^\pi = \frac{5}{2}^-$ or $\frac{7}{2}^-$ are reported at 7.740 and 8.277 MeV [estimated $\pm$ 0.04 MeV]. It is suggested that ^{19}F* (7.26, 9.287) are $\frac{3}{2}^+$ and $(\frac{7}{2}, \frac{9}{2})^+$, respectively (85SM04, 87AJ02). See also (83AJ01), and see the more recent application of molecular orbital theory to heavy ion scattering in (88DI08).

52. (a) ^{19}F(^{14}N, ^{14}N$'$)^{19}F
(b) ^{19}F(^{15}N, ^{15}N$'$)^{19}F

Elastic scattering angular distributions have been studied at $E(^{14}$N) = 19.5 MeV and at $E(^{15}$N) = 23, 26, and 29 MeV: see (83AJ01). See also the analysis of (89HO1H).

53. (a) ^{19}F(^{16}O, ^{16}O$'$)^{19}F
(b) ^{19}F(^{18}O, ^{18}O$'$)^{19}F

Elastic angular distributions have been studied at $E(^{16}$O) = 21.4 and 25.8 MeV and at $E(^{19}$F) = 27, 30, 33, and 36 MeV (reaction (a)) [also to ^{19}F* (1.46) at the two higher energies], and $E(^{16}$O) = 60 and 80 MeV (86FUZV; also to ^{19}F* (0.20, 1.55, 2.78)). See also the measurements of evaporation residue at $E(^{19}$F) = 32–72 MeV reported in (89AN1D, 90AN14). For reaction (b) at $E(^{18}$O) = 27, 30, 33 MeV, see (78AJ03) and at $E(^{18}$O) = 10–16 MeV, see (90XE01). See also (87AJ02).

54. ^{19}F(^{23}Na, ^{23}Na$'$)^{19}F

See (83AJ01, 87AJ02).

55. ^{19}F(^{24}Mg, ^{24}Mg′)^{19}F

See (83AJ01, 87AJ02). A dynamical model analysis of deep inelastic interaction is reported in (89BR14).

56. (a) ^{19}F(^{27}Al, ^{27}Al′)^{19}F
(b) ^{19}F(^{28}Si, ^{28}Si′)^{19}F
(c) ^{19}F(^{30}Si, ^{30}Si′)^{19}F

See (83AJ01, 87AJ02). Evaporation residues were measured for reaction (a) with $E_{\rm lab}(^{19}{\rm F}) = 32$–$72$ MeV and are reported in (89AN1D, 90AN14). See also (89NI1D).

57. ^{19}F(^{40}Ca, ^{40}Ca′)^{19}F

For fusion cross sections see (85RO01). See also (87AJ02). Measurements of evaporation residue for $E_{\rm lab}(^{19}{\rm F}) = 32$–$72$ MeV are reported in (89AN1D, 90AN14). A parametrization of measured fusion-evaporation residue excitation functions is described in (88DO07). See also the comment (89FR05) on this work and the reply (89DO03). See also (90SC18).

58. ^{19}Ne(β^+)^{19}F $\qquad Q_{\rm m} = 3.238$

See reaction 1 of ^{19}Ne.

59. ^{20}Ne(d, ^{3}He)^{19}F $\qquad Q_{\rm m} = -7.350$

See (78AJ03).

60. ^{20}Ne(t, α)^{19}F $\qquad Q_{\rm m} = 6.970$

See Table 19.23 in (78AJ03).

61. ^{21}Ne(p, ^{3}He)^{19}F $\qquad Q_{\rm m} = -11.887$

^{3}He groups are observed at $E_p = 45$ MeV leading to some $T = \frac{1}{2}$ states in ^{19}F and to ^{19}F* (7.66), the $\frac{3}{2}^+$; $T = \frac{3}{2}$ analog of ^{19}O* (0.095): see reaction 15 in ^{19}Ne and (78AJ03).

62. ^{22}Ne(p, α)^{19}F $\qquad Q_m = -1.673$

The parity violating asymmetry of the 110 keV γ-rays emitted by polarized ^{19}F* nuclei is $A_\gamma = -(6.8 \pm 2.1) \times 10^{-5}$ (82EL08, 87EL03). See also (78AJ03).

63. ^{22}Na(n, α)^{19}F $\qquad Q_m = 1.951$

Cross sections have been measured at thermal energies and reported in (88KO25, 89KO16). See also (88CA1N).

64. ^{23}Na(n, nα)^{19}F $\qquad Q_m = -10.468$

An evaporation-model calculation of the cross section for this reaction at $E_n = 12.6$–19.9 MeV was reported in (91ZH19). See also (78AJ03).

65. ^{23}Na(d, ^{6}Li)^{19}F $\qquad Q_m = -8.993$

See (84NE1A).

