Energy Levels of Light Nuclei
$A = 20$

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Abstract: An evaluation of $A = 20$ was published in *Nuclear Physics A*636 (1998), p. 247. This version of $A = 20$ differs from the published version in that we have corrected some errors discovered after the article went to press. The introduction and introductory tables have been omitted from this manuscript. Reference key numbers are in the NNDC/TUNL format.

(References closed 21 April 1997)

This work is supported by the US Department of Energy, Office of High Energy and Nuclear Physics, under: Contract No. DEFG05-88-ER40441 (North Carolina State University); Grant No. DEFG05-91-ER40619 (Duke University); Contract No. DEAC05-96-OR22464 (Oak Ridge National Laboratory).

Table of Contents for $A = 20$

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

^{20}n, ^{20}He, ^{20}Li, ^{20}Be

(Not observed)

See (1977CE05, 1983ANZQ, 1986AN07, 1987SIZX).

^{20}B

(Not observed)

The mass excess of ^{20}B is predicted to be 69.08 MeV (1974TH01). ^{20}B is then unstable with respect to breakup into ^{19}B + n by 0.9 MeV: see ^{19}B in (1995TI07) and (1978AJ03, 1983ANZQ) and see the work on effective interactions for the (0p1s0d) nuclear shell-model space (1992WA22).

^{20}C

(Not illustrated)

^{20}C has been observed in heavy ion projectile fragmentation reactions (1987GI05, 1990MU06, 1991MU19) and in proton-induced target-fragmentation reactions (1987VI13, 1988MU08, 1993WOZZ). The atomic mass excess is 37.560 ± 0.200 MeV (1995AU04). It is then stable with respect to ^{19}C+n and ^{18}C + 2n by 3.3 and 3.5 MeV, respectively. β-delayed neutron emission has been observed (1987GI05, 1990MU06, 1991MU19).

The half life and neutron emission probability have been measured to be $\tau_{1/2} = 16^{+14}_{-7}$ ms, $P_\mathrm{n} = 50 \pm 30$ (1989LE16) and $\tau_{1/2} = 14^{+6}_{-5}$ ms, $P_\mathrm{n} = 72 \pm 14$ (1990MU06).

Shell model calculations for exotic light nuclei are described in (1988POZS, 1993PO11). Shell model interactions constructed for the 0p1s0d nuclear shell model space are reported in (1992WA22). Self-consistent calculations of light nuclei using the density functional method are reported in (1990LO11). See also the calculation of ground state properties reported in (1996GR21, 1996RE19), and see (1996SH13) for a description of a simple model of neutron "halo nuclei" applied to ^{20}C. Microscopic calculations of beta-decay half-lives for $6 \leq Z \leq 108$ neutron-rich nuclei are reported in (1990ST08). See also (1987SN01, 1993SA16, 1994HA39).

^{20}N

(Not illustrated)

^{20}N is particle stable. Its atomic mass excess is 21.770 ± 0.050 MeV (1995AU04). It has been observed in heavy-ion transfer (1989OR03) and projectile fragmentation reactions (1987GI05, 1988DUZT, 1988MU08, 1990MU06, 1991OR01) and in target fragmentation reactions (1988WO09, 1991RE02, 1993WOZZ). See also the review (1988VIZP). Mass measurements were reported in (1987GI05, 1988WO09, 1989OR03, 1991OR01, 1993WOZZ). Nuclear matter rms radii have been derived from measurements of interaction cross sections of ^{20}N on carbon by (1995CH1X, 1996CH24, 1996KR1A). Measurements of beta-delayed neutron emission are described in (1988DUZT).

The half-life of ^{20}N is 70 ± 40 ms (1988DUZT), 100^{+30}_{-20} ms (1988MU08, 1990MU06), 142 ± 19 ms (1991RE02).

The delayed neutron probability is 53^{+11}_{-7}% (1988MU08, 1990MU06), 66.1 ± 5.0% (1991RE02). See also (1987BAZI, 1987DE1O, 1987DUZU, 1987SIZX, 1989HU1E, 1993REZX).

A review of the production of nuclei far from stability is presented in (1989VOZM). Production mechanisms are discussed in (1988BAYZ). Predictions of beta-decay half-lives are described in (1990ST08). Results of shell model calculations related to exotic light nuclei are discussed in (1992WA22, 1993PO11). Bulk properties have been calculated with relativistic mean field theory in (1993PA14).

^{20}O
(Figs. 1 and 5)

GENERAL: See Table 20.1.

1. ^{20}O$(\beta^-)^{20}$F $\qquad Q_{\rm m} = 3.814$

^{20}O decays with a half-life of 13.51 ± 0.05 s to the 1^+ states ^{20}F* (1.06, 3.49) with branching ratios (99.973 ± 0.003) and (0.027 ± 0.003)%, $\log f_0 t = 3.740 \pm 0.006$ and 3.65 ± 0.06, respectively (1987AL06). Upper limits for the branching to other states of ^{20}F are shown in Table II of (1987AL06). See also (1985BR29).

2. ^{18}O(t, p)^{20}O $\qquad Q_{\rm m} = 3.082$

$Q_0 = 3082.4 \pm 1.3$ keV (1985AN17). See also (1982AN12).

Figure 1: Energy levels of ^{20}O. In level diagrams of this work (Figures 1–5), energy values are plotted vertically in MeV, based on the ground state as zero. Uncertain levels or transitions are indicated by dashed lines; levels which are known to be particularly broad are cross-hatched. Values of total angular momentum J, parity, and isobaric spin T which appear to be reasonably well established are indicated on the levels; less certain assignments are enclosed in parentheses. For reactions in which ^{20}O is the compound nucleus, some typical thin-target excitation functions are shown schematically, with the yield plotted horizontally and the bombarding energy vertically. Bombarding energies are indicated in laboratory coordinates and plotted to scale in cm coordinates. Excited states of the residual nuclei involved in these reactions have generally not been shown; where transitions to such excited states are known to occur, a brace is sometimes used to suggest reference to another diagram. For reactions in which the present nucleus occurs as a residual product, excitation functions have not been shown. Further information on the levels illustrated, including a listing of the reactions in which each has been observed, is contained in the master table, entitled “Energy levels of ^{20}O”.

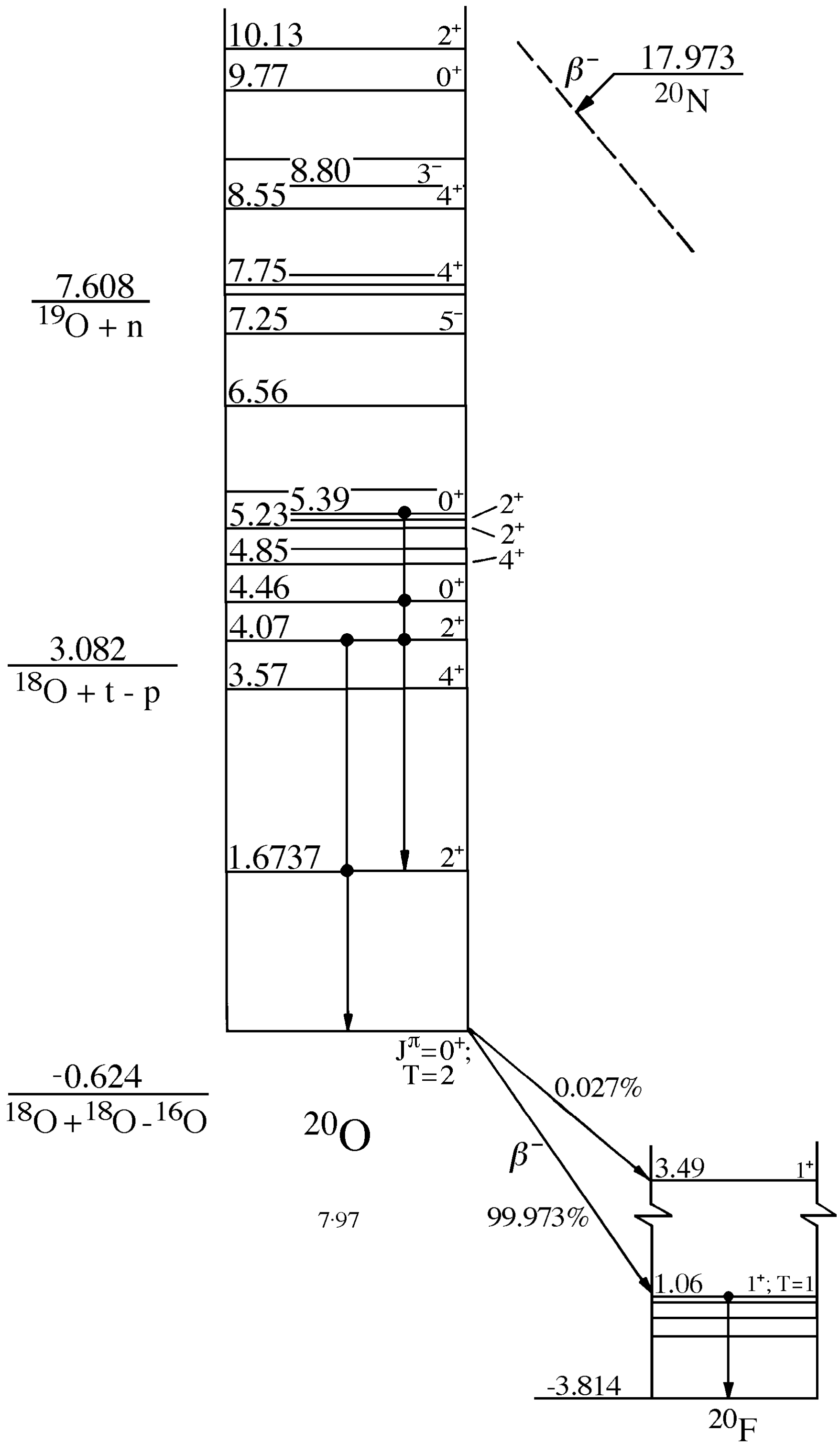
10.13 2+
9.77 0+
8.80 3−
8.55 4+
7.75 4+
7.25 5−
6.56
5.39 0+
5.23 2+
2+
4.85 4+
4.46 0+
4.07 2+
3.57 4+
1.6737 2+
Jπ=0+;
T=2
20O
7.97
7.608
19O + n
3.082
18O + t - p
-0.624
18O + 18O - 16O
β−
17.973
20N
β−
0.027%
99.973%
3.49 1+
1.06 1+; T=1
-3.814
20F

Table 20.1: ^{20}O – General

Reference	Description
	Models
1987BL18	Gogny's effective inter. used to calc. gnd. & excited states of specific spin-isospin order
1987CH1J	Nucl. struc. calcs. using mixed-config. shell model: effective & surface δ-interactions
1987CO31	Simple parametrization for low energy octupole modes of sd-shell nuclei
1987KR08	Discontinuity in ground state band plot of even-even nuclei is traced to p-n interaction
1987LI1F	Double delta & surface delta interactions used to calc. low-lying spectra of $^{17-22}$O
1988BR11	Semi-empirical effective interactions for the 1s-0d shell
1988HI05	Effect on GT strength of config. mixing and p-n correl. in even-even sd-shell nucl.
1990SK04	$A = 18$ nuclei, effective interaction in the sd shell (also calc. $A = 20$ energy spectra)
1990ZH01	Nuclear structure studies of double Gamow-Teller and double beta decay strength
1991MA41	Finite nuclei calculations with realistic potential models (Bonn, Paris, Argonne)
1991WA11	Composite particle representation theory calcs. for $A = 20$ states compared to shell model
1992JI04	Bonn potential used to evaluate energy spectra of some light sd-shell nuclei
1993AM08	6p-2h core excitations in ^{20}O
1993PO11	Shell-model calcs. of several properties of exotic light nuclei ($A = 4$–30)
	Complex reactions
Review:	
1988JO1B	Exp. & theor. liquid drop & microscopic study of heavy ion radioactivity
Other articles:	
1987MU03	Evaporation model calc. of the emission of clusters by excited compound nuclei
1988BL11	Systematics of cluster-radioact.-decay constants from microscop. calcs. compared to data
1988IV02	Microscopic approach to the rates of radioactive decay by emission of heavy clusters
1989SA10	Total cross sections of reactions induced by neutron-rich light nuclei
1990GU02	Particle stability of O & Ne isotopes in the reaction 44 MeV/nucleon ^{48}Ca + Ta
	Other topics
Reviews:	
1989RA16	Predxns. from systematics & tabulation of B(E2; $0^+_1 \to 2^+_1$) values for even-even nucl.
1989SP01	Reduced electric-octupole transition probabilities, B(E3; $0^+_1 \to 3^-_1$), for even-even nucl.
1990TH1E	Summary of topics presented at Workshop on Primordial Nucleosynthesis
Other articles:	
1987LI1F	Double delta & surface delta interactions used to calc. low-lying spectra of $^{17-22}$O
1990ZH01	Nuclear structure studies of double Gamow-Teller and double beta decay strength
	Ground state properties
Review:	
1989RA17	Compilation of exp. data on nuclear moments for ground & excited states of nucl.
Other articles:	
1987BL18	Gogny's-plus-tensor inter. for gnd. & excited states with specific spin-isospin order
1989SA10	Total cross sections of reactions induced by neutron-rich light nuclei
1990LO11	Self-consistent calcs. of light neutron-rich nuclei using density-functional method

Table 20.1: ^{20}O – General (continued)

Reference	Description
	Ground state properties – continued
1993PA14	Relativistic mean field theory; calc. binding energy, rms radii, deformation parameters
1993PA19	Continuation of 93PA14: effects of pairing correlations
1994CI02	Nuclear SU3 scheme used to calc. specific heat and shape transitions in light sd nuclei
1996GR21	Bulk prop. of light deformed nucl. derived from medium-modified meson-exchange interaction
1996KR1A	Nucl. matter radii calc. for $A = 20$ nucl.; evidence found for proton & neutron skins

Table 20.2: Energy Levels of ^{20}O

E_x (MeV $\pm$ keV)	$J^\pi; T$	τ	Decay	Reactions
0	0^+; 2	$\tau_{1/2} = 13.51 \pm 0.05$ s	β^-	1, 2, 3, 4
1.67368 ± 0.15	2^+	$\tau_m = 10.5 \pm 0.4$ ps	γ	2, 3, 4
		$g = -0.352 \pm 0.015$		
3.570 ± 7	4^+		(γ)	2, 3, 4
4.072 ± 4	2^+		γ	2, 4
4.456 ± 5	0^+		γ	2, 4
4.850 ± 15	4^+		(γ)	2
5.002 ± 6			(γ)	2
5.234 ± 5	2^+		(γ)	2
5.304 ± 6	2^+		(γ)	2
5.387 ± 6	0^+		γ	2
5.614 ± 3	(3^-)		(γ)	2
6.555 ± 8	(2)		(γ)	2
7.252 ± 8	5^-		(γ)	2
7.622 ± 7	$3^- + 4^-$			2
7.754 ± 5	4^+			2, 3
7.855 ± 6	(5^-)			2, 3
8.554 ± 8	4^+			2
8.804 ± 9	3^-			2, 3
8.962 ± 21	(0^+)			2
9.770 ± 8	0^+			2
10.125 ± 11	2^+			2, 3

Table 20.3: Energy Levels of ^{20}O from ^{18}O(t, p)^{20}O [a]

E_x (keV)	L	J^π
0.0	0	0^+
1674 ± 3 [b]	2	2^+
3570 ± 7	4	4^+
4072 ± 4	2	2^+
4456 ± 5 [c]	0	0^+
4850 ± 15	4	4^+
5002 ± 6		
5234 ± 5	2	2^+
5304 ± 6 [c]	2	2^+
5387 ± 6	0	0^+
5614 ± 3	(3)	(3^-)
6555 ± 8		(2)
7252 ± 8	5	5^-
7622 ± 7	$3 + 4$	$3^- + 4^+$
7754 ± 5	4	4^+
7855 ± 6	(5)	(5^-)
8554 ± 8	4	4^+
8804 ± 9	3	3^-
8962 ± 21	(0)	(0^+)
9770 ± 8 [d]	0	0^+
10125 ± 11	2	2^+

[a] (1979LA18): $E_t = 15$ MeV. See also Table 20.3 in (1978AJ03) and (1979FO17, 1979PI01).

[b] E_γ leads to $E_x = 1673.68 \pm 0.15$ keV (1973WA19).

[c] 6p-2h structure: see (1979LA04, 1979LA18).

[d] This strong state suggests that (fp)^2 excitations are important (1979LA18).

Observed proton groups are displayed in Tables 20.2 and 20.3. ^{20}O* (4.07) decays to ^{20}O* (0, 1.67) with branchings of (26 ± 4) and (74 ± 4)%. The p-γ angular correlations lead to $J = 2$; the strength of the transition favors $\pi = +$, [$\delta(\mathrm{E2/M1}) = -0.18 \pm 0.08$ for the $2^+ \to 2^+$ transition.] ^{20}O*(4.46) and ^{20}O*(5.39) decay primarily via ^{20}O*(1.67); the direct ground-state decay is < 4% for the first and < 7% for the second of these states. The angular correlations are essentially isotropic, favoring $J^\pi = 0^+$. The transition ^{20}O*($5.39 \to 4.07$) is not observed: the upper limit is 8%. See also (1978AJ03, 1983AJ01). For a discussion of $A = 20$ isobaric states see (1982AN12, 1985AN17).

3. ^{18}O(α, pp)^{20}O $\quad\quad Q_\mathrm{m} = -16.732$

See (1983AJ01).

4. ^{18}O(^{18}O, ^{16}O)^{20}O $\quad\quad Q_\mathrm{m} = -0.624$

See (1983AJ01).

^{20}F

(Figs. 2 and 5)

GENERAL: See Table 20.4.

$\mu = +2.0935(9)$ nm (1989RA17)
$Q = -0.042(3)$ b (1989RA17)

1. ^{20}F$(\beta^-)^{20}$Ne $\quad\quad Q_\mathrm{m} = 7.025$

The half-life of ^{20}F is (11.163 ± 0.008) s (1992WA04), (11.11 ± 0.04) s (1995ITZY). For earlier measurements see (1987AJ02). ^{20}F decays principally to ^{20}Ne* (1.63): see ^{20}Ne, reaction 37.

2. (a) ^{6}Li(^{15}N, p)^{20}F $\quad\quad Q_\mathrm{m} = 6.915$
(b) ^{7}Li(^{15}N, d)^{20}F $\quad\quad Q_\mathrm{m} = 1.068$

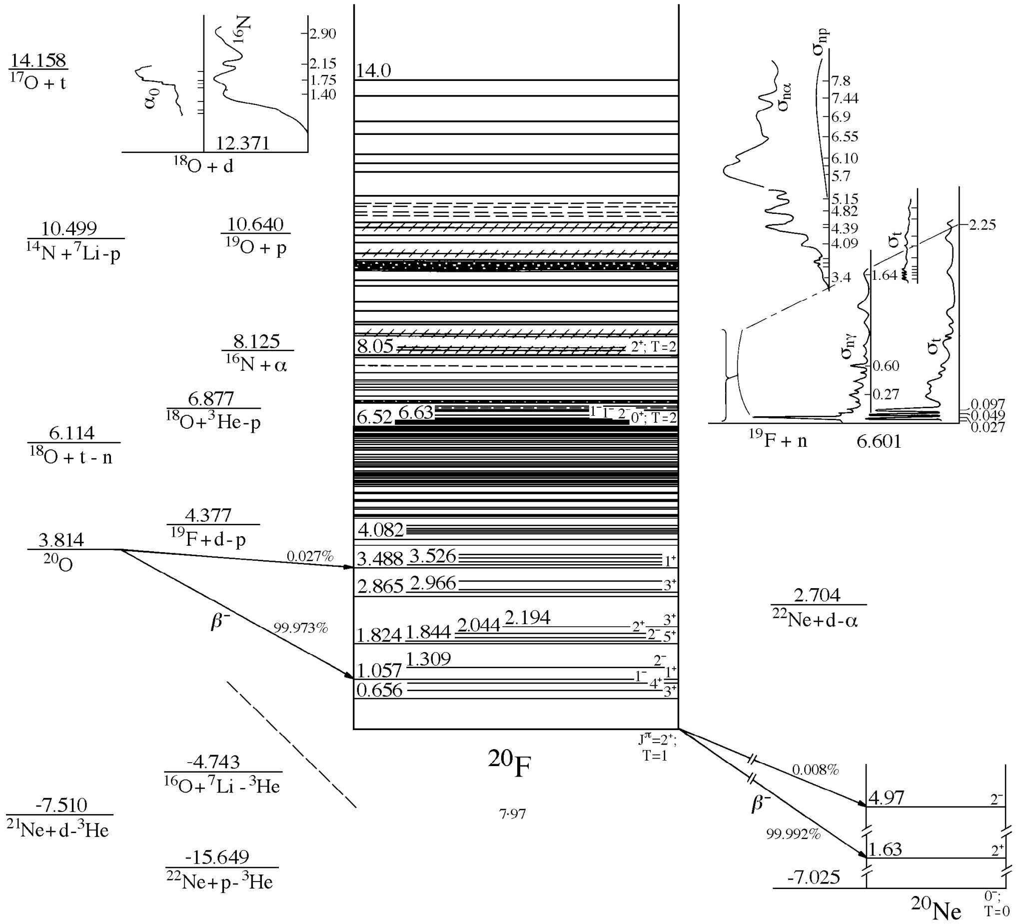

Figure 2: Energy levels of ^{20}F. For notation see Fig. 1.

Excitation functions were measured for incident energies $E_i = 10$–30 MeV (1989CO22).

3. ^{6}Li(^{18}O, α)^{20}F $\qquad Q_m = 10.896$

Activation cross sections were measured for $E_i = 10$–40 MeV by (1987DI07).

4. (a) ^{10}B(^{11}B, p)^{20}F $\qquad Q_m = 13.447$
   (b) ^{11}B(^{11}B, d)^{20}F $\qquad Q_m = 4.217$

Excitation functions have been measured at $E_i = 6$–32 MeV (1988CO12).

Table 20.4: ^{20}F – General

Reference	Description
	Model calculations
1988BR11	Semi-empirical effective interactions for the 1s-0d shell
1988ET01	Analysis of magnetic dipole transitions between sd-shell states
1990DE34	^{20}F & ^{20}Na nuclei and the ^{19}Ne(p, γ)^{20}Na reaction in a microscopic three-cluster model
1990SH12	Extreme collective limits for the magnetic moments of odd-odd nuclei
1990SK04	$A = 18$ nuclei, effective interaction in the sd shell (also calc. $A = 20$ energy spectra)
1991BO45	Democratic mapping used to calc. low-lying states of sd- and fp-shell nuclei
1991MA41	Calculations of sd-shell nuclei with realistic potential models (Bonn, Paris, Argonne)
1991PI09	Differential cross section data analyzed using microscopic model; ^{20}F levels deduced
1991WA11	Composite Particle Representation Theory calcs. for $A = 20$ states compared to shell model
1992BE14	Nuclear level densities and spin cut-off factors deduced from microscopic theory
1992JI04	Bonn potential used to evaluate energy spectra of some light sd-shell nuclei using G-matrix
1992WA22	Effective interactions for the 0p1s0d nuclear shell-model space
1993PO11	Shell-model calcs. of properties of exotic (and normal) light nuclei ($A = 4$–30)
1995BE54	sd-shell study with multiconfiguration mixing approach for large scale nucl. struc. calcs.
1996GO38	Calc. low nucl. excitations using method of successive addition of nucleons
1996RA04	Large-basis (1s0d and 0f1p) shell-model calcs.
	Special States
1990DE34	^{20}F & ^{20}Na nuclei and the ^{19}Ne(p, γ)^{20}Na reaction; a possible 1^- state in ^{20}Na, ^{20}F
1993BR12	Nature of the ^{20}Na 2646-keV level and the stellar reaction rate for ^{19}Ne(p, γ)^{20}Na
1996RA04	Spin and parity of the ^{20}F 3172-keV level
	Electromagnetic transitions
Review:	
1993EN03	Strengths of γ-ray transitions in $A = 5$–44 nuclei
1996RA04	Meas. & calc. lifetimes of excited states in ^{20}F
Other articles:	
1988ET01	Analysis of magnetic dipole transitions between sd-shell states
1990DE34	^{20}F & ^{20}Na nuclei and the ^{19}Ne(p, γ)^{20}Na reaction in a microscopic three-cluster model
	Astrophysics
Review:	
1988AP1A	Neutrino diffusion, primordial nucleosynthesis and the r-process
1990TH1E	Summary of topics presented at Workshop on Primordial Nucleosynthesis

Table 20.4: ^{20}F – General (continued)

Reference	Description
	Astrophysics (continued)
1993SO13	Methods for producing unstable nuclei & their relevance to major explosive stellar processes
Other articles:	
1990MA1Z	Nuclear reaction uncertainties in standard and non-standard cosmologies
1992CA1J	Quasi-static evolution of ONeMg cores, explosive ignition densities & collapse explosion
1993BR12	Nature of the ^{20}Na 2646-keV level and the stellar reaction rate for ^{19}Ne(p, γ)^{20}Na
1996RA04	Spin and parity of the ^{20}F 3172-keV level
	Complex reactions
1987BA1T	Spin-isospin excitations in nuclei with relativistic heavy ions
1987BU07	Projectile-like fragments from ^{20}Ne + ^{197}Au — counting simultaneously emitted neutrons
1987EL14	Isovector excitations in nuclei with composite projectiles: (^{3}He, t), (d, ^{2}He) & heavy ions
1987MU03	Study of the emission of clusters by excited compound nuclei
1989SA10	Total cross sections of reactions induced by neutron-rich light nuclei
1989YO02	Quasi-elastic & deep inelastic transfer in ^{16}O + ^{197}Au for $E < 10$ MeV/u
	Other topics
1988RO19	Predictions for observation of ^{20}F(Λ) levels using ^{20}Ne(γ, K^{+}) reaction
1989GE10	Threshold pion-nucleus amplitudes as predicted by current algebra
1990DE45	Searches for admixture of massive neutrinos into the electron flavour
1993NA08	Charge-symmetry-breaking N-N interaction in 1s0d-shell nucl. from ρ^0–ω and π^0–η mixing
1994GO49	Shell effects in systematization of cross sections for (n, α) reactions on 14 MeV neutrons
	Ground state properties
Review:	
1989RA17	Compilation of exp. data on nuclear moments for ground & excited states of nuclei
1992PY1A	Nuclear quadrupole moments for $Z = 1$–20: precise calcs. on atoms & small molecules
Other articles:	
1989SA10	Total cross sections of reactions induced by neutron-rich light nuclei
1990SH12	Extreme collective limits for the magnetic moments of odd-odd nuclei
1993RO22	Determination of k$_0$- and Q_0-factors of short-lived nuclides
1996KR1A	Nucl. matter radii calc. for $A = 20$ nucl.; evidence found for proton & neutron skins

Table 20.5: Energy Levels of ^{20}F [a]

E_x (MeV ± keV)	$J^\pi; T$	τ [b] or Γ	Decay	Reactions [c]
0	$2^+; 1$	$\tau_{1/2} = 11.163 \pm 0.008$ s	β^-	1, 5, 7, 8, 9, 10, 12, 13, 14, 17, 19, 24, 25, 27, 30
0.65602 ± 0.03	3^+	$\tau_m = 440 \pm 30$ fs	γ	8, 9, 10, 12, 13, 14, 17, 24, 25, 27
0.82273 ± 0.03	4^+	$\tau_m = 79 \pm 6$ ps	γ	8, 9, 10, 12, 13, 14, 17, 24, 25, 27
0.98359 ± 0.03	1^-	$\tau_m = 1.96 \pm 0.09$ ps	γ	8, 9, 10, 12, 13, 14, 17, 18, 19, 24, 25, 27
1.056848 ± 0.004	1^+	$\tau_m = 7.4 \pm 1.6$ fs	γ	9, 10, 12, 13, 14, 17, 18, 19, 24, 25, 27
1.30919 ± 0.03	2^-	$\tau_m = 1.87 \pm 0.09$ ps	γ	8, 9, 10, 12, 14, 17, 19, 24, 25, 27
1.8238 ± 1.6	5^+	$\tau_m \leq 65$ fs	γ	5, 8, 9, 10, 12, 13, 17, 25, 27
1.84380 ± 0.03	2^-	$\tau_m = 66 \pm 5$ fs	γ	5, 10, 12, 14, 17, 24
1.97083 ± 0.04	(3^-)	$\tau_m = 0.61 \pm 0.09$ ps	γ	5, 8, 9, 10, 12, 14, 17, 25, 27
2.04398 ± 0.03	2^+	$\tau_m = 3.9 \pm 0.7$ fs	γ	5, 8, 9, 10, 12, 14, 17, 24, 25, 27
2.19430 ± 0.03	3^+	$\tau_m = 4.1 \pm 1.2$ fs	γ	5, 8, 9, 10, 12, 13, 14, 17, 24, 25, 27
2.86486 ± 0.10	(3^-)	$\tau_m = 29 \pm 4$ fs	γ	8, 9, 10, 12, 14, 17, 25, 27
2.96611 ± 0.03	3^+	$\tau_m = 5.2 \pm 1.1$ fs	γ	<u>8</u>, <u>9</u>, <u>10</u>, <u>12</u>, 14, <u>17</u>, <u>22</u>, <u>25</u>, <u>27</u>
2.9680 ± 1.5	(4^-)		γ	<u>8</u>, <u>9</u>, <u>10</u>, <u>12</u>, <u>17</u>, <u>25</u>, <u>27</u>
3.17169 ± 0.14	$(0^-, 1^+)$		γ	8, 9, 10, 12, 14, 17, 25, 27
3.48841 ± 0.03	1^+	$\tau_m = 11.7 \pm 0.7$ fs	γ	8, 9, 10, 12, 14, 17, 18, 25, 27
3.52631 ± 0.04	(0^+)	$\tau_m = 5.5 \pm 0.6$ fs	γ	12, 14, 17, 25
3.58654 ± 0.03	(2)	$\tau_m = 1.1 \pm 0.6$ fs	γ	<u>8</u>, <u>9</u>, <u>10</u>, <u>12</u>, 14, <u>17</u>, <u>25</u>
3.58980 ± 0.04	(3)			<u>8</u>, <u>9</u>, <u>10</u>, <u>12</u>, 14, <u>17</u>, <u>25</u>

Table 20.5: Energy Levels of ^{20}F (continued)

E_x (MeV ± keV)	$J^\pi; T$	τ [b] or Γ	Decay	Reactions [c]
3.669 ± 3	(4^+)		γ	8, 9, 12
3.68017 ± 0.04	(2)	$\tau_m = 22.1 \pm 2.3$ fs	γ	9, 10, 12, 14, 17, 25, 27
3.7610 ± 2.0	(≥ 3)		γ	8, 9, 10, 12, 17, 25, 27
3.96507 ± 0.04	(1^+)	$\tau_m = 6.9 \pm 2.1$ fs	γ	8, 9, 10, 12, 14, 17, 25, 27
4.08217 ± 0.04	(1^+)	$\tau_m = 3.6 \pm 0.7$ fs	γ	8, 9, 10, 11, 12, 14, 17, 25, 27
4.1993 ± 2.7	≥ 3		(γ)	8, 9, 17
4.2081 ± 2.6	≥ 3		(γ)	10, 12, 17, 27
4.27709 ± 0.04	$(1^+,\ 2^+)$	$\tau_m = 7 \pm 4$ fs	γ	8, 9, 10, 12, 14, 17, 27
4.3120 ± 2.6	(0^+)	$\tau_m = 5.1 \pm 0.6$ fs	(γ)	17
4.37147 ± 0.11		$\tau_m < 4$ fs	γ	9, 10, 14, 17, 27
4.509 ± 3			(γ)	8, 9, 10, 17
4.518 ± 4			(γ)	9, 10, 12, 27
4.5846 ± 3.0			(γ)	8, 9, 10, 17
4.59172 ± 0.07			γ	12, 14, 17, 27
4.722 ± 12			(γ)	12
4.7312 ± 2.9			(γ)	9, 10, 17, 27
4.744 ± 12			(γ)	8, 12
4.7648 ± 2.7			(γ)	9, 10, 12, 17, 27
4.89276 ± 0.17			γ	8, 9, 14, 17, 27
4.8994 ± 2.8			(γ)	10, 12, 17
5.0415 ± 3.1			(γ)	9, 10, 12, 17, 27
5.0668 ± 3.1			(γ)	8, 9, 10, 17
5.130 ± 3			(γ)	8, 9, 10, 12, 17, 27
5.2261 ± 0.4		$\tau_m = 1.4 \pm 1.1$ fs	(γ)	9, 10, 12, 14, 17, 27
5.255 ± 15			(γ)	8
5.28279 ± 0.17		$\tau_m = 3.3 \pm 1.3$ fs	γ	9, 12, 14, 17, 27
5.31917 ± 0.04		$\tau_m = 4.9 \pm 1.1$ fs	γ	8, 9, 10, 12, 14, 17, 27
5.3461 ± 3.3			(γ)	10, 12, 17
5.352 ± 3			(γ)	9, 17

Table 20.5: Energy Levels of ^{20}F (continued)

E_x (MeV ± keV)	J^π; T	τ [b] or Γ	Decay	Reactions [c]
5.407 ± 3			(γ)	8, 9, 10, 12, 17, 27
5.4521 ± 3.8			(γ)	8, 9, 10, 12, 17, 27
5.4572 ± 3.2			(γ)	10, 17
5.46589 ± 0.17			γ	10, 14, 17
5.55534 ± 0.04		$\tau_m = 6.0 \pm 1.5$ fs	γ	10, 12, 14, 17, 27
5.574 ± 6			(γ)	9, 10, 12, 27
5.588 ± 2			(γ)	17
5.62313 ± 0.06			γ	9, 10, 12, 14, 17, 27
5.645 ± 12			(γ)	12
5.661 ± 12			(γ)	12
5.710 ± 6			(γ)	12, 17, 27
5.725 ± 10			(γ)	9
5.7649 ± 3.4			(γ)	8, 9, 10, 12, 17, 27
5.795 ± 14			(γ)	10, 12
5.8101 ± 0.4			(γ)	9, 14, 17, 27
5.93613 ± 0.03	2^-	$\tau_m < 2$ fs	γ	8, 12, 14, 17, 27
5.93910 ± 0.10			γ	8, 12, 14, 17, 27
5.951 ± 4			(γ)	10
6.007 ± 14			(γ)	8, 12
6.01778 ± 0.03	2^-	$\tau_m = 3.3 \pm 1.2$ fs	γ	9, 10, 14, 17
6.04498 ± 0.08			γ	10, 12, 14, 17, 27
6.065 ± 14			(γ)	12
6.079 ± 14			(γ)	12
6.095 ± 14			(γ)	12
6.111 ± 14			(γ)	12
6.136 ± 14			(γ)	12
6.154 ± 14			(γ)	8, 9, 12, 27
6.189 ± 14			(γ)	9, 10, 12
6.213 ± 14			(γ)	10, 12, 27
6.251 ± 14			(γ)	12, 27
6.287 ± 14			(γ)	12