^{19}Ne

(Figs. 19.3 and 19.4)

GENERAL: See Table 19.26.

$$\mu_{g.s.} = -1.88542\ (8)\ \text{n.m.}\ (82MA39)$$
$$\mu_{0.239} = -0.740\ (8)\ \text{n.m.}\ (78LEZA)$$

1. ^{19}Ne(β^+)^{19}F $\qquad Q_m = 3.238$

Table 19.26
^{19}Ne – General

Reference	Description
	Nuclear Properties
Reviews:	
89RA17	Compilation of exp. data on nuclear moments for ground & excited states of nucl.
93EN03	Strengths of gamma-ray transitions in $A = 5$–44 nuclei
Other articles:	
87BR30	Empirically optimum M1 operator for sd-shell nuclei
89RA1G	Spin-isospin response in nuclei & nuclear structure implications
90SK04	$A = 18$ nuclei, effective interaction in the sd shell (also calc. $A = 19$ energy spectra)
91SAZX	Meas. β asymmetry of first forbidden branch of ^{19}Ne decay; parity violation (A)
92AV03	The proton neutron interaction and masses of nuclei with $Z > N$
	Astrophysics
Reviews:	
93HA1D	Core-collapse supernovae & other topics that combine nuclear, particle and astrophysics
93SO13	Methods for producing unstable nuclei; also review of major explosive stellar processes
Other articles:	
87BU12	Proposal for ISOL/post-accelerator facility for nuclear astrophysics at TRIUMF
87RA1D	Nuclear processes & accelerated particles in solar flares
88CA1N	Analytic expressions for thermonuclear reaction rates involving $Z \leq 14$ nuclei
88WO1C	Supernova neutrinos, neutral currents & the origin of fluorine
90TH1C	Explosive nucleosynthesis in SN 1987A: composition, radioactivities, neutron star mass
91RY1A	Detecting solar boron neutrinos with Cerenkov and scintillation detectors
92GO10	Beta-delayed proton decay of ^{20}Mg and its astrophysical implications
93BR12	Nature of the ^{20}Na 2646-keV level and the stellar reaction rate for ^{19}Ne(p, γ)^{20}Na
93UTZZ	^{19}Ne and breakout from the hot CNO cycle (A)
	Other Topics
Reviews:	
89MO1J	Theoretical ideas beyond the standard model of weak, electromag. & strong interactions
89TA1O	On the possible use of secondary radioactive beams
Other articles:	
87BU07	Projectile-like fragments from ^{20}Ne + ^{197}Au – counting simultaneously emitted neutrons
89AR1J	Production & acceleration of radioactive ion beams at Louvain-la-Neuve
89BA2N	Evaluation of hypernucleus production cross-sections in relativistic heavy-ion collisions
89MC1C	Nuclear tests of fundamental interactions
89SA1H	Second class currents & neutrino mass in mirror transitions
90FO04	One-nucleon-transfer reactions induced by ^{20}Ne at 500 and 600 MeV
91NA05	Left-right symmetry breaking sensitivity of β-asymmetry measurements
92CA12	Possible indication for existence of right-handed weak currents in nuclear beta decay
92HE12	First forbidden β-decays as a probe of T-odd nuclear forces
93CA1K	Tests of time-reversal invariance in nuclear beta decay of polarized ^{19}Ne (A)
93EV01	Diffraction model analysis of the high-energy spectra of particles in transfer reactions
93SE1B	Weak vector coupling from neutron β-decay & indications for right-handed currents

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

Table 19.27
Energy levels of ^{19}Ne [a])

E_x (MeV ± keV)	$J^\pi; T$	K^π	τ_m or $\Gamma_{c.m.}$	Decay	Reactions
0	$\frac{1}{2}^+; \frac{1}{2}$	$\frac{1}{2}^+$	$[\tau_{1/2} = 17.22 \pm 0.02$ s]	β^+	1, 3, 4, 5, 7, 9, 10, 11, 13, 14
0.23827 ± 0.11	$\frac{5}{2}^+$	$\frac{1}{2}^+$	$\tau_m = 26.0 \pm 0.8$ ns [$g = -0.296 \pm 0.003$]	γ	4, 5, 7, 10, 11, 13, 14
0.27509 ± 0.13	$\frac{1}{2}^-$	$\frac{1}{2}^-$	$\tau_m = 61.4 \pm 3.0$ ps	γ	4, 5, 7, 10, 13
1.50756 ± 0.3	$\frac{5}{2}^-$	$\frac{1}{2}^-$	$\tau_m = 1.4^{+0.5}_{-0.6}$ ps	γ	4, 5, 7, 10, 13
1.5360 ± 0.4	$\frac{3}{2}^+$	$\frac{1}{2}^+$	$\tau_m = 28 \pm 11$ fs	γ	4, 5, 7, 10, 11, 13
1.6156 ± 0.5	$\frac{3}{2}^-$	$\frac{1}{2}^-$	$\tau_m = 143 \pm 31$ fs	γ	4, 5, 7, 10, 13
2.7947 ± 0.6	$\frac{9}{2}^+$	$\frac{1}{2}^+$	$\tau_m = 140 \pm 35$ fs	γ	4, 5, 6, 7, 9, 10, 11, 13, 14
4.0329 ± 2.4	$\frac{3}{2}^+$		$\tau_m < 50$ fs	α, γ	2, 5, 8, 13, 14
4.140 ± 4	$(\frac{9}{2})^-$	$(\frac{1}{2}^-)$	$\tau_m < 0.3$ ps	γ	5, 8, 13
4.1971 ± 2.4	$(\frac{7}{2})^-$	$(\frac{1}{2}^-)$	$\tau_m < 0.35$ ps	γ	4, 5, 8, 13
4.3791 ± 2.2	$\frac{7}{2}^+$	$(\frac{1}{2}^+)$	$\tau_m < 0.12$ ps	α, γ	2, 5, 8, 13
4.549 ± 4	$(\frac{1}{2}, \frac{3}{2})^-$		$\tau_m < 80$ fs	α, γ	2, 5, 8, 13
4.600 ± 4	$(\frac{5}{2}^+)$		$\tau_m < 0.16$ ps	γ	2, 5, 8
4.635 ± 4	$\frac{13}{2}^+$	$\frac{1}{2}^+$	$\tau_m > 1$ ps	γ	4, 5, 6, 7, 8, 9, 13
4.712 ± 10	$(\frac{5}{2}^-)$			α	2, 5
4.783 ± 20					13
5.092 ± 6	$\frac{5}{2}^+$			α, γ	2, 5, 8, 13, 14
5.351 ± 10	$\frac{1}{2}^+$				13
5.424 ± 7	$(\frac{7}{2}^+)$	$(\frac{1}{2}^+)$			4, 5, 13
5.463 ± 20					13
5.539 ± 9					13
5.832 ± 9					13
6.013 ± 7	$(\frac{3}{2}, \frac{1}{2})^-$				13
6.092 ± 8					5, 13
6.149 ± 20					14
6.288 ± 7					5, 13
6.437 ± 9					13
6.742 ± 7	$(\frac{3}{2}, \frac{1}{2})^-$				13
6.861 ± 7					5, 13
7.067 ± 9					13
7.21 ± 20					5, 13
7.253 ± 10					13
(7.326 ± 15)					13
(7.531 ± 15)					13
7.616 ± 16	$\frac{3}{2}^+; \frac{3}{2}$				4, 13, 14

Table 19.27 (continued)
Energy levels of ^{19}Ne [a])

E_x (MeV ± keV)	$J^\pi; T$	K^π	τ_m or $\Gamma_{c.m.}$	Decay	Reactions
7.700 ± 10					13
(7.788 ± 10)					13
7.994 ± 15					13
8.069 ± 12					5, 13
8.236 ± 10					13
8.442 ± 9					4, 5, 13
8.523 ± 10					13
(8.810 ± 25)					13
8.920 ± 9	$(\frac{11}{2}^-)$				4, 5, 6, 7, 13
9.013 ± 10					13
9.100 ± 20					13
9.240 ± 20					4, 13
9.489 ± 25					13
9.81 ± 20	$(\frac{11}{2}^+)$				4, 5, 6, 7, 8, 13
10.01 ± 20					5
10.407 ± 30	$\frac{3}{2}^+$		$\Gamma = 45$ keV	p, ^{3}He, α	3, 4, 7, 13
10.46	$\frac{1}{2}^+$		$\Gamma = 355$ keV	p, ^{3}He, α	3
10.613 ± 20					13
11.08 ± 20					4, 5, 6
11.24 ± 20					5
11.40 ± 20					5
11.51 ± 50	$\frac{3}{2}^-, (\frac{1}{2}^-)$		$\Gamma = 25$ keV	^{3}He, α	4
12.23 ± 50	$\frac{5}{2}^+$		$\Gamma = 200 \pm 25$ keV	^{3}He, α	4, 6, 7
12.40 ± 50	$\frac{7}{2}^+$		$\Gamma = 180 \pm 25$ keV	^{3}He, α	3
12.56 ± 20					5
12.69 ± 50	$\frac{1}{2}^+$		$\Gamma = 180 \pm 40$ keV	p, ^{3}He	3
13.1 ± 30					5
13.22 ± 30					5
13.8 ± 250			$\Gamma = 670 \pm 250$ keV	γ, ^{3}He	3
14.18 ± 30					5, 6
14.44 ± 30					5
14.78 ± 30			$\Gamma = 620 \pm 130$ keV	γ, ^{3}He	3, 5
16.23 ± 130			$\Gamma = 400 \pm 130$ keV	γ, n, ^{3}He	3
18.4 ± 500			$\Gamma = 4400 \pm 500$ keV	γ, ^{3}He	3

[a]) See also Table 19.28.

Table 19.28
Radiative decay of ^{19}Ne levels [a]