Table 20.5: Energy Levels of ^{20}F (continued)

E_x (MeV ± keV)	$J^\pi; T$	τ [b] or Γ	Decay	Reactions [c]
6.2991 ± 0.3			(γ)	9, 14, 27
6.335 ± 14			(γ)	9, 12, 27
6.355 ± 14			(γ)	8, 9, 12, 27
6.391 ± 14			(γ)	9, 12, 27
6.413 ± 14			(γ)	9, 12, 27
6.444 ± 14			(γ)	12, 27
6.458 ± 14			(γ)	8, 12
6.481 ± 14			(γ)	9, 12, 27
6.509 ± 14			(γ)	12
6.519 ± 3	$0^+; T = 2$		γ	12, 26
6.578 ± 14			(γ)	9, 12, 27
6.6270 ± 0.3	2^-	$\Gamma_{cm} = 0.31 \pm 0.02$ keV	γ, n	14, 15
6.6426 ± 0.3	(3, 4)	$\Gamma_{cm} < 0.08$ keV	γ, n	14
6.6475 ± 0.4	1^-	$\Gamma_{cm} = 1.59 \pm 0.10$ keV	γ, n	14, 15
6.6934 ± 0.6	1^-	$\Gamma_{cm} = 13.8 \pm 0.8$ keV	γ, n	9, 14, 15
6.7661 ± 0.9	(2^-, 3, 4^+)	$\Gamma_{cm} \leq 0.6$ keV	γ, n	9, 14, 22, 27
6.825 ± 5			n	9, 15, 27
6.8567 ± 1.0	2	$\Gamma_{cm} = 10 \pm 2$ keV	γ, n	14
6.905 ± 8				27
6.936 ± 4				9
6.9678 ± 1.0	1^-	$\Gamma_{cm} = 5 \pm 1$ keV	γ, n	9, 14, 15
(7.0670 ± 1.2)	0^-	($\Gamma_{cm} = 2.4 \pm 0.6$ keV)	γ, n	14, 15
7.08	(1^+)	$\Gamma_{cm} = 24$ keV	n	9, 15
7.166 ± 2	$2^{(+)}$	$\Gamma_{cm} = 8 \pm 1$ keV	γ, n	9, 14, 15, 16
7.232 ± 7				9
7.283 ± 4				9
7.319 ± 8	(1)	$\Gamma_{cm} = 33$ keV	γ, n	9, 14, 15
7.37 ± 20	(1)	$\Gamma_{cm} = 19$ keV	n	9, 15
7.42 ± 20	(2^+)	$\Gamma_{cm} = 10$ keV	γ, n	9, 14, 15
7.495 ± 5	(2)	$\Gamma_{cm} = 80$ keV	γ, n	9, 14, 15
7.655 ± 5	(2^+)	$\Gamma_{cm} = 65$ keV	γ, n	9, 14, 15

Table 20.5: Energy Levels of ^{20}F (continued)

E_x (MeV ± keV)	$J^\pi; T$	τ [b] or Γ	Decay	Reactions [c]
7.734 ± 6		$\Gamma_{cm} = 140$ keV	n	9, 15
7.843 ± 11	1^-	($\Gamma_{cm} = 50 \pm 10$ keV)	γ, n	9, 14
7.985 ± 4	1	$\Gamma_{cm} = 14 \pm 2$ keV	γ, n	9, 14
8.05 ± 100	$2^+; T = 2$			26
8.062 ± 8				9
8.113 ± 4		$\Gamma_{cm} = 195$ keV	γ, n	9, 14, 15
8.147 ± 6		$\Gamma_{cm} = 15$ keV	n	9, 15
8.268 ± 12				9
8.349 ± 4				9
8.421		$\Gamma_{cm} = 27$ keV	n	15
8.50		$\Gamma_{cm} = 140$ keV	n	15
8.72		$\Gamma_{cm} \leq 30$ keV	n	9, 15
8.77		$\Gamma_{cm} = 76$ keV	n	9, 15
8.94		$\Gamma_{cm} = 73$ keV	n	9, 15
9.01				9
9.2			n	13, 15
9.52		$\Gamma_{cm} = 110$ keV	n	15
9.65		$\Gamma_{cm} = 100$ keV	n	15
9.83		$\Gamma_{cm} = 33$ keV	n	15
9.85		$\Gamma_{cm} = 120$ keV	n	15
(9.886 ± 10)			n	15
9.90		$\Gamma_{cm} \leq 30$ keV	n	15
(9.929 ± 10)			n	15
(9.981 ± 10)			n	15
10.024 ± 10		$\Gamma_{cm} = 150$ keV	n, α	15, 16
10.10 ± 50			n, α	16
10.228 ± 10	0^-, 1	$\Gamma_{cm} \approx 200$ keV	n, α	15, 16
10.480 ± 10		$\Gamma_{cm} \approx 10$ keV	n, α	15, 16
10.641 ± 10	1, 2	$\Gamma_{cm} = 70$ keV	n	15
10.807 ± 10	0^-, 1	$\Gamma_{cm} \approx 310$ keV	n, α	15, 16
10.99		$\Gamma_{cm} = 190$ keV	n	15

Table 20.5: Energy Levels of ^{20}F (continued)

E_x (MeV $\pm$ keV)	$J^\pi; T$	τ [b] or Γ	Decay	Reactions [c]
(11.045 ± 10)		$\Gamma_{cm} \approx 30$ keV	n	15
(11.130 ± 10)		$\Gamma_{cm} < 25$ keV	n	15
(11.244 ± 10)		$\Gamma_{cm} < 25$ keV	n	15
(11.287 ± 10)			n	15
11.49 ± 50			n, α	16
12.0			n, α	16
12.2 ± 100			n, α	16
12.4			n, α	16
12.7			n, α	13, 16
13.2			n, α	16
13.7			n, α	15, 16
14.0				16

[a] See also Tables 20.6–20.15.
[b] Lifetimes quoted here are those adopted by (1996RA04); see Table VII of that work.
[c] Reaction numbers are underlined in cases where the resolution of the experiment was inadequate for unequivocal identification of the level observed.

5. ^{12}C(^{9}Be, p)^{20}F $\qquad Q_m = 4.076$

For excitation curves involving ^{20}F* (0, $1.82 + 1.84 + 1.97 + 2.04 + 2.19$) see (1982HU06, 1983JA09). At $E(^9\text{Be}) = 12$ to 27 MeV angular distributions are reported for p_0 and $p_{1+2+3+4}$: see (1983AJ01).

6. ^{13}C(^{7}Li, ^{7}Li)^{13}C $\qquad E_b = 18.050$

For fusion cross sections see (1982DE30). See also ^{13}C in (1991AJ01).

7. ^{13}C(^{9}Be, d)^{20}F $\qquad Q_m = 1.354$

See (1983AJ01).

Table 20.6: Radiative transitions in ^{20}F [a]

E_i (MeV ± keV)	J_i^π	E_f (MeV ± keV)	Branching (%)	δ
0.65602 ± 0.03	3^+	0	100	0.10 ± 0.05
0.82273 ± 0.03	4^+	0	33.2 ± 2.4	
		0.65602 ± 0.03	66.8 ± 2.4	
0.98359 ± 0.03	1^-	0	100	[b]
1.056848 ± 0.004	1^+	0	100	
1.30919 ± 0.03	2^-	0	91.7 ± 0.6	[b]
		0.65602 ± 0.03	2.4 ± 0.4	
		0.98359 ± 0.03	4.9 ± 0.4	
		1.056848 ± 0.004	1.0 ± 0.3	
1.8238 ± 1.6	5^+	0.82273 ± 0.03	100	-0.03 ± 0.07
1.84380 ± 0.03	2^-	0	91.3 ± 0.6	
		0.65602 ± 0.03	6.7 ± 0.5	
		1.30919 ± 0.03	1.9 ± 0.3	
1.97083 ± 0.04	(3^-)	0	17.7 ± 1.7	-0.06 ± 0.14
		0.82273 ± 0.03	51.9 ± 2.7	$+0.27 \pm 0.30$
		0.98659 ± 0.03	0.8 ± 0.4	
		1.30919 ± 0.03	29.7 ± 3.0	
2.04398 ± 0.03	2^+	0	7.5 ± 0.6	
		0.65602 ± 0.03	91.8 ± 0.7	$0.08^{+0.06}_{-0.1}$
		1.30919 ± 0.03	0.7 ± 0.3	
2.19430 ± 0.03	3^+	0	47.0 ± 1.9	0.00 ± 0.09
		0.82273 ± 0.03	51.2 ± 1.9	$+0.07 \pm 0.10$
		1.30919 ± 0.03	1.8 ± 0.4	
2.86486 ± 0.10	(3^-)	0	38.1 ± 6.8	
		0.65602 ± 0.03	4.8 ± 2.4	
		0.82273 ± 0.03	11.9 ± 4.5	
		1.30919 ± 0.03	11.9 ± 2.6	
		1.84380 ± 0.03	7.1 ± 2.4	
		1.97083 ± 0.04	7.1 ± 2.4	
		2.04398 ± 0.03	11.9 ± 4.5	
		2.19430 ± 0.03	7.1 ± 2.4	

Table 20.6: Radiative transitions in ^{20}F [a] (continued)

$E_{\rm i}$ (MeV $\pm$ keV)	$J_{\rm i}^{\pi}$	$E_{\rm f}$ (MeV $\pm$ keV)	Branching (%)	δ
2.96611 ± 0.03	3^{+}	0	27.1 ± 1.4	
		0.65602 ± 0.03	12.2 ± 1.2	
		0.82273 ± 0.03	58.3 ± 1.7	
		2.19430 ± 0.03	2.4 ± 0.6	
2.96800 ± 1.50	(4^{-})	0.65602 ± 0.03	10 ± 10	
		0.82273 ± 0.03	38 ± 10	
		1.30919 ± 0.03	12 ± 10	
		1.97083 ± 0.04	40 ± 10	
3.17169 ± 0.14	$(0^{-},\ 1^{+})$	0.98359 ± 0.03	100	
3.48841 ± 0.03	1^{+}	0	72.6 ± 2.5	
		0.98359 ± 0.03	3.8 ± 0.5	
		1.056848 ± 0.004	7.1 ± 2.9	
		1.30919 ± 0.03	9.2 ± 0.7	
		1.84380 ± 0.03	7.4 ± 0.7	
3.52631 ± 0.04	(0^{+})	1.056848 ± 0.004	100	
3.58654 ± 0.03	(2)	0	32.9 ± 1.6	
		0.65602 ± 0.03	9.8 ± 0.7	
		0.98359 ± 0.03	4.0 ± 0.4	
		1.056848 ± 0.004	10.2 ± 3.1	
		1.84380 ± 0.03	0.7 ± 0.3	
		2.04398 ± 0.03	31.1 ± 1.5	
		2.19430 ± 0.03	8.8 ± 0.8	
		2.96611 ± 0.03	2.6 ± 0.3	
3.58980 ± 0.04	(3)	0	83.2 ± 1.5	
		0.65602 ± 0.03	10.7 ± 1.3	
		2.04398 ± 0.03	6.1 ± 0.9	
3.669 ± 3		0	100	
3.68017 ± 0.04	(2)	0	46.5 ± 2.3	
		0.65602 ± 0.03	17.1 ± 1.9	
		1.056848 ± 0.004	23.5 ± 1.6	
		1.30919 ± 0.03	4.3 ± 1.1	

Table 20.6: Radiative transitions in ^{20}F [a] (continued)

E_i (MeV ± keV)	J^π_i	E_f (MeV ± keV)	Branching (%)	δ
		1.84380 ± 0.03	8.6 ± 1.1	
3.96507 ± 0.04	(1^+)	0.98359 ± 0.03	26.1 ± 2.6	
		1.30919 ± 0.03	58.2 ± 2.9	
		1.84380 ± 0.03	10.4 ± 1.5	
		3.17169 ± 0.14	5.2 ± 1.5	
4.08217 ± 0.04	(1^+)	0	35.5 ± 2.2	
		0.98359 ± 0.03	4.6 ± 1.3	
		1.056848 ± 0.004	50.0 ± 2.3	
		2.04398 ± 0.03	9.9 ± 1.3	
4.27709 ± 0.04	$(1^+,\ 2^+)$	0.98359 ± 0.03	24.1 ± 2.4	
		1.056848 ± 0.004	56.5 ± 2.8	
		2.04398 ± 0.03	19.4 ± 2.5	
4.37147 ± 0.11		0.98359 ± 0.03	93.8 ± 3.0	
		3.68017 ± 0.04	6.2 ± 3.0	
4.59172 ± 0.07		0.98359 ± 0.03	60.0 ± 6.2	
		1.056848 ± 0.004	40.0 ± 6.2	
4.89276 ± 0.17		0.82273 ± 0.03	35.0 ± 7.6	
		2.19430 ± 0.03	20.0 ± 4.9	
		3.58654 ± 0.03	45.0 ± 7.5	
5.28279 ± 0.17		0	57 ± 10	
		1.056848 ± 0.004	43 ± 10	
5.31917 ± 0.04		0	22.6 ± 3.1	
		0.98359 ± 0.03	56.0 ± 3.7	
		1.056848 ± 0.004	3.6 ± 1.2	
		1.30919 ± 0.03	11.9 ± 3.3	
		1.84380 ± 0.03	6.0 ± 1.2	
5.46589 ± 0.17		2.86486 ± 0.10	100	
5.55534 ± 0.04		0	30.6 ± 2.0	
		0.65602 ± 0.03	4.1 ± 1.2	
		1.30919 ± 0.03	54.7 ± 2.3	
		1.84380 ± 0.03	7.1 ± 1.7	

Table 20.6: Radiative transitions in ^{20}F [a] (continued)

E_{i} (MeV $\pm$ keV)	J^{π}_{i}	E_{f} (MeV $\pm$ keV)	Branching (%)	δ
		2.86486 ± 0.10	3.5 ± 0.6	
5.62313 ± 0.06		0	13.8 ± 3.3	
		0.98359 ± 0.03	39.7 ± 5.1	
		1.30919 ± 0.03	31.0 ± 4.5	
		2.04398 ± 0.03	15.5 ± 3.3	
5.93613 ± 0.03	2^-	0	6.6 ± 0.7	
		0.65602 ± 0.03	28.7 ± 1.1	
		0.98359 ± 0.03	4.0 ± 0.4	
		1.056848 ± 0.004	0.6 ± 0.2	
		1.30919 ± 0.03	0.5 ± 0.2	
		1.84380 ± 0.03	1.2 ± 0.2	
		1.97083 ± 0.04	30.0 ± 1.0	
		2.04398 ± 0.03	1.2 ± 0.2	
		2.19430 ± 0.03	4.0 ± 0.4	
		2.86486 ± 0.10	1.4 ± 0.2	
		2.96611 ± 0.03	1.1 ± 0.2	
		3.48841 ± 0.03	9.6 ± 0.5	
		3.58654 ± 0.03	2.1 ± 0.2	
		3.58980 ± 0.04	1.4 ± 0.3	
		3.68017 ± 0.04	5.9 ± 0.4	
		3.96507 ± 0.04	0.7 ± 0.2	
		4.08217 ± 0.04	0.9 ± 0.2	
5.93910 ± 0.10		0	12.4 ± 3.1	
		0.98359 ± 0.03	23.6 ± 3.1	
		1.84380 ± 0.03	31.5 ± 3.2	
		2.04398 ± 0.03	13.5 ± 3.1	
		3.58654 ± 0.03	19.1 ± 3.1	
6.01778 ± 0.03	2^-	0	26.0 ± 1.0	
		0.65602 ± 0.03	3.3 ± 0.2	
		0.98359 ± 0.03	17.2 ± 0.7	
		1.056848 ± 0.004	0.7 ± 0.1	

Table 20.6: Radiative transitions in ^{20}F [a] (continued)

E_i (MeV $\pm$ keV)	J^π_i	E_f (MeV $\pm$ keV)	Branching (%)	δ
		1.30919 ± 0.03	1.4 ± 0.2	
		1.84380 ± 0.03	4.6 ± 0.2	
		1.97083 ± 0.04	1.0 ± 0.1	
		2.04398 ± 0.03	0.7 ± 0.1	
		2.19430 ± 0.03	2.9 ± 0.2	
		2.86486 ± 0.10	0.4 ± 0.1	
		2.96611 ± 0.03	8.2 ± 0.4	
		3.48841 ± 0.03	16.0 ± 0.8	
		3.58654 ± 0.03	9.7 ± 0.8	
		3.58980 ± 0.04	5.3 ± 0.2	
		3.68017 ± 0.04	0.4 ± 0.1	
		3.96507 ± 0.04	0.14 ± 0.03	
		4.08217 ± 0.04	2.0 ± 0.2	
6.04498 ± 0.08		1.30919 ± 0.03	27.7 ± 1.8	
		1.84380 ± 0.03	55.4 ± 2.1	
		3.48841 ± 0.03	8.2 ± 1.5	
		3.58654 ± 0.03	3.1 ± 0.6	
		3.96507 ± 0.04	5.6 ± 1.0	
6.519 ± 3 [c]	0^+	1.056848 ± 0.004	> 90	
6.60135 ± 0.04 [d]		0	9.85 ± 0.42	
		0.98359 ± 0.03	1.45 ± 0.07	
		1.056848 ± 0.004	4.30 ± 0.18	
		1.30919 ± 0.03	2.47 ± 0.12	
		1.84380 ± 0.03	1.98 ± 0.09	
		1.97083 ± 0.04	0.06 ± 0.02	
		2.04398 ± 0.03	5.47 ± 0.23	
		3.48841 ± 0.03	2.52 ± 0.11	
		3.52631 ± 0.04	1.98 ± 0.10	
		3.58654 ± 0.03	4.24 ± 0.18	
		3.68017 ± 0.04	0.99 ± 0.06	
		3.96507 ± 0.04	1.02 ± 0.06	

Table 20.6: Radiative transitions in ^{20}F [a] (continued)

E_i (MeV ± keV)	J^π_i	E_f (MeV ± keV)	Branching (%)	δ
		4.08217 ± 0.04	0.73 ± 0.06	
		4.27709 ± 0.04	1.23 ± 0.06	
		4.37147 ± 0.11	0.54 ± 0.04	
		4.59172 ± 0.07	0.49 ± 0.05	
		4.89276 ± 0.17	0.27 ± 0.04	
		5.22610 ± 0.40	0.05 ± 0.02	
		5.28279 ± 0.17	0.24 ± 0.03	
		5.31917 ± 0.04	0.90 ± 0.06	
		5.46589 ± 0.17	0.09 ± 0.03	
		5.55534 ± 0.04	1.85 ± 0.10	
		5.62313 ± 0.06	0.64 ± 0.11	
		5.81010 ± 0.40	0.04 ± 0.01	
		5.93613 ± 0.03	15.6 ± 0.8	
		5.93910 ± 0.10	1.07 ± 0.16	
		6.01778 ± 0.03	37.7 ± 1.1	
		6.04498 ± 0.08	2.12 ± 0.14	
		6.29910 ± 0.03	0.05 ± 0.02	
[e]				

[a] Branching ratios from Table II of (1996RA04) renormalized to add to 100%. For unobserved transition upper limits see Table VI of (1996RA04).

[b] Pure E1.

[c] See ^{20}F, reaction 12.

[d] Capturing state. See Table 20.11 and (1996RA04).

[e] For higher states see Table 20.9. See also Table 20.7 in (1987AJ02).

8. ^{13}C(^{11}B, α)^{20}F $\qquad Q_m = 9.385$

The upper of the two states at 2.97 MeV has an excitation energy of 2968 ± 2 keV and γ branching ratios of (40 ± 10) and (38 ± 10)%, respectively, to ^{20}F* (1.97, 0.82) $[J^\pi = (3^-),\ 4^+]$: this is consistent with $J^\pi = (4^-)$ for ^{20}F* (2.968) (1978LE19, 1996RA04).

The reactions ^{13}C(^{11}B, α)^{20}F and ^{11}B(^{13}C, α)^{20}F were used to populate ^{20}F states up to $E_x = 10.1$ MeV by (1988LI28). Comparisons with ^{14}N(^{7}Li, p)^{20}F were discussed.

Table 20.7: Some states of ^{20}F reported in ^{14}N(^{7}Li, p) [a]

E_x (keV)	J^π	E_x (keV)	J^π
0	2^+	5282 ± 11	[c]
657 ± 6	3^+	5316 ± 7	[c]
820 ± 5	4^+	5350 ± 5	3^+
984 ± 5	1^-	5405 ± 4	[c]
1049 ± 5	1^+	5448 ± 6 [b]	
1310 ± 6	2^-	5560 ± 6 [b]	
1826 ± 4 [b]	5^+	5612 ± 5 [b]	[c]
1969 ± 5	(3^-)	5725 ± 10	$(2, 3, 4, 5)$
2040 ± 3	2^+	5765 ± 8	3^+
2194 ± 6	3^+	5803 ± 7	1^+
2863 ± 5	(3^-)	5940 ± 5	[c]
2962 ± 3 [b]		6021 ± 4 [b]	
3171 ± 4	1^+	6090 ± 7	(0^-)
3491 ± 3 [b]	0^+	6160 ± 5	$((1^-), 2, 3^+)$
3578 ± 5 [e]		6193 ± 6	$(2^-, 3, 4^+)$
3674.2 ± 2.8 [e]		6297 ± 5 [b]	[c]
3756.5 ± 2.3	$(2^-, 3^+)$ [f]	6344 ± 9 [b]	[c]
3967 ± 5	1^+	6379 ± 5 [b]	[c]
4080 ± 4 [e]		6417 ± 4	$(3^-, 4, 5, (6^+))$
4198 ± 3 [b]		6470 ± 4	[c]
4274 ± 3 [b]		6565 ± 6 [b]	[c]
4366 ± 8	$0^{(-)}$	6600 ± 8 [b]	[c]
4512 ± 4	$(3^-, 4^-, 5^+, 6^+)$	6633 ± 3 [b]	
4579 ± 4 [b]		6695 ± 3	[c]
4728 ± 5	$(3^-, 4^-, 4^+, 5^+)$	6756 ± 3	$(2^-, 3, 4^+)$
4760 ± 5	$(4^-, 5^-, 6^-, 6^+, 7^+, 8^+)$	6823 ± 3	
4889 ± 4 [b]	[c]	6936 ± 4	
5032 ± 4	2^-	6968 ± 4	
5064 ± 5	$(1^-, 2, 3^+)$	6991 ± 7	
5128 ± 5	$(2^-, 3, 4^+)$	7034 ± 9 [d]	
5222 ± 4	$(1, 2)^-$	7080 ± 7	

Table 20.7: Some states of ^{20}F reported in ^{14}N(^{7}Li, p) [a] (continued)

E_x (keV)	J^π	E_x (keV)	J^π
7154 ± 5		8113 ± 4	
7232 ± 7		8147 ± 6	
7283 ± 4		8268 ± 12	
7319 ± 8		8349 ± 4	
7370 ± 20		8573	
7419 ± 20		8697	
7495 ± 5		8754	
7655 ± 5		8792	
7734 ± 6		8907	
7865 ± 16		8946	
7975 ± 5		9022	
8062 ± 8			

[a] $E(^{7}\text{Li}) = 16$ MeV. Levels for $E_x = 0 - 4366$ keV are from (1977FO11). Levels for $4512 - 9022$ are from (1985FO07). Please note that the density of states is very high and that when J^π assignments are made [based on cross sections and the $2J_f + 1$ relationship, with slopes which are different for even- and odd-parity states], these depend on the states having been resolved.

[b] Unresolved.

[c] See (1985FO07).

[d] All the observed groups for $E_x \geq 7.0$ MeV appear to be due to unresolved states. See (1985FO07) for $\sigma_{\text{tot}}(0° - 90°)$ and J^π.

[e] Possible doublet.

[f] If single state.

9. ^{14}N(^{7}Li, p)^{20}F $\qquad Q_m = 10.499$

Tables 20.7 here and 20.6 in (1983AJ01) display ^{20}F states reported in this reaction.

10. ^{16}O(^{7}Li, ^{3}He)^{20}F $\qquad Q_m = -4.743$

For reported states see Table 20.6 in (1983AJ01).

11. (a) ^{18}O(d, n)^{19}F $Q_{\rm m} = 5.770$ $E_{\rm b} = 12.371$
(b) ^{18}O(d, p)^{19}O $Q_{\rm m} = 1.731$
(c) ^{18}O(d, d)^{18}O
(d) ^{18}O(d, ^{3}He)^{17}N $Q_{\rm m} = -10.448$
(e) ^{18}O(d, α)^{16}N $Q_{\rm m} = 4.246$

See (1983AJ01) for a listing of the polarization measurements. For VAP measurements at $E_{\rm d} = 52$ MeV (reaction (e)), see (1982MA25). See also ^{19}O and ^{19}F in (1995TI07), and ^{16}N and ^{17}N in (1993TI07). See also (1986SE1B).

12. ^{18}O(^{3}He, p)^{20}F $Q_{\rm m} = 6.877$

In earlier work, proton groups have been observed to states of ^{20}F with $E_{\rm x} < 4.1$ MeV: see Table 20.8 in (1978AJ03). Angular distributions, γ-ray polarization data and branching ratios lead to the J^{π} values shown in that table. A state at $E_{\rm x} = 6519 \pm 3$ keV is also populated. It decays primarily ($> 90\%$) to ^{20}F* (1.06) $[J^{\pi} = 1^{+}]$: the γ-rays are isotropic. ^{20}F* (6.52) is the 0^{+}; $T = 2$ analog of the ground state of ^{20}O: see (1978AJ03, 1977BA50).

More recently, the reaction was studied at $E(^{18}{\rm O}) = 18$ MeV (1992CH39). Energy levels were measured up to $E_{\rm x} \approx 8$ MeV. See Table 20.8. See also (1987SE17).

13. ^{18}O(α, d)^{20}F $Q_{\rm m} = -11.476$

At $E_{\alpha} = 64.4$ MeV angular distributions have been reported to ^{20}F* (0, 0.66, 0.82, 1.06, 1.82, 2.20, 2.97, 4.24, 5.07, 5.44, 5.80, 6.67, 7.29, 7.75, 8.34, 8.75, 9.00, 9.24, 9.78, 10.01, 10.51, 10.85, 11.56, 12.32, 12.72): L assignments are made [the groups above $E_{\rm x} \approx 2.9$ MeV are probably unresolved] (1986KA36).

14. ^{19}F(n, γ)^{20}F $Q_{\rm m} = 6.601$
$Q_{0} = 6601.35 \pm 0.04$ keV (1996RA04)

The thermal capture cross section is 9.51 ± 0.09 mb. A number of resonances have been observed: see Table 20.9. The primary γ-rays resulting from capture at thermal energies (^{20}F* (6.60); $J^{\pi} = 1^{+}$) and at $E_{\rm n} = 27$, 44, and 49 keV (^{20}F* (6.63, 6.643, 6.647); $J^{\pi} = 2^{-}$, (3, 4) and 1^{-}) have been studied by several groups: see (1972AJ02) and Table 20.7 in (1987AJ02). For more recent high precision work see (1987KE09) and the comprehensive study of (1996RA04), which included measurements of excitation energies and lifetimes and comparison of level properties

Table 20.8: Some states in ^{20}F from ^{18}O(^{3}He, p)^{20}F [a]

E_x (keV) [b]	L transfer	J^π	E_x (keV) [b]	L transfer	J^π
0	2		5404 ± 10		$(3,4,5)^+$
656 ± 10	2		5445 ± 14	2	$(1,2,3)^+$
823 ± 10	4		5543 ± 12	1	$(0,1,2)^-$
997 ± 10			5562 ± 12	1	$(0,1,2)^-$
1058 ± 11	$0+2$		5627 ± 12	1	$(0,1,2)^-$
1317 ± 10	1		5645 ± 12	3	$(2,3,4)^-$
1824 ± 10	4		5661 ± 12		
1974 ± 11	3		5708 ± 12		
2047 ± 11	2		5761 ± 14	2	
2201 ± 11	$2+4$	3^+	5795 ± 14	0	
2860 ± 11	(2)	$(1,2,3)^+$	5930 ± 14	1	
2968 ± 10	$2+4$		6006 ± 14		
3176 ± 11	2		6049 ± 14		
3486 ± 10	$0+2$		6065 ± 14		
3587 ± 10	2		6079 ± 14		
3680 ± 11	4	$(3,4,5)^+$	6095 ± 14		
3762 ± 11	3	2^-	6111 ± 14		
3961 ± 12	$0+2$		6136 ± 14		
4082 ± 10	0	1^+	6154 ± 14	4	3^+
4210 ± 14	4	$(3,4,5)^+$	6189 ± 14		
4282 ± 10	4	$(3,4,5)^+$	6213 ± 14	1	2^-
4516 ± 10	3	2^-	6251 ± 14		
4590 ± 12			6287 ± 14		
4722 ± 12	4	$(3,4,5)^+$	6335 ± 14		
4744 ± 12	4	$(3,4,5)^+$	6355 ± 14		
4768 ± 11			6391 ± 14		
4904 ± 12			6413 ± 14		
5041 ± 10	1		6444 ± 14		
5126 ± 12			6458 ± 14		
5223 ± 10	1		6481 ± 14		
5278 ± 10	0	$(1)^+$	6509 ± 14	0	
5319 ± 10	1		6578 ± 14		
5340 ± 12	2				

[a] (1992CH39). For earlier work see Table 20.8 in (1978AJ03).

[b] Uncertainties in E_x were supplied by M.S. Chowdhury in a private communication to S. Raman, 22 March 1994.

Table 20.9: Resonances in ^{19}F(n, γ)^{20}F [a]

E_n (keV)	J^π [b]	Γ_γ (eV)	$\Gamma_{c.m.}$ (keV)	E_x in ^{20}F (MeV)
27.07 ± 0.05	2^-	1.4 ± 0.3	0.355 ± 0.03	6.6270
43.5 ± 0.1	(3, 4)	[c]	< 0.08	6.6426
48.7 ± 0.3	1^-	1.6 ± 0.3	1.96 ± 0.3	6.6475
97.0 ± 0.5	1^-	6.0 ± 1.8 [d]	13.5 ± 1.5	6.6934
173.5 ± 0.9		[e]	≤ 0.6	6.7661
269 ± 1	2	3.5 ± 0.8	10 ± 2	6.8567
(270 ± 8)	1	≤ 4.4		(6.859)
386 ± 1	1^-	2.4 ± 0.8	5 ± 1	6.9678
(490.5 ± 1)	0^-	$(\geq 10 \pm 3)$	(2.4 ± 0.6)	(7.0671)
595 ± 2	2	6.3 ± 1.2	8 ± 1	7.166
760		2.9	60	7.32
865			60	7.42
950		2.8	95	7.50
1125		3.9	80	7.67
(1295 ± 12)	1^-	8.6	(50 ± 10)	(7.831)
1460 ± 3	1	$\geq 11 \pm 3$	14 ± 2	7.988
1635		11 ± 3	180	8.15

[a] For complete references see Table 20.9 in (1978AJ03).

[b] Assumed.

[c] $g\Gamma_n = 0.086 \pm 0.020$ eV.

[d] May be two resonances.

[e] $g\Gamma_n = 0.35 \pm 0.10$ eV.

Table 20.10: Primary capture transitions in ^{19}F(n, γ)^{20}F [a]

Final state	I_γ [b] from		
^{20}F* (MeV)	^{20}F*(6.63)	^{20}F*(6.64)	^{20}F*(6.65)
0	2.0 ± 0.5		
0.66	6 ± 1	42 ± 7	
0.82		23 ± 7	
0.98			18 ± 4
1.06			9 ± 4
1.31	31 ± 2		
1.84	8 ± 2		
1.97	46 ± 4		
2.04	1.5 ± 1		59 ± 6
2.97		35 ± 9	
3.49	3 ± 1		14 ± 5
3.53	8 ± 1		
4.08	2.5 ± 1		

[a] For complete references see Table 20.10 in (1978AJ03). See also Tables 20.6 and 20.9 here.

[b] In unit of photons/100 captures.

with a large-basis shell-model calculation. It appears that the thermal capture [^{20}F* (6.60)] is dominated by two intense transitions (E1) to ^{20}F* (5.94, 6.02) [both $J^\pi = 2^-$]. If the ground-state transition is mainly M1, these two E1 transitions are about 150 times stronger (in terms of W.u.) than the M1 transition (1968SP01). See also (1983HU12). It appears also that at ^{20}F* (6.63, 6.64, 6.65) [$J^\pi = 2^-$, (3, 4) and 1^-] the E1 transitions to the ground state are very weak, even though other E1 transitions in the decay of these three states have approximately normal strengths. The strongest transitions from the 27 keV resonance appear to be M1. On the basis of the J^π values of the final states involved in the decay of the 44 keV resonance, it appears that $J = 3$ or 4 for this resonance, assuming dipole transitions. Branching ratios for other ^{20}F states involved in this reaction are shown in Table 20.6.

Table 20.11 displays excitation energies for ^{20}F states involved in cascade and in primary γ-transitions from the recent work of (1996RA04). For earlier references see (1978AJ03). See also (1991IG1A, 1991HI23).

15. (a) ^{19}F(n, n′)^{19}F $\qquad E_b = 6.601$

Table 20.11: States of ^{20}F involved in ^{19}F(n, γ)^{20}F [a]

E_x (keV)	E_x (keV)	E_x (keV)	E_x (keV)
0	2864.86 ± 0.10	4082.17 ± 0.04	5555.34 ± 0.04
656.02 ± 0.03	2966.11 ± 0.03	4277.09 ± 0.04	5623.13 ± 0.06
822.73 ± 0.03	3171.69 ± 0.14	4371.47 ± 0.11	5810.1 ± 0.4
983.59 ± 0.03	3488.41 ± 0.03	4591.72 ± 0.07	5936.13 ± 0.03
1056.82 ± 0.03	3526.31 ± 0.04	4892.76 ± 0.17	5939.10 ± 0.10
1309.19 ± 0.03	3586.54 ± 0.03	5226.1 ± 0.4	6017.78 ± 0.03
1843.80 ± 0.03	3589.80 ± 0.04	5282.79 ± 0.10	6044.92 ± 0.03
1970.83 ± 0.04	3680.17 ± 0.04	5319.17 ± 0.04	6299.1 ± 0.3
2043.98 ± 0.03	3965.07 ± 0.04	5465.89 ± 0.17	6601.35 ± 0.03
2194.30 ± 0.03			

[a] (1996RA04). For the earlier work see Tables 20.11 in (1978AJ03) and 20.8 in (1987AJ02).