E_i (MeV) [b]	J_i^π	E_f (MeV)	J_f^π	Branch (%)	τ_m
0.24	$\frac{5}{2}^+$	0	$\frac{1}{2}^+$	100	26.0 ± 0.8 ns
0.28	$\frac{1}{2}^-$	0	$\frac{1}{2}^+$	(100) [c]	61.4 ± 3.0 ps
1.51	$\frac{5}{2}^-$	0.24	$\frac{5}{2}^+$	12 ± 3	
		0.28	$\frac{1}{2}^-$	88 ± 3 [d]	$1.4^{+0.5}_{-0.6}$ ps
1.54	$\frac{3}{2}^+$	0.24	$\frac{5}{2}^+$	95 ± 3 [d]	28 ± 11 fs
		0.28	$\frac{1}{2}^-$	5 ± 3	
1.62	$\frac{3}{2}^-$	0	$\frac{1}{2}^+$	20 ± 3 [d]	
		0.24	$\frac{5}{2}^+$	10 ± 3	
		0.28	$\frac{1}{2}^-$	70 ± 4	143 ± 31 fs
2.79	$\frac{9}{2}^+$	0.24	$\frac{5}{2}^+$	100 [d]	140 ± 35 fs
4.03	$\frac{3}{2}^+$	0	$\frac{1}{2}^+$	80 ± 15	< 50 fs
		0.28	$\frac{1}{2}^-$	5 ± 5	
		1.54	$\frac{3}{2}^+$	15 ± 5	
4.14	$(\frac{9}{2})^-$	1.51	$\frac{5}{2}^-$	100	< 0.3 ps
4.20	$(\frac{7}{2})^-$	0.24	$\frac{5}{2}^+$	20 ± 5	
		1.51	$\frac{5}{2}^-$	80 ± 5	< 0.35 ps
4.38	$\frac{7}{2}^+$	0.24	$\frac{5}{2}^+$	85 ± 4	< 0.12 ps
		2.79	$\frac{9}{2}^+$	15 ± 4	
4.55	$(\frac{1}{2}, \frac{3}{2})^-$	0	$\frac{1}{2}^+$	35 ± 25	
		0.28	$\frac{1}{2}^-$	65 ± 25	< 80 fs
4.60	$(\frac{5}{2}^+)$	0.24	$\frac{5}{2}^+$	90 ± 5	< 0.16 ps
		1.54	$\frac{3}{2}^+$	10 ± 5	
4.64	$\frac{13}{2}^+$	2.79	$\frac{9}{2}^+$	100	> 1 ps

[a]) See Table 19.26 in (78AJ03) for additional data and for references.
[b]) $E_x = 238.27 \pm 0.11$, 275.09 ± 0.13, 1507.56 ± 0.3, 1536.0 ± 0.4, 1615.06 ± 0.5, and 2794.7 ± 0.6 keV from E_γ measurements: see Table 19.25 in (78AJ03).
[c]) $B(\mathrm{E1}) = (1.06 \pm 0.05) \times 10^{-3}$ W.u.
[d]) $\Gamma_\gamma = 0.17 \pm 0.08$, 24^{+27}_{-8}, $3.7^{+1.8}_{-0.9}$ and $2.0^{+1.3}_{-0.6}$ meV: see Table 19.26 in (78AJ03).

Table 19.29
Branchings in ^{19}Ne(β^+)^{19}F [a])

Decay to ^{19}F* (MeV)	J^π	Branch (%)	log ft [b])
0	$\frac{1}{2}^+$	99.99	3.237 ± 0.002
0.11	$\frac{1}{2}^-$	$(1.2 \pm 0.2) \times 10^{-2}$	7.061 ± 0.072
1.55 [c])	$\frac{3}{2}^+$	$(2.22 \pm 0.21) \times 10^{-3}$ [d])	5.700 ± 0.041

[a]) (83AD03). See also (81AD05).
[b]) See also (85BR29).
[c]) E_γ for ^{19}F* ($1.55 \to 0.20$) = 1356.92±0.15 keV (76AL07), 1356.84±0.13 keV (83AD03).
[d]) From (76AL07, 83AD03).

We adopt the half-life of ^{19}Ne suggested by (83AD03): 17.34 ± 0.09 sec. See also (78AJ03). The decay is principally to ^{19}F$_{\text{g.s.}}$: see Table 19.29. The ^{19}Ne decay to ^{19}F* (0.11) [$J^\pi = \frac{1}{2}^+ \to \frac{1}{2}^-$] proceeds by vector and axial vector weak currents, with the former making a negligible contribution. The measured decay rates are roughly an order of magnitude smaller than predicted using the $0\hbar\omega + 1\hbar\omega$ shell model (81AD05, 83AD03). Decay of polarized ^{19}Ne is consistent with time-reversal invariance: see (87AJ02, 88SE11, 93CA1K). See also (88BR1D, 88SA12, 89SA55, 91NA05, 91SAZX, 92HE12, 92SE08, 93SE1B).

2. ^{15}O(α, γ)^{19}Ne $\qquad Q_{\text{m}} = 3.529$

(86LA07) have recalculated the ^{15}O(α, γ) direct capture rate at stellar energies. (90MA05) have measured the branching ratios $\Gamma_\alpha/\Gamma_{\text{total}}$ for $E_{\text{cm}} = 850$, 1020, 1071, 1183 and 1563 keV resonances in ^{15}O + α. The strengths of these resonances were determined (see Table 19.30) and the reaction rate for temperatures between 7×10^8 and 3×10^9 K was determined to differ from theoretical calculations (86LA07, 88CA1N) by no more than 20%. See also (88BU01, 88TR1C). A recent measurement by (95MA1A) determined Γ_α for $E_{\text{x}} = 4.033$ keV and hence the resonant rate for ^{15}O(α, γ) at astrophysical energies