(b) ^{19}F(n, nn)^{18}F $\qquad Q_m = -10.431$

The scattering length (bound) $b = 5.654 \pm 0.010$ fm, $\sigma_{\text{free}} = 3.641 \pm 0.010$ b (1979KO26). The difference in the spin-dependent bound scattering lengths, $b^+ - b^- = -0.19 \pm 0.02$ fm (1979GL12). The total cross section has been measured for $E_n = 0.5$ to 29.1 MeV: see (1978AJ03). Observed resonances are displayed in Table 20.12.

Average cross sections for the region $E_n = 0.55$–5.5 MeV were measured by (1988KO18). See also the neutron cross section tables and curves of (1988MCZT, 1990NAZH).

Observed resonances in the excitation functions involving ^{19}F*(0.11, 1.5(u)) are displayed in Table 20.13. For reaction (b) see (1983CSZX). See also (1986BAYL, 1986SA40).

16. ^{19}F(n, α)^{16}N $\qquad Q_m = -1.524 \qquad E_b = 6.601$

Reported resonances are shown in Table 20.14. See also the neutron cross section curves and tables of (1990NAZH).

17. ^{19}F(d, p)^{20}F $\qquad Q_m = 4.377$

States of ^{20}F observed in this reaction are displayed in Table 20.15. See (1978AJ03) for a discussion of the earlier work. See also (1983JI04, 1988RO10, 1992WA04, 1994GO16).

Table 20.12: Resonances in ^{19}F(n, n)^{19}F [a]

E_n (keV)	Γ_{cm} (keV)	J^π	^{20}F* (MeV)
26.99	0.309 ± 0.019	2^-	6.6269
48.78	1.59 ± 0.10	1^-	6.6476
97.50	13.8 ± 0.8	1^-	6.6939
500	24 [b]	(1^+)	7.076
600	14 [b]	(2^+)	7.171
747	33 [b]	(1)	7.311
794	19	(1)	(7.355)
852	10 [b]	(2^+)	7.410
935	57	(2)	7.489
1100	48	(2^+)	7.65
1250	143		7.79
1620	209		8.14
2000	143		8.50
2250	≤ 29		8.74
2280	76		8.77
2520	143		8.99
3250	143		9.69
3420	124		9.85
3460 ± 10			(9.886)
3505 ± 10			(9.929)
3560 ± 10			(9.981)
3605 ± 10	190		10.024
3820 ± 10	≈ 190	0^-, 1	10.228
4085 ± 10	≈ 9.5		10.480
4255 ± 10	≈ 57	1, 2	10.641
4430 ± 10	≈ 314	0^-, 1	10.807
4680 ± 10	≈ 29		11.045
4770 ± 10	< 24		11.130
4890 ± 10	< 24		11.244
(4935)			(11.287)

[a] For references see Table 20.12 in (1978AJ03).

[b] $\Gamma_\gamma = 3.3 \pm 1.0$, 6.3 ± 1.2, 2.4 ± 0.8 and 1.5 ± 0.5 eV for ^{20}F*(7.08, 7.17, 7.31, 7.41).

Table 20.13: States of ^{20}F from resonances in ^{19}F(n, n′γ)^{19}F

E_n (keV)	Γ_{cm} (keV)	Resonance in		E_x in ^{20}F (MeV)
		$\gamma_{0.11}$ [a]	$\gamma_{1.5}$ [b]	
240		*		6.829
270		*		6.858
386		*		6.968
420		*		7.000
490		*		7.066
620		*		7.190
800		*		7.361
860		*		7.418
1150 [c]		*		7.693
1250		*		7.788
1580		*		8.101
1645	14	*	*	8.163
1916	27		*	8.421
2240	43		*	8.728
2465	71	*	*	8.942
2700		*		9.165
3075	114		*	9.521
3215	76		*	9.654
3400	33		*	9.830
3475	≤ 29		*	9.901
3620	114	*	*	10.038
4240	86	*	*	10.627
4620	190		*	10.988
4900	≤ 48		*	11.254
7300		*		13.532

[a] Resonances in yield of 0.11 MeV γ-rays at $\theta = 92°$: values for E_n read by F. Ajzenberg-Selove from differential cross section tables. See Table 20.13 in (1978AJ03) for references.

[b] Resonances in (n, n′γ) yields with $E_x(^{19}F) \approx 1.5$ MeV: see (1973MA14).

[c] Appears to be unresolved.

Table 20.14: Resonances in ^{19}F(n, α)^{16}N [a]

E_n (MeV $\pm$ keV)	E_x (MeV)
3.4	9.8
3.61 ± 50	10.03
3.69 ± 50	10.10
3.76 ± 40	10.17
4.09 ± 40	10.48
4.39 ± 40	10.77
4.52 [b]	10.89
4.82 ± 40	11.18
5.15 ± 50	11.49
5.40 [b]	11.73
5.7	12.0
5.9 ± 100 [b]	12.2
6.10	12.39
6.55	12.82
6.9	13.2
7.44	13.66
7.8	14.0

[a] For references see Table 20.14 in (1978AJ03). See also graph in (1976GAYV).

[b] Not resolved.

Table 20.15: States in ^{20}F from ^{19}F(d, p)^{20}F [a]

E_x (keV) [b]	l_n [c]	J^π	$(2J+1)S$ [e]	n, l, j [c]
0	2	2^+	0.054	$1d_{5/2}$
656.02 ± 0.03	2	3^+	2.32	$1d_{5/2}$
822.73 ± 0.03	[d]	4^+	0.32	$1g_{9/2}$
983.59 ± 0.03	[d]	1^-	0.014	$1p_{1/2}$
1056.82 ± 0.03	$0+2$	1^+	0.013	$2s_{1/2}$
1309.19 ± 0.03	[d]	2^-	0.017	$1p_{3/2}$
1823.8 ± 1.6	[d]	(5^+)	0.35	$1g_{9/2}$

Table 20.15: States in ^{20}F from ^{19}F(d, p)^{20}F [a] (continued)

E_{x} (keV) [b]	l_{n} [c]	J^{π}	$(2J+1)S$ [e]	n, l, j [c]
1843.80 ± 0.03	[d]	2^-	0.007	$2\text{p}_{3/2}$
1970.83 ± 0.04	[d]	(3^-)	0.038	$1\text{f}_{3/2}$
2043.98 ± 0.03	2	2^+	2.32	$1\text{d}_{5/2}$
2194.30 ± 0.03	2	3^+	0.55	$1\text{d}_{5/2}$
2864.86 ± 0.10	[d]		0.044	$1\text{f}_{7/2}$
2966.11 ± 0.03	2	3^+	0.38	$1\text{d}_{3/2}$
3171.69 ± 0.14	[d]		0.019	$1\text{d}_{5/2}$
3488.41 ± 0.03	0	1^+	1.20 [f]	$2\text{s}_{1/2}$
3526.31 ± 0.04	0	0^+	0.28 [f]	$2\text{s}_{1/2}$
3586.54 ± 0.03	2	$\pi = +$	0.038	$1\text{d}_{3/2}$
3680.17 ± 0.04	2	$\pi = +$	0.031	$1\text{d}_{5/2}$
3761.0 ± 2.0	[d]		[c]	
3965.07 ± 0.04	2	$\pi = +$	0.036	$1\text{d}_{5/2}$
4082.17 ± 0.04	$0 + 2$	$\pi = +$	0.13	$1\text{s}_{1/2}$
4199.3 ± 2.7				
	[d]		0.083	$1\text{d}_{3/2}$
4208.1 ± 2.6				
4277.09 ± 0.04	2	$\pi = +$	0.087	$1\text{d}_{5/2}$
4312.0 ± 2.6	0	$(0, 1)^+$	0.20	$2\text{s}_{1/2}$
4371.47 ± 0.11				
4509 ± 3				
4584.6 ± 3.0			0.02	$2\text{p}_{3/2}$
	1	$(0-2)^-$		
4591.72 ± 0.07			(< 0.05)	$(1\text{f}_{7/2})$
4731.2 ± 2.9	2, 3			
4764.8 ± 2.7	2, 3			
4892.76 ± 0.17				
4899.4 ± 2.8				
5041.5 ± 3.1				
5066.8 ± 3.1	2	$(1, 2, 3)^+$	0.09	$1\text{d}_{5/2}$
5130 ± 3				

Table 20.15: States in ^{20}F from ^{19}F(d, p)^{20}F [a] (continued)

E_x (keV) [b]	l_n [c]	J^π	$(2J+1)S$ [e]	n, l, j [c]
5226.1 ± 0.4	1, 3		0.09	$2p_{3/2}$
5282.79 ± 0.17	0	$(1, 0)^+$	0.34	$2s_{1/2}$
5319.17 ± 0.04	2 or $1+3$	$(1, 2, 3)^+$ or 2^-	0.10	$1d_{5/2}$
5352 ± 3	2	$(1, 2, 3)^+$	0.06	$1d_{5/2}$
5407 ± 3				
5452.1 ± 3.8				
5457.2 ± 3.2				
5465.89 ± 0.17	2	$(1, 2, 3)^+$	0.27	$1d_{5/2}$
5555.34 ± 0.04	1	$(0, 1, 2)^-$	0.03	$2p_{3/2}$
5588 ± 2				
5623.13 ± 0.06	[d]			
5710 ± 6	[d]			
5764.9 ± 3.4	2	$(1, 2, 3)^+$	0.15	$1d_{5/2}$
5810.1 ± 0.4	$0+2$, or $1+3$	$(2^-, 1^+)$		
5936.13 ± 0.03	$1(+3)$	$(1^-, 2^-)$	0.43	$2p_{3/2}$
6017.78 ± 0.03	$1+3$	(2^-)	0.68	$2p_{3/2}$
			1.40	$1f_{7/2}$
6044.98 ± 0.08				

[a] For complete references see Table 20.15 in (1978AJ03) and see also Table 20.14 in (1983AJ01).

[b] Level energies from Table 20.5.

[c] Assumed in analysis; $E_d = 12$ MeV.

[d] Weak groups.

[e] (1972FO11, 1974FO21).

[f] At $E_d = 16$ MeV.

18. ^{20}O$(\beta^-)^{20}$F $\qquad Q_m = 3.814$

The decay is to ^{20}F*(1.06, 3.49), $J^\pi = 1^+$: see ^{20}O. For ^{20}F*(1.06) $E_x = 1056.848 \pm 0.004$ keV. The β branch to ^{20}F* (3.17) $(0^-, 1^+)$ is < 0.012%, $\log f_0 t > 5.1$ (1987AL06).

19. ^{20}Ne$(\pi^-, \gamma)^{20}$F $\qquad Q_m = 132.543$

The branching ratio to ^{20}F* (1.06) $[J^\pi = 1^+]$ is compared to the analogous M1 decay width ^{20}Ne* (11.26) $[J^\pi = 1^+] \rightarrow {}^{20}\mathrm{Ne_{gs}}$. The M1 amplitude contains (47 ± 16)% spin-flip, in agreement with shell-model calculations. The population of ^{20}F* (0, 1.31, 1.84) [$J^\pi = 2^+$, 2^-, 2^-] is also reported (1981MA04). See also (1986BA16) and (1983KN05).

20. ^{20}Ne(n, p)^{20}F $\qquad Q_\mathrm{m} = -6.243$

Differential cross sections were measured at $E_\mathrm{n} = 198$ MeV to study Gamow-Teller strength up to $E_\mathrm{x} \approx 10$ MeV in ^{20}F (1990HE1G, 1991PO14). See also the measurement of ground-state correlations described in (1988MA53). Cross sections for 14 MeV neutrons are presented for use in activation analysis by (1989PE04).

21. ^{20}Ne(d, pp)^{20}F $\qquad Q_\mathrm{m} = -8.467$

Angular distribution measurements with polarized deuterons ($E \approx 2$ GeV) were made in a study of spin-isospin excitations by (1988HE1I).

22. ^{20}Ne(t, ^{3}He)^{20}F $\qquad Q_\mathrm{m} = -7.006$

Measurements at $E_\mathrm{t} = 33.4$ MeV (1990CL06) reveal a strongly excited state in ^{20}F at $E_\mathrm{x} = 6.75 \pm 0.04$ MeV with an angular distribution suggesting $(3 < J < 6)$. In more recent work by the same authors (1993CL09), the reactions ^{20}Ne(t, ^{3}He)^{20}F and ^{20}Ne(^{3}He, t) were studied at $E_\mathrm{t} = 33.4$ MeV. Evidence was obtained that the $J^\pi = 3^+$, $E_\mathrm{x} = 2.966$ MeV state in ^{20}F should be identified as the analog of the $E_\mathrm{x} = 2.646$ MeV state in ^{20}Na.

23. ^{20}Ne(^{12}C, ^{20}F)^{12}N $\qquad Q_\mathrm{m} = -13.870$

Measurements at 900 MeV/nucleon for studies of spin-isospin excitations were reported by (1988RO1H).

24. ^{21}Ne(d, ^{3}He)^{20}F $\qquad Q_\mathrm{m} = -7.510$

The ^{20}F states observed at $E_\mathrm{d} = 26$ MeV in this reaction and analog $[T = 1]$ states observed in ^{20}Ne in the (d, t) reaction are displayed in Table 20.16 of (1978AJ03). The spectroscopic factors of analog states are consistent to within 20% for states excited by a single l-transfer.

25. ^{21}Ne(t, α)^{20}F $Q_{\rm m} = 6.810$

Angular distributions were measured at $E_{\rm t} = 15.0$ MeV by (1988LI10). States in ^{20}F up to $E_{\rm x} = 4.0$ MeV were observed and analyzed with DWBA calculations. Spectroscopic factors were deduced.

26. ^{22}Ne(p, ^{3}He)^{20}F $Q_{\rm m} = -15.649$

At $E_{\rm p} = 43.7$ to 45.0 MeV analog states have been studied in ^{20}F and ^{20}Ne [the latter via ^{22}Ne(p, t)^{20}Ne]. Angular distributions for the ^{3}He ions and the tritons corresponding to the first $T = 2$ states $(J^{\pi} = 0^{+})$ [^{20}Ne*(16.7329 ± 0.0027) and ^{20}F*(6.519 ± 0.003)] have been compared. There is indication also for the excitation of the 2^{+}; $T = 2$ states [at $E_{\rm x} = 8.05$ MeV in ^{20}F and at 18.430 ± 0.007 MeV in ^{20}Ne]: see (1978AJ03).

27. ^{22}Ne(d, α)^{20}F $Q_{\rm m} = 2.704$

Angular distributions have been obtained at $E_{\rm d} = 10$ MeV to ^{20}F states with $E_{\rm x} < 4.4$ MeV: they are generally featureless. Observed states are displayed in Table 20.17 of (1978AJ03).

An experiment which would use this reaction to investigate the weak parity-nonconserving coupling in ^{20}F by observing the asymmetry in the gamma rays from the ^{20}F $E_{\rm x} = 0.983$ MeV 1^{-} state has been proposed (1993HO14, 1993HO1N).

28. ^{23}Na(n, α)^{20}F $Q_{\rm m} = -3.866$

Reaction-model calculations for cross sections are described in (1993ST10). The use of this reaction in connection with neutron detection is discussed in (1987LE1G).

29. ^{24}Mg(n, pα)^{20}F $Q_{\rm m} = -15.559$

Cross sections calculated with pre-equilibrium emission, constant temperature evaporation models were reported in (1993KH09).

30. ^{27}Al(^{20}Ne, ^{27}Si)^{20}F $Q_{\rm m} = -11.838$

The Δ resonance is very strongly excited in this reaction at $E(^{20}\text{Ne}) = 950$ MeV/A (1986BA16).

^{20}Ne
(Figs. 3 and 5)

GENERAL: See Table 20.16.

Static quadrupole moment: $Q_{1.63} = -0.23 \pm 0.03\ e \cdot$ b (1989RA17)

$\mu_{1.63} = 1.08 \pm 0.08$ nm (1989RA17)

$B(\text{E2})\uparrow\ [0 \rightarrow 1.63] = 0.0330 \pm 0.0015\ e^2 \cdot \text{b}^2$ (1978GR06). See also (1987RA01).

Intrinsic hexadecapole moment: $Q_{4.25} = 0.022 \pm 0.003\ e^2 \cdot \text{b}^2$ (1978GR06)

$\mu_{4.25} = 0.52 \pm 0.60$ nm (1989RA17).

Isotopic abundance: (90.51 ± 0.09)% (1984DE53).

1. ^{9}Be(^{18}O, ^{20}Ne)^{7}He $\qquad Q_{\text{m}} = -8.502$

Observation of ^{20}Ne in this reaction and measurement of the cross section was reported by (1990BEYY).

2. (a) ^{10}B(^{10}B, ^{10}B)^{10}B $\qquad E_{\text{b}} = 31.144$
   (b) ^{10}B(^{10}B, α)^{16}O $\qquad Q_{\text{m}} = 26.414$

Excitation functions have been measured for $E(^{10}\text{B}) = 6$ to 30 MeV (reaction (a)) and 6 to 20 MeV (reaction (b)). Large resonant structures are observed in reaction (b), particularly at $E_{\text{x}} \approx 38$ MeV (α_0) and 38.6 MeV (α to ^{16}O* (7.0, 10.3, 16.2 (u)), $\Gamma \approx 0.6$ MeV. See also (1983KAZF) and (1978AJ03). More recently, cross sections for fusion of $^{10}\text{B}+^{10}\text{B}$ were measured for $E(^{10}\text{B}) = 1.5$–5 MeV/nucleon, and evidence for fissionlike decay of ^{20}Ne was observed (1989SZ01). Mass distributions from the sequential decay of the compound nucleus measured at $E(^{10}\text{B}) \approx 110$ MeV show no evidence for nuclear structure effects (1993SZ02).

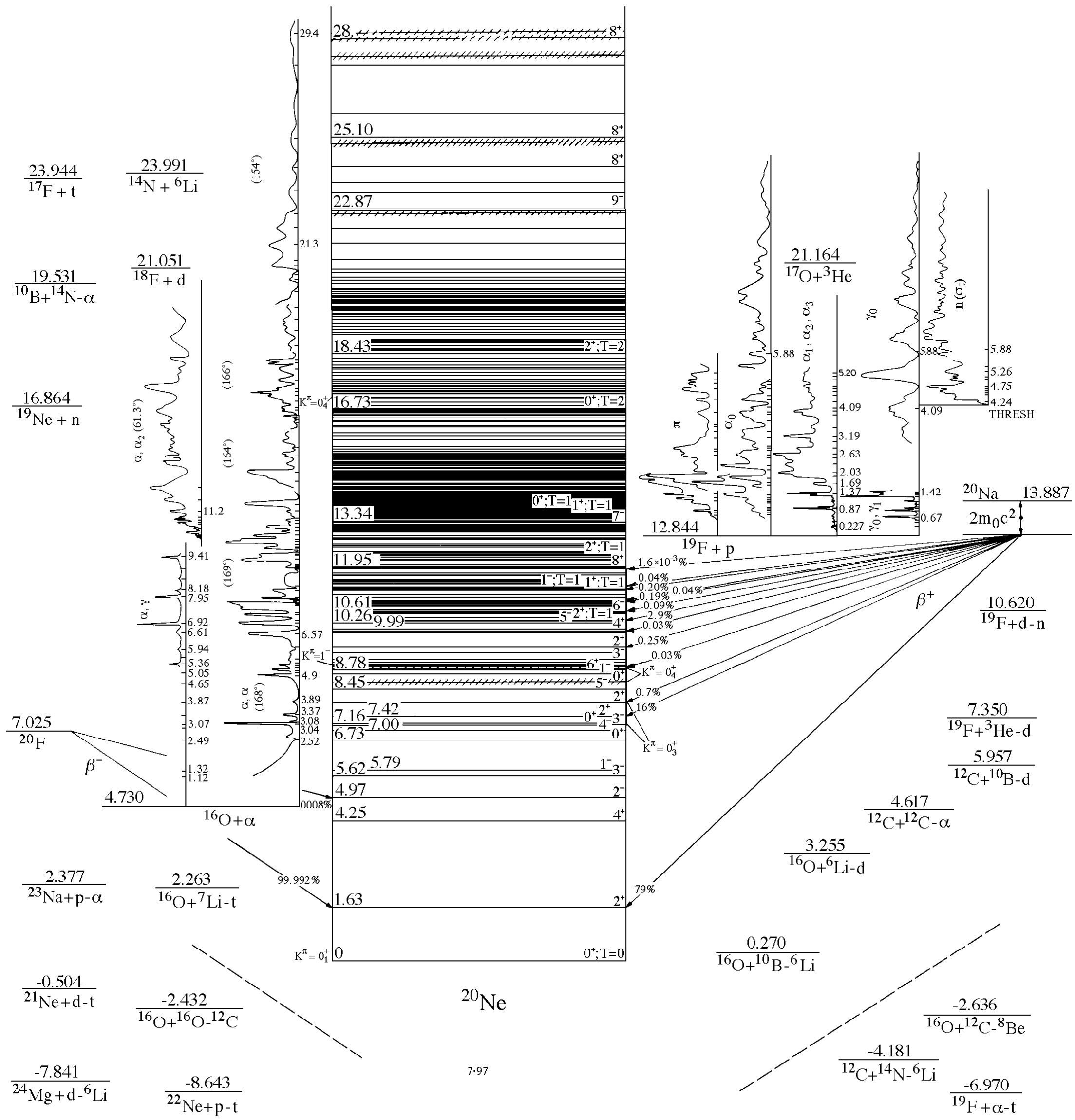

Figure 3: Energy levels of ^{20}Ne. For notation see Fig. 1.

Table 20.16: ^{20}Ne – General

Reference	Description
	Shell model
Review:	
1987SC1J	Microscopic nuclear structure theory in large single particle basis systems
1988BR1P	Status of the nuclear shell model
1988RA1G	Clustering phenomena & shell effects in nuclear structure and reactions
1993PI1E	Unified shell-model picture of nuclear deformation
Other articles:	
1987HA16	Test of the fermion dynamical symmetry model microscopy in the sd shell
1987HA41	SU(3) $\times$ SU(4) limit of an isospin invariant fermion dynamical symmetry model
1987HI08	Systematics of total strength & contribution of orbital current for M1 excitations
1987KR08	Discontinuity in ground state band plot of even-even nuclei is traced to p-n interaction
1987LI26	Rotational model and shell model pictures of magnetic dipole excitations
1987MU16	Relativistic effects in the low-energy spectra of 1s0d-shell nuclei
1987SU13	Symplectic model for isoscalar giant resonances & its coupling with cluster basis in ^{20}Ne
1988BR11	Semi-empirical effective interactions for the 1s-0d shell
1988CA09	Rotational collectivity in shell model wave functions for $A = 20$–28 nuclei
1988FI01	Effective interactions from sd-shell-model calculations
1988HI05	Effect on Gamow-Teller strength of config. mixing & p-n correlation in e-e sd-shell nucl.
1988MU10	The BAGEL approach in the nuclear shell model
1989CA05	Contracted symplectic model with sd-shell applications
1989ET01	n-p weak coupling: reducing shell-model dimensions by truncations in n & p subspaces
1989OR02	Empirical isospin-nonconserving Hamiltonians for shell-model calculations
1989PO04	Shell-model realization of scissors mode; collect. features described in Elliott's SU(3) limit
1989SA26	Gamow-Teller & M1 strength sums for sd shell nuclei by spectral distribution methods
1989SC14	Variational proced. for struct. calcs., beyond symmetry-projected quasi-particle mean fields
1989ZH05	Evidence for unnatural parity-pairing correlations in some light nuclei
1990BR26	Isospin-forbidden β-delayed proton emission
1990DI12	Hybrid treatment of rotational symmetry; calc. low-lying states of ^{20}Ne, ^{21}Ne, ^{28}Si
1990GU35	Calc. charge density distrib. using Hartree-Fock method & harmonic oscillator model
1990HA07	Neutrino nucleosynthesis in supernovae: shell model predictions
1990HA38	Resonating group model study of the ^{16}O + nucleon problem
1990RE06	1^+ excitations in light nuclei: SU(3) versus realistic shell model results
1990SK04	$A = 18$ nuclei, effective interaction in the sd shell (also calc. $A = 20$ energy spectra)
1990ZH01	Nuclear structure studies of double Gamow-Teller and double beta decay strength
1991BO45	Democratic mapping used to calc. low-lying states of sd- and fp-shell nuclei
1991DU05	SU(3) Elliott model used to study the thermal description of ^{20}Ne; e.g. phase transitions
1991MA41	Calculations of sd-shell nuclei with realistic potential models (Bonn, Paris, Argonne)
1992GU02	Effective sd-shell interaction from nuclear multishell configurations
1992HA1N	Cluster-orbital shell model applied to α-cluster formation in ^{20}Ne
1992JI04	Bonn potential used to evaluate energy spectra of some light sd-shell nuclei using G-matrix

Table 20.16: ^{20}Ne – General (continued)

Reference	Description
	Shell model (continued)
1992JO07	Monte Carlo methods used to calc. the shell model Hamiltonian
1992QU02	Effect of model space size on finite-temperature Hartree-Fock calculations
1992RO08	Electron scattering multipoles for symplectic shell model applications
1992WA22	Effective interactions for the 0p1s0d nuclear shell-model space
1993AU01	Correlation between the quenching of total GT$_+$ strength and the increase of E2 strength
1993KU1F	Criteria for distinguishing spherical nuclei; advantages of deformed-shell model
1993LA24	Monte Carlo evaluation of path integrals for the nuclear shell model
1993VO01	Spin-isospin SU(4) symmetry in sd- and fp-shell nuclei
1994CI02	Specific heat and shape transitions in light sd nuclei: finite size vs. phase transition
1994OR02	Application of auxilliary-field Monte Carlo techniques to GDR in hot nuclei
1994VE04	Spectroscopic factors from one-proton stripping reactions on sd-shell nuclei
1994ZH03	Systematic relativistic Hartree-Fock calculation of deformed nuclei in s-d shell
1995BE54	sd-shell study with multiconfiguration mixing approach for large scale nucl. struc. calcs.
1995BU25	Unified treatment of scattering and cluster structure in α+closed shell nuclei: ^{20}Ne & ^{44}Ti
1996BE01	Multi-configuration mixing approach with symmetry-projected complex HFB determinants
1996GO38	Calc. low nucl. excitations using method of successive addition of nucleons
1996KA41	Low-lying states in ^{20}Ne studied using isomorphic shell model; α-planar structure
	Collective, deformed & rotational models
Review:	
1987TA1C	Microscopic cluster theory review from conf. on few-body syst. & multiparticle dynamics
Other articles:	
1987HA41	SU(3) $\times$ SU(4) limit of an isospin invariant fermion dynamical symmetry model
1987KR08	Discontinuity in ground state band plot of even-even nuclei is traced to p-n interaction
1987LI26	Rotational model and shell model pictures of magnetic dipole excitations
1987PA29	Relativistic mean-field theory used to describe ground-state deformation of nuclei
1987PR03	Self-consistent Hartree description of deformed nuclei in a relativistic quantum field theory
1987RE04	The generator coordinate method and quantised collective motion in nuclear systems
1987SU13	Symplectic model for isoscalar giant resonances & its coupling with cluster basis in ^{20}Ne
1988CA09	Rotational collectivity in shell model wave functions for $A = 20$–28 nuclei
1988JO02	Relativistic DWBA calculations for proton inelastic scattering
1989CA05	Contracted symplectic model with sd-shell applications
1989KO13	A relativistic description of rotating nuclei: the yrast line of ^{20}Ne
1989MI18	Evidence for phase transitions in finite systems
1989MI1M	The phase structure of nuclei at low temperatures
1989PO04	Shell-model realization of scissors mode; collect. features described in Elliott's SU(3) limit
1989RI1D	Relativistic mean field theory of nuclear structure
1989RO1G	Broken symplectic dynamical symmetry in the microscopic collective model (A)

Table 20.16: ^{20}Ne – General (continued)

Reference	Description
	Collective, deformed & rotational models (continued)
1989TO05	α-decay widths of ground band of ^{20}Ne studied with cluster & deformed models
1990CA07	Momentum distributions in axially symmetric deformed nuclei: the Nilsson model
1990CO04	Effect of the continuum on thermally induced phase transitions in nuclei
1990DI12	Hybrid treatment of rotational symmetry; calc. low-lying states of ^{20}Ne, ^{21}Ne, ^{28}Si
1990GA09	Studies of (e, e$'\gamma$) reactions and electromagnetic currents in rotational nuclei
1990PH01	Inelastic ^{20}Ne-$\vec{p}$ scattering data analyzed for evidence of a real tensor potential
1990YA08	Competition between α clustering and the spin-orbit force in the ground bands of ^{20}Ne
1991AM1A	Analysis of inelastic ^{20}Ne-p scattering (exciting gs rot. band) using several models
1992HJ01	Folded-diagram effective interactions with the Bonn meson-exchange potential model
1992RO16	Self-consistent anisotropic oscillator with cranked angular and vortex velocities
1993BY03	Study of the quadrupole resonances in α-^{16}O scattering
1993SA31	Dynamic microscopic basis for IBM-2; compared with shell model calcs. & exp. data
1994CI02	Specific heat and shape transitions in light sd nuclei: finite size vs. phase transition
1994MI05	Correlated finite temperature mean field approximations
1995SH26	Struct. of hot rotating even-even sd-shell nucl. studied using Landau theory of phase trans.
1996HI12	Triaxial deformation of unstable nuclei in the relativistic mean-field theory
1996KH05	Spontaneous sym. breaking & dissipation of nucl. collect. degrees of freedom at finite temp.
	Cluster models
Reviews:	
1987TA1C	Microscopic cluster theory review from conf. on few-body syst. & multiparticle dynamics
1988RA1G	Clustering phenomena & shell effects in nuclear structure and reactions
1997FR04	Developments in the study of nuclear clustering in light even-even nuclei
Other articles:	
1987DE40	The α+^{20}Ne cluster structure of ^{24}Mg in a microscopic three-cluster model
1987KA24	Structure of yrast states in ^{20}Ne investigated in the framework of a cluster model
1987SA55	The orthogonality condition model applied to (α, α) scattering on ^{12}C and ^{16}O
1987SU13	Symplectic model for isoscalar giant resonances & its coupling with cluster basis in ^{20}Ne
1988CS01	Core-plus-alpha-particle states of ^{20}Ne and ^{16}O in terms of vibron models
1988KA1Z	Systematic construction method of multi-cluster Pauli-allowed states
1988LE05	Distribution of alpha-particle strength in light nuclei
1988LE06	Influence of target clustering on exchange effects in internuclear interaction
1989DE32	Distortion effects in a microscopic ^{16}O + 2α and ^{20}Ne + α description of ^{24}Mg
1989GA05	Parity-dependent potential for ^{16}O + ^{20}Ne (linear combination of nuclear orbitals model)
1989RU08	Binding energies & gs band levels of light nuclei in the strictly restricted dynamics model
1989TO05	α-decay widths of ground band of ^{20}Ne studied with cluster & deformed models
1990BA01	α-like part of four-nucleons moving in a single-particle potential of arbitrary shape
1990VA14	Features of α-cluster type nuclei in the framework of the restricted dynamics model

Table 20.16: ^{20}Ne – General (continued)

Reference	Description
	Cluster models (continued)
1990YA08	Competition between α clustering and the spin-orbit force in the ground bands of ^{20}Ne
1991CS01	Cluster spectroscopic factor in the vibron model
1991OM03	The role of the Pauli principle in the elastic scattering of $\alpha + {}^{16}$O clusters
1991SZ02	Alpha particles from the reaction ^{12}C + ^{12}C at 28.7 MeV/nucleon
1991WA11	Composite Particle Representation Theory calcs. for $A = 20$ nuclei compared to shell model
1992AN1F	α-particle momentum distributions in nuclei in the coherent density fluctuations model
1992AR11	α-cluster structure of excited states in light nuclei
1992CS03	The relation between cluster and superdeformed states of light nuclei
1992HA1N	Cluster-orbital shell model applied to α-cluster formation in ^{20}Ne
1992KR12	Elimination of Pauli resonances in the generator-coordinate description of scattering
1992ME09	Alpha-chain states in 4N-nuclei from ^{20}Ne to ^{32}S
1992ME11	Systematics of alpha-chain states in 4N-nuclei
1993AB02	α-^{16}O & α-^{15}N optical potentials in the range between 0 and 150 MeV
1993BY03	Study of the quadrupole resonances in α-^{16}O scattering
1993CS03	^{16}O+α cluster states in terms of a $U_q(3)$ anharmonic oscillator model
1993LI25	Alpha-particle elastic scattering on ^{16}O in the four α-particle model
1993RA1G	Shape eigenstates & other one- and two-dimensional α-cluster structures in light nuclei
1993SZ02	Treatment of hot composite systems (^{19}F & ^{20}Ne) as liquid droplets
1993VA07	Relation between phenomenological algebraic cluster model & effective nn forces
1993YA08	Description of $\alpha + {}^{16}$O elastic scattering by a single-folding potential
1993ZH22	Systematics of 2-dimensional α-cluster configurations in 4N nuclei from ^{12}C to ^{44}Ti
1994ME18	Alpha chain states in 4N-nuclei
1994RA03	Geometry and collectivity in the Bloch-Brink α-cluster model
1994TO04	New effective internucleon forces in microscopic α-cluster model
1996HE20	Geometrical interpretation of the semi-microscopic algebraic cluster model
	Special states
Reviews:	
1987SC1J	Large-scale nuclear structure studies
1988RA1G	Clustering phenomena & shell effects in nuclear structure and reactions
1992MA29	High spin spectra in light nuclei in terms of the rotating harmonic oscillator
1993EN03	Strengths of γ-ray transitions in $A = 5$–44 nuclei
1987BL18	Gogny's effective inter. used to calc. ground & excited states of specific spin-isospin order
Other articles:	
1987CO31	Simple parametrization for low energy octupole modes of sd-shell nuclei
1987DE40	The $\alpha + {}^{20}$Ne cluster structure of ^{24}Mg in a microscopic three-cluster model
1987KA24	Structure of yrast states in ^{20}Ne investigated in the framework of a cluster model
1987MU16	Relativistic effects in the low-energy spectra of 1s0d-shell nuclei

Table 20.16: ^{20}Ne – General (continued)

Reference	Description
	Special States (continued)
1987PR03	Self-consistent Hartree description of deformed nuclei in a relativistic quantum field theory
1987SU13	Symplectic model for isoscalar giant resonances & its coupling with cluster basis in ^{20}Ne
1988BA16	Dynamics of nuclear integral characteristics
1988CA09	Rotational collectivity in shell model wave functions for $A = 20$–28 nuclei
1988GU12	Electron scattering from ^{20}Ne (and other light nuclei) and transition charge densities
1988KU07	Electron scattering from ^{20}Ne and ^{24}Mg in a microscopic boson model
1988KU17	Microscopic boson descrip. of p-n systems applied to electron scatt. from ^{18}O and ^{20}Ne
1988KU22	Microscopic foundation of the interacting boson model in sd-shell nuclei
1988MU10	The BAGEL approach in the nuclear shell model
1988ST04	Spectral distribution calculations of the level density of ^{20}Ne
1989DE12	Spectroscopy of ^{20}Ne & ^{24}Mg nuclei in the interacting boson model including g bosons
1989ET01	n-p weak coupling: reducing shell-model dimensions by truncations in the n & p subspaces
1989KO13	A relativistic description of rotating nuclei: the yrast line of ^{20}Ne
1989PO04	Shell-model realization of scissors mode; collect. features described in Elliott's SU(3) limit
1989PO05	Isobaric multiplets reconstructed from the equidistance rule for separation & decay energies
1989RO1G	Broken symplectic dynamical symmetry in the microscopic collective model (A)
1989SC14	Extension of the variational mean field procedure for structure calcs.
1989TO05	α-decay widths of ground state band of ^{20}Ne studied with cluster & deformed models
1989ZH05	Evidence for unnatural parity-pairing correlations in some light nuclei
1990AM01	Large basis space effects in electron scattering form factors of ^{12}C, ^{20}Ne, ^{24}Mg
1990RE06	1^+ excitations in light nuclei: SU(3) versus realistic two-rotor and shell model results
1990SK04	$A = 18$ nuclei, effective interaction in the sd shell (also calc. $A = 20$ energy spectra)
1990YA08	Competition between α clustering and the spin-orbit force in the ground bands of ^{20}Ne
1991BA25	Collective 3^- and 2^- excitations with Skyrme forces
1992CA05	Fragmentation of stretched spin strength in N=Z sd-shell nuclei
1992DE31	Higher order deformations in sd-shell nucl. from CC analysis of inelastic $\vec{\mathrm{p}}$ scattering
1992HA18	Coupled-channel description of rotational and vibrational states in ^{20}Ne and ^{22}Ne
1993PA25	Shapes of N=Z nucl. studied with axially symmetric deformed relativistic mean-field theory
1993PE18	Nucleon pair structure of realistic many body wave functions
1994HE02	Systematics of rotational isomers & band terminations in the $A = 20$–26 region
	Electromagnetic transitions
Reviews:	
1989RA16	Predictions of B(E2; $0^+_1 \rightarrow 2^+_1$) values for even-even nuclei
1989SP01	Reduced electric-octupole transition probabilities, B(E3; 0^+_1–3^-_1), for even-even nucl.
1993EN03	Strengths of γ-ray transitions in $A = 5$–44 nuclei
Other articles:	
1986SC1E	Large scale calculations of the nuclear spectrum (calc. isoscalar E2 resonance in ^{20}Ne)

Table 20.16: ^{20}Ne – General (continued)

Reference	Description
	Electromagnetic transitions (continued)
1987HI08	Systematics of total strength & contribution of orbital vs. spin current for M1 excitations
1987SU13	Symplectic model for isoscalar giant resonances & its coupling with cluster basis in ^{20}Ne
1988BA80	Dynamics of integral characteristics of atomic nuclei (M2 resonance calc. for ^{20}Ne)
1989CA05	Contracted symplectic model with ds-shell applications (calc. excit. spectra & E2 strengths)
1989DE12	Spectroscopy of ^{20}Ne & ^{24}Mg nuclei in the interacting boson model including g bosons
1989ET01	n-p weak coupling: reducing shell-model dimensions by truncations in n & p subspaces
1989PO04	Shell-model realization of scissors mode; collect. features described in Elliott's SU(3) limit
1989RO1G	Broken symplectic dynamical symmetry in the microscopic collective model (A)
1989SA26	Gamow-Teller and M1 strength sums for sd-shell nuclei by spectral distribution methods
1989VAZN	E2 transition probabilities in strongly restricted dynamics model
1990GUZV	Calc. charge density distrib., rms radii, moments by Hartree-Fock meth& harm. osc. model
1990RE06	1^+ excitations in light nuclei: SU(3) versus realistic two-rotor and shell model results
1992ZA10	Relation between E2 and orbital M1 transition strengths using a $Q \cdot Q$ interaction
1993AU01	Correlation between the quenching of total GT_+ strength and the increase of E2 strength
1993RUZX	Electromagnetic properties of light nuclei in the strictly restricted dynamics model
1994STZY	Many-particle approach used to calc. characteristics of giant multipole resonances
1995HA47	Sum rules for B(M1, $0^+_1 \rightarrow 1^+_i$) strength derived for even-even nucl. in IBM-3 & IBM-4
1995KA14	Transverse electron scattering form factors; violation of current conservation in nucl. models
1995SH42	Reduced probabilities for $E2$ transitions in deformed nonaxial even-even nuclei
1996TR06	Correl. between quadrupole deformation, B(E2; $0_1 \rightarrow 2_1$) value, and total GT^+ strength
1997UT01	Distribution of $E2$ excitations in sd-shell nuclei
	Astrophysics
Reviews:	
1986WO1A	Physics of supernova explosions
1987RA1D	Nuclear processes and accelerated particles in solar flares
1988BA86	Solar models, neutrino experiments, and helioseismology
1989AR1R	Supernova 1987A: observations, analysis, implications
1990AR10	Nuclear reactions in astrophysics
1990SC1N	New physics from supernova 1987A
1990SI1D	Spallation processes and nuclear interaction products of cosmic rays
1993HA48	Core-collapse supernovae & other topics that combine nuclear, particle, and astrophysics
1993LE1J	Solar-neutrino problem (A)
1996LA1G	Nucleosynthesis in the Big Bang and in stars
1996RE16	Coulomb dissociation experiments of astrophysical significance
Other articles:	
1987DW1A	Cosmic-ray elemental abundances from 1 to 10 GeV per amu for boron through nickel
1988AP1B	Primordial nucleosynthesis as a probe of cosmological QCD

Table 20.16: ^{20}Ne – General (continued)

Reference	Description
	Astrophysics (continued)
1988BU01	Stellar reaction rates of α capture on light $(N \neq Z)$ nuclei; astrophysical implications
1988CA26	Reaction rates of astrophysically important thermonuclear reactions involving light nucl.
1988CUZX	Compos. of anomal. cosmic-ray component; implications for local interstellar medium (A)
1988FO1E	Observ. & analysis of 27 April 1981 flare yield info on solar atmosphere elem. abundances
1988MA1U	Late-time neutron diffus. & nucleosynthesis in post-QCD inhomogeneous $\Omega_b = 1$ universe
1988RE1F	Solar neon abundances from gamma-ray spectroscopy and ^{3}He-rich particle events
1988WO1C	Supernova neutrinos, neutral currents and the origin of fluorine
1989BE2H	The effect of enhanced α-elements in helium-burning population II stars
1989GO1N	Hydrogen burning in the NeNa cycle: ^{23}Na(p, α)^{20}Ne and ^{23}Na(p, γ)^{24}Mg
1989GU28	Thermonuclear breakup reactions of light nuclei, part 1: Processes and effects
1989GU1J	Thermonuclear ... ” , part 2: Gamma-ray line production and other applications
1989GU1Q	Abundance of ^{14}N at the cosmic-ray source obtained using new fragmentation cross sections
1989HE1N	O & Ne abundance in planetary nebulae: implications for stellar nucleosynthesis
1989JI1A	Nucleosynthesis inside thick accretion disks around massive black holes
1989ME1C	Isotope abundances of solar coronal material derived from solar energetic particle meas.
1989SA26	Gamow-Teller & M1 strength sums for sd-shell nuclei by spectral distribution methods
1989TA26	Microscopic calc. of rates of electron captures which induce O + Ne + Mg core collapse
1990BL1K	Slowly accreting neutron stars and the origin of gamma-ray bursts
1990CO1N	Space-based meas. of elemental abundances and their relation to solar abundances
1990HA07	Neutrino nucleosynthesis in supernovae: shell model predictions
1990MU1H	Nuclear line spectroscopy of the 27 April 1981 solar flare
1990SI1A	An explanation for cosmic-ray source abundances including nitrogen
1990TH1C	Explosive nucleosynthesis in SN 1978A: composition, radioactivities & neutron star mass
1990WE14	Total charge and mass changing cross sections of relativistic nuclei in H, He, C targets
1990WE1I	Cosmic-ray source charge & isotopic abund. obtained using new fragmentation X-sects.
1991RA1C	Carbon burning and galactic enrichment in massive stars
1992CA1J	Quasi-static evolution of ONeMg cores, explosive ignition densities & collapse explosion
1993DE32	Microscopic three-cluster study of 21-nucleon systems
1994PA42	Exp. limit on ^{19}Ne(p, γ)^{20}Na resonance strength; implications for stellar H burning
	Complex reactions
1986MA13	Experimental search for nonfusion yield in the heavy residues emitted in ^{11}B + ^{12}C
1987BA1T	Spin-isospin excitations in nuclei with relativistic heavy ions
1987BE58	Target fragmentation at ultrarelativistic energies
1987BO23	Intermediate-mass fragments from nonbinary processes in ^{14}N + $^{\rm nat}$Ag at $E/A = 35$ MeV
1987BU07	Projectile-like fragments from ^{20}Ne + ^{197}Au – counting simultaneously emitted neutrons
1987KA46	Measurement of the decay time of excited products of inelastic Ne + Ge interactions
1987LY04	Fragmentation and the emission of particle stable and unstable complex nuclei

Table 20.16: ^{20}Ne – General (continued)

Reference	Description
	Complex reactions (continued)
1987MU03	Study of the emission of clusters by excited compound nuclei
1987SH23	Dissipative phenomena and α-particle emission in ^{16}O + ^{27}Al between 46 and 85 MeV
1987SO15	Angular momentum dependence of complex fragment emission
1987SU07	Correlated fluctuations in the ^{89}Y(^{19}F, x)y excitation functions
1987VI14	Mechanisms of momentum and energy transfer in intermediate-energy collisions
1987SH27	Radioactive decay of ^{234}U via Ne and Mg emission
1987YI1A	Research for the deep inelastic collision induced by 93 MeV ^{14}N on $^{\rm nat}$Ca (A)
1988AI03	Quantum molecular dynamics approach to HI collisions compared to fragmentation data
1988CA27	Experimental indications of selective excitations in disspative heavy ion collisions
1988CE01	Multifragmentation & incomplete fusion in heavy ion collisions; schematic model
1988CH28	Nucleon transfer contribution to absorptive heavy ion potential by Monte Carlo simulation
1988GA31	Formation and decay of hot nuclei
1988MI28	Multifragmentation as a possible signature of liquid-gas phase transitions
1988SM07	Cross section for the ^{12}C(^{139}La, X)^{11}C reaction at relativistic energies
1988UT02	Quasi-free stripping reactions studied using extended Serber model
1989BA92	Strangeness production by heavy ions
1989BE17	Fusion of ^{16}O + ^{40}Ca at $E_{\rm lab}$(^{16}O) = 13.4 MeV/nucleon
1989BR35	Fragmentation cross sections of ^{28}Si at 14.5 GeV/nucleon
1989CA15	Fusion and binary reactions in the collision of 32S on 26Mg at Elab=163.5 MeV
1989FI05	Non-eq. vs. equilibrium emission of complex frag.; ^{14}N + Ag,Au at E/A = 20–50 MeV
1989GH01	Subthreshold π^0 production in heavy-ion collisions induced by nuclear cooperation
1989HO16	Radioactivities by light fragment (C, Ne, Mg) emission
1989KI13	Fragment production in ^{14}N + C, Ni, Ho reactions at 35 MeV/nucleon
1989MA45	Target excitation & ang. mom. transfer in ^{28}Si + ^{181}Ta from multiplicity meas.
1989PA06	Complete & incomplete fusion of 6 MeV/nucleon light heavy ions on ^{51}V
1989SA10	Total cross sections of reactions induced by neutron-rich light nuclei
1989YO09	Energy damping feature in light heavy-ion reactions
1989ZHZY	Mass measurement of Z = 7–19 neutron-rich nuclei using the TOFI spectrometer (A)
1990BEYY	Production of neutron-rich He isotopes in the ^{9}Be + ^{18}O reaction
1990BL09	Elastic magnetic electron scattering and vacuum polarization
1990BO01	Critical excitation energy in fusion-evaporation reactions
1990BO04	Three paths for intermediate-mass fragment formation from 640 MeV ^{86}Kr + ^{63}Cu
1990BO16	Revising the chart of the nuclides by exotic decay
1990CH09	Coulomb-modified Glauber model description of heavy-ion reaction cross sections
1990FO04	One-nucleon-transfer reactions induced by ^{20}Ne at 500 and 600 MeV
1990GU08	Deviations from pure target fragmentation in ^{16}O induced heavy ion reactions
1990WE14	Total charge & mass changing cross sections of relativistic nuclei in H, He & C targets
1990YE02	Intermediate mass fragment emission in the 161-MeV p + Ag reaction
1991LI33	Subthreshold pion production in nucleus-nucleus collisions; quantum molecular dynamics

Table 20.16: ^{20}Ne – General (continued)

Reference	Description
	Muons & neutrinos
1987HE1D	Nuclear charge radii of stable neon isotopes from muonic atoms
1989AD13	Coherent pion prod. by charged-current interactions of neutrinos & antineutrinos on Ne
1989MA1U	Coherent production of π^+ mesons in ν-neon interactions
1989SO1C	Radiative muon capture in light atoms
1990CH13	Muon capture rates in nuclei calculated & compared to experimental values
1990DEZO	Neutral strange particle production in ν_μ-Ne interactions (A)
1990HA07	Neutrino nucleosynthesis in supernovae: shell model predictions
1990LAZQ	Proton production in charged-current ν_μ-Ne interactions (A)
1992FR01	Nuclear charge radii systematics in the sd shell from muonic atom measurements
1992RO09	Hyperfine interaction of μ^- & an e^- shell in forming P-odd correlations in μ^{20}Ne
1995FR22	Nuclear ground state charge radii from electromagnetic interactions
	Pions & kaons
Reviews:	
1988BA82	Production and decay of hypernuclei
1988HA12	Charge exchange reactions and the study of giant resonances
Other articles:	
1987SU20	Neutral pion production cross sections in Ne + NaF collisions from 80 to 219 MeV/nucleon
1988EL06	On the s-wave repulsion of the pion-nuclear interaction
1988FR02	Strong-interaction finite-range effects in light pionic atoms
1988RO19	Photoproduction of ^{20}F(Λ); analogy to ^{20}Ne(Λ) also discussed
1989AD13	Coherent pion prod. by charged-current interactions of neutrinos & antineutrinos on Ne
1989GA09	Pionic distortion factors for radiative pion capture studies
1989GE10	Threshold pion-nucleus amplitudes as predicted by current algebra
1989GH01	Subthreshold π^0 prod. via ^{16}O and ^{27}Al beams at $E = 38$–200 MeV/A by nucl. cooperation
1989KA37	Finite-range effects in pionic atoms
1989MA1U	Coherent production of π^+ mesons in ν-neon interactions
1989SH40	Subthreshold $\bar{\mathrm{p}}$, K$^-$, K$^+$, and energetic-pion production in relativistic nuclear collisions
1989WA14	Mesonic atom production in high-energy nuclear collisions
1989ZU02	Statistical description of multiple production of π-mesons in nuclear collisions
1991AM1B	Scaling properties of π^- spectra in π^- Ne interactions at initial momentum 6.2 GeV/c
1991CI08	Momentum-space method for pionic atoms
1991CI11	Nuclear structure effects in light π-mesoatoms
1991GO21	Pionic atoms, the relativistic mean-field theory and the pion-nucleon scattering lengths
1991LI33	Subthreshold pion production in nuclear collisions; quantum molecular dynamics approach
1992KI31	Multiplicities of secondary particles in inelastic $\pi^- +$ Ne at initial momentum 6.2 GeV/c
1993PE09	Isospin symmetry in nuclear transitions from pion scattering
1995KI14	Multiplicity of secondary particles in π-Ne interactions with strange particles in final state

Table 20.16: ^{20}Ne – General (continued)

Reference	Description
	Antiproton interactions
Review:	
1989CU06	Summary of experimental work on antiproton-nucleus interactions
Other articles:	
1987BA88	Neutral strange-particle production in $\bar{\mathrm{p}}$ ^{20}Ne reactions at 607 MeV/c
1987DA12	$\bar{\mathrm{p}}$-nucleus scattering at $E = 20$–200 MeV; Glauber approx. compared to data
1987DA1D	Interaction of low-energy antiprotons with nuclei
1988CU03	Charge distribution and charge correlation in the annihilation of antiprotons on nuclei
1988CU1D	Dynamical model of antiproton annihilation on nuclei
1988SI23	Recent results on antiprotonic atoms using a cyclotron trap at LEAR
1989BA10	Antiproton-neon annihilation at rest and at 607 MeV/c
1989BA91	An observation of a leading meson in $\bar{\mathrm{p}} +$ Ne reaction at 607 MeV/c incident momentum
1989TO13	Strangeness production by antiprotons
1990CU01	Strangeness production in antiproton annihilation on nuclei
1990CU04	Antiproton annihilation at rest on light nuclei
1991BA18	Strangeness production in antiproton annihilation at rest on ^{3}He, ^{4}He and ^{20}Ne
1991BA49	Glueball candidates seen in the reactions $\bar{\mathrm{p}}$ ^{20}Ne and $\bar{\mathrm{p}}$ ^{4}He at 607 MeV/c
1991KH09	Strange-particle production in antiproton annihilation on nuclei at low energies
1991MA1D	Coherent production of a_1^- mesons and $(\rho\pi)^-$ systems by antineutrinos on neon
1993DA24	Observation of parton fragmentation in $\bar{\mathrm{p}}$ ^{20}Ne reactions at 607 MeV/c
1993ZA01	$\bar{\mathrm{p}}$ annihilation on nuclei at $E = 50$–2000 MeV as a result of one or more collisions
	Hypernuclei
1987SA1Q	Structure of ^{20}Ne(Λ) hypernucleus: prediction of the negative parity ground state
1988BA82	Production and decay of hypernuclei using the $(\pi$, K$^{+})$ reaction
1988IW02	Isotropic features of Λ-particle production in central collisions of light nuclei; cascade model
1988MA1Q	Identification of one glue-like mechanism of the Λ-hyperon in hypernuclei
1988RO19	Photoproduction of ^{20}F(Λ) via ^{20}Ne$(\gamma$, K$^{+})^{20}$F(Λ); analogy to ^{20}Ne(Λ) also discussed
1988WA16	Hypernucleus formation in high-energy nuclear collisions
1989TO13	Strangeness production by antiprotons
	Other topics
1987HA16	Test of the fermion dynamical symmetry model microscopy in the sd shell
1987LI34	Probability of forming six-quark clusters and the increase of nucleon radius in nuclei
1987SA48	Spectral distribution calculations using Wildenthal's universal sd interaction
1988BO27	Quasiparticle model for nuclear dynamics studies used to calc. ground state properties
1988HI05	Effect on Gamow-Teller strength of config. mixing & p-n correlation in e-e sd-shell nucl.
1988ME09	Three-dimensional, spherically symmetric, saturating model of an N-boson condensate

Table 20.16: ^{20}Ne – General (continued)

Reference	Description
	Other topics (continued)
1988ST04	Spectral distribution calculations of the level density of ^{20}Ne; Lanczos method
1989FI04	Systematic study of potential energy surfaces of light nuclei in relativistic Hartree calcs.
1989MI1M	The phase structure of nuclei at low temperatures studied in the canonical ensemble
1989OR02	Empirical isospin-nonconserving Hamiltonians for shell-model calculations
1989PO05	Isobaric multiplets reconstructed from the equidistance rule for separation & decay energies
1989QU01	Comparison of finite temperature Hartree-Fock approximation & canonical ensemble calcs.
1989QU1A	Strategy for finding low-lying solutions of the restricted nuclear Hartree-Fock equations
1989RO01	Fission barrier of projectiles in heavy-ion reactions
1990CO04	Effect of the continuum on thermally induced phase transitions in nuclei
1990PR1B	Electron capture by protons from K-shell of C, N, O, Ne and Ar; binary encounter approx.
1991RE10	Fast-neutron-induced cross sections on ^{20}Ne, theory vs. experiment, $E = 1$–30 MeV
1992CA19	Dynamical dependence of thermal phase transformations in finite systems
1992GR11	Parameterization of the nuclear level density at energies above 100 MeV
1992MU01	Nuclear level densities at high excitations
1993SZ02	Treatment of hot composite systems (^{19}F & ^{20}Ne) as liquid droplets
1993ZH18	Effects of the Dirac sea on deformed nuclei (^{20}Ne & ^{24}Mg)
1995SUZV	Correlation of low-lying excitations to non-statistical effects in level spectra of nuclei
1996CA16	Proton-nucleus total reaction cross sections and total cross sections up to 1 GeV
	Ground state properties
Reviews:	
1989RA17	Compilation of exp. data on nuclear moments for ground & excited states of nuclei
1992PY1A	Nuclear quad. moments for $Z = 1$–20 rev., related to numerical methods in quant. chem.
Other articles:	
1987BL18	Gogny's effective inter. used to calc. ground & excited states of specific spin-isospin order
1987FU12	Systematics of even-even sd-shell nuclei in relativistic mean-field models
1987HE1D	Nuclear charge radii of stable neon isotopes from muonic atoms
1987PA29	Relativistic mean-field theory used to describe ground-state deformation of nuclei
1987PR03	Self-consistent Hartree description of deformed nuclei in a relativistic quantum field theory
1987SA48	Spectral distribution calcs. using Wildenthal's universal sd interaction
1988AI03	Quantum molecular dynamics approach to HI collisions compared to fragmentation data
1988BO27	Quasiparticle model for nuclear dynamics studies used to calc. ground state properties
1988DO17	Classical simulation of nuclear systems; calc. sizes and binding energies of finite nuclei
1988ME09	Three-dimensional, spherically symmetric, saturating model of an N-boson condensate
1988RA1G	Clustering phenomena & shell effects in nuclear structure and reactions
1988ZH09	Relativistic Hartree calculation of deformed $A = 16$–40 nucl.; underpredict deformations
1989AN12	A-dependence of the difference $(\mathrm{r_{el}} - \mathrm{r_{mu}})$, a dispersion effect in electron scattering
1989FI04	Systematic study of potential energy surfaces of light nuclei in relativistic Hartree calcs.

Table 20.16: ^{20}Ne – General (continued)

Reference	Description
	Ground state properties (continued)
1989GA05	Parity-dependent potential for ^{16}O + ^{20}Ne (linear combination of nuclear orbitals model)
1989GA16	Relativistic mean-field description of ground-state nuclear properties
1989KO13	A relativistic description of rotating nuclei: the yrast line of ^{20}Ne
1989RU08	Binding energies & grnd. state band levels of light nucl.; strictly restricted dynamics model
1989SA10	Total cross sections of reactions induced by neutron-rich light nuclei
1989TO05	α-decay widths of ground band of ^{20}Ne studied with cluster & deformed models
1990GA10	Relativistic mean field theory for finite nuclei
1990GU10	Charge densities of sp- and sd-shell nuclei & occupation numbers of 2s states
1990GUZV	Calc. charge density distrib., rms radii, moments by Hartree-Fock meth& harm. osc. model
1990LO11	Self-consistent calcs. of light nuclei using density-functional method
1990MA63	Correlated charge form factor and densities of the s-d shell nuclei
1990VA14	Features of α-cluster type nuclei in the framework of the restricted dynamics model
1991PO11	Single-nucleon transfer sum-rules in the 2s1d shell; compared to data
1991ZH02	Relativistic Hartree-Fock calcs. of deformed nuclei in rel. quantum-field-theory framework
1991ZH05	Vacuum polariztion in a relativistic description of open shell nuclei
1991ZH06	Relativistic Hartree study of deformed nucl.; binding energies, moments, single part. spec.
1992FR01	Behavior of nuclear charge radii systematics in the sd shell from muonic atom meas.
1992KN06	Exchange correlation function and surface effects; uses density matrix formalism
1992RO06	Correlated finite temperature mean field approximations comp. with canonical results
1992ZA10	Relation between E2 and orbital M1 transition strengths using a $Q \cdot Q$ interaction
1993GO38	^{20,22}Ne masses determined by Fourier transform ion cyclotron resonance mass spectrometry
1993PA25	Shapes of light N=Z nucl. studied using axially symmetric deformed rel. mean-field theory
1996GR21	Bulk prop. of light deformed nucl. derived from medium-modified meson-exchange interaction
1996KR1A	Nucl. matter radii calc. for $A = 20$ nucl.; evidence found for proton & neutron skins

(A) identifies references for which only an abstract is available.

Table 20.17: Energy Levels of ^{20}Ne [a]

E_x (MeV ± keV)	$J^\pi; T$	K^π	τ_m [b] or Γ_{cm} (keV)	Decay	Reactions
0	$0^+; 0$	0_1^+		stable	3, 4, 8, 9, 16, 19, 20, 22, 24, 28, 29, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 45, 46, 47, 48, 49, 51, 52, 53, 54, 55, 56, 57, 58, 59, 61, 63, 64, 65, 68, 69, 70, 71, 72, 74
1.633674 ± 0.015	$2^+; 0$	0_1^+	$\tau_m = 1.05 \pm 0.06$ ps $g = +0.54 \pm 0.04$	γ	3, 4, 8, 9, 12, 14, 16, 19, 20, 22, 23, 24, 27, 28, 29, 33, 34, 35, 36, 37, 39, 40, 46, 47, 48, 49, 52, 53, 55, 58, 59, 61, 62, 63, 64, 69, 70
4.2477 ± 1.1	$4^+; 0$	0_1^+	$\tau_m = 93 \pm 9$ fs $g = +0.13 \pm 0.15$	γ	3, 4, 8, 9, 12, 16, 19, 20, 22, 23, 24, 27, 28, 33, 34, 35, 36, 37, 40, 41, 43, 47, 48, 53, 59, 61, 64, 69, 70
4.96651 ± 0.20	$2^-; 0$	2^-	$\tau_m = 4.8 \pm 0.5$ ps	γ	3, 4, 8, 9, 12, 16, 19, 28, 29, 33, 34, 35, 36, 37, 59, 61, 63, 64, 69, 70
5.6214 ± 1.7	$3^-; 0$	2^-	$\tau_m = 200 \pm 50$ fs	γ, α	3, 4, 8, 9, 16, 19, 33, 34, 36, 37, 62, 63, 64, 69, 70
5.7877 ± 2.6	$1^-; 0$	0^-	$\Gamma_{cm} = (2.8 \pm 0.3) \times 10^{-2}$	γ, α	3, 4, 8, 9, 16, 18, 19, 20, 22, 34, 36, 37, 58, 62, 69
6.706 ± 47				α	59
6.725 ± 5	$0^+; 0$	0_2^+	19.0 ± 0.9	γ, α	9, 16, 18, 19, 28, 33, 34, 36, 37, 40, 58, 69
7.004 ± 4	$4^-; 0$	2^-	$\tau_m = 440 \pm 90$ fs	γ	3, 8, 9, 19, 34, 37, 63, 69

Table 20.17: Energy Levels of ^{20}Ne [a] (continued)

E_x (MeV $\pm$ keV)	$J^\pi; T$	K^π	τ_m [b] or Γ_{cm} (keV)	Decay	Reactions
7.1563 ± 0.5	$3^-; 0$	0^-	8.2 ± 0.3	γ, α	3, 5, 8, 9, 18, 19, 20, 22, 24, 27, 28, 33, 34, 58
7.191 ± 3	$0^+; 0$	0_3^+	3.4 ± 0.2	γ, α	6, 7, 8, 16, 18, 40, 69
7.4219 ± 1.2	$2^+; 0$	0_2^+	15.1 ± 0.7	γ, α	3, 6, 7, 8, 16, 18, 19, 33, 34, 36, 40, 41, 59, 62, 69
7.8334 ± 1.5	$2^+; 0$	0_3^+	2	γ, α	3, 7, 8, 16, 18, 28, 34, 40, 59, 62, 69
8.453 ± 4	$5^-; 0$	2^-	0.013 ± 0.004	γ, α	3, 7, 8, 16, 18, 19, 34, 69
≈ 8.7	$0^+; 0$	0_4^+	> 800	α	18
8.708 ± 7	$1^-; 0$		2.1 ± 0.8	γ, α	8, 16, 18, 34, 69
8.7776 ± 2.2	$6^+; 0$	0_1^+	0.11 ± 0.02	γ, α	3, 5, 7, 8, 10, 16, 18, 19, 20, 22, 23, 24, 27, 28, 34, 41, 58, 69
8.82	$(5^-); 0$		< 1	α	18
8.854 ± 5	$1^-; 0$	1^-	19	α	8, 18, 62
9.00 ± 180	$2^+; 0$	0_4^+	≈ 800	α	18, 34, 41
9.031 ± 7	$4^+; 0$	0_3^+	3	γ, α	3, 7, 8, 16, 18, 28, 34, 41, 69
9.116 ± 3	$3^-; 0$		3.2	γ, α	3, 8, 16, 18, 33, 34, 69
9.196 ± 30	2^+			α	59
9.318 ± 2	$(2^-); 0$			γ	8, 16, 34, 69
9.483 ± 3	$2^+; 0$		29 ± 15	γ, α	16, 18, 59, 69
9.873 ± 4	$3^+; 0$			γ	8, 34, 59
9.935 ± 12	$(1^+); 0$		$\tau_m < 35$ fs	γ	8, 34, 69
9.990 ± 8	$4^+; 0$	0_2^+	155 ± 30	γ, α	3, 8, 16, 18, 33, 34, 41, 69
10.262 ± 5	$5^-; 0$	0^-	145 ± 40	α	3, 5, 8, 18, 19, 20, 22, 24, 34, 58
10.2732 ± 1.9	$2^+; 1$		≤ 0.3	γ, α	16, 18, 59, 62

Table 20.17: Energy Levels of ^{20}Ne [a] (continued)

E_x (MeV ± keV)	$J^\pi; T$	K^π	τ_m [b] or Γ_{cm} (keV)	Decay	Reactions
10.406 ± 5	$3^-; 0$	1^-	80	α	8, 18, 34, 69
10.553 ± 5	$4^+; 0$		16	α	8, 18, 34
10.584 ± 5	$2^+; 0$		24	α	18, 34, 59, 69
10.609 ± 6	$6^-; 0$	2^-	$\tau_m = 23 \pm 7$ fs	γ	3, 7, 8
10.694 ± 6	$4^-, 3^+; 0$			γ	7, 8
10.80 ± 80	$4^+; 0$	0_4^+	350	α	18, 19, 34, 41
10.840 ± 6	$3^-; 0$		45	γ, α	8, 18
10.843 ± 4	$2^+; 0$		13	α	18, 59, 69
10.884 ± 3	$3^+; 1$		$\tau_m < 30$ fs	γ	59, 62
10.917 ± 6	$3^+; 0$			γ	8
10.941 ± 9	2^+			α	59
10.97 ± 120	$0^+; 0$	0_5^+	580	α	18
11.020 ± 8	$4^+; 0$		24	α	7, 8, 18, 69
11.090 ± 3	$4^+; 1$		≤ 0.5	γ, α	16, 18, 34, 62
11.116 ± 9	2^+			α	59
11.24 ± 30	$1^-; 0$		175	α	18, 34
11.2623 ± 1.9	$1^+; 1$			γ	16, 39, 40, 43, 59
11.270 ± 5	$1^-; 1$		≤ 0.3	γ, α	16, 18
11.320 ± 9	$2^+; 0$		40 ± 10	α	18, 59
11.528 ± 6	$3^+, 4^-; 0$		$\tau_m \leq 30$ fs	γ	8, 34
11.555 ± 6	$(3^+); 0$			γ	8, 34
11.558 ± 4	$0^+; 0$	0_6^+	1.1 ± 0.4	γ, α	16, 18
11.601 ± 10	$2^-; 1$				62
11.653 ± 5	$(3^+); 0$			γ	7, 8, 40
11.885 ± 7	$2^+; 0$		46	γ, α	8, 18, 34, 59, 69
11.928 ± 4	$4^+; 0$		0.44 ± 0.15	γ, α	16, 18, 69
11.951 ± 4	$8^+; 0$	0_1^+	$(3.5 \pm 1.0) \times 10^{-2}$	γ, α	5, 7, 8, 9, 16, 18, 19, 20, 22, 23, 27, 34, 58
11.985 ± 16	$1^-; 0$		30 ± 5	γ, α	8, 16, 18
12.098 ± 6	$2^-; 1$			γ	8, 34, 43, 62
12.137 ± 5	$6^+; 0$	0_3^+		α	6, 7, 8, 9, 18, 19

Table 20.17: Energy Levels of ^{20}Ne [a] (continued)

E_x (MeV ± keV)	$J^\pi; T$	K^π	τ_m [b] or Γ_{cm} (keV)	Decay	Reactions
12.221 ± 4	$2^+; 1$		< 1	γ, α	8, 16
12.253 ± 10	$4^+; 0$		155 ± 15	α	18
12.256 ± 3	$3^-; 1$		< 1	γ, α	16, 18
12.327 ± 10	$2^+; 0$	0^+_5	390 ± 50	α	18
12.401 ± 5	3^-; (1)	0^+_7	37.3 ± 0.9	γ, α	7, 8, 16, 18, 33, 69
12.436 ± 4	$0^+; 0$		24.4 ± 0.5	γ, α	8, 16, 18
12.472 ± 10	$(2^+); 0$		124 ± 6	α	18
12.585 ± 5	$6^+; 0$	(0^+_2)	72 ± 9	α	7, 8, 18, 19, 20, 22, 23
12.592 ± 15	$(2^+); 0$		145 ± 25	α	18
12.713 ± 5	$5^-; 0$	1^-	84 ± 8	α	7, 8, 18
12.743 ± 10	$(2^+); 0$		61 ± 12	α	7, 8, 18
12.836 ± 5	$1^-; 0$		30 ± 5	α	8, 18
12.957 ± 5	$2^+; 0$	(0^+_7)	38 ± 4	α	8, 18, 69
13.048 ± 5	$4^+; 0$		18 ± 3	α	7, 8, 18
13.0607 ± 2.1	2^-		1.0	p, α	32
13.095 ± 6	$2^+; 0$		162 ± 13	α	3, 5, 18
13.105 ± 5	$6^+; 0$	(0^+_2)	102 ± 5	α	18
13.137 ± 5	$3^-; 0$		48 ± 4	α	18
13.1713 ± 2.1	1^+; (1)		2.3 ± 0.2	γ, p, α	29, 30, 32, 33
13.222 ± 10	$0^+; 0$		40 ± 13	α	8, 18, 32
13.224 ± 15	$1^-; 0$		80	p, α	18, 32
13.226 ± 5	$3^-; 0$		53 ± 4	α	18
13.3075 ± 2.1	1^+		0.9 ± 0.1	γ, p, α	29, 30, 32
13.338 ± 5	$7^-; 0$	2^-	$(8 \pm 3) \times 10^{-2}$	α	7, 8, 9, 18
13.341 ± 5	$4^+; 0$		26 ± 3	α	18
13.414 ± 2	$3^-; 0$		24 ± 3	α	18, 29, 30, 32
13.426 ± 5	$(5^-); 0$		49 ± 7	α	18
13.461 ± 10	1^-		195 ± 25	p, α	18, 32
13.484 ± 2	$1^+; 1$		6.4 ± 0.3	γ, p, α	29, 30, 32, 43
13.507 ± 5	$1^-; 0$		24 ± 8	p, α	18, 30, 32