3. (a) ^{16}O(^{3}He, γ)^{19}Ne $\qquad Q_{\text{m}} = 8.443$
(b) ^{16}O(^{3}He, n)^{18}Ne $\qquad Q_{\text{m}} = -3.196$ $\qquad E_{\text{b}} = 8.443$
(c) ^{16}O(^{3}He, p)^{18}F $\qquad Q_{\text{m}} = 2.032$
(d) ^{16}O(^{3}He, d)^{17}F $\qquad Q_{\text{m}} = -4.894$
(e) ^{16}O(^{3}He, ^{3}He′)^{16}O
(f) ^{16}O(^{3}He, α)^{15}O $\qquad Q_{\text{m}} = 4.914$
(g) ^{16}O(^{3}He, ^{7}Be)^{12}C $\qquad Q_{\text{m}} = -5.576$

Table 19.30
Resonances in $^{15}O(\alpha, \gamma)^{19}Ne$ [a]

$E^*(^{19}Ne)$ (keV)	E_α(cm) [b] (keV)	Γ_γ [c] (meV)	Γ_α (meV)	$\omega\gamma$ (meV)
4033	504	73 ± 41 [h]	0.0072 [d]	0.014
4379	850	> 60		> 10
4549	1020	39^{+34}_{-15}	< 3.8 [e]	4.5 ± 2.5
4600	1071	> 13	88 ± 18 [e]	198 ± 51
4712	1183	43 ± 8	420 ± 70 [f]	113 ± 17
5092	1563	$\Gamma_T(^{19}F) > 22$	$\gamma(^{19}F) = 4.3 \pm 2.7$ [g]	< 60

[a]) See Table 1 in (90MA05).
[b]) The energies of these resonances are known to ± 4 keV or better, except for the 1183-keV resonance, which is ± 10 keV.
[c]) Widths from analog states in ^{19}F.
[d]) Based on a reduced α-particle width of 0.06 from the $^{15}N(^6Li, d)^{19}F$ reaction populating the bound mirror state in ^{19}F.
[e]) (87MA31).
[f]) (72RO01).
[g]) (87AJ02).
[h]) See also (95MA1A).

Table 19.31
Resonances reported in $^{16}O + {}^3He$ [a]

$E(^3He)$ (MeV)	Resonance in	$\Gamma_{c.m.}$ (MeV)	E_x (MeV)	J^π
2.400	$p_{1\to4}$, $p_{5,6,7}$, α_0	0.355	10.46	$\frac{1}{2}^+$
2.425	$p_{1\to4}$, $p_{5,6,7}$, α_0	0.045	10.48	$\frac{3}{2}^+$
3.65	$p\gamma$, ^3He, α_0	0.025	11.51 ± 0.05	$\frac{3}{2}^-$, $(\frac{1}{2}^-)$
4.50	^3He, α_0	0.200 ± 0.025	12.23 ± 0.05	$\frac{5}{2}^+$
4.70	^3He, α_0	0.180 ± 0.025	12.40 ± 0.05	$\frac{7}{2}^+$
5.05	p_0, p_1, p_5, ^3He	0.18 ± 0.04	12.69 ± 0.05	$\frac{1}{2}^+$
6.37 [b]	γ_0, γ_{1+2}	0.67 ± 0.25	13.8 ± 0.25	
7.65 [b]	γ_{1+2}	0.62 ± 0.13	14.88 ± 0.13	
9.26 [b]	γ_{1+2}, n	0.40 ± 0.13	16.23 ± 0.13	
11.8 [b]	$\gamma_{0\to2}$	4.4 ± 0.5	18.4 ± 0.5	

[a]) See reaction 2, ^{19}Ne, in (78AJ03) for references.
[b]) $(2J+1)\Gamma_{3He}\Gamma_\gamma = 30 \pm 17$, 89 ± 44, 18 ± 4, and 17000 ± 5300 keV^2 for $^{19}Ne^*$ (13.8, 14.9, 16.2, 18.4) (83WA05).

Excitation functions at 90° for γ_{0-2}, γ_{3-5} and γ_6 [reaction (a)] have been measured for $E(^3\text{He}) = 3$ to 19 MeV (83WA05): see Table 19.31 for a listing of the resonances reported in this and in the other channels. See also (83AJ01, 87AJ02) and (90AB1G, 91SU17, 92CO08).

4. ^{16}O(α, n)^{19}Ne $\qquad Q_\text{m} = -12.134$

Gamma transitions have been observed from the first six excited states of ^{19}Ne: see Table 19.25 in (78AJ03) and Table 19.28 here. Angular distributions of many neutron groups have been studied at $E_\alpha = 41$ MeV: see (83AJ01).

5. ^{16}O(^{6}Li, t)^{19}Ne $\qquad Q_\text{m} = -7.352$

This reaction and the mirror reaction ^{16}O(^{6}Li, ^{3}He)^{19}F have been studied at $E(^6\text{Li}) =$ 24, 35, 36, and 46 MeV: see (78AJ03, 83AJ01). Table 19.16 displays the analog states observed in the two reactions. In addition triton groups are reported to states with $E_\text{x} =$ 6.08, 6.28, 6.85, 7.21, 8.08, 8.45, 8.94, 9.81, 10.01, 11.08, 11.24, 11.40, 12.56 [all$\pm$0.02], 13.1, 13.22, 14.18, 14.44, 14.78 [remaining, $\pm$0.3] MeV. See also (83CU02) and the preliminary report in (92ROZZ).