Table 20.17: Energy Levels of ^{20}Ne [a] (continued)

E_x (MeV ± keV)	$J^\pi; T$	K^π	τ_m [b] or Γ_{cm} (keV)	Decay	Reactions
13.529 ± 5	$2^+; 0$		61 ± 8	α	18
13.530 ± 15	$(0^+); 0$		76 ± 32	α	18
13.573 ± 5	$2^+; 0$		12 ± 5	α	8, 18, 32
13.586 ± 3	2^+		9 ± 1	p, α	30, 32
13.642 ± 3	$0^+; 1$		17 ± 1	p, α	8, 30, 32, 33
13.676 ± 3	(2^-)		4.5 ± 0.2	γ, p, α	29, 30, 32
13.677 ± 5	$5^-; 0$		11 ± 2	α	7, 18
13.692 ± 10	$7^-; 0$	0^-	310 ± 30	α	18
13.736 ± 3	$7^-; 0$	0^-	7.7 ± 0.5	γ, p, α	29, 30, 32
13.744 ± 20	$0^+; 0$		≈ 80	α	18
13.827 ± 10	$3^-; 0$		136 ± 15	α	8, 18
13.866 ± 30	$1^-; 0$		≈ 175	p, α	8, 18, 32
13.881 ± 3	$2^+; 1$		0.14 ± 0.05	γ, p, α	8, 9, 29, 30, 32, 33
13.908 ± 5	$2^+; 0$		74 ± 10	α	18, 32
13.926 ± 3	(0^+)		3.5 ± 0.4	p, α	32
13.928 ± 5	$6^+; 0$		65 ± 3	α	18, 19, 20
13.948 ± 10	$0^+; 0$		79 ± 15	α	18
13.965 ± 5	$4^+; 0$	(0_6^+)	8.1 ± 1	α	18
14.02	1^-		≈ 70	p, α	32
14.063 ± 3	2^+		≈ 140	p, α	30, 32
14.115 ± 5	$2^+; 0$		42 ± 6	α	18
14.128 ± 2	2^-		4.7 ± 0.7	γ, p, α	29, 30, 32
14.150 ± 3	2^-		11.8 ± 1.0	γ, p, α	29, 30, 32
14.20	1^+		14 ± 1	γ, p	29, 30
14.270 ± 10	$4^+; 0$		92 ± 9	α	18
14.304 ± 10	$(6^+); 0$		60 ± 13	α	7, 8, 18
14.311 ± 5	$6^+; 0$		117 ± 8	α	7, 8, 18, 19, 20, 22
14.313 ± 15	$(3^-); 0$		≈ 45	α	18
14.370 ± 3			≈ 5	p, α	30, 32
14.454 ± 5	$5^-; 0$		≈ 15	α	18
14.455 ± 3	$(0^+, 2^+); 0$		33 ± 3	p, α	18, 30, 32

Table 20.17: Energy Levels of ^{20}Ne [a] (continued)

E_x (MeV $\pm$ keV)	$J^\pi; T$	K^π	τ_m [b] or Γ_{cm} (keV)	Decay	Reactions
14.475 ± 6	0^+		68 ± 2	p, α	30, 32
14.593 ± 10	4^+; 0		260 ± 25	α	18
14.597 ± 7	1^-; 0		116 ± 5	p, α	18, 32
14.653 ± 10	(0^+)		25	p, α	30, 32
14.699 ± 4	(1^+)		36 ± 10	p, α	18, 30, 32
14.731 ± 10	(4^+); 0		60 ± 25	α	18
14.761 ± 5	6^+; 0		7.3 ± 4.8	α	18
14.776 ± 4	(1^-)		110 ± 20	p, α	30, 32
14.807 ± 5	6^+; 0		86 ± 7	α	7, 18, 32
14.816 ± 5	5^-; 0		117 ± 13	α	7, 18
14.839 ± 10	(4^+); 0		79 ± 15	α	18
14.888 ± 10	2^+; 0		100 ± 30	p, α	18, 32
15.047 ± 10	2^+; 0		66 ± 20	p, α	8, 18, 32
15.073 ± 10	5^-; 0		160 ± 25	α	18
15.142 ± 15	(2^+); 0		≈ 60	α	18
15.159 ± 5	6^+; 0		60 ± 15	α	8
15.174 ± 10	5^-; 0		230 ± 25	α	7, 18
15.23			28	p, α	32
15.27	(1^-)		285	p, α	5, 7, 8, 18, 19, 20, 22
15.330 ± 5	4^+; 0		34 ± 10	α	5, 7, 8, 18
15.346 ± 2	6^+; 0			α	18
15.366 ± 5	7^-; 0		110 ± 10	α	18, 19, 20, 22, 23
15.436 ± 15	(3^-); 0		90 ± 20	p, α	8, 18, 32
15.5			55	p, α	18, 32
15.70 ± 20	(8^-); 0	(2^-)		α	7, 8, 18
15.874 ± 9	8^+		100 ± 15	α	6, 7, 8, 19, 22, 23
15.97	(6^+); 0			α	18
16.01 ± 30	$(2^+; 1)$		100	p, α	32
16.139 ± 15			38	α	7, 8, 18, 32
16.25				α	7, 18
16.329 ± 11	4^+; 0		45	p, α	18, 32

Table 20.17: Energy Levels of ^{20}Ne [a] (continued)

E_x (MeV $\pm$ keV)	J^π; T	K^π	τ_m [b] or Γ_{cm} (keV)	Decay	Reactions
16.437 ± 11	$(0,2,4)^+$; 0		35	α	18
16.505 ± 15	6^+; 0	(0_6^+)	24 ± 4	α	7, 18
16.559 ± 15	5^-; 0		90 ± 30	α	18
16.581 ± 15	7^-; 0	1^-	92 ± 8	α	8, 18
16.628 ± 20	3^-; 0		80 ± 25	α	18
16.63 ± 20	(7^-)			α	19, 20, 22
16.667 ± 15	4^+; 0		100 ± 25	α	18
16.717 ± 15	5^-; 0		≈ 25	α	7, 8, 18
16.7329 ± 2.7	0^+; 2		2.0 ± 0.5	γ, p, α	28, 29, 30, 32, 63
16.746 ± 25	8^+; 0		160 ± 50	α	18
16.847 ± 15	5^-; 0		16 ± 8	α	18
16.871 ± 20	6^+; 0		350 ± 50	α	18
17.072 ± 20	4^+; 0		180 ± 30	α	18
17.155 ± 15	5^-; 0		26 ± 5	α	18
17.213 ± 15	4^+; 0		225 ± 30	α	18
17.284 ± 15	3^-; 0		86 ± 25	α	18
17.295 ± 15	8^+; 0		200 ± 25	α	5, 18, 19, 20, 22, 23
17.390 ± 15			< 10	α	18
17.430 ± 15	9^-; 0	(0^-)	220 ± 25	α	7, 8, 9, 18
17.541 ± 15	6^+; 0		86 ± 9	α	18
17.55 ± 10	$(2^+$; 1)		19	n, p, α	31, 32
17.606 ± 15	5^-; 0		140 ± 20	α	18
17.769 ± 20	4^+; 0		≈ 125	p, α	18, 32
17.851 ± 15	5^-; 0		200 ± 30	α	18
17.91 ± 20	(0^+)			n, p	31
18.005 ± 15	7^-; 0		< 10	α	18
18.024 ± 5	5^-; 0		34 ± 7	α	18
18.083 ± 25	4^+; 0		140 ± 60	α	18
18.125 ± 5	7^-; 0		29 ± 6	α	7, 8, 9, 18
18.286 ± 10	6^+; 0		190 ± 300	α	7, 18
18.430 ± 7	2^+; 2		9.5 ± 3.0	γ, n, p, α	29, 30, 31, 32, 63

Table 20.17: Energy Levels of ^{20}Ne [a] (continued)

E_x (MeV ± keV)	$J^\pi; T$	K^π	τ_m [b] or Γ_{cm} (keV)	Decay	Reactions
18.430 ± 20	$7^-; 0$		185 ± 40	α	18
18.494 ± 20	$5^-; 0$		130 ± 30	α	18
18.538 ± 7	8^+		138 ± 33	α	8
18.621 ± 20	$8^+; 0$	(0_6^+)	185 ± 30	α	18
18.745 ± 25	$6^+; 0$		140 ± 50	α	18
18.768 ± 20	$7^-; 0$		140 ± 35	α	18, 19
18.960 ± 25	$8^+; 0$		200 ± 60	α	18
19.051 ± 15	$5^-; 0$		≈ 90	α	18
19.15 ± 20	$6^+; 0$		200 ± 50	α	9, 18
19.284 ± 15	$6^+; 0$		140 ± 25	α	18
19.298 ± 25	$7^-; 0$		430 ± 60	α	18, 19
19.443 ± 10	$6^+; 0$	(0_7^+)	130 ± 15	α	18
19.536 ± 25	$6^+; 0$		250 ± 60	α	18
19.655 ± 20	$6^+; 0$		140 ± 35	α	18
19.731 ± 20	$8^+; 0$		330 ± 60	α	18
19.845 ± 40	$6^+; 0$		360 ± 120	α	18
19.859 ± 10	$5^-; 0$		170 ± 25	α	18
19.884 ± 40	$7^-; 0$		≈ 120	α	18, 19
19.991 ± 30	$4^+; 0$		130 ± 100	α	18
20.027 ± 15	$6^+; 0$		80 ± 35	α	18
20.106 ± 25	$7^-; 0$		190 ± 35	α	18
20.15 ± 150			broad	γ, n	38
20.168 ± 35	$6^+; 0$		285 ± 100	α	18
20.296 ± 15	$7^-; 0$		255 ± 40	α	18
20.341 ± 20	$5^-; 0$		190 ± 40	α	18
20.344 ± 15	$7^-; 0$		135 ± 35	α	18
20.419 ± 30	$6^+; 0$		215 ± 90	α	18
20.445 ± 25	$6^+; 0$		370 ± 55	α	18
20.468 ± 30	$5^-; 0$		280 ± 70	α	18
20.686 ± 6	$9^-; 0$	(1^-)	78 ± 11	α	8, 18, 20
20.76 ± 30	$7^-; 0$		240 ± 50	α	18, 19

Table 20.17: Energy Levels of ^{20}Ne [a] (continued)

E_x (MeV ± keV)	$J^\pi; T$	K^π	τ_m [b] or Γ_{cm} (keV)	Decay	Reactions
20.800 ± 25	$5^-; 0$		170 ± 60	α	18
20.95 ± 40	$7^-; 0$		300 ± 50	α	8, 18
21.062 ± 6	$9^-; 0$	(1^-)	60 ± 6	α	5, 8, 18, 20, 22, 23
21.3 ± 100	$7^-; 0$		300	α	10, 18, 19
21.8 ± 100	$7^-; 0$		300	α	8, 10, 18, 19
22.3 ± 100	$7^-; 0$		500	α	8, 10, 18, 19
22.6 ± 300			broad	γ, n	38
22.8 ± 100	$9^-; 0$		500	α	8, 18
22.87 ± 40	$9^-; 0$		225 ± 40	α	5, 8, 18, 20, 22
23.4 ± 200	$8^+; 0$		500	α	18
23.70 ± 30	(9^-)		≤ 200	α	19, 20
24.21 ± 30	$8^+; 0$		350	α	18, 20
24.9 ± 500			broad	γ, n	38
25.10 ± 50	$8^+; 0$		≈ 200	α	18, 20
25.67 ± 50			≈ 400	α	18, 20
27.1 ± 100	(9^-)		700	α	18, 19, 22
27.5	10^+		broad	γ, n	10, 38
28	$8^+; 0$		1600	α	18
28.2 ± 300			700	α	18

[a] See also Tables 20.18 and 20.20. For other states with $E_x > 15.5$ MeV see Tables 20.30 in (1978AJ03), Tables 20.27, 20.28 and 20.29 here, and reactions 2, 38, and 40. It is clear that there are many states with low angular momentum and with unnatural parity which have not been located at high E_x.
[b] See Table 20.20 in (1978AJ03).

3. ^{10}B(^{14}N, α)^{20}Ne $\qquad Q_m = 19.531$

Angular distributions of α-particles to many states of ^{20}Ne below $E_x = 10.7$ MeV have been measured at $E(^{14}\text{N}) = 23.5$ to 35 MeV. See also (1978AJ03, 1983AJ01). Numerical calculations of differential cross sections using CWBA and DWBA are reported by (1990OS1B).

Table 20.18: Radiative decays in ^{20}Ne [a]

E_{i} (MeV)	$J^{\pi}_{\mathrm{i}}; T$	E_{f} (MeV)	Branch (%)	Γ_{γ} (meV)
1.63	$2^{+}; 0$	0	100	0.63 ± 0.04 [b]
4.25	$4^{+}; 0$	1.63	≈ 100	7.1 ± 0.7 [b]
4.97	$2^{-}; 0$	0	0.6 ± 0.2	$(8 \pm 3) \times 10^{-4}$ [b]
		1.63	99.4 ± 0.2	0.14 ± 0.02 [b]
				δ(M2/E1) $= 0.076 \pm 0.011$
				δ(E3/E1) $= 0.043 \pm 0.016$
5.62	$3^{-}; 0$	0	7.6 ± 1.0	0.018 ± 0.006
		1.63	87.6 ± 1.0	0.21 ± 0.06
		4.97	4.8 ± 1.6	0.012 ± 0.005
5.79	$1^{-}; 0$	0	18 ± 5	0.8 ± 0.3
		1.63	82 ± 5	3.8 ± 0.8
6.73	$0^{+}; 0$	0		$\lvert M\rvert^{2} = 7.4 \pm 2.0$ fm^{2} [d]
		1.63	100	33
7.00	$4^{-}; 0$	1.63	0.5 ± 0.2	$(7 \pm 3) \times 10^{-3}$ [b]
		4.25	13	0.19 [b]
		4.97	64.5	0.96 [b]
		5.62	22	0.32 [b]
7.16	$3^{-}; 0$	4.25	60 ± 5	0.97 ± 0.11
		5.79	40 ± 5	0.64 ± 0.10
7.19	$0^{+}; 0$	0		$\Gamma_{\pi} = 3.9 \times 10^{-2}$
				6.9 ± 1.4 fm^{2} [d]
		1.63	100	4.35 ± 0.75
7.42	$2^{+}; 0$	0	$\leq 9.4 \pm 1.4$	$\leq 3.0 \pm 0.6$
		1.63	$\geq 90.6 \pm 1.4$ [f]	29 ± 4
		4.25	≤ 7.6	
7.83	$2^{+}; 0$	0	83 ± 1	57 ± 7
		1.63	17 ± 1	11.7 ± 1.6
		4.25	< 2	< 2
8.45	$5^{-}; 0$	5.62	100	13 ± 3
8.71	$1^{-}; 0$	0	87 ± 8	61 ± 16
		1.63	13 ± 8	9 ± 6

Table 20.18: Radiative decays in ^{20}Ne (continued)

E_i (MeV)	$J^\pi_i; T$	E_f (MeV)	Branch (%)	Γ_γ (meV)
8.78	6^+; 0	4.25	100	100 ± 15
9.03	4^+; 0	1.63	100	340 ± 42
		4.25	< 2	< 6.8
9.12	3^-; 0	1.63	50 ± 5	13 ± 2
		4.97	33 ± 5	8.6 ± 1.7
		5.62	17 ± 4	4.4 ± 1.1
9.32 [l]	(2^-; 0)	1.63		
9.48	2^+; 0	0		≤ 60
		1.63	(100)	260 ± 100
9.87	3^+; 0	0	< 0.5	
		1.63	78	[g]
		4.25	12 ± 3	
		4.97	≤ 5	
		5.62	≈ 7	
		7.43	≈ 3	
9.94	(1^+); 0	1.63	78 ± 5	
		4.97	22 ± 5	
9.99	4^+; 0	0		≤ 70
		1.63	(100)	900 ± 400
10.27	2^+; 1	0	0.65 ± 0.14	29 ± 8
		1.63	88.9 ± 0.5	4080 ± 440
		4.97	1.3 ± 0.1	60 ± 8
		5.62	2.1 ± 0.2	97 ± 14
		7.43	6.9 ± 0.4	310 ± 40
		7.83	0.22 ± 0.06	8 ± 2
10.61	6^-; 0	7.00	95.5 ± 1.2	29 ± 9 [b]
		8.46	4.5 ± 1.2	1.3 ± 0.4
10.69	$4^-, 3^+$; 0	4.25	25 ± 4	
		4.97	75 ± 4	
10.88	3^+; 1	1.63	77 ± 5	[h]
		4.25	23 ± 5	

Table 20.18: Radiative decays in ^{20}Ne (continued)

E_i (MeV)	$J^{\pi}_{i}; T$	E_f (MeV)	Branch (%)	Γ_{γ} (meV)
11.09 [c]	4^+; 1	1.63	0.5 ± 0.3	2 ± 1
		4.25 [i]	99.5 ± 0.3	338 ± 40
11.26 [j]	1^+; 1	0	84 ± 5	$(11.2 \pm 2.0) \times 10^3$
		1.63	16 ± 5	$(2.1 \pm 0.7) \times 10^3$
11.27 [c]	1^-; 1	0	55 ± 2	390 ± 47
		1.63	2.5 ± 1.0	18 ± 7
		4.97	6.5 ± 1.0	46 ± 9
		8.85	27 ± 1.5	189 ± 24
		9.32	9 ± 1	63 ± 10
11.53	3^+, 4^-; 0	4.25	30 ± 3	
		4.97	70 ± 3	
		7.00	[f]	
11.555	(3^+; 0)	1.63		
		7.00		
11.558	0^+; 0	1.63	100	
		4.25	< 8	
11.65	(3^+); 0	1.63	14 ± 3	
		4.25	86 ± 3	
11.93	4^+; 0	1.63	21 ± 11	5.5 ± 3.0
		4.25	79 ± 11	20.5 ± 5.5
11.95	8^+; 0	8.78	100	7.7 ± 1.1
12.22 [k]	2^+; 1	1.63	(100)	
12.26	3^-; 1	1.63	63 ± 2	
		5.62	37 ± 2	
12.40	3^-; (1)	0	≈ 1	
		1.63	≈ 29	80
		4.25	≈ 70	200
12.43	0^+; 0	1.63	100	170 ± 50
13.48	1^+; 1	1.63	95	
		4.97	5	
13.88	2^+; 1	1.63	20	

Table 20.18: Radiative decays in ^{20}Ne (continued)

E_i (MeV)	$J^\pi_i; T$	E_f (MeV)	Branch (%)	Γ_γ (meV)
		4.97	80	
16.73	$0^+; 2$	1.63	[e]	
		5.79	[e]	
		11.23	(100)	≈ 5000 [e]
18.43	$2^+; 2$	12.22	(100)	≈ 300

[a] For earlier references see Tables 20.19 in (1978AJ03) and 20.18 in (1983AJ01). See also Tables 20.21 and 20.24 here.
[b] From τ_m: see Table 20.20 in (1978AJ03) and branching ratios.
[c] See also Table 20.19 in (1978AJ03).
[d] Monopole matrix element.
[e] See footnote (a) in Table 2 of (1976MA01).
[f] δ(E2/M1) $= -8.36^{+1.0}_{-1.5}$.
[g] $\Gamma_\gamma(\text{total})/\Gamma = 0.82 \pm 0.27$.
[h] $\Gamma_\gamma(\text{total})/\Gamma < 0.3$ (1977MA07). See also (1987FI01).
[i] $\delta = +0.01 \pm 0.06$.
[j] (1983BE19): see reaction 39.
[k] (1984CA08).
[l] (1987FI01).

4. ^{10}B(^{16}O, ^{6}Li)^{20}Ne $\qquad Q_m = 0.270$

At $E(^{16}\text{O}) = 19.5$ to 42 MeV angular distributions for the ^{6}Li ions corresponding to transitions to ^{20}Ne* (0, 1.63, 4.25, 4.97, 5.62 + 5.79, 6.7–7.2) are in good agreement with Hauser-Feshbach calculations. See also (1978AJ03, 1985ST1B).

5. ^{11}B(^{16}O, ^{7}Li)^{20}Ne $\qquad Q_m = -3.935$

At $E(^{11}\text{B}) = 115$ MeV, angular distributions are reported to ^{20}Ne* (7.16, 8.78, 10.26, 11.95, 15.4). ^{20}Ne* (8.78, 15.4, 17.3, 21.0 ± 0.07, 22.78 ± 0.06) are particularly strongly populated. It is suggested that these five states have $J^\pi = 6^+$, 7^-, (8^+), 9^-, and 9^-: see (1983AJ01).

6. ^{12}C(^{9}Be, n)^{20}Ne $\qquad Q_m = 10.319$

At $E(^9\text{Be}) = 16$ and 24 MeV, angular distributions have been measured for ^{20}Ne* (7.3 ± 0.4, 9.2 ± 0.4, 10.9 ± 0.3, 12.2 ± 0.3, 15.7 ± 0.3): see (1983AJ01).

7. (a) ^{12}C(^{10}B, d)^{20}Ne $Q_m = 5.957$
   (b) ^{12}C(^{11}B, t)^{20}Ne $Q_m = 0.760$

Table 20.19: Excited states of ^{20}Ne from ^{12}C(^{12}C, α)^{20}Ne [a]

E_x (MeV $\pm$ keV) [b]	J^π [c]	Γ_γ/Γ [d]	Γ_{cm} (keV)	θ^2_α [e]
1.6329 ± 1.0	2^+			
4.2456 ± 2.5	4^+			
4.9663 ± 2.5	2^-			
5.618 ± 4	3^-			
5.774 ± 6	1^-			
6.725 ± 6	0^+			
7.004 ± 4	4^-			
7.169 ± 6	3^-			
7.196 ± 6	0^+			0.026 [f]
7.435 ± 6	2^+			
7.835 ± 6	2^+			0.015 [f]
8.449 ± 6	5^-			$(1.6 \pm 0.5) \times 10^{-3}$ [g]
8.694 ± 6	1^-			0.0027 [f]
8.779 ± 6	6^+			
8.85	1^-			0.0179 [f]
9.033 ± 6	4^+			0.033 [f], 0.022 [g]
9.110 ± 6				
9.318 ± 6	2^-	> 0.90		
9.533 ± 6				
9.872 ± 6	$1^+, 2^-, 3^+$	> 0.8		
9.948 ± 5 [d]	$1^+, 2^-, 3^+$	> 0.7		
10.024 ± 6				
10.264 ± 6	5^-			
10.407 ± 6	(3^-)			0.078 [f]

Table 20.19: Excited states of ^{20}Ne from ^{12}C(^{12}C, α)^{20}Ne [a] (continued)

E_x (MeV ± keV) [b]	J^{π} [c]	Γ_γ/Γ [d]	Γ_{cm} (keV)	θ^2_α [e]
10.545 ± 6				
10.609 ± 5	6^-	$\equiv 1$		
10.693 ± 5	$4^-; 3^+$	> 0.95		
10.840 ± 6	(3^-)			0.0099 [f]
10.917 ± 6	$3^+; T = 0$	> 0.7		
11.013 ± 6				
11.528 ± 5 [d]	$(3^+; 4^-)$	> 0.90		
11.568 ± 10 [d]	$(3^+; T = 0)$	0.75 ± 0.10		
11.653 ± 5 [d]	(3^+)	> 0.90		
11.892 ± 8 [d]		0.16 ± 0.02		
11.949 ± 6	8^+			$(7.6 \pm 2.2) \times 10^{-3}$ [g]
12.014 ± 10 [d]		> 0.10		
12.097 ± 8 [d]		> 0.20		
12.135 ± 5 [h]	6^+			$(4.9 \pm 2.6) \times 10^{-4}$ [g, i]
12.172 ± 8 [d]		> 0.45		
12.219 ± 10 [d]	$2^+; T = 1$	> 0.45		
12.379 ± 8 [d]		0.005 ± 0.001		
12.436 ± 5 [j]	0^+ [k]		24 ± 1	[g, k]
12.596 ± 5	6^+		50 ± 10	0.09 ± 0.01 [g]
12.730 ± 6	(5^-)			0.129 [f]
12.919 ± 6				
13.010 ± 6				
13.049 ± 6				
13.190 ± 6				
13.277 ± 6				
13.335 ± 6	7^-			$(2.4 \pm 1.0) \times 10^{-4}$ [g, l]
13.441 ± 6	(5^-)			≤ 0.023 [f]
13.569 ± 15				
13.631 ± 15				
13.679 ± 15				
13.845 ± 15				

Table 20.19: Excited states of ^{20}Ne from ^{12}C(^{12}C, α)^{20}Ne [a] (continued)

E_x (MeV ± keV) [b]	J^{π} [c]	Γ_γ/Γ [d]	Γ_{cm} (keV)	θ^2_α [e]
13.886 ± 15				
13.927 ± 5	6^+		113 ± 7	0.10 ± 0.01 [g]
14.144 ± 15				
14.308 ± 10	6^+		< 50 [g]	< 0.45 [g]
14.60				
14.812 ± 15				
15.034 ± 15				
15.159 ± 5 [m]	6^+		60 ± 15	$< 8 \times 10^{-4}$ [g, n]
15.364 ± 14 [o]	7^-		410 ± 130	
5.438 ± 10 [p]			100 ± 20	
15.691 ± 15				
15.874 ± 8 [q]	8^+		100 ± 15	0.047 ± 0.013 [g, r]
16.139 ± 15				
16.600 ± 15 [s]	7^-		160 ± 30	0.10 ± 0.02 [g, t]
16.717 ± 10			37 ± 10	
17.259 ± 11 [u]	7^- (9^-)		162 ± 20	0.019 ± 0.004 [g, v]
18.153 ± 10 [w]	7^-			
18.538 ± 7 [x]	8^+		138 ± 33	$(3.2 \pm 1.5) \times 10^{-3}$ [g, y]
20.478 ± 11 [z]	(8^+)		250 ± 30	0.11 ± 0.04 [g, aa]
20.704 ± 11 [bb]	(9^-)		≈ 120	[g]
20.89 ± 30				
21.05 ± 20			140 ± 50	
21.65 ± 100	$(7^-, 9^-)$		240 ± 50	
22.03 ± 70	(8^+)		630 ± 80	
22.7 ± 100			490 ± 110	
23.2 ± 100			300 ± 100	
23.74 ± 100			230 ± 100	
24.374 ± 30	7^- (5^-)		210 ± 50	

[a] For complete references see Table 20.21 in (1978AJ03). Table 20.19 in (1983AJ01) has a number of errors.
[b] Uncertainties shown for $E_{\rm x} > 5.7$ MeV are approximate, except for states flagged [d]: see footnote [c] in Table 20.21 of (1978AJ03).
[c] See discussions in (1975ME04), (1983HI06), (1984LE19) and (1987FI01). See also Table 20.18 here.
[d] (1987FI01). ^{20}Ne* (11.89, 12.38) also decay via α_2.
[e] See also (1984LE19).
[f] (1979YO04).
[g] θ^2_α shown are $\theta^2_{\alpha_0}$ (1983HI06). See also (1987FI01).
[h] Alpha decay is by α_2 to ^{16}O* (6.13): $\Gamma'_\alpha/\Gamma = (6.0 \pm 0.15)$%: assuming $\Gamma_\alpha \Gamma'_\alpha/\Gamma = 7.7 \pm 3.8$ eV this leads to $\Gamma_\alpha = 0.128 \pm 0.072$ keV for this 6^+ state: see (1978AJ03). (1983HI06) report an α_0 branching ratio of (90 ± 6)%.
[i] $\theta^2_{\alpha_2} = 0.66 \pm 0.36$ (1983HI06).
[j] (1992LA01) determined $E_{\rm x} = 12.436 \pm 0.004$ MeV, $\theta^2_{\alpha_1} \approx 1.15$.
[k] See footnote [f] in Table 20.21 of (1983AJ01).
[l] $\theta^2_{\alpha_2} = 0.025 \pm 0.010$ (1983HI06).
[m] Alpha decay is (2 ± 2)% by α_0, (46 ± 2)% via α_{1+2} (mainly α_2) and (52 ± 2)% via α_{3+4} (mainly α_3) (1979YO04). See also (1992LA01).
[n] $\theta^2_{\alpha_2} = 0.05 \pm 0.013$, $\theta^2_{\alpha_3} = 0.91 \pm 0.23$ (1983HI06).
[o] Alpha decay is (32 ± 2)% by α_0, (58 ± 2)% via α_{1+2} (mainly α_2) and (10 ± 2)% via α_{3+4} (mainly α_3); $\Gamma_{\alpha_0}/\Gamma = 0.3 \pm 0.02$, assuming a single state. The state may correspond to a doublet (1979YO04). See also (1983HI06).
[p] Alpha decay is (20 ± 5)% by α_0, (57 ± 7)% by α_{1+2} and (23 ± 4)% by α_{3+4} (1983HI06).
[q] Alpha decay is (9 ± 2)% by α_0, (79 ± 2)% via α_{1+2} (mainly α_2) and (12 ± 4)% via α_{3+4} (mainly α_3) (1979YO04); (24 ± 5)% via α_0, (51 ± 7)% via α_{1+2}, (25 ± 5)% via α_{3+4} (1983HI06).
[r] $\theta^2_{\alpha_2} = 0.94 \pm 0.14$, $\theta^2_{\alpha_3} = 4.2 \pm 0.9$ (1983HI06).
[s] Alpha decay is (72 ± 3)% via α_0, (20 ± 3)% via α_{1+2} (mainly α_2) and (8 ± 3)% via α_{3+4} (mainly α_3) (1979YO04); (60 ± 5)% via α_0, (20 ± 5)% via α_{1+2} and (20 ± 5) via α_{3+4} (1983HI06).
[t] $\theta^2_{\alpha_2} = 0.048 \pm 0.013$, $\theta^2_{\alpha_3} = 0.44 \pm 0.12$ (1983HI06).
[u] Alpha decay is (15 ± 2)% via α_0, (50 ± 6)% via α_{1+2} and (35 ± 7)% via α_{3+4} (1983HI06). See also (1979YO04).
[v] $\theta^2_{\alpha_2} = 0.071 \pm 0.013$, $\theta^2_{\alpha_3} = 0.32 \pm 0.08$ [all θ^2_α assume $J^\pi = 7^-$] (1983HI06).
[w] Alpha decay is (71 ± 6)% via α_0 and (29 ± 6)% via α_{1+2} (mainly α_2) (1979YO04).
[x] Alpha decay is (1.8 ± 0.9)% via α_0, (60 ± 8)% via α_{1+2} and (26 ± 4)% via α_{3+4}. Decay to $^{12}{\rm C}_{\rm g.s.} + {}^8{\rm Be}_{\rm g.s.}$ is also observed: the branching ratio is (12 ± 1.2)%. This may be a member of an excited 8p-4h $(K^\pi = 0^+_6)$ band of which ^{20}Ne* (12.44) is the 0^+ band head (1983HI06). The results of (1992LA01), however, argue against this identification.
[y] $\theta^2_{\alpha_2} = 0.085 \pm 0.014$, $\theta^2_{\alpha_3} = 0.24 \pm 0.04$, $\theta^2(^{12}{\rm C}) = 1.50 \pm 0.21$ (1983HI06).
[z] Decay is (66 ± 26)% via α_0, (14 ± 7)% via α_{1+2} and (13.2 ± 2.5)% via $^{12}{\rm C} + {}^8{\rm Be}$ (1983HI06).
[aa] $\theta^2_{\alpha_2} = 0.016 \pm 0.008$, $\theta^2(^{12}{\rm C}) = 0.24 \pm 0.05$ (1983HI06).
[bb] Decay is ≤ 14% via α_0, (25 ± 15)% via α_{1+2}, (46 ± 22)% via α_{3+4} and (4.5 ± 0.9)% via $^{12}{\rm C} + {}^8{\rm Be}$ (1983HI06). See also (1979YO04).

Table 20.20: K^π assignments to states of ^{20}Ne [a]

K^π	J^π	E_x (MeV)	K^π	J^π	E_x (MeV)
0_1^+	0^+	0		6^+	(16.51)
	2^+	1.63		8^+	(18.62)
	4^+	4.25	0_7^+ [b]	0^+	12.43
	6^+	8.78		2^+	(12.96)
	8^+	11.95		6^+	(19.44)
0_2^+	0^+	6.73	0^- [c]	1^-	5.79
	2^+	7.42		3^-	7.16
	4^+	9.99		5^-	10.26
	6^+	(12.59, 13.11)		7^-	13.69
0_3^+	0^+	7.20		9^-	(17.43)
	2^+	7.83	1^-	1^-	8.85
	4^+	9.03		3^-	10.41
	6^+	12.14		5^-	12.71
0_4^+	0^+	8.7		7^-	16.58
	2^+	8.8		9^-	(20.69, 21.06)
	4^+	10.80	2^- [c]	2^-	4.97
	6^+ [d]	(12.59)		3^-	5.62
	8^+ [d]	(17.30)		4^-	7.00
0_5^+	0^+	10.97		5^-	8.46
	2^+ [e]	12.33		6^-	10.61
0_6^+ [b]	0^+	11.55		7^-	13.34
	4^+	(13.97)		8^-	(15.70) [f]
				9^-	17.43

[a] See Tables 20.19, 20.20, 20.21, 20.22, and 20.23 in (1983AJ01) and (1984RI01, 1984RI07, 1985MU14, 1986MA48). See also Table 20.15 in (1987AJ02).

[b] See also (1992LA01).

[c] See (1992HA18).

[d] However (1987MI07) predict the $J^\pi = 6^+$, 8^+ and 10^+ members of the 0_4^+ band to be at $E_x \approx 14$–15 MeV [$\Gamma \approx 1$–2 MeV], ≈ 21 MeV [$\Gamma \approx 2$ MeV] and ≈ 29 MeV [$\Gamma \approx 29$ MeV], suggesting that the 0_4^+ band has a moment of inertia which is very similar to that of the 0^- band.

[e] For the location of higher J^π members of this band see (1984RI01).

[f] See (1970PA08) and (1984RI01).

At $E(^{12}C) = 45$ MeV the population of states of ^{20}Ne with $E_x = 8.46$, 8.78, 9.03, 10.61, 10.67, 10.99, 11.01, 11.66, 11.94, 12.14, 12.39, 12.58, 12.73, 13.05, 13.17, 13.34 $[7^-]$, 13.69, 13.91, 14.29, 14.36, 14.81, 15.17 $[6^+]$, 15.38 $[7^-]$, 15.71 [(7,8)], 15.89 [(7)], 16.16, 16.22, 16.51 [(8)], 16.73, 17.39 $[9^-]$, 18.18 and 18.32 MeV is reported (1976KL03). [Values in brackets are J^π suggested on basis of Hauser-Feshbach calculations. The underlined states are well resolved: the authors indicate ± 20 keV for such states.] The relative intensities of the groups to ^{20}Ne* (17.39, 15.38) [$J^\pi = 9^-$, 7^-] argue against the existence of a superband: see (1978AJ03). See also (1983AJ01).

8. ^{12}C(^{12}C, α)^{20}Ne $\qquad Q_m = 4.617$

Double and triple (α, α, γ) correlations and γ-ray branching measurements [see Table 20.18] lead to the J^π assignments shown in Table 20.19. See Table 20.20 for assignments to rotational bands. Angular distributions for many states have been reported at $E(^{12}C) = 4.9$ to 51 MeV [see (1978AJ03, 1983AJ01, 1987AJ02)], at 5.2 to 5.8 MeV (1988BA12; α_0), and at 69.5 MeV (1985XI1B). At $E(^{12}C) = 38$ to 64 MeV, ^{20}Ne* (7.17, 7.83, 8.54, 8.78, 9.03, 11.95, 12.13, 12.59, 13.90) are strongly populated and subsequently decay to $^{16}O_{g.s.}$ (1987RA02). Alpha decay of the $J^\pi = 6^+$ level at $E_x = 15.16$ MeV and the $J^\pi = 8^+$ level at $E_x = 18.54$ MeV to the first excited state of ^{16}O was studied by (1992LA01). See Table 20.19. For γ-decay measurements see (1987FI01), Table 20.19 and (1978AJ03). Resonant characteristics of statistical fluctuations in ^{12}C(^{12}C, α)^{20}Ne leading to the 12 lowest ^{20}Ne states were studied by (1993GA02).

The yields of various groups of α-particles and their relevance to states of ^{24}Mg, and fusion cross sections, have been studied by many groups: see (1978AJ03, 1983AJ01, 1987AJ02).

Sub-Coulomb cross sections calculated in a statistical framework are discussed in (1990KH05). A review of the state of theory and experiments on $^{12}C + ^{12}C$ reactions with formation of molecular states is presented in (1987DA1L).

See also (1987ER1B, 1988GO1G, 1988DE18, 1991SZ02).

9. (a) ^{12}C(^{14}N, ^{6}Li)^{20}Ne $\qquad Q_m = -4.181$
(b) ^{12}C(^{14}N, d)^{24}Mg $\to \alpha + {}^{20}$Ne $\qquad Q_m = 7.480$

Angular distributions of the ^{6}Li ions to many states of ^{20}Ne below 17.5 MeV have been reported for $E(^{14}N) = 30$ to 78 MeV and $E(^{12}C) = 67.2$ MeV. At the latter energy ^{20}Ne* (16.67, 17.38, 18.11, 19.16, 19.6) are particularly strongly populated: see (1978AJ03). For reaction (b) to $^{20}Ne_{g.s.}$ see the angular correlation measurements at $E(^{14}N) = 30$–42 MeV reported by (1988AR24, 1994ZU03), and see the review of (1987GO12). An analysis of differential cross sections and angular correlation functions within a compound nuclear model is described in (1994BE55). Earlier work is cited in (1987AJ02). See also (1988BEYB, 1989BEXN, 1992ARZX).

10. (a) ^{12}C(^{16}O, ^{8}Be)^{20}Ne $\quad Q_{\rm m} = -2.636$
(b) ^{12}C(^{16}O, $\alpha\alpha$)^{20}Ne $\quad Q_{\rm m} = -2.545$

Reaction (a) was studied at 150 MeV in a search for high-spin α-cluster resonances in ^{20}Ne. A broad 10^{+} resonance was located at 27.5 MeV (1988AL07). See also (1988CAZV, 1994RA04).

Excitation functions in the range $E_{\rm cm} = 25.7$–38.6 MeV were measured by (1993ES01). See also the comment (1993ZH21) and reply (1993ES03) on the work. Excitation functions for reaction (a) leading to members of the ^{20}Ne ground state rotational band were measured for $E_{\rm cm} = 22$–29 MeV by (1995SU06).

A triple coincidence measurement of reaction (b) through the ^{20}Ne 6^{+} level at $E_{\rm x} = 8.78$ MeV was reported by (1989WUZZ). α–α coincidence measurements by (1994KU18) at $E_{\rm cm} = 26.9$ MeV were used to study the connection of highly deformed isomeric states in ^{28}Si, ^{24}Mg and ^{20}Ne.

11. ^{12}C(^{19}F, ^{20}Ne)^{11}B $\quad Q_{\rm m} = -3.113$

This reaction was studied with the use of molecular orbital theory (1988DI08).

12. ^{13}C(^{9}Be, 2n)^{20}Ne $\quad Q_{\rm m} = 5.373$

For cross sections see (1986CU02).

13. ^{14}N(^{12}C, ^{6}Li)^{20}Ne $\quad Q_{\rm m} = -4.181$

See reaction 9.

14. ^{14}N(^{14}N, 2α)^{20}Ne $\quad Q_{\rm m} = 7.918$

For yields of 1.63 MeV γ-rays see (1982DE39).

15. ^{14}N(^{20}Ne, ^{14}N)^{20}Ne

Spectra were measured for $E(^{20}{\rm Ne}) = 150$ MeV/nucleon (1992EGZZ).

Table 20.21: Resonances in $^{16}O(\alpha, \gamma)^{20}Ne$ [a]

E_α (MeV ± keV)	Γ_{cm} (keV)	$\omega\gamma$ (eV) [b]	E_x (MeV ± keV)	$J^\pi; T$
1.116 ± 4	2.6×10^{-6} [c]	$(1.7 \pm 0.3) \times 10^{-3}$	5.627 ± 4	$3^-; 0$
1.3174 ± 2.2 [d]	$(2.8 \pm 0.3) \times 10^{-2}$ [c]	$(1.7 \pm 0.3) \times 10^{-2}$ [e]	5.7877 ± 3.0	$1^-; 0$
2.490 ± 8	20 ± 3 [c, f]	$(7.1 \pm 1.2) \times 10^{-2}$ [f]	6.726 ± 6	$0^+; 0$
3.0359 ± 2.3 [d]	8.2 ± 0.3 [e]		7.1563 ± 0.5	$3^-; 0$
3.069	4	$(4.4 \pm 0.8) \times 10^{-3}$	7.189 ± 3	$0^+; 0$
3.359	8	0.146 ± 0.019	7.421 ± 1	$2^+; 0$
3.868	2.4	0.343 ± 0.035	7.828 ± 3	$2^+; 0$
(4.647 ± 3)			(8.451 ± 3)	$(5^-; 0)$
4.969 ± 9	2.1 ± 0.8	0.21 ± 0.05	8.708 ± 7	$1^-; 0$
5.05	< 3	1.35 ± 0.15	8.776 ± 4	$6^+; 0$
5.364	3.2	3.05 ± 0.38	9.024 ± 3	$4^+; 0$
5.477 ± 4	< 4	0.18 ± 0.02	9.114 ± 3	$3^-; 0$
5.94 ± 30	29 ± 15	1.3 ± 0.5	9.48 ± 30	$2^+; 0$
6.61 ± 30	155 ± 30	8 ± 3	10.02 ± 30	$(4^+); 0$
6.924 ± 7 [g]	≤ 1	19.5 ± 1.5 [h]	10.271 ± 7 [i]	$2^+; 1$
7.948 ± 4	< 1	30.2 ± 3.5	11.090 ± 3	$4^+; 1$
8.180 ± 5 [j]	< 1	2.06 ± 0.25 [k]	11.276 ± 4	$1^-; 1$
8.535 ± 6	1.3 ± 0.8	0.41 ± 0.05	11.559 ± 6	$0^+; 0$ [l]
8.994 ± 8	< 1	0.23 ± 0.05 [m]	11.926 ± 6	$4^+; 0$
9.02		0.131 ± 0.002	11.950 ± 4	$8^+; 0$
(9.05 ± 50)	< 40		(11.97)	
(9.15 ± 50)	< 40		(12.05)	
9.362 ± 5	< 1	1.41 ± 0.23	12.221 ± 4	$2^+; 1$
9.406 ± 4	< 1	6.6 ± 0.8 [j]	12.256 ± 3	$3^-; 1$
9.57 ± 10	33 ± 4	1.94 ± 0.15	12.39	$3^-; (1)$
9.70 ± 30	≤ 10	0.17 ± 0.05	12.49	

[a] For complete references see Tables 20.22 in (1978AJ03) and 20.20 in (1983AJ01). See also Table 20.22 here.
[b] $\omega\gamma = (2J+1)\Gamma_\alpha\Gamma_\gamma/\Gamma$.
[c] This is also Γ_α.
[d] The strength of the γ-decay of $^{20}Ne^*$ (7.16) to $^{20}Ne^*$ (5.79) (see Table 20.18) is strong evidence that these two states are members of the $K^\pi = 0^-$ band.
[e] Best value including the recent work by (1987HA24).
[f] (1987HA24).
[g] See also (1984RO04).
[h] Other values are $\omega\gamma = 19.2 \pm 1.9$ eV; $\Gamma_\alpha = 116 \pm 20$ eV; $\Gamma_\gamma = 4.26 \pm 0.23$ eV: see (1983AJ01).
[i] The measurements of the decay of this state lead to $E_x = 4247.9 \pm 1.3, 4966.0 \pm 1.9, 5621.0 \pm 3.5, 7423.1 \pm 3.0, 7828.1 \pm 3.8$ and 8776.7 ± 2.3 keV.
[j] See also Table 20.20 in (1983AJ01).
[k] The γ-decay is partly (see Table 20.18) to a state at $E_x = 9318 \pm 2$ keV. The strength of this transition and the subsequent decay to $^{20}Ne^*$ (1.63) (and not to the ground state) favor 2^- for $^{20}Ne^*$ (9.32). The other M1 transition $[11.27 \rightarrow 8.85]$ is also strong suggesting similar structures for $^{20}Ne^*$ (8.85, 9.32) (1980FI01).
[l] Also observed as a resonance in the yield of 6.13 MeV γ-rays with $(2J+1)\Gamma_{\alpha_0}\Gamma_{\alpha_2}/\Gamma = 5.2 \pm 0.9$ eV (1980FI01).
[m] From (α, α_0): see (1984RI07).

Table 20.22: Resonances in $^{16}O(\alpha, \alpha)$ [a]

E_α (MeV ± keV)	Γ_{cm} (keV)	Outgoing particles	Γ_{α_0}/Γ	θ^2 (%)	E_x (MeV ± keV)	J^π
1.3174 ± 2.2	$(2.8 \pm 0.3) \times 10^{-2}$ [b]	α_0			5.7877 ± 2.6	1^-
2.522 ± 3 [c]	19.0 ± 0.9	α_0		22	6.751 ± 3	0^+
3.0382 ± 2.0 [a, c]	8.1 ± 0.3 [b]	α_0		36	7.164	3^-
3.082 ± 4 [c]	3.4 ± 0.2 [c]	α_0		1.1	7.199 ± 3	0^+
3.372 ± 4 [c]	15.1 ± 0.7 [c]	α_0		4.7	7.431 ± 3	2^+
3.885 ± 10	2	α_0		0.6	7.841 ± 8	2^+
4.653 ± 5	0.013 ± 0.004	α_0		0.07	8.455 ± 5	5^-
≈ 4.9	> 800	α_0		≈ 70	≈ 8.7	0^+
5.002	2.5	α_0		0.23	8.734	1^-
5.058 ± 3	0.11 ± 0.02	α_0		8.5 ± 1.5	8.779 ± 3	6^+
≈ 5.1	> 800	α_0		≈ 95	≈ 8.8	2^+
5.11	< 1	α_0			8.82	(5^-)
5.152 ± 5	19	α_0		1.1	8.854 ± 5	1^-
5.395 ± 5	3	α_0		3.9	9.049 ± 5	4^+
5.486 ± 5	3.2	α_0		0.49	9.121 ± 5	3^-
5.955 ± 10	24	α_0		1.4	9.496 ± 8	2^+
6.569 ± 10	97	α_0		17	9.987 ± 8	4^+
6.912 ± 5	141	α_0		66	10.262 ± 5	5^-
6.92 ± 10	≤ 0.3	α_0		$\leq 1.3 \times 10^{-3}$	10.27 ± 10	(2^+)
7.092 ± 5	81	α_0		4.8	10.406 ± 5	3^-
7.276 ± 5	16	α_0		1.8	10.553 ± 5	4^+
7.314 ± 10	24	α_0		0.85	10.583 ± 8	2^+
7.580 ± 100	349	α_0		33	10.80 ± 80	4^+
7.635 ± 5	13	α_0		0.42	10.840 ± 5	2^+
7.636	45	α_0		2.1	10.841	3^-
(7.75)	80	α_0			(10.93)	
7.80 ± 150	576	α_0		14	10.97 ± 120	0^+

Table 20.22: Resonances in ^{16}O(α, α) [a] (continued)

E_α (MeV ± keV)	Γ_{cm} (keV)	Outgoing particles	Γ_{α_0}/Γ	θ^2 (%)	E_x (MeV ± keV)	J^π
7.860 ± 10	24	α_0		2.0	11.020 ± 8	4^+
7.93 ± 10	≤ 0.5	α_0		≤ 0.05	11.08 ± 10	(4^+)
8.132 ± 30	172	α_0		4.2	11.24 ± 30	1^-
8.16 ± 10	≤ 0.3	α_0		≤ 0.009	11.26 ± 10	(1^-)
8.24 ± 10	40 ± 10	α_0		1.4	11.32 ± 10	2^+
8.528 ± 10	1.0 ± 0.5	α_0		0.03	11.551 ± 8	0^+ [i]
(≈ 8.6)	≈ 500	α_0			(≈ 11.6)	(2^+)
8.930 ± 20	46	α_0		1.1	11.875 ± 15	2^+
8.997 ± 5	0.44 ± 0.15	$\alpha_0, \gamma_{6.13}$		0.04 ± 0.01	11.929 ± 5	4^+
9.026 ± 5	$(35 \pm 10) \times 10^{-3}$	α_0		1.0 ± 0.3	11.952 ± 5	8^+
9.043 ± 10	30 ± 5	α_0		0.72	11.966 ± 8	1^-
9.25 [d]		$\alpha_0, \gamma_{6.13}$		[e]	12.137 ± 5	6^+
9.403 ± 9	155 ± 15	α_0	0.89 ± 0.05	6.8	12.253 ± 10	4^+
9.406 ± 4 [f]	< 1	$\gamma_{6.13}$		[e]	12.256 ± 4	$3^-; T = 1$
9.495 ± 13	390 ± 50	α_0	0.92 ± 0.04	8	12.327 ± 10	2^+
9.587 ± 2	37.3 ± 0.9	$\alpha_0, \gamma_{6.13}$	1.00 ± 0.04	1.2	12.401 ± 5	3^-
9.628 ± 5	24.4 ± 0.5	α_0, α_1	0.62 ± 0.15	0.3	12.433 ± 5 [k]	0^+
9.677 ± 8	124 ± 6	α_0	0.88 ± 0.05	2.4	12.472 ± 10	(2^+)
9.818 ± 6	72 ± 9	α_0	0.68 ± 0.05	14	12.585 ± 5	6^+
9.827 ± 14	145 ± 25	α_0	0.78 ± 0.09	2.5	12.592 ± 15	(2^+)
9.978 ± 6	84 ± 8	α_0	1.00 ± 0.05	7.3	12.713 ± 5	5^-
10.015 ± 7	61 ± 12	α_0	0.72 ± 0.09	0.9	12.743 ± 10	(2^+)
10.132 ± 2	30 ± 5	$\alpha_0, \gamma_{6.13}$	0.83 ± 0.09	0.45	12.836 ± 5	1^-
(10.27)	(580)	(α_0)	(0.92)	(21)	(12.95)	(4^+)
10.283 ± 2	38 ± 4	$\alpha_0, \gamma_{6.13}$	1.00 ± 0.08	0.8	12.957 ± 5	2^+
10.397 ± 1	18 ± 3	$\alpha_0, \gamma_{6.13}$	0.55 ± 0.05	0.4	13.048 ± 5	4^+
(10.419 ± 15)	(305 ± 55)	(α_0)	(0.42 ± 0.03)	(3.2)	(13.066 ± 15)	$(3^-, 5^-)$

Table 20.22: Resonances in $^{16}O(\alpha, \alpha)$ [a] (continued)

E_α (MeV ± keV)	Γ_{cm} (keV)	Outgoing particles	Γ_{α_0}/Γ	θ^2 (%)	E_x (MeV ± keV)	J^π
10.456 ± 5 [l]	162 ± 13	α_0			13.095 ± 6	2^+
10.468 ± 5	102 ± 5	α_0	0.52 ± 0.04	11	13.105 ± 5	6^+
10.508 ± 2	48 ± 4	α_0	1.00 ± 0.05	1.2	13.137 ± 5	3^-
10.614 ± 7	40 ± 13	α_0	0.55 ± 0.13	0.4	13.222 ± 10	0^+
10.617 ± 19	≈ 80	α_0	0.22 ± 0.07	0.3	13.224 ± 15	1^-
10.620 ± 2	53 ± 4	α_0	1.00 ± 0.04	1.3	13.226 ± 5	3^-
10.759 ± 6 [f]	$(8 \pm 3) \times 10^{-2}$	α_0		0.08 ± 0.03	13.338 ± 5	7^-
10.763 ± 1	26 ± 3	$\alpha_0, \gamma_{6.13}$	0.70 ± 0.05	0.6	13.341 ± 5	4^+
10.854 ± 3	34 ± 5	$\alpha_0, \gamma_{6.13}$	0.46 ± 0.05	0.4	13.414 ± 5	3^-
10.857 ± 4	≈ 16	α_0	0.16 ± 0.06	0.06	13.416 ± 5	(3^-)
10.870 ± 4	49 ± 7	α_0	0.38 ± 0.04		13.426 ± 5	(5^-)
10.913 ± 8	195 ± 25	α_0	0.99 ± 0.05	3.2	13.461 ± 10	1^-
10.971 ± 4	24 ± 8	α_0	0.36 ± 0.07	0.15	13.507 ± 5	1^-
10.999 ± 4	61 ± 8	α_0	0.72 ± 0.05	0.8	13.529 ± 5	2^+
11.000 ± 15	76 ± 32	α_0	0.52 ± 0.13	0.6	13.530 ± 15	(0^+)
11.054 ± 3	12 ± 5	α_0	0.19 ± 0.06	0.04	13.573 ± 5	2^+
11.183 ± 1	11 ± 2	α_0	0.33 ± 0.05	0.2	13.677 ± 5	5^-
11.202 ± 12	310 ± 30	$\alpha_0, \gamma_{6.13}$	0.51 ± 0.03	84	13.692 ± 10	7^-
11.267 ± 26	≈ 80	α_0	0.33 ± 0.12	0.4	13.744 ± 20	0^+
11.371 ± 9	136 ± 15	α_0	0.73 ± 0.04	2.1	13.827 ± 10	3^-
11.420 ± 34	≈ 175	α_0	0.21 ± 0.06	0.6	13.866 ± 30	1^-
11.473 ± 5	74 ± 10	α_0	0.75 ± 0.06	1.0	13.908 ± 5	2^+
11.498 ± 5	65 ± 3	α_0	0.86 ± 0.04	6.9	13.928 ± 5	6^+
11.522 ± 7	79 ± 15	α_0	1.0 ± 0.1	1.3	13.948 ± 10	0^+
11.544 ± 2	8.1 ± 1	α_0	0.46 ± 0.05	0.11	13.965 ± 5	4^+
(11.607 ± 19)	(≈ 80)	(α_0)	(0.19 ± 0.05)	(0.25)	(14.015 ± 15)	(1^-)
(11.663 ± 19)	(150 ± 50)	(α_0)	(0.24 ± 0.05)	(0.6)	(14.060 ± 15)	(2^+)

Table 20.22: Resonances in ^{16}O(α, α) [a] (continued)

E_α (MeV $\pm$ keV)	Γ_{cm} (keV)	Outgoing particles	Γ_{α_0}/Γ	θ^2 (%)	E_x (MeV $\pm$ keV)	J^π
11.732 ± 4	42 ± 6	$\alpha_0, \gamma_{6.9+7.1}$	0.71 ± 0.06	0.5	14.115 ± 5	2^+
11.925 ± 7	92 ± 9	α_0	0.64 ± 0.04	1.6	14.270 ± 10	4^+
11.968 ± 8	60 ± 13	$\alpha_0, \gamma_{6.13}, \gamma_{6.9+7.1}$	0.31 ± 0.05	1.9	14.304 ± 10	(6^+)
11.977 ± 6	117 ± 8	α_0	0.82 ± 0.04	9.6	14.311 ± 5	6^+
11.979 ± 15	≈ 45	α_0	0.13 ± 0.06	0.1	14.313 ± 15	(3^-)
12.148 ± 28	≈ 95	α_0	0.18 ± 0.06 [e]	0.3	14.448 ± 25	$(0^+, 2^+)$
12.156 ± 4	≈ 15	α_0	0.09 ± 0.04	0.05	14.454 ± 5	5^-
12.322 ± 25	140 ± 50	α_0	0.45 ± 0.08	0.9	14.587 ± 20	1^-
12.329 ± 13	260 ± 25	$\alpha_0, \gamma_{6.9+7.1}$	0.79 ± 0.04	5.3	14.593 ± 10	4^+
12.447 ± 11	90 ± 30	α_0	0.35 ± 0.06	0.6	14.687 ± 10	(3^-)
12.502 ± 10	60 ± 25	α_0	0.25 ± 0.06	0.4	14.731 ± 10	(4^+)
12.539 ± 2	7.3 ± 4.8	α_0	0.18 ± 0.05	0.1	14.761 ± 5	6^+
12.597 ± 4	86 ± 7	α_0	0.95 ± 0.04	6.5	14.807 ± 5	6^+
12.608 ± 5	117 ± 13	α_0	0.69 ± 0.04	3.1	14.816 ± 5	5^-
12.637 ± 8	79 ± 15	α_0	0.45 ± 0.05	0.9	14.839 ± 10	(4^+)
12.699 ± 12	100 ± 30	α_0	0.44 ± 0.06	0.7	14.888 ± 10	2^+
12.897 ± 10	66 ± 20	α_0	0.31 ± 0.06	0.3	15.047 ± 10	2^+
12.930 ± 12	160 ± 25	α_0	0.40 ± 0.04	2.3	15.073 ± 10	5^-
13.016 ± 20	≈ 60	α_0	≈ 0.12	0.11	15.142 ± 15	(2^+)
13.056 ± 10	230 ± 25	α_0	0.70 ± 0.04	5.5	15.174 ± 10	5^-
13.237 ± 29	280 ± 40	α_0	0.39 ± 0.04	20	15.319 ± 25	7^-
(13.238 ± 10)	(130 ± 20)	(α_0)	(0.99 ± 0.08)		(15.319 ± 10)	(1^-)
13.251 ± 6	34 ± 10	α_0	0.29 ± 0.05	0.2	15.330 ± 5	4^+
(13.266 ± 12)	(50 ± 25)	(α_0)	(0.69 ± 0.17)		(15.342 ± 10)	(0^+)
13.27 [l]		α_1			15.346 ± 2	6^+
13.296 ± 5	110 ± 10	$\alpha_0, \gamma_{6.13}, \gamma_{6.9+7.1}$	0.71 ± 0.04	14	15.366 ± 5	7^-
13.384 ± 15 [d]	85 ± 35	α_0	0.26 ± 0.05	0.4	15.436 ± 15	(3^-)

Table 20.22: Resonances in $^{16}O(\alpha, \alpha)$ [a] (continued)

E_α (MeV ± keV)	Γ_{cm} (keV)	Outgoing particles	Γ_{α_0}/Γ	θ^2 (%)	E_x (MeV ± keV)	J^π
13.58		$\alpha_0, \gamma_{6.13}, \gamma_{6.9+7.1}$			15.59	
13.73		$\alpha_0, \gamma_{6.13}, \gamma_{6.9+7.1}$			15.71	(6^+)
14.05		$\alpha_0, \gamma_{6.13}, \gamma_{6.9+7.1}$			15.97	(6^+)
14.26		$\gamma_{6.13}, \gamma_{6.9+7.1}$			16.14	
14.40		$\gamma_{6.13}$			16.25	
14.501 ± 15	45	α_0, α_{1+2}			16.329 ± 11	4^+
14.636 ± 15 [g]	35	$\alpha_0, \alpha_{1+2}, \alpha_3$			16.437 ± 11	$(0, 2, 4)^+$
14.721 ± 15	24 ± 4	$\alpha_0, \alpha_{1+2}, \alpha_3, \alpha_4$	0.36 ± 0.03	0.38 ± 0.07	16.505 ± 15	6^+
14.789 ± 18	90 ± 30	α_0	0.16 ± 0.03	0.37 ± 0.13	16.559 ± 15	5^-
14.816 ± 15	92 ± 8	α_0, α_3	0.45 ± 0.03	4.1 ± 0.5	16.581 ± 15	7^-
14.875 ± 22	80 ± 25	α_0	0.18 ± 0.04	0.22 ± 0.08	16.628 ± 20	3^-
14.924 ± 20	100 ± 25	$\alpha_0, (\alpha_3)$	0.23 ± 0.03	0.42 ± 0.11	16.667 ± 15	4^+
14.987 ± 18	≈ 25	$\alpha_0, \alpha_{1+2}, \alpha_3, \alpha_4$	0.08 ± 0.03	≈ 0.05	16.717 ± 15	5^-
15.023 ± 33	160 ± 50	α_0	0.10 ± 0.02	4.8 ± 1.9	16.746 ± 25	8^+
15.149 ± 16	16 ± 8	$\alpha_0, \alpha_{1+2}, \alpha_3, \alpha_4$	0.11 ± 0.02	0.04 ± 0.02	16.847 ± 15	5^-
15.179 ± 25	350 ± 50	α_0	0.28 ± 0.03	3.9 ± 0.7	16.871 ± 20	6^+
15.430 ± 21	180 ± 30	α_0	0.32 ± 0.03	1.0 ± 0.2	17.072 ± 20	4^+
15.535 ± 15	26 ± 5	$\alpha_0, \alpha_{1+2}, \alpha_3, \alpha_4$	0.22 ± 0.02	0.13 ± 0.03	17.155 ± 15	5^-
15.607 ± 19	225 ± 30	α_0	0.32 ± 0.02	1.2 ± 0.2	17.213 ± 15	4^+
15.696 ± 20	86 ± 25	$\alpha_0, \alpha_{1+2}, \alpha_3, \alpha_4$	0.16 ± 0.03	0.20 ± 0.07	17.284 ± 15	3^-
15.710 ± 17	200 ± 25	α_0	0.26 ± 0.02	11.6 ± 1.4	17.295 ± 15	8^+
15.828 ± 15 [f]	< 10	α_{1+2}			17.390 ± 15	
15.878 ± 18	220 ± 25	α_0	0.24 ± 0.01	48 ± 6	17.430 ± 15	9^-
16.017 ± 16	86 ± 9	$\alpha_0, \alpha_{1+2}, \alpha_3, \alpha_4$	0.45 ± 0.03	1.3 ± 0.2	17.541 ± 15	6^+
16.099 ± 17	140 ± 20	α_0, α_4	0.36 ± 0.03	1.05 ± 0.15	17.606 ± 15	5^-
16.302 ± 23	≈ 125	α_0	0.13 ± 0.03	≈ 0.3	17.769 ± 20	4^+
16.405 ± 17	200 ± 30	α_0	0.38 ± 0.03	1.6 ± 0.3	17.851 ± 15	5^-

Table 20.22: Resonances in ^{16}O(α, α) [a] (continued)

E_α (MeV $\pm$ keV)	$\Gamma_{\rm cm}$ (keV)	Outgoing particles	Γ_{α_0}/Γ	θ^2 (%)	$E_{\rm x}$ (MeV $\pm$ keV)	J^π
16.598 ± 15 [f]	< 10	α_0, α_{1+2}			18.005 ± 15	7^-
16.622 ± 6	34 ± 7	α_0, α_{1+2}, α_3, α_4	0.34 ± 0.04	0.23 ± 0.06	18.024 ± 5	5^-
16.695 ± 30	140 ± 60	α_0	0.20 ± 0.05	0.4 ± 0.2	18.083 ± 25	4^+
16.748 ± 6	29 ± 6	α_0, α_{1+2}, α_3, α_4	0.46 ± 0.06	0.8 ± 0.2	18.125 ± 5	7^-
16.949 ± 13	190 ± 30	α_0, α_4	0.32 ± 0.02	1.7 ± 0.3	18.286 ± 10	6^+
17.129 ± 24	185 ± 40	α_0, (α_{1+2}), α_3, α_4	0.19 ± 0.02	1.8 ± 0.4	18.430 ± 20	7^-
17.210 ± 21	130 ± 30	α_0, α_3	0.21 ± 0.03	0.5	18.494 ± 20	5^-
17.368 ± 23	185 ± 30	α_0, α_4	0.24 ± 0.03	5.5 ± 1.1	18.621 ± 20	8^+
17.524 ± 29	140 ± 50	α_0, α_{1+2}	0.17 ± 0.04	0.6 ± 0.3	18.745 ± 25	6^+
17.552 ± 24	140 ± 35	α_0	0.22 ± 0.03	1.5 ± 0.4	18.768 ± 20	7^-
17.793 ± 29	200 ± 60	α_0	0.15 ± 0.02	3.2 ± 1.1	18.960 ± 25	8^+
17.906 ± 18	≈ 90	α_0, α_{1+2}	0.18 ± 0.03	≈ 0.3	19.051 ± 15	5^-
18.03 ± 20	200 ± 50	α_0, α_1, (α_2), α_4, α_5	0.38 ± 0.04 [d]	≈ 2	19.15 ± 20	6^+
18.198 ± 17	140 ± 25	α_1, (α_5)	0.12 ± 0.02 [h]		19.284 ± 15	6^+
18.216 ± 30	430 ± 60	α_0	0.36 ± 0.03	6.4 ± 1.1	19.298 ± 25	7^-
18.397 ± 11	130 ± 15	α_1, α_3, α_4	0.38 ± 0.01 [h]		19.443 ± 10	6^+
18.514 ± 29	250 ± 60	α_0, α_2, α_3	0.27 ± 0.04	1.6 ± 0.4	19.536 ± 25	6^+
(18.563 ± 25)	(140 ± 50)	(α_1)	(0.09 ± 0.02) [h]		(19.576 ± 20)	(7^-)
18.662 ± 23	140 ± 35	α_1	0.14 ± 0.02 [h]		19.655 ± 20	6^+
18.757 ± 28	330 ± 60	α_0, (α_2), α_3	0.23 ± 0.02	6.3 ± 1.2	19.731 ± 20	8^+
18.900 ± 48	360 ± 120	α_0	0.18 ± 0.03	1.4 ± 0.5	19.845 ± 40	6^+
18.918 ± 11	170 ± 25	α_1	0.26 ± 0.02 [h]		19.859 ± 10	5^-
18.949 ± 52	≈ 120	α_0	0.08 ± 0.03	≈ 0.35	19.884 ± 40	7^-
19.083 ± 39	130 ± 100	α_0, α_2, (α_5)	0.11 ± 0.04	0.19 ± 0.04	19.991 ± 30	4^+
19.128 ± 16	80 ± 35	α_1, α_4	0.10 ± 0.04 [h]		20.027 ± 15	6^+
19.227 ± 28	190 ± 35	α_1	0.29 ± 0.03 [h]		20.106 ± 25	7^-
19.304 ± 47	285 ± 100	α_0, α_3	0.18 ± 0.04	1.1 ± 0.4	20.168 ± 35	6^+

Table 20.22: Resonances in ^{16}O(α, α) [a] (continued)

E_α (MeV ± keV)	Γ_{cm} (keV)	Outgoing particles	Γ_{α_0}/Γ	θ^2 (%)	E_x (MeV ± keV)	J^π
19.464 ± 19	255 ± 40	α_1, α_5	0.28 ± 0.03 [h]		20.296 ± 15	7^-
19.521 ± 22	190 ± 40	α_1	0.26 ± 0.03 [h]		20.341 ± 20	5^-
19.524 ± 16	135 ± 35	α_0, α_3	0.25 ± 0.04	1.1 ± 0.3	20.344 ± 15	7^-
19.618 ± 39	215 ± 90	α_0	0.14 ± 0.03	0.6 ± 0.3	20.419 ± 30	6^+
19.651 ± 32	370 ± 55	α_1	0.32 ± 0.03 [h]		20.445 ± 25	6^+
19.679 ± 35	280 ± 70	α_0, α_2	0.20 ± 0.03	0.86 ± 0.25	20.468 ± 30	5^-
19.952 ± 8	78 ± 11	α_0, α_1, α_2, α_3	0.33 ± 0.03 [j]	4.5 ± 0.8	20.686 ± 6	9^-
20.04	240 ± 50	α_0, α_1, α_4	0.2 [j]	1.8 ± 0.5	20.76 ± 30	7^-
20.095 ± 32	170 ± 60	α_1	0.11 ± 0.02		20.800 ± 25	5^-
20.28	300 ± 50	α_0, α_1	0.23 ± 0.03 [j]	2.1 ± 0.6	20.95 ± 40	7^-
20.423 ± 8 [g]	60 ± 6	α_0, α_3	0.46 ± 0.03	4.1 ± 0.5	21.062 ± 6	9^-
20.7	300	α_0			21.3	7^-
21.3 ± 200	300	α_0			21.8 ± 200	7^-
22.0 ± 200	500	α_0			22.3 ± 200	7^-
22.5 ± 300	500	α_0			22.7 ± 200	9^-
22.65 ± 130	250	α_0			22.84 ± 100	9^-
23.3 ± 300	500	α_0			23.4 ± 200	8^+
24.24 ± 150	350	α_0			24.11 ± 100	8^+
25.4 ± 300	600	α_0			25.0 ± 250	8^+
26.2 ± 200	400	α_0			25.7 ± 150	
28.1 ± 350	700	α_0			27.2 ± 300	
29	1600	α_0			28	8^+
29.4 ± 350	700	α_0			28.2 ± 300	

[a] For earlier references see Tables 20.23 in (1978AJ03) and 20.21 in (1983AJ01). For K^π assignments see Table 20.20 here. The uncertainties in the excitation energies are calculated by taking the uncertainty in E_α in the cm [$\frac{4}{5}\times$ uncertainty in the lab] and adding the uncertainty in $E_{\rm b}$ [2 keV], in quadrature, rounding upwards. See (1987AJ02).

[b] $\Gamma_{\rm cm} = \Gamma_\alpha$.

[c] (1985JA17).

[d] Resonances with $9.25 \leq E_\alpha \leq 13.39$ MeV are from (1985CA09), except for the states labelled [f]. Certain values are rounded upwards. See also (1983CA1F) and Table 20.21 in (1983AJ01).

[e] $(2J+1)\Gamma_{\alpha_0}\Gamma_{\alpha_2}/\Gamma_{\rm g} = 81 \pm 12$ eV and 14 ± 2 eV, respectively, for ^{20}Ne* (12.14, 12.25) [for the latter see Table 20.21] (1980FI01).