6. ^{16}O(^{10}B, ^{7}Li)^{19}Ne $\qquad Q_\text{m} = -9.345$

This as well as the analog reaction [^{16}O(^{10}B, ^{7}Be)^{19}F] have been studied at $E(^{10}\text{B}) =$ 100 MeV. On the basis of similar yields and E_x, and in addition to the low-lying analogs, it is suggested that the following pairs of states are analogs in ^{19}F-(^{19}Ne): 8.98 (8.94), 11.33 (11.09), 12.79 (12.48), 14.15 (14.17), 14.99 (14.61) and 15.54 (15.40) [$\pm$100 keV]; however, problems of energy resolution are evident. See (83AJ01) for references on this and on other heavy-ion induced reactions.

7. ^{16}O(^{12}C, ^{9}Be)^{19}Ne $\qquad Q_\text{m} = -17.836$

This ^{3}He stripping reaction was studied at $E(^{12}\text{C}) = 480$ MeV (88KR11). The ground state, 0.2 MeV doublet and 1.5 MeV multiplet were weakly populated. High spin states at 2.8 MeV ($\frac{9}{2}^+$) and 4.64 MeV ($\frac{13}{2}^+$) were strongly populated and were inferred to belong to the (sd)^3, 2N + L, g.s. band with $((1\text{d}_{5/2})^2 2\text{s}_{1/2})_{9/2^+}$ and $(1\text{d}_{5/2})^3_{13/2^+}$ configurations. Levels at 8.9, 9.88 and 10.41 MeV were inferred to have spin parities of $\frac{11}{2}^-$, $\frac{11}{2}^+$, and $\frac{13}{2}^+$. A $\frac{17}{2}^-$ spin parity was proposed for the strongly populated 12.3 MeV level.

8. ^{17}O(^{3}He, n)^{19}Ne $\qquad Q_m = 4.300$

Neutron-γ coincidence measurements lead to the determination of excitation energies [$E_x = 4032.9 \pm 2.4$, 4140 ± 4, 4197.1 ± 2.4, 4379.1 ± 2.2, 4549 ± 4, 4605 ± 5, 4635 ± 4 and (5097 ± 10) keV], τ_m and branching ratios (see Table 19.28). On the basis of these it is suggested that ^{19}Ne* (4.14, 4.20) are the analogs of ^{19}F* (4.03, 4.00) [$J^\pi = \frac{9}{2}^-, \frac{7}{2}^-$] and that ^{19}Ne* (4.55, 4.60) are the analogs of ^{19}F* (4.556, 4.550) $J^\pi = \frac{5}{2}^+, \frac{3}{2}^-$]. There is no evidence for a reported state at $E_x = 4.78$ MeV: see (78AJ03).

9. ^{18}O(p, π^-)^{19}Ne $\qquad Q_m = -134.812$

This reaction (at $E_p = 201$ MeV) selectively populates stretched 2p-1h states, in particular ^{19}Ne* (4.64) [$J^\pi = \frac{13}{2}^+$] and a structure near 10 MeV. Angular distributions and A_y are reported for ^{19}Ne* (0, 2.80, 4.6) (86KE04). See also (87AJ02) and (90KU1H).

10. ^{19}F(p, n)^{19}Ne $\qquad Q_m = -4.020$

For a review of threshold measurements see (72AJ02, 76FR13). Measurements of the total cross section from threshold ($E_p = 4.24$ MeV) to $E_p = 28$ MeV are reported by (90WA10). Excited states of ^{19}Ne determined from γ-spectra are displayed in Table 19.25 of (78AJ03). Branching ratio and τ_m measurements are summarized in Table 19.28 here. For the g-factor of ^{19}Ne* (0.24) see Table 19.27. Angular distributions have been measured at $E_p = 160$ MeV to ^{19}Ne* (0[0], 1.54[$(0+2)$], 5.4[0], 6.2[$(0+1)$], 7.1[$(0+1)$], 7.7[$(0+1)$], 8.60[(0)], 10.2[(1)], 11.0 [0], 12.1) (84RA22; [transferred angular momentum in brackets] also forward-angle $\sigma(\theta)$ at $E_p = 120$ MeV). Spin-transfer coefficients were measured at $E_p = 120$, 160 MeV by (90HUZY). See also ^{20}Ne in (87AJ02) and (87TA13, 89RA1G).

11. ^{19}F(^{3}He, t)^{19}Ne $\qquad Q_m = -3.257$

Angular distributions have been obtained for the triton groups to ^{19}Ne* (0.24, 1.54, 2.79) at $E(^3\text{He}) = 26$ MeV: see (78AJ03). ^{19}Ne levels at $E_x = 7.060/7.088$, 7.500, 7.531 and 7.620 MeV were measured to obtain Γ_p/Γ_α branching ratios (0.58 ± 0.08, 2.7 ± 0.9, 0.29 ± 0.09, and 0.34 ± 0.05, respectively) for determination of possible HCNO breakout reactions ^{18}F(p, γ)^{19}Ne and ^{18}F(p, α)^{15}O(α, γ)^{19}Ne (93UTZZ).