[f] See Table 20.21 in (1983AJ01).

[g] Resonances with $14.6 < E_\alpha < 20.4$ MeV are from the re-analysis of the data of (1979BI10) by (1984RI06). Certain values are rounded upwards.

[h] $(\Gamma_{\alpha_0}\Gamma_{\alpha_1})^{1/2}/\Gamma$.

[i] (1984RI07).

[j] For information on the α_1 strength see (1984RI06).

[k] (1992LA01) determine $E_{\rm x} = 12.436 \pm 0.004$ MeV.

[l] (1992LA01).

16. ^{16}O(α, γ)^{20}Ne $\qquad Q_m = 4.730$

Observed resonances in the yield of capture γ-rays over the range $E_\alpha = 0.8$ to 10 MeV are displayed in Table 20.21. For a discussion of ^{20}Ne* (11.26) [$J^\pi = 1^+$; $T = 1$], to which excitation by this reaction is parity forbidden, see (1983FI02). See also (1984BU01). Total cross sections have been measured in the range $E_{cm} = 1.7$ to 2.35 MeV. Assuming that S does not vary with energy over that interval, the astrophysical factor for non-resonant capture to ^{20}Ne$_{gs}$ is 0.26 ± 0.07 MeV · b. An estimate of 0.7 ± 0.3 MeV · b for S at 300 keV is deduced (1987HA24). A comment (1988BA66) on this work summarizes the status of theoretical descriptions of ^{16}O(α, γ)^{20}Ne and discusses the (1987HA24) result in the light of a microscopic calculation. See also Table 20.21. For other papers on astrophysical considerations see (1985CA41, 1988CA26, 1990BL1K, 1991RA1C). For earlier work, see (1987AJ02).

A microscopic description of the α + ^{16}O system in a multicluster model is discussed in (1994DU09). An anharmonic oscillating model description is presented in (1993CSZU).

17. (a) ^{16}O(α, p)^{19}F $\qquad Q_m = -8.114$
(b) ^{16}O(α, d)^{18}F $\qquad Q_m = -16.321$ $\qquad E_b = 4.730$

For reaction (a) see (1990KOZG).

For reaction (b) see (1986KA36). A theoretical study of clustering in Yrast states is described in (1995KA53).

18. (a) ^{16}O(α, α)^{16}O $\qquad E_b = 4.730$
(b) ^{16}O(α, $\alpha\alpha$)^{12}C $\qquad Q_m = -7.162$

Excitation functions have been measured over a wide range of energies for elastically and inelastically scattered α-particles and γ-rays from the decay of ^{16}O* (6.13, 6.92, 7.13) [see (1978AJ03, 1983AJ01)] and (1986LE23; 1.8 to 4.8 MeV; α_0), (1985JA17; 2.0 to 3.6 MeV; α_0), (1983CA1F, 1985CA09; 9.2 to 13.5 MeV; α_0), (1992LA01; 10.2 to 18 MeV; α_1) and (1979BI10, 1984RI06; 14.6 to 20.4 MeV; $\alpha_0 \rightarrow \alpha_5$). See also (1983FR14, 1985ISZU) and ^{16}O in (1993TI07).

A number of anomalies are observed: see Table 20.22. K^π parameter assignments derived from this and other work are displayed in Table 20.20 (1984RI07). See also (1983MI22, 1990WE14, 1992AR18). Backscattering cross section measurements and other application-related studies are reported in (1990LE06, 1991LE33, 1992DE10, 1993CH48, 1993SO19). For reaction (b) see ^{12}C in (1985AJ01).

In theoretical work related to ^{16}O(α, α)^{16}O, studies have been reported for: optical potentials in the range E_α = 0–150 MeV (1993AB02, 1995MI13), phase equivalent complex potentials (1996BA26), quadrupole resonances (1993BY03), a single-folding potential model (1993LI25, 1993YA08), an R-matrix analysis of elastic cross sections in the range $E_\alpha = 2$–9 MeV (1994SH35), the orthogonality condition model (1987SA55), Yrast structure change of ^{20}Ne (1987KA24), microscopic cluster theory (1987TA1C), core-plus-alpha states in terms of vibron models (1988CS01), distribution of α-particle strength (1988LE05), α cluster formation in the cluster-orbital shell model (1990HA38), the microscopic complex effective interaction for α-^{16}O (1991YA08), and the generator-coordinate description (1987RE04, 1992KR12).

19. ^{16}O(^{6}Li, d)^{20}Ne $\quad Q_{\rm m} = 3.255$

Deuteron groups have been observed to many states of ^{20}Ne: see Table 20.23. Angular distributions have been measured for $E(^{6}{\rm Li}) = 5.5$ to 75.4 MeV: see (1978AJ03, 1983AJ01, 1984MO08). Measurements of angular diestribution at $E(^{6}{\rm Li} = 22$ MeV provided data that were used to determine the ratios of α-particle widths in ^{19}Ne relative to ^{20}Ne (1995MA28) and to obtain alpha spectroscopic factors for ^{20}Ne states up to $E_{\rm x} = 6$ MeV (1996MA07). Angular correlations [(d, α_0) to $^{16}{\rm O}_{\rm g.s.}$] have been measured at $E(^{6}{\rm Li}) = 60$, 75, and 95 MeV (1982AR20, 1988ARZU). An experimental study of the competition between evaporation and direct transfer is described in (1995XE01). See also references cited in (1987AJ02).

In theoretical work published since the previous review, Hauser-Feshbach theory was applied to this reaction by (1987AR13), and angular distributions were analyzed with DWBA formalism by (1992RA22). See also (1994OS05).

20. ^{16}O(^{7}Li, t)^{20}Ne $\quad Q_{\rm m} = 2.263$

States observed in this reaction are displayed in Table 20.23. Angular distributions have been measured at $E(^{7}{\rm Li}) = 15$ to 68 MeV: see (1978AJ03, 1983AJ01). See also (1986CO15). The reaction ^{7}Li(^{16}O, t)^{20}Ne was used in a lifetime measurement by (1995YU05).

Theoretical work related to this reaction includes studies on: the form of the α particle potential in direct α-transfer reactions (1986GR29, 1988GR1I), a Hauser Feshbach theory application (1987AR13), the optical potential (1989BE51), clustering phenomena and shell effects (1988RA1G), DWBA analysis (1992RA22).

21. ^{16}O(^{9}Be, ^{5}He)^{20}Ne $\quad Q_{\rm m} = 2.263$

See (1985CU1A).

22. (a) ^{16}O(^{12}C, ^{8}Be)^{20}Ne $\quad Q_{\rm m} = -2.636$
(b) ^{16}O(^{12}C, 2α)^{20}Ne $\quad Q_{\rm m} = -2.545$
(c) ^{16}O(^{12}C, α^{12}C)^{12}C $\quad Q_{\rm m} = -7.162$

Table 20.23: States of ^{20}Ne from ^{16}O(^{6}Li, d), ^{16}O(^{7}Li, t) and ^{16}O(^{12}C, ^{8}Be) [a]

E_x (MeV ± keV)			Γ_{cm} (keV)	Γ_{α_0}/Γ	S [b]	J^π
(^{6}Li, d)	(^{7}Li, t)	(^{12}C, ^{8}Be)				
0	0	0			1.00	0^+
1.63	1.63	1.63			0.41	2^+
4.25	4.25	4.25			0.22	4^+
4.97						2^-
5.62					0.06	3^-
5.79	5.79	5.79			0.54	1^-
6.73					0.56	0^+
7.00						4^-
7.16	7.16	7.16			0.26	3^-
7.43					0.13	2^+
8.46					0.04	5^-
8.78	8.78	8.78			0.20	6^+
10.3 ± 100	10.26	10.26	145 ± 40	1	0.15	5^-
10.7 ± 100						4^+
11.95	11.95	11.95		0.85 ± 0.15	0.51	8^+
12.14					0.05	6^+
12.6 ± 100	12.591 ± 10	12.59	110 ± 40	0.80 ± 0.10		6^+
13.9	13.904 ± 20		≈ 100			6^+
14.3	14.310 ± 20	14.3 [d]	< 100			6^+
15.35 ± 100	15.336 ± 15	15.34	380 ± 60	0.90 ± 0.10		7^-
15.9 ± 100		15.87	< 250			7^-
16.7 ± 100	16.63 ± 20	16.63	190 ± 40	0.90 ± 0.10		7^- [e]
17.35 ± 100	17.30 ± 20	17.30	220 ± 40	$\geq 0.40 \pm 0.10$		8^+ [e]
18.7 ± 100						7^-
19.4 ± 100			400			7^-
19.9 ± 100			400			7^-
	20.67 ± 40	20.5 [d]				
20.8 ± 100						7^- (6^+)
	21.08 ± 30	21.08	100 ± 50	0.65 ± 0.15		9^-
21.3 ± 100			300			8^+

Table 20.23: States of ^{20}Ne from ^{16}O(^{6}Li, d), ^{16}O(^{7}Li, t) and ^{16}O(^{12}C, ^{8}Be) [a] (continued)

E_x (MeV ± keV)			Γ_{cm} (keV)	Γ_{α_0}/Γ	S [b]	J^π
(^{6}Li, d)	(^{7}Li, t)	(^{12}C, ^{8}Be)				
21.8 ± 100			300			8^+
22.3 ± 100			300			8^+
	22.87 ± 40	22.87	225 ± 40	0.90 ± 0.10		9^-
23.5 ± 100	23.70 ± 30		≤ 200			9^- (8^+)
	24.21 ± 25		≈ 500			
	25.10 ± 50		≤ 200			
	25.67 ± 50		≈ 500			
27.1 ± 100 [c]		27.0 [d]				9^-
28.1 ± 100 [c]						10^+
(29.4) [c]						(10^+)
(33.4)						(10^+)

[a] For complete references see Tables 20.24 in (1978AJ03) and 20.22 in (1983AJ01).

[b] Relative α-particle spectroscopic factors (DWBA). Other S_α values have also been reported, see, e.g. (1996MA07) for levels up to $E_x = 5.79$ MeV.

[c] (1982AR20, 1988AL07).

[d] (1983SH26).

[e] An admixture of 6^+ or 8^+ in the d-α angular correlation involving ^{20}Ne* (16.6) and a doublet $(8^+ + 7^-)$ at $E_x = 17.4$ MeV have been suggested. See also Table 20.22.

Angular distributions in reaction (a) have been measured for $E(^{16}\text{O}) = 27.1$ to 53.0 MeV and for $E(^{12}\text{C}) = 22.7$ to 78 MeV [see (1978AJ03, 1983AJ01)] as well as at $E(^{12}\text{C}) = 109$ MeV (1984MU04, 1985MU14; ^{20}Ne* (1.63, 4.25, 5.79, 7.16, 8.78, 10.26, 11.95, 12.59, 15.34, 15.87, 17.30, 21.08, 22.87); $\sigma(\theta)$ at several angles; EFR-DWBA analysis). See also (1988CAZV). Γ_{α_0}/Γ are displayed in Table 20.23: see (1983AJ01, 1987AJ02) and (1983SH26). Spectroscopic factors were extracted in a direct reaction study reported by (1989OS02). Evidence for 10^+ strength at $E_x = 27.5$ MeV is reported by (1988AL07). See also (1983DEZW). For discussion of ^{28}Si states reached in this reaction see (1993ES01, 1993ES03, 1993ZH21). See also the discussion of instrumentation development for ^{8}Be detection reported in (1991SU15). For reaction (b) see (1978AJ03) and (1986CA19). For reaction (c) and for a discussion of ^{24}Mg states reached in this reaction see (1983SH26, 1984MU04). See also (1985BE37, 1986BE19, 1987SU03).

23. ^{16}O(^{13}C, ^{9}Be)^{20}Ne $\qquad Q_m = -5.918$

At $E(^{13}\text{C}) = 105$ MeV angular distributions to ^{20}Ne* (1.63, 4.25, 8.78, 11.95, 15.34, 21.0) have been studied by (1979BR03): the first four states are the 2^+, 4^+, 6^+, and 8^+ members of the 0^+_1 band; the two higher states [$J^\pi = 7^-, 9^-$] belong to the 0^- band for which the band head is ^{20}Ne* (5.79). In addition, distributions are reported to ^{20}Ne* (12.59, 15.9, 17.3) [$J^\pi = 6^+$, 8^+, 8^+] (1979BR03). See also (1985MU14). Spectroscopic factors were extracted in a direct reaction study reported by (1989OS02). For fusion cross sections see (1986PA10).

24. ^{16}O(^{16}O, ^{12}C)^{20}Ne $\quad Q_\text{m} = -2.432$

Angular distributions have been reported to a number of states of ^{20}Ne at $E(^{16}\text{O}) = 23.9$ to 95.2 MeV [see (1978AJ03, 1983AJ01)] and at $E(^{16}\text{O}) = 26$, 28, and 30 MeV (1986CA24). (1983ME13) have studied the quasi-elastic spectrum at $E(^{16}\text{O}) = 50$, 60, 68, and 72 MeV. Measurements of the energy dependence for $E(^{16}\text{O} = 51$–66 MeV were performed by (1996FR09). For excitation functions see (1986CA24; ^{20}Ne* (0, 1.63)). See also (1982KO1C, 1984ME10, 1985ST1B, 1982KO1D, 1984AP03, 1984KO13).

Studies of the direct-reaction mechanism for this reaction have been carried out by (1988GA1L, 1988GA19, 1989OS02, 1990OS03). See also (1988AU03) and references cited in (1987AJ02).

25. (a) ^{17}O(^{3}He, ^{3}He)^{17}O $\quad E_\text{b} = 21.164$
(b) ^{17}O(^{3}He, α)^{16}O $\quad Q_\text{m} = 16.434$

The excitation function for α_0 shows a resonance corresponding to ^{20}Ne* (28.): see (1978AJ03). Measurements of A_y at $E(^3\text{He}) = 33$ MeV, have been reported for the elastic scattering [reaction (a)] (1983LE03) and for many α-groups [see ^{16}O in (1993TI07)] (1982KA12). For the earlier work and for other channels see (1983AJ01, 1987AJ02).

26. ^{17}O(α, n)^{20}Ne $\quad Q_\text{m} = 0.587$

Neutron emission from this reaction was measured for $E_\alpha = 5.15$ and 5.49 MeV by (1987SM09). Excitation functions were measured at astrophysical energies and S-factor curves were determined by (1995KU1H). See also work cited in (1978AJ03). In a recent theoretical study, the three-cluster generator coordinate method was applied to calculation of the low energy cross section by (1993DE32).

27. (a) ^{17}O(^{11}B, ^{8}Li)^{20}Ne $\quad Q_\text{m} = -6.045$
(b) ^{17}O(^{12}C, ^{9}Be)^{20}Ne $\quad Q_\text{m} = -5.115$

Table 20.24: Resonances in ^{19}F(p, γ)^{20}Ne [a]

$E_{\rm p}$ (keV)	$\Gamma_{\rm cm}$ (keV)	$\Gamma_{\gamma 0}$ (eV)	$\Gamma_{\gamma 1}$ (eV)	^{20}Ne* (MeV)	$J^\pi; T$
340		< 0.07	0.28 ± 0.06	13.171	
484		≈ 0.05	0.42	13.308	
597 ± 1	29 ± 3	< 0.6	12	13.415	
671 ± 1	5.7 ± 0.7	1.0×10^{-2}	2.2	13.485	1^+
874				13.678	
935				13.736	
980				13.779	
1091	0.8		1.1	13.884	2^+; 1
1280				14.063	
1320	3.8			14.101	
1350				14.130	
1370				14.149	
1420	14.9			14.196	
4090 ± 5				16.732 [b]	0^+; 2
5879 ± 7	9.5 ± 2.8	$\Gamma_\gamma \approx 0.3$ eV		18.430	2^+; 2

[a] For earlier references see Tables 20.26 in (1978AJ03) and 20.24 in (1983AJ01). See also Table 20.18 here.

[b] Decays $\approx$ 100% to the $E_{\rm x} = 11.26$ MeV $J^\pi;\ T = 1^+;\ 1$ state with $\Gamma_\gamma \approx 5$ eV. See discussion under reaction 29.

At $E = 115$ MeV the 8^+ state at $E_{\rm x} = 11.95$ MeV is strongly populated in both reactions: see (1983AJ01).

28. ^{18}O(^{3}He, n)^{20}Ne $\qquad Q_{\rm m} = 13.120$

Angular distributions have been measured for $E(^3{\rm He}) = 2.8$ to 18.3 MeV. States of ^{20}Ne observed in this reaction are displayed in Table 20.23 of (1983AJ01). These include a state at $E_{\rm x} = 16.7329 \pm 0.0027$ MeV, $\Gamma_{\rm cm} = 2.0 \pm 0.5$ keV: $J^\pi = 0^+$, $T = 2$. Differential cross sections were measured at $E(^3{\rm He}) = 30$ MeV by (1995FUZT).

29. ^{19}F(p, γ)^{20}Ne $\qquad Q_{\rm m} = 12.844$

The previous review (1987AJ02), observed that over the range $E_{\rm p} = 2.9$ to 12.8 MeV, the γ_0 and γ_1 yields are dominated by the E1 giant resonance ($\Gamma \approx 6$ MeV) with the γ_1 giant resonance displaced upward in energy. Strong well-correlated structures are observed with characteristic widths $\Gamma \approx 175$ keV. Angular distributions taken over the energy range do not vary greatly with energy. They are incompatible with γ_0 and γ_1 coming from the same levels in ^{20}Ne. The $90°$ γ_0 yield for $E_{\rm p} = 3.5$ to 10 MeV has been measured: the results are interpreted in terms of four primary doorway states at $E_{\rm x} = 16.7$, 17.8, 19.1 and 20.2 MeV. See also (1985WAZV; $E_{\rm p} = 5.9$ to 10.3 MeV; E2 strength; prelim.). See also (1986OUZZ).

More recently, polarized and unpolarized angular distributions were measured for $E_{\rm p} = 16.1$–23.0 MeV (1988KU08). Data for (p, γ_1) were also presented and a doorway state calculation was discussed. Cross section and analyzing powers for (p, $\gamma_0\gamma_1$) were measured in the range $E_{\rm p} = 3.5$–13.3 MeV by (1988WA13) in a study of the E2 strength in ^{20}Ne. See also the review of giant resonance work in (1988HA12).

The yield curve for 11.2 MeV γ-rays [from the decay of ^{20}Ne* (11.26), $J^\pi = 1^+$, $T = 1$, to the ground state] displays a resonance at $E_{\rm p} = 4.090 \pm 0.005$ MeV [^{20}Ne* (16.73)]. The 11.2 MeV γ-rays are isotropic which is consistent with the presumed 0^+ character of this lowest $T = 2$ state in ^{20}Ne: $\Gamma_{\rm p}\Gamma_\gamma/\Gamma \approx 0.5$ eV. Since $\Gamma_{\rm p}/\Gamma$ (from the elastic scattering) is ≈ 0.1, $\Gamma_\gamma \approx 5$ eV. For $E_{\rm p} = 5.65$ to 6.21 MeV, the γ_0 and γ_1 yields are not resonant but the yield of 10.6-MeV γ-rays is resonant at 5.879 ± 0.007 MeV [$\Gamma_{\rm c.m.} = 9.5 \pm 3$ keV, $\Gamma_{\rm p_0}\Gamma_\gamma/\Gamma \approx 0.05$ eV; $\Gamma_\gamma \approx 0.3$ eV]. The 10.6 MeV γ-ray is due to the cascade decay of ^{20}Ne* (18.43), $J^\pi = 2^+$, $T = 2$ via ^{20}Ne* (12.22) to the 2^+ state at 1.63 MeV. For the upper limits to the strengths of the transitions to various states of ^{20}Ne from the 0^+ and 2^+ $T = 2$ states, see (1983AJ01). Internal pair conversion of the GDR at $E_{\rm x} \approx 18$ MeV was observed by (1989MOZY). Resonances observed in the capture reaction are displayed in Table 20.24. For references see (1978AJ03, 1983AJ01). See also the astrophysics-related work in (1987RO25, 1988CA26). A study of absolute thick-target yields for elemental analysis at $E_{\rm p} = 7$, 9 MeV is reported in (1987RA23).

30. (a) ^{19}F(p, p$'$)^{19}F $\qquad E_{\rm b} = 12.844$
(b) ^{19}F(p, d)^{18}F $\qquad Q_{\rm m} = -8.207$

The elastic scattering has been studied in the range $E_{\rm p} = 0.5$ to 7.5 MeV and 24.9 to 46.3 MeV [see (1978AJ03)] and at $E_{\rm p} = 1.5$ to 3.5 MeV (1985OU01, 1986OUZZ, 1986OU01). See also the measurements for $E_{\rm p} = 0.85$–1.01 MeV at $\theta_{\rm lab} = 165°$ by (1989KN01), and the work reported in (1994CO12) in which a ^{19}F radioactive beam was used in scattering off polyethelyne targets. The observed anomalies are displayed in Table 20.25.

Resonances for inelastic scattering [$\rm p_1$ and $\rm p_2$] are listed in Table 20.26. In general the resonances observed are identical with those reported from other ^{19}F+p reactions, although the relative intensities differ greatly. Cross sections for production of 110 and 197 keV γ-rays are reported for

Table 20.25: Levels of ^{20}Ne from ^{19}F(p, p_0) [a]

E_p (keV)	Γ_{cm} (keV)	l	$J^\pi; T$	Γ_p/Γ	θ^2_p (%)	^{20}Ne* (MeV)
340	2.8	0	1^+	0.016	3.8	13.171
483			1^+			13.307
598	35	1	2^-	0.0012	0.38	13.416
669	7.1	0	1^+	0.98	9.6	13.483
843	22	0	0^+	0.996	10.8	13.649
873	4.9	1	2^- [b]	0.21	1.5	13.677
935	7.0	0	1^+	0.17	0.44	13.736
1346	4.3	1	2^- [b]	0.067	0.07	14.126
1372	14	1	2^- [b]	0.17	0.52	14.151
1422	13.9	0	1^+	0.85	0.92	14.198
1710 [c]	86	0	0^+	0.8		14.472
1896 [c]	24	0	0^+	0.3		14.648
1943 [c]	38	0	(1^+)	0.5		14.693
2030 [c]	67	1	(1^-)	0.75		14.776
2763 [c]		2				15.472
2970 [c]		2				15.668
4094 ± 3	2.0 ± 0.5	0	$0^+; 2$	0.062 ± 0.004		16.735
5879 ± 7 [d]	9.5 ± 3	2	$2^+; 2$	≈ 0.2		18.430

[a] For references see Table 20.27 in (1978AJ03). For θ^2 see Table 20.28 in (1978AJ03).

[b] 1^- not excluded by elastic scattering alone.

[c] (1985OU01, 1986OU01; R-matrix analysis). Weak resonances at $E_p = 1.75$ and 1.78 MeV are also suggested.

[d] Resonance also observed in p_1, p_3, p_4 and p_5 yields.

Table 20.26: Resonances in $^{19}F(p, p')^{19}F^*$ [a]

E_p (keV)	$J^\pi; T$	Γ_{cm} (keV)	Γ_{p_1} (eV)	Γ_{p_2} (eV)	$\theta^2_{p_1}$ (%)	$\theta^2_{p_2}$ (%)	E_x in ^{20}Ne (MeV)
340	1^+	2.8	< 0.5	< 0.1	< 15		13.171
483	1^+	2.1	< 1.3	< 1.2			13.307
598	2^-	35	< 100	< 60	< 28	< 145	13.416
669	1^+	7.1	46	< 0.5	0.6	< 0.4	13.483
720		≈ 29	< 10000	< 10000			13.532
780		≈ 9.5	< 400	≈ 9000			13.589
831		7.9	< 6	≈ 2300			13.637
845	0^+	22	≈ 50	< 10	≈ 0.14	< 0.92	13.650
873	2^-	4.9	< 2	570	< 0.07	2.7	13.677
900		4.6	< 30	≈ 2200			13.703
935	1^+	7.6	3000	< 20	5.0	< 0.8	13.736
1092 [b]	2^+	0.8	173	592			13.885
1137		3.5	< 40	≈ 2100			13.928
≈ 1250		≈ 76	≈ 70000	< 4000			14.03
1290		18	< 600	≈ 900			14.073
1346	2^-	4.3	300	600	0.92	0.24	14.126
1372	2^-	14	700	1400	1.93	0.56	14.151
1422	1^+	13.9 ± 1	2200	≤ 35	0.56	≤ 0.11	14.198
1610		≈ 5					14.377
1660							14.424
1700							14.462
2763 [c]							15.472
2970 [c]							15.668
5879 [d]	$2^+; 2$		resonant				18.430

[a] For references see Tables 20.29 in (1978AJ03) and 20.26 in (1983AJ01).

[b] $\Gamma_{p_0} = 29$ eV.

[c] Reported in $p_{1\to4}$ yield (1986OU01).

[d] Resonance also observed in p_3, p_4, and p_5 yields.

$E_p = 0.5$ to 4.3 MeV by (1986CHYY). See also (1983LE28; astrophysics) and (1986BA88). For reaction (b) see (1986KA1U; applied) and ^{18}F.

31. ^{19}F(p, n)^{19}Ne $\qquad Q_m = -4.020 \qquad E_b = 12.844$

Observed resonances are displayed in Table 20.30 of (1978AJ03). See also (1984BA1R, 1985CA41). The transfer polarization coefficient for $E_p = 120$, 160 MeV at $\theta = 0°$ was measured by (1990HUZY). Total cross sections for production of ^{19}Ne measured by the activation method are reported by (1990WA10).

32. ^{19}F(p, α)^{16}O $\qquad Q_m = 8.114 \qquad E_b = 12.844$

Many resonances occur in this reaction. They are displayed in Tables 20.27, 20.28, and 20.29 depending on whether they are observed in the α_0 yield [20.23], in the α_1 [or α_π] yield to ^{16}O* (6.05) [20.24] or in the α_2, α_3, and α_4 yields [or in the yield of the γ-rays from ^{16}O* (6.13, 6.92, 7.12) [20.25]]. See also tables 2 and 3 in (1993DA23) which list a number of new resonances for $E_p = 0.3$–3.0 MeV. Resonances for α_0 and α_1 are required to have even J, even π or odd J, odd π, while the α_2, α_3, and α_4 resonances are all odd-even or even-odd, with the exception of the $T = 2$ resonance.

Listings of the earlier yield studies are given in (1972AJ02, 1978AJ03, 1983AJ01). A detailed discussion of the evidence leading to many of the J^π assignments is given in (1959AJ76). For values of θ^2 see Table 20.28 in (1978AJ03). Other measurements are reported by (1985OU01; 1.5 to 2.1 MeV; $\alpha_0 \rightarrow \alpha_3$) and (1984IN04; 4.15 to 13 MeV; $\alpha_0 \rightarrow \alpha_5$). In the latter work there are no marked correlations between the different channels.

Longitudinally and transversely polarized protons with $E_p \approx 0.67$ MeV have been used to study ^{20}Ne* (13.48) [$J^\pi = 1^+; T = 1$] via a parity- (and isospin-) forbidden α-transition. The state is not excited. The upper limits for the process, and their significance in the determination of f_π, the weak pion-nucleon coupling constant, are discussed by (1983KN01, 1986KN1C, 1990KN01). See also (1983AJ01, 1984KN1A).

Internal pair conversion for ^{19}F(p, α_π) of the 18 MeV GDR in ^{20}Ne was studied by (1989MOZY) at $E_p = 5.2$ MeV.

A DWBA analysis for energies below the Coulomb barrier is used to determine the astrophysical S-factor in (1991HE16). See also (1993YA18).

Application-related work is reported in (1987EV01, 1989MC04, 1989MC03, 1989TA1N). See also the earlier work cited in (1987AJ02).

33. ^{19}F(d, n)^{20}Ne $\qquad Q_m = 10.620$

Levels of ^{20}Ne derived from this reaction are displayed in Tables 20.31 in (1972AJ02) and 20.34 in (1978AJ03). See also (1983LIZW).

Table 20.27: Resonances for ground-state α-particles (α_0) in ^{19}F(p, α_0) [a]

E_p (keV)	Γ_{cm} (keV)	θ^2_α (%)	$J^\pi; T$	^{20}Ne* (MeV)
400	95		1^-	13.228
400	95		0^+	13.228
650 ± 20	190		1^-	13.465
710	33	0.6	(1^-)	13.522
733	63	1.0	2^+	13.544
777 ± 2	9 ± 1	0.02	2^+	13.586
842 ± 2	17 ± 1	0.16 [b]	(2^+) [c]	13.648
≈ 860	114	2.1	1^-	13.66
≈ 930	≈ 171	2.9	0^+	13.73
≈ 1080	≈ 190	3.4	1^-	13.87
1115	48	0.55	2^+	13.907
1160	≈ 67	1.1	0^+	13.950
1235	≈ 67	1.2	1^-	14.021
≈ 1250	≈ 143	2.7	2^+	14.03
1350 ± 3	34 ± 1		2^+	14.130
1652 ± 5	86 ± 5		1^-	14.417
1713 ± 6	68 ± 2		0^+	14.475
1842 ± 7	116 ± 5		1^-	14.597
1901 ± 10	24 [d]		0^+	14.653
2110	71		$(2^+, 4^+)$	14.85
2310	86		(2^+)	15.04
2550	285		(1^-)	15.27
2590	285		(0^+)	15.31
2680	76			15.39
2730	57			15.44
2820	152			15.53
2940				(15.64)
3120	162			(15.81)
3340	100			16.02
3680	(95)			16.34
3860				16.51

Table 20.27: Resonances for ground-state α-particles (α_0) in ^{19}F(p, α_0) [a] (continued)

E_p (keV)	Γ_{cm} (keV)	θ^2_α (%)	$J^\pi; T$	^{20}Ne* (MeV)
3980	128			16.63
4130	95			16.77
4360	95			16.99
4460	90			17.08
4690	62			17.30
4900	86			17.50
4990	38			17.59
5879 ± 7	9.5 ± 2.8	[d]	$2^+; 2$	18.430

[a] For earlier references and additional comments see Tables 20.31 in (1978AJ03) and 20.28 in (1983AJ01). See also (1985OU01, 1986OU01).
[b] $\Gamma_{\alpha_0} \approx 0.06$ keV.
[c] $J = 0$ from ^{19}F(p, p); possibly $T = 0$.
[d] $\Gamma_{\alpha_0} \approx 0.3$ keV.

34. ^{19}F(^{3}He, d)^{20}Ne $\qquad Q_m = 7.350$

Levels of ^{20}Ne observed in this reaction are displayed in Tables 20.35 in (1978AJ03) and 20.32 in (1983AJ01). Deuteron angular distributions have been studied at $E(^3\text{He}) = 9.5$ to 21 MeV: see (1978AJ03). A more recent measurement of differential cross sections at $E(^3\text{He}) = 22.3$ MeV and DWBA analysis was reported by (1994ARZY).

The excitation energy difference (ΔE_x) between the 1^+ and 1^-, $T = 1$ states ^{20}Ne* (11.26, 11.27) is 11.1 ± 0.7 keV (1983FI02). $\Gamma_\gamma/\Gamma_\alpha = 0.88 \pm 0.05$ for ^{20}Ne* (12.22) [2^+; $T = 1$] (1984CA08). Using $(2J + 1)\Gamma_\alpha\Gamma_\gamma/\Gamma = 1.41 \pm 0.23$ eV (1980FI01), $\Gamma_\alpha = 0.32 \pm 0.06$ eV for ^{20}Ne* (12.22) (1984CA08). The value of Γ_γ/Γ of ^{20}Ne* (12.22) implies B(M1) $= 0.07$ W.u. for the transition from ^{20}Ne* (18.43) [2^+; $T = 2$]. This is much weaker than other isovector M1 transitions in ^{20}Ne and a factor of five lower than predicted by shell model calculations: see (1984CA08).

In recent work at $E(^3\text{He}) = 25$ MeV, differential cross sections were measured (1994VE04) for ^{20}Ne levels at $E_x = 0$, 1.634 MeV. DWBA calculations were carried out and absolute values of C^2S were extracted and compared with shell model calculations.

35. ^{19}F(α, t)^{20}Ne $\qquad Q_m = -6.970$

Table 20.28: Nuclear pair resonances (α_π) in ^{19}F(p, α_π) [a]

E_p (keV)	Γ_{cm} (keV)	σ (mb)	θ^2_α (%)	J^π	^{20}Ne* (MeV)
710	33	≈ 0.2	2	1^-	13.522
780	≈ 9.5	≈ 0.2	0.15	2^+	13.589
842	22	3.4	0.27	2^+ [b]	13.648
1115	48	1.5	3.6	2^+	13.907
1236	≈ 67	3	1.0	1^-	14.022
1367	29	6.0	0.29	2^+	14.146
1640	57			1^-	14.41
1720	90	≈ 18		0^+	14.48
1850	162			1^-	14.60
1896	24			0^+	14.65
2080 [c]	57	12.1		(2^+)	14.82
2170 [c]	67	12.2		(0^+)	14.91
2330 [c]	67	17.0		(2^+)	15.06
2600	95				15.32
2680	95				15.39
2820	119				15.53
3120	138				15.81
3340	95				16.02
(3500)	(76)				(16.17)
(3590)	(109)				(16.26)
3960	190				16.61
4360	90				16.99
4690	< 143				17.30
4900	109				17.50
4990	38				17.59
5170	209				17.76

[a] For references see Tables 20.32 in (1978AJ03) and 20.29 in (1983AJ01). See also (1985OU01, 1986OU01).

[b] See footnote [c] in Table 20.27.

[c] (1980CU09): see also for partial widths.

Table 20.29: Resonances for 6–7 MeV γ-rays (α_2, α_3, α_4) in ^{19}F(p, α) [a]

E_p (keV)	Γ_{cm} (keV)	Γ_{α_2} (eV)	Γ_{α_3} (eV)	Γ_{α_4} (eV)	$J^\pi; T$	^{20}Ne* (MeV)
223.99 ± 0.07 [b]	0.94 ± 0.02	1000	< 2.5	< 2.5	2^-	13.0607
340.46 ± 0.04 [b, c]	2.22 ± 0.04	2800	16	75	1^+	13.1713
483.91 ± 0.10 [b]	0.86 ± 0.03	700	19	190	1^+	13.3075
594 ± 3	24 ± 3					13.412
667.5 ± 2.0	6.4 ± 0.3					13.482
832.1 ± 1.0						13.638
872.11 ± 0.20 [d]	4.30 ± 0.15	2200	620	180	2^-	13.6762
935.4 ± 1.3	7.7 ± 0.5	2900	110	720	1^+	13.736
1087.7 ± 1.0	0.14 ± 0.05					13.881
1135.6 ± 1.0						13.926
1280 ± 1						14.063
1347.1 ± 1.0	4.7 ± 0.7	2250	650	1200	2^-	14.128
1371.0 ± 1.0	11.8 ± 1.0	6650	700	300	2^-	14.150
1603 ± 2						14.370
1692 ± 2	33 ± 3				$(1, 2)^-$	14.455
1949 ± 3	38 ± 10				$(0, 1)^+$	14.699
2030 ± 3	114 ± 19					14.776
2320	81					15.05
2510	29					15.23
2630	86					15.35
2800	57					15.51
3020	29					15.72
3190	76					15.88
3490	38					16.16
3920	29					16.57
4000	105					16.65
4090					$0^+; 2$	16.73
4290	48					16.92
4490	29					17.11
4570	29					17.19
4710	29					17.32

Table 20.29: Resonances for 6–7 MeV γ-rays (α_2, α_3, α_4) in ^{19}F(p, α) [a] (continued)

E_p (keV)	Γ_{cm} (keV)	Γ_{α_2} (eV)	Γ_{α_3} (eV)	Γ_{α_4} (eV)	$J^\pi; T$	^{20}Ne* (MeV)
4780	33					17.39
4990	19					17.59
5070	33					17.66
5200	67					17.79

[a] See Tables 20.33 in (1978AJ03) and 20.30 in (1983AJ01) for earlier references and for additional comments. See also (1985OU01, 1986OU01), and see tables 2 and 3 in (1993DA23).
[b] (1985UH01). See also (1977FR20).
[c] (1982BE29): $\sigma = 88 \pm 3$ mb, $\omega\gamma = 22.3 \pm 0.8$ eV.
[d] (1982BE29): $\sigma = 440 \pm 13$ mb, $\omega\gamma = 570 \pm 30$ eV.

Angular distributions have been measured at $E_\alpha = 18.5$ and 28.5 MeV: see (1978AJ03, 1983AJ01). The double differential cross section was measured at $E_\alpha = 30.3$ MeV in a study of the reaction mechanism involving excitation of the 0^+, 2^+ and 4^+ states at $E_x = 0$, 1.63, 4.25 MeV (1995IG03).

36. ^{19}F(^{7}Li, ^{6}He)^{20}Ne $\qquad Q_m = 2.869$

Angular distributions have been studied at $E(^7\text{Li}) = 34$ MeV to a number of states of ^{20}Ne. C^2S values are consistent with those reported in the (d, n) and (^{3}He, d) reactions: see (1978AJ03).

37. ^{20}F(β^-)^{20}Ne $\qquad Q_m = 7.025$

The decay is primarily to ^{20}Ne* (1.63) with a half-life of 11.163 ± 0.008 s (1992WA04): see reaction 1 in ^{20}F. Besides the principal decay to ^{20}Ne* (1.63) [$\log f_0t = 4.97$], ^{20}F also decays to ^{20}Ne* (4.97) [$J^\pi = 2^-$] with a branching ratio of (0.0082 ± 0.0006)% (1987AL06) [$\log f_0t = 7.20 \pm 0.03$; D.E. Alburger and E.K. Warburton, see (1987AJ02)]. The upper limit for the ground-state decay is 0.001% [$\log f_0t > 10.5$]. For other values and earlier references see Table 20.36 in (1978AJ03). The energy of the γ-ray from ^{20}Ne* (1.63) is 1633.602 ± 0.015 keV. E_γ for the $4.97 \to 1.63$ transition is 3332.54 ± 0.19 keV which gives $E_x = 4966.51 \pm 0.20$ keV based on $E_x = 1633.674 \pm 0.015$ keV for the first excited state. The shape of the β-spectrum is in good agreement with the predictions of CVC (1983AJ01, 1987AJ02, 1989HE11). $\beta - \gamma$ angular correlations reported by (1988RO10) are close to the expectations based on CVC theory. For earlier work see (1978AJ03, 1983AJ01, 1987AJ02). The ^{20}F(β^-)^{20}Ne decay is thought to play a part in heavy element nucleosynthesis (1988AP1A). See also (1989MA1U, 1989TA26).

38. (a) ^{20}Ne(γ, n)^{19}Ne $\qquad Q_{\mathrm{m}} = -16.864$

(b) ^{20}Ne(γ, nn)^{18}Ne $\qquad Q_{\mathrm{m}} = -28.491$

(c) ^{20}Ne(γ, α)^{16}O $\qquad Q_{\mathrm{m}} = -4.730$

The photoneutron cross section (bremsstrahlung photons) shows peaks at $E_{\mathrm{x}} = 17.78 \pm 0.05$, 19.00 ± 0.05, 20.15 ± 0.15 [main peak of the GDR], 22.6 ± 0.3, 24.9 ± 0.5 and 27.5 MeV [the latter three states are broad]: the integrated cross section to 28.5 MeV is 58 ± 6 MeV · mb [exhausting ≈ 20% of the dipole sum]. The cross section for (γ, tot) using monoenergetic photons shows a structure at 18 MeV and some fluctuations atop the broad giant dipole resonance, $\sigma_{\mathrm{max}} \approx 7$ mb. The double photoneutron cross section, $\sigma(\gamma$, 2n), is dominated by a single peak at $E_{\gamma} \approx 20.5$ MeV, $\sigma_{\mathrm{max}} \approx 1.1$ mb. For references see (1978AJ03, 1983AJ01) and see the atlas of photoneutron cross sections with monoenergetic photons (1988DI02). The significance of reaction (c) to astrophysics is discussed by (1982SA1A, 1984FO1A).

39. ^{20}Ne(γ, γ)^{20}Ne

The first 1^{+}; $T = 1$ state in ^{20}Ne is measured at $E_{\mathrm{x}} = 11262.3 \pm 1.9$ keV. The branchings to ^{20}Ne* (0, 1.63) are (84 ± 5) and (16 ± 5)%, respectively (1983BE19). See also (1984BE26).

40. (a) ^{20}Ne(e, e′)^{20}Ne

(b) ^{20}Ne(e, e′p)^{19}F $\qquad Q_{\mathrm{m}} = -12.844$

(c) ^{20}Ne(e, e′α)^{16}O $\qquad Q_{\mathrm{m}} = -4.730$

The ^{20}Ne charge radius, $\langle r^2 \rangle_{1/2} = 3.004 \pm 0.025$ fm. Form factors for many excited states of ^{20}Ne with $E_{\mathrm{x}} < 8$ MeV have been reported: see (1978AJ03).

At $E_{\mathrm{e}} = 39$ and 56 MeV, the $180°$ inelastic scattering is dominated by the transition to a $J^{\pi} = 1^{+}$, $T = 1$ state at $E_{\mathrm{x}} = 11.22 \pm 0.05$ MeV with $\Gamma_{\gamma_0} = 11.2^{+2.1}_{-1.8}$ eV. A subsidiary peak is observed corresponding to a state 0.35 ± 0.03 MeV higher [if $J^{\pi} = 1^{+}$ or 2^{+}, $\Gamma_{\gamma_0} = 0.65 \pm 0.18$ or 0.40 ± 0.13 eV]. A number of small peaks are also reported corresponding to $E_{\mathrm{x}} \approx 12.0$, 12.9, 13.9, 15.8, 16.9, 18.0 and 19.0 MeV. Prominent electric dipole peaks are reported at $E_{\mathrm{x}} = 17.7$, 19.1, 20.2, and 23 MeV, in addition to weaker structures between 12.5 and 15 MeV; and prominent electric quadrupole peaks are observed at $E_{\mathrm{x}} = 13.0$, 13.7, 14.5, 15.0, 15.4 and 16.2 MeV and there is broad quadrupole excitation between 16 and 25 MeV. The GDR cross section integrated from 11 to 25 MeV contains about 65% of the dipole EWSR while over 90% of the isoscalar quadrupole EWSR is exhausted by the strength in the region 10–25 MeV.

For $11 < E_{\mathrm{x}} < 24$ MeV only two isovector M2 transitions appear: these are to ^{20}Ne* (11.62, 12.10) with B(M2, k)↑$= 64 \pm 13$ and 56 ± 13 μ_{N}^2fm^2 [orbital contributions are non-negligible].

The M1 transition to ^{20}Ne* (11.26) is also observed but that to ^{20}Ne* (13.48) is not: it is $< 0.2\ \mu_{\rm N}^2$ (1985RA08). For reaction (b) see (1978AJ03).

Reaction (c) has been studied in order to obtain the (γ, α_0) cross section in the giant resonance region: the cross section at 90° for $E_{\rm x} = 15$ to 24 MeV is dominated by an E1 resonance [1^-; $T = 1$, with an admixture of $T = 0$ which permits the α_0 decay] at $E_{\rm x} = 20$ MeV; lesser E1 structures are reported at $E_{\rm x} = 16.7$, 17.1, 21 and 22 MeV. A relatively strong 2^+; $T = 0$ resonance appears at $E_{\rm x} = 18.5$ MeV, and evidence is reported for increasing E2 strength below 16 MeV. For references to the early work see (1978AJ03, 1987AJ02). For more recent work see the reviews on nuclear dipole excitations (1987BE1G) and status of the shell model (1988BR1P). Other more recent theoretical work includes studies of large basis space effects in electron scattering form factors (1990AM01), correlated charge form factors and densities for s-d shell nuclei (1990MA63), electron scattering multipoles for symplectic shell model application (1992RO08), mass number dependence of the difference between electron- and muon-scattering charge radii (1989AN12), electron scattering from ^{20}Ne in a microscopic boson model (1988KU07, 1988KU22, 1988KU17), and studies of (e, e′γ) reactions and electromagnetic currents in rotational nuclei (1990GA09). See also (1988BR1D, 1988ZH1F, 1990MO1J).

41. (a) ^{20}Ne($\pi^\pm$, $\pi^{\pm\prime}$)^{20}Ne
(b) ^{20}Ne($\pi^\pm$, X)

Inelastic pion scattering experiments at $T_\pi = 120$ MeV and 180 MeV indicate a broad 2^+ member of the $K^\pi = 0_4^+$ band in ^{20}Ne (1989BU14, 1995BU01). They report $E_{\rm x} = 9.00 \pm 0.18$ MeV, $\Gamma = 0.8$ MeV, B(E2$\uparrow$) $= 40.9 \pm 2.0\ e^2{\rm fm}^4$. Several other states in the first four $K^\pi = 0^+$ bands were studied by (1995BU01). See Table 20.30.

For reaction (b), spectra have been measured and analyzed for initial pion momenta of 6.2 GeV/c (1991AM1B, 1992KI31).

42. ^{20}Ne(n, n′)^{20}Ne

An evaluation of neutron-induced reaction cross sections of ^{20}Ne for $E_{\rm n} = $ 1–30 MeV is presented in (1991RE10). See also (1993DE32) and earlier work cited in (1978AJ03).

43. (a) ^{20}Ne(p, p′)^{20}Ne
(b) ^{20}Ne(p, p′α)^{16}O $\qquad Q_{\rm m} = -4.730$

Angular distributions of elastically scattered protons and of a number of inelastic groups have been measured for $E_{\rm p} = 2.15$ to 65 MeV [see (1978AJ03, 1983AJ01)] and at $E_{\rm p} = 0.8$ GeV

Table 20.30: Ground-state transition strengths in ^{20}Ne from ^{20}Ne($\pi^{\pm}$, $\pi^{\pm\prime}$) [a]

E_x (MeV) [b]	J^π [b]	K^π [b]	$B(E\lambda)(e^2\text{fm}^{2\lambda})$ [c]
1.63	2^+	0_1^+	322.9 ± 1.8
4.24	4^+	0_1^+	42400 ± 600
8.78	6^+	0_1^+	$2.2 \pm 0.9 \times 10^6$
7.42	2^+	0_2^+	2.9 ± 0.4
9.99	4^+	0_2^+	5000 ± 600
7.83	2^+	0_3^+	16.6 ± 0.5
9.03	4^+	0_3^+	9800 ± 900
9.00	2^+	0_4^+	40.9 ± 2.0
10.79	4^+	0_4^+	6000 ± 300

[a] See table 1 of (1995BU01).

[b] See (1987AJ02).

[c] (1995BU01) notes that all $B(E\lambda)$'s were obtained by fitting 180 MeV π^+ and π^- data simultaneously with the constraint $M = M_n = M_p$ where $B(E\lambda) = |M_p|^2$. The errors given are statistical only.

(1984BL14, 1988BL13; to ^{20}Ne* (0, 1.63, 4.25, 8.7) (u); also A_y). The latter work confirms the large hexadecapole deformation of ^{20}Ne. At $E_p = 201$ MeV, probable 1^+ states at $E_x = 11.25 \pm 0.01$, 13.51 ± 0.03 and 15.72 ± 0.05 MeV are reported by (1987WI03): There does not appear to be any quenching of the M1 strength. In addition 2^- states are observed at 11.58 and 12.08 MeV with $B(\text{M2}) = 64 \pm 13$ and 56 ± 13 μ_N^2 as is a state of unknown J^π at $E_x \approx 17$ MeV (1987WI03). See also (1988CR1B), the measurements at $E_p = 6.4$–7.7 MeV (1992WI13), measurements at $E_p = 60$–180 MeV (1993PLZY), and the earlier work cited in (1978AJ03). For reaction (b) see (1984CA09, $E_p = 101.5$ MeV), (1992WI13, $E_p = 6.4$–7.7 MeV), and the earlier experimental and theoretical work cited in (1987AJ02). See also (1993MU28).

Theoretical work reported since the previous compilation includes relativistic DWBA calculations on inelastic scattering at $E_p = 200$–800 MeV (1988JO02), a large-basis-space microscopic-model analysis of 800-MeV inelastic scattering (1991AM1A), studies with a coalescence model of hypernuclear formation and mesonic atom production (1989WA14) in high energy collisions (1988WA16, 1989SA58), analysis of 800-MeV inelastic scattering with the Dirac formalism (1990PH01, 1990PH02, 1992DE31). See also the microscopic three-cluster study of 21-nucleon systems presented in (1993DE32).

44. ^{20}Ne(p, $\pi^{\pm}$)

Experimental data on multiplicity, correlations, and inclusive spectra of mesons and other particles produced in $p + {}^{20}Ne$ reactions at $E_p = 300$ GeV are presented in (1992YU1A) and compared with model predictions.

45. $^{20}Ne(\overline{p}, \overline{p})^{20}Ne$

For references to work on antiproton interactions see Table 20.16, ^{20}Ne – general.

46. (a) $^{20}Ne(d, d')^{20}Ne$
(b) $^{20}Ne(t, t')^{20}Ne$

Angular distributions of deuterons have been reported at $E_d = 10.0$ to 52 MeV [see (1978AJ03, 1983AJ01)] and at $E_d = 52$ MeV (1987NU01). Differential cross sections for elastic and inelastic scattering of tritons (reaction b) were measured at $E_t = 33.4$ MeV by (1992HA12) and analyzed by the coupled channels method. Potential parameters, deformation lengths and multipole moments were deduced. See also the calculations for these data described in (1992HA18) in which spin, parity and band assignments are discussed. The calculations suggest the assignments of $K^\pi = 2^-$, 2^- and 0^- respectively to the $J^\pi = 2^-, 3^-, 3^-$ states at $E_x = 4.97$, 5.62 and 5.79 MeV. See also (1978AJ03, 1987AJ02).

47. $^{20}Ne(^3He, {}^3He')^{20}Ne$

Angular distributions have been measured at $E(^3He) = 10$ to 35 MeV and at 68 MeV: see (1978AJ03). See references cited in (1978AJ03). More recently differential cross section for elastic and inelastic scattering of ^3He were measured at $E(^3He) = 33.4$ MeV by (1992HA12) and analyzed by the coupled channels method. Comparisons were made with triton scattering. Calculations for these data were described in (1992HA18) in which spin, parity and band assignments are discussed. Elastic scattering measurements at $E(^3He) = 30$ and 45 MeV are described in (1992NAZQ).

48. (a) $^{20}Ne(\alpha, \alpha')^{20}Ne$
(b) $^{20}Ne(\alpha, \alpha\alpha)^{16}O$ $\qquad Q_m = -4.730$

Angular distributions have been measured at $E_\alpha = 3.8$–155 MeV [see references cited in (1978AJ03)]. More recently measurements were made at $E_\alpha = 54.1$ MeV (1987AB03), $E_\alpha = 50$

MeV (1991FR02) and at $E_\alpha = 3.8$–11 MeV (1991AB05). Inelastic cross sections were measured at $E_\alpha = 5.6$–11.0 MeV (1992DA10), $E_\alpha = 50$ MeV (1991FR02), and $E_\alpha = 50.5$ MeV (1987BU27).

For reaction (b) see references cited in (1983AJ01, 1987AJ02) and the measurements at $E_\alpha = 155$ MeV of cross sections and decay branching ratios for several excited states of ^{20}Ne up to the giant quadrupole resonance by (1987SU09).

Theoretical studies related to these reactions include: $\alpha + {}^{20}$Ne structures of ^{24}Mg in a microscopic three-cluster ($\alpha + \alpha + {}^{16}$O model (1987DE40), distributions of α-particle strengths in light nuclei (1988LE05), target clustering and exchange effects in internuclear interactions (1988LE06), stationary-state currents in nuclear reactions (1988MA30), a DWIA analysis of $^{20}\mathrm{Ne}(\alpha,\ 2\alpha)^{16}\mathrm{O}$ at $E_\alpha = 140$ MeV (1988SH05), distortion effects in a microscopic $^{16}\mathrm{O} + 2\alpha$ description of ^{24}Mg (1989DE32), evidence for a parity dependence in the $\alpha + {}^{20}$Ne interactions (1989MI12), an l-dependent representation of a Majorana potential (1990CO38), a strong-absorption model analysis of α scattering (1992RA21), a calculation of quasimolecular states in $^{20}\mathrm{Ne}(\alpha,\ \alpha)$ (1992GR15), optical model analysis of $^{20}\mathrm{Ne}(\alpha, \alpha)$ at $E_\alpha = 22.9$ MeV (1993AOZZ).

49. ^{20}Ne(^{7}Li, ^{7}Li$'$)^{20}Ne

Angular distributions have been studied at $E(^7\mathrm{Li}) = 36$, 68, and 89 MeV: see (1983AJ01).

50. ^{20}Ne(^{9}Be, ^{9}Be$'$)^{20}Ne

For pion production see (1985FR13).

51. (a) ^{20}Ne(^{10}B, ^{10}B)^{20}Ne
(b) ^{20}Ne(^{11}B, ^{11}B)^{20}Ne

Elastic angular distributions have been measured at $E(^{10}\mathrm{B}) = 65.9$ and $E(^{11}\mathrm{B}) = 115$ MeV: see (1983AJ01).

52. (a) ^{20}Ne(^{12}C, ^{12}C$'$)^{20}Ne
(b) ^{20}Ne(^{12}C, α^8Be)^{20}Ne $Q_\mathrm{m} = -7.366$

Elastic angular distributions have been obtained at $E(^{12}\mathrm{C}) = 22.2$ to 77.4 MeV and at $E(^{20}\mathrm{Ne}) = 65.9$, 74 and 75.2 MeV [see (1978AJ03, 1983AJ01)] as well as at $E(^{20}\mathrm{Ne}) = 72.6$, 74.0 and 75.2

MeV (1982SH29). Elastic and inelastic scattering differential cross sections at $E(^{20}\text{Ne}) = 390$ MeV were measured by (1993BO28).

For yield, fusion, total reaction cross section and fragmentation studies see the references cited in (1987AJ02). More recently fragmentation studies at $E(^{20}\text{Ne}) = 540$–1096 MeV/nucleon were reported by (1990WE14) and at $E(^{20}\text{Ne}) = 400$, 800 MeV/nucleon by (1988DU01). See also (1987AN20, 1994FU01). For pion production and for reaction (b) see references cited in (1987AJ02).

Theoretical studies carried out since the previous compilation include: resonances, heavy-ion radioactivity and new predictions for medium mass collective systems (1989CI1C), cascade model study of Λ particle productions in central collisions of light nuclei (1988IW02), comparison of quantized ATDHF and GCM theory applied to the $^{12}\text{C} + ^{20}\text{Ne}$ system (1990SL01).

53. $^{20}\text{Ne}(^{16}\text{O}, ^{16}\text{O}')^{20}\text{Ne}$

Angular distributions have been studied at $E(^{20}\text{Ne}) = 50$ and 94.8 MeV involving $^{16}\text{O}_{\text{g.s.}}$ and $^{20}\text{Ne}^*$ (0, 1.63, 4.25) [see (1983AJ01)], at $E(^{16}\text{O}) = 25.6$ to 44.5 MeV (elastic; also to $^{20}\text{Ne}^*$(1.63) at 31.3, 33.3 and 44.5 MeV)) and at $E(^{20}\text{Ne}) = 66.8$, 115, 137 and 156 MeV (elastic) [see (1987AJ02) for references]. Yield and fusion cross section measurements have also been reported in several references cited in (1987AJ02). Excitation functions at $\theta_{\text{cm}} = 90°$ for $E_{\text{cm}} = 21.5$–31.2 MeV were measured by (1988HE06) and at $\theta_{\text{lab}} = 13°$ for $E_{\text{cm}} = 22.8$ to 38.6 MeV by (1989SA14). Measurements at projectile energies of 3.6 MeV/nucleon are reported in (1987AN20), and at 4.2 and 4.5 GeV/nucleon by (1988BO46, 1988BE2A).

Theoretical studies related to this reaction reported since the previous review include: calculation within the framework of the cascade model (1988IW02), molecular orbital theory for elastic and inelastic scattering (1989HE1I), derivation of the parity-independent interaction for $^{16}\text{O}+^{20}\text{Ne}$ (1989GA1L), optical model analysis of resonant structure in $^{16}\text{O} + ^{20}\text{Ne}$ (1991GA14), and local representation of a deep parity- and L-dependent $^{16}\text{O} + ^{20}\text{Ne}$ potential (1993AI02).

54. $^{20}\text{Ne}(^{20}\text{Ne}, ^{20}\text{Ne}')^{20}\text{Ne}$

Elastic angular distributions are reported at $E(^{20}\text{Ne}) = 68$, 117, 140, and 156 MeV (1983SH25). For yield and fusion measurements see references cited in (1983AJ01, 1987AJ02). High-spin shape isomers for sd-shell nuclei were studied at E_{cm} near 1.6 times the Coulomb barrier for $^{20}\text{Ne} + ^{20}\text{Ne}$ by (1993BAZZ). Studies of the average number of interacting protons in $^{20}\text{Ne} + ^{20}\text{Ne}$ collisions of 36 GeV/nucleon were reported by (1987AN20).

Theoretical work related to the reaction includes: a study of mesonic atom production by a coalescence model (1989WA14), a formulation of the mesonic atom production probability with a coalescence model (1989SA58), hypernucleus production by heavy ions by a coalescence process (1989BA92, 1989WA14, 1989BA93).

55. (a) ^{20}Ne(^{24}Mg, ^{24}Mg′)^{20}Ne
(b) ^{20}Ne(^{26}Mg, ^{26}Mg′)^{20}Ne

Elastic angular distributions for reaction (a) have been measured at $E(^{20}\text{Ne}) = 50$, 60, 80, 90, and 100 MeV [see (1983AJ01)] at 40 MeV (1983NA04; S_α for the system ^{20}Ne + ^{24}Mg $= 0.08 \pm 0.02$) and at $E_{\text{lab}} = 55$, 80 and 160 MeV/nucleon (1987BE38). For yield and fusion cross sections for reactions (a) and (b) see references cited in (1987AJ02). See also the review of high energy gamma production in heavy ion collisions (1989NI1D).

56. ^{20}Ne(^{27}Al, ^{27}Al′)^{20}Ne

Elastic angular distributions are reported at $E(^{20}\text{Ne}) = 55.7$, 63, 125, and 151 MeV (1983NG01). For yield, fusion and evaporation residue studies see references cited (1987AJ02) and the study at $E(^{20}\text{Ne} = 217$, 194 and 384 MeV (1988GR12, 1989BA17, 1990BA18). A search for incomplete deep inelastic collisions at $E(^{20}\text{Ne}) = 216$ MeV is reported by (1988ZH12). Neutral pion production was studied at $E(^{20}\text{Ne}) = 4$ GeV by (1988JU02, 1989FO07, 1989FO1G). A description of those data by the cooperative model is discussed in (1989GH01). See also the calculation of total reaction cross sections presented in (1988JO02).

57. (a) ^{20}Ne(^{28}Si, ^{28}Si′)^{20}Ne
(b) ^{20}Ne(^{29}Si, ^{29}Si′)^{20}Ne

See (1983DU13).

58. ^{20}Ne(^{40}Ca, ^{40}Ca′)^{20}Ne

Angular distributions have been studied at $E(^{20}\text{Ne}) = 44.1$ to 70.4 MeV and at 151 MeV: see (1983AJ01). For an evaporation residue study see (1982MO15). For yield and fusion measurements see (1983AJ01). The breakup of ^{20}Ne at $E(^{20}\text{Ne}) = 92$, 149 and 213 MeV involves ^{20}Ne* (5.79, 6.73, 7.16, 8.78, 10.26, 11.95) (1986SH30).

See also the references cited in (1987AJ02) and see the Monte Carlo simulation method calculation for nuclear transfer (1988CH28), and the study of alpha clustering and shell effects related to this reaction (1989PU1C).

59. ^{20}Na$(\beta^+)^{20}$Ne $\qquad Q_{\text{m}} = 13.887$

^{20}Na has a half-life of 447.9 ± 2.3 ms: see reaction 1 in ^{20}Na. It decays to a number of states of ^{20}Ne, principally ^{20}Ne* (1.63): see Table 20.31. The ratio of the mirror decays ^{20}Na(β^+)^{20}Ne* (1.63) and ^{20}F(β^-)^{20}Ne* (1.63), $(ft)^+/(ft)^- = 1.03 \pm 0.02$. β–γ correlation measurements, as in the decay of ^{20}F, lead to an upper limit for the second-class contribution to the correlation which is consistent with zero: see (1983AJ01). A more recent measurement (1988RO10) concluded that the β–γ angular correlations in $A = 20$ are close to and may be in agreement with conserved vector current theory. β–ν–α triple correlation coefficient measurements for the transitions via the α-unstable 2^+ states shown in Table 20.31 lead to values of the isospin mixing amplitudes [and to a determination of the vector weak coupling constant] (1983CL01, 1989CL02). See also references cited in (1987AJ02) and the measurements of (1992KUZO, 1992KUZQ).

60. ^{21}Ne(e, e′n)^{20}Ne $\qquad Q_{\rm m} = -6.761$

A general expression of the polarized spectral function for the (e, e′n) transitions is used by (1994CA27) to model this reaction.

61. ^{21}Ne(p, d)^{20}Ne $\qquad Q_{\rm m} = -4.537$

See (1978AJ03).

62. ^{21}Ne(d, t)^{20}Ne $\qquad Q_{\rm m} = -0.504$

The $T = 1$ states observed in this reaction, and the analog states observed in ^{20}F in the (d, ^{3}He) reaction, are displayed in Table 20.16 of (1978AJ03). $T = 0$ states are presented in Table 20.38 of (1978AJ03).

63. ^{22}Ne(p, t)^{20}Ne $\qquad Q_{\rm m} = -8.643$

Angular distributions have been reported at $E_{\rm p} = 26.9$ to 43.7 MeV: see (1978AJ03, 1983AJ01). The angular distributions of the tritons to the ground state of ^{20}Ne and to the first 0^+, $T = 2$ state [$E_{\rm x} = 16.7329 \pm 0.0027$ MeV] have been fitted by $L = 0$ and the tritons to ^{20}Ne* (18.4) by $L = 2$. The latter is the first 2^+, $T = 2$ state. The 0^+, $T = 2$ state [^{20}Ne* (16.73)] decays by $\alpha_0[(6 \pm 5)\%]$, $\alpha_1 + \alpha_2[(35 \pm 12)\%]$, $\alpha_3 + \alpha_4[(29 \pm 12)\%]$, ${\rm p}_0 + {\rm p}_1 + {\rm p}_2[(14 \pm 9)\%]$ and ${\rm p}_3 + {\rm p}_4 + {\rm p}_5[(13 \pm 8)\%]$ [measured branching ratios in percent are given in the brackets] to the final states in ^{16}O and ^{19}F. See (1978AJ03) for references and additional information.

Table 20.31: Decay of ^{20}Na [a]

Decay to ^{20}Ne* (keV)	J^π	Branching ratio (%)	ft [b] (s)	log ft
1633.674 ± 0.015	2^+	79.44 ± 0.27	$(9.802 \pm 0.068) \times 10^4$	4.99
4966.51 ± 0.20	2^-	0.157 ± 0.022	$(9.3 \pm 1.3) \times 10^6$	6.97
6706 ± 47		0.0032 ± 0.0007	$(1.41 \pm 0.32) \times 10^8$	8.15
7421.9 ± 1.2	2^+	15.96 ± 0.22	$(1.588 \pm 0.026) \times 10^4$	4.20
7833.4 ± 1.5	2^+	0.583 ± 0.010	$(3.019 \pm 0.058) \times 10^5$	5.48
8058 ± 8	$(1^-, 2^+, 3^-)$	0.0119 ± 0.0009	$(1.198 \pm 0.092) \times 10^7$	7.08
9196 ± 30	2^+	0.0625 ± 0.0064	$(6.63 \pm 0.73) \times 10^5$	5.82
9483 ± 3	2^+	0.241 ± 0.005	$(1.190 \pm 0.028) \times 10^5$	5.08
9873 ± 4	3^+	0.028 ± 0.014	$(5.9 \pm 3.0) \times 10^5$	5.77
10274 ± 3	2^+	2.877 ± 0.042	$(2.983 \pm 0.061) \times 10^3$	3.48
10578 ± 4	2^+	0.0883 ± 0.0027	$(5.71 \pm 0.20) \times 10^4$	4.76
10840 ± 4	2^+	0.174 ± 0.005	$(1.705 \pm 0.058) \times 10^4$	4.23
10884 ± 3	3^+	0.117 ± 0.042	$(2.3 \pm 0.8) \times 10^4$	4.36
10941 ± 9	2^+	0.0119 ± 0.0015	$(2.00 \pm 0.26) \times 10^5$	5.30
11116 ± 9	2^+	0.0087 ± 0.0011	$(1.81 \pm 0.24) \times 10^5$	5.26
11262.3 ± 1.9	1^+	0.205 ± 0.026	$(5.30 \pm 0.68) \times 10^3$	3.72
11295 ± 5	2^+	0.0263 ± 0.0017	$(3.78 \pm 0.26) \times 10^4$	4.58
11856 ± 8	2^+	0.0016 ± 0.0004	$(9.9 \pm 2.5) \times 10^4$	4.99

[a] (1989CL02). See table 3 of that work for references and details.
[b] Allowed decay assumed.

64. ^{23}Na(p, α)^{20}Ne $\qquad$ $Q_{\rm m} = 2.377$

Angular distributions have been measured at $E_{\rm p} = 10.0$ and 45.5 MeV: see (1972AJ02). High resolution measurement at $E_{\rm p} = 1.08$–4.15 MeV were carried out in a study of 94 resonances in ^{24}Mg by (1987VA24) at $E_{\rm p} = 6.25$–6.55 MeV. A study of ^{24}Mg resonances excited by protons in the range $E_{\rm p} = 6.25$–6.55 MeV is described in (1990MI24, 1991MI24). Detailed-balance tests of time reversal invariance are reported in (1994DR01, 1993MI19, 1993MI25). Parity non-conservation experiments are discussed in (1995MI28). See also (1987PA06, 1989KA06) which describe analyzing power measurements for this reaction. Measurements of the cross section at $E_{\rm p} \leq 350$ keV were carried out by (1989GO1N). Astrophysical implications are discussed. See also references to earlier work cited in (1987AJ02).

65. ^{23}Na(^{3}He, ^{6}Li)^{20}Ne $\qquad$ $Q_{\rm m} = -1.642$

See (1978AJ03).

66. ^{24}Mg(γ, α) ^{20}Ne $\qquad$ $Q_{\rm m} = -9.316$

Cross sections for this reaction were calculated by (1987KA30) in a study of molecular structure of highly-excited states.

67. ^{24}Mg(n, nα)^{20}Ne $\qquad$ $Q_{\rm m} = -9.316$

Production cross sections for ^{20}Ne were measured at $E_{\rm n} = 5.20$, 7.00, 16.20 and 19.05 MeV (1990LA09). Cross sections were calculated with preequilibrium emission and constant-temperature evaporation models by (1993KH09).

68. ^{24}Mg(p, pα)^{20}Ne $\qquad$ $Q_{\rm m} = -9.316$

See (1984CA09). See also (1978AJ03).

69. ^{24}Mg(d, ^{6}Li)^{20}Ne $\qquad$ $Q_{\rm m} = -7.841$

Angular distributions have been studied to many states of ^{20}Ne at $E_{\rm d} = 28$ to 80 MeV [see (1978AJ03, 1983AJ01)] and at $E_{\rm d} = 54.2$ MeV (1984UM04; to ^{20}Ne* (0, 1.63, 4.25, 5.62)). Table 20.35 in (1983AJ01) displays the observed states and S_α obtained from several analyses. For newer values of S_α see (1984UM04, 1986OE01). See also (1984PA18, 1986PAZJ). Measurements at several different incident energies were reported by (1988RA27, 1988RA20). Data were analyzed with finite-range DWBA calculations, and spectroscopic factors were obtained with different potentials. Comparisons with spectroscopic factors from ^{24}Mg(^{3}He, ^{7}Be)^{20}Ne were made.

70. ^{24}Mg(^{3}He, ^{7}Be)^{20}Ne $\qquad$ $Q_{\rm m} = -7.730$

Angular distributions have been studied at $E(^3{\rm He}) = 25.5$ and 70 MeV: see (1978AJ03). See also (1983AJ01) and (1986RA15). Measurements at $E(^3{\rm He}) = 41$ MeV were reported by (1988RA20, 1988RA27). Data were analyzed with finite-range DWBA calculations and spectroscopic factors were obtained with different potentials. Comparisons with spectroscopic factors from ^{24}Mg(d, ^{6}Li)^{20}Ne were made.

71. ^{24}Mg(α, ^{8}Be)^{20}Ne $\qquad$ $Q_{\rm m} = -9.407$

See (1983AJ01).

72. ^{24}Mg(^{12}C, ^{16}O)^{20}Ne $\qquad$ $Q_{\rm m} = -2.154$

The angular distribution for the ground state transition has been measured at $E(^{12}{\rm C}) = 40$ MeV (1982LI16) and at $E_{\rm cm} = 25.2$ MeV (1990LE12). Coupled-channels calculations were used to study the back angle anomaly. The backward angle yield in the inverse reaction was studied at $E(^{24}{\rm Mg}) = 90$–126 MeV by (1990GL01). See also (1983AJ01, 1989OB1C).

73. ^{24}Mg(^{16}O, ^{20}Ne)^{20}Ne $\qquad$ $Q_{\rm m} = -4.586$

Excitation functions were measured at $\theta_{\rm cm} = 90°$, $E_{\rm cm} = 25$–34 MeV by (1989LE19). Data