12. (a) ^{20}Ne(n, 2n)^{19}Ne $\qquad Q_m = -16.864$
(b) $^{20}\text{Ne} \rightarrow {}^{19}\text{Ne} + \text{n}$

Theoretical calculations of neutron-induced reaction cross sections on ^{20}Ne in the energy range 1–30 MeV were performed (91RE10). The shape and magnitude of the neutron yield from the breakup of ^{20}Ne [reaction (b)] was calculated in the high-energy region. using diffraction theory of processes of fragmentation of complex nuclei.

13. ^{20}Ne(^{3}He, α)^{19}Ne $\qquad\qquad Q_{\mathrm{m}} = 3.713$

Alpha groups have been observed to ^{19}Ne states with $E_{\mathrm{x}} < 10.6$ MeV: see Tables 19.27 and 19.32. Angular distributions have been measured for $E(^{3}\mathrm{He}) = 10$ to 35 MeV: see (72AJ02). DWBA analysis of the strongest transitions leads to the l and J^{π} values shown in Table 19.32. ^{19}Ne* (0, 0.24, 1.54, 2.79) are identified as members of the $K^{\pi} = \frac{1}{2}^{+}$ rotational band [with ^{19}Ne* (4.38) as the $\frac{7}{2}^{+}$ member] and ^{19}Ne* (0.28, 1.51, 1.62) with the $K^{\pi} = \frac{1}{2}^{-}$ band. Candidates for the $\frac{7}{2}^{-}$ and $\frac{9}{2}^{-}$ members of the $K^{\pi} = \frac{1}{2}^{-}$ band are thought to be ^{19}Ne* (4.15, 4.20). Possible matching of other ^{19}Ne states with those in ^{19}F is also discussed: see (72AJ02). For lifetime and radiative decay measurements see Table 19.28. See also (87AJ02) and see (89MC1C) for use of this reaction for observing parity-violating effects.

14. ^{21}Ne(p, t)^{19}Ne $\qquad\qquad Q_{\mathrm{m}} = 15.144$

At $E_{\mathrm{p}} = 40$ MeV the angular distributions to ^{19}Ne* (0.24, 4.03, 5.09) are well described by $L = 2$, 0 and 4, respectively. ^{19}Ne* (4.03), $J^{\pi} = \frac{3}{2}^{+}$, has a dominant 5p-2h configuration. ^{19}Ne* (5.09) has positive parity and the data are consistent with $J = \frac{5}{2}$. At $E_{\mathrm{p}} = 45$ MeV the triton group to a state with $E_{\mathrm{x}} = 7.620 \pm 0.025$ MeV has an angular distribution [$L = 0$] which is similar to that for ^{19}F* (7.66); both are thought to be the analogs of the $(J^{\pi}; T) = (\frac{3}{2}^{+}; \frac{3}{2})$ 0.096 MeV first excited state of ^{19}O. The ground state of ^{19}O has $J^{\pi} = \frac{5}{2}^{+}$; L for the analog state should be 2. ^{19}Ne* (0, 2.79) are also populated: see (78AJ03, 83AJ01).

^{19}Na

(Fig. 19.4)

This nucleus was observed in the ^{24}Mg(p, ^{6}He)^{19}Na reaction at $E_{\mathrm{p}} = 54.7$ MeV (69CE01). A study via the ^{24}Mg(^{3}He, ^{8}Li)^{19}Na reaction at $E(^{3}\mathrm{He}) = 76.3$ MeV leads to an atomic mass excess of 12.929 ± 0.012 MeV for ^{19}Na; it is then unstable with respect to breakup into $^{18}\mathrm{Ne} + \mathrm{p}$ by 321 ± 13 keV. An excited state at $E_{\mathrm{x}} = 120 \pm 10$ keV is also reported (75BE38, 93AU05). See also (87AJ02) and (87PO01, 87SA24, 88CO15, 90PO04, 92AV03).

^{19}Mg

(Not observed)

See (87AJ02) and (87GU1K, 87PO01, 93HI08).

Table 19.32
^{19}Ne levels from ^{20}Ne(^{3}He, α) [a]

E_x (MeV ± keV)	l_n	J^π	E_x (MeV ± keV)	l_n	J^π
0	0	$\frac{1}{2}^+$	6.862 ± 7		
0.2384 ± 0.15	2	$\frac{5}{2}^+$	7.067 ± 9		
0.27530 ± 0.2	1	$\frac{1}{2}^-$	(7.178 ± 15)		
1.5040 ± 3		$(\frac{5}{2}^-)$	7.253 ± 10		
1.5324 ± 3		$(\frac{3}{2})^+$	(7.326 ± 15)		
1.6115 ± 3	1	$(\frac{3}{2})^-$	(7.531 ± 15)		
2.7917 ± 3	4, 5	$(\frac{9}{2}^+)$	7.614 ± 20		
4.036 ± 10	2	$(\frac{3}{2}, \frac{5}{2})^+$	7.700 ± 10		
4.142 ± 10			(7.788 ± 10)		
4.200 ± 10			7.994 ± 15		
4.379 ± 10			8.063 ± 15		
4.551 ± 10	1	$(\frac{1}{2}, \frac{3}{2})^-$	8.236 ± 10 [b]		
4.625 ± 10			8.440 ± 10		
4.712 ± 10			8.523 ± 10		
4.783 ± 20			(8.810 ± 25)		
5.089 ± 7			8.915 ± 10		
5.351 ± 10	0	$\frac{1}{2}^+$	9.013 ± 10		
5.424 ± 7			9.100 ± 20		
5.463 ± 20			9.240 ± 20		
5.539 ± 9			9.489 ± 25		
5.832 ± 9			9.886 ± 50 [b]		
6.013 ± 7	1	$(\frac{3}{2}, \frac{1}{2})^-$	10.407 ± 30 [b]		
6.094 ± 8			10.613 ± 20		
6.149 ± 20					
6.289 ± 7					
6.437 ± 9					
6.742 ± 7	1	$(\frac{3}{2}, \frac{1}{2})^-$			

[a]) See Table 19.27 of (78AJ03) for additional results and for a listing of the references.
[b]) Unresolved states.

Table 19.33
Mirror states in $A = 19$ nuclei [a]

^{19}F		^{19}Ne		ΔE_x (MeV) [b]
E_x (MeV)	J^π	E_x (MeV)	J^π	
0	$\frac{1}{2}^+$	0	$\frac{1}{2}^+$	—
0.110	$\frac{1}{2}^-$	0.275	$\frac{1}{2}^-$	+0.17
0.197	$\frac{5}{2}^+$	0.238	$\frac{5}{2}^+$	+0.04
1.35	$\frac{5}{2}^-$	1.51	$\frac{5}{2}^-$	+0.16
1.46	$\frac{3}{2}^-$	1.62	$\frac{3}{2}^-$	+0.16
1.55	$\frac{3}{2}^+$	1.53	$\frac{3}{2}^+$	−0.02
2.78	$\frac{9}{2}^+$	2.79	$\frac{9}{2}^+$	+0.01
3.91	$\frac{3}{2}^+$	4.03	$\frac{3}{2}^+$	+0.12
4.00	$\frac{7}{2}^-$	4.20	$(\frac{7}{2})^-$	+0.20
4.03	$\frac{9}{2}^-$	4.14	$(\frac{9}{2})^-$	+0.11
4.38	$\frac{7}{2}^+$	4.38	$(\frac{7}{2})^+$	+0.001
4.55	$\frac{5}{2}^+$	4.60	$(\frac{5}{2})^+$	+0.05
4.56	$\frac{3}{2}^-$	4.55	$(\frac{1}{2}, \frac{3}{2})^-$	−0.007
4.65	$\frac{13}{2}^+$	4.64	$\frac{13}{2}^+$	−0.01
4.68	$\frac{5}{2}^-$	4.72	$(\frac{5}{2})^-$	+0.03
5.11	$\frac{5}{2}^+$	5.09	$\frac{5}{2}^+$	−0.01
5.34	$\frac{1}{2}^{(+)}$	5.35	$\frac{1}{2}^+$	+0.01

[a]) As taken from Tables 19.9 and 19.27.
[b]) Defined as $E_x(^{19}\text{Ne}) - E_x(^{19}\text{F})$.

Table 19.34
Isospin quadruplet components ($T = \frac{3}{2}$) in $A = 19$ nuclei [a])

^{19}O		^{19}F		^{19}Ne		^{19}Na	
E_x (MeV)	J^π	E_x (MeV)	$J^\pi; T$	E_x (MeV)	$J^\pi; T$	E_x (MeV)	J^π
0	$\frac{5}{2}^+$	7.54	$\frac{5}{2}^+; \frac{3}{2}$				
0.096	$\frac{3}{2}^+$	7.66	$\frac{3}{2}^+; \frac{3}{2}$	7.62	$\frac{3}{2}^+; \frac{3}{2}$		
1.47	$\frac{1}{2}^+$	8.79	$\frac{1}{2}^+; \frac{3}{2}$				
2.37	$\frac{9}{2}^+$	9.93	$\frac{9}{2}^+; \frac{3}{2}$				
3.07	$(\frac{3}{2})^+$	10.56	$\frac{3}{2}^+; (\frac{3}{2})$				
3.15	$\frac{5}{2}^+$	10.61	$\frac{5}{2}^+; \frac{3}{2}$				
		11.57	$T = \frac{3}{2}$				
4.11	$\frac{3}{2}^+$	11.65	$\frac{3}{2}^+; (\frac{3}{2})$				
4.58	$\frac{3}{2}^-$	12.14	$\frac{3}{2}^-; \frac{3}{2}$				
5.08	$\frac{1}{2}^-$	12.58	$\frac{1}{2}^-; \frac{3}{2}$				
5.15	$\geq \frac{5}{2}^+$	12.78	$\frac{5}{2}^+; \frac{3}{2}$				
5.54	$\frac{3}{2}^+$	12.86	$\frac{3}{2}^+; \frac{3}{2}$				
5.70	$\frac{7}{2}^-$	13.32	$\frac{7}{2}^-; (\frac{3}{2})$				
6.27	$\frac{7}{2}^-$	13.73	$\frac{7}{2}^-; \frac{3}{2}$				

[a]) As taken from Tables 19.2, 19.9 and 19.27.

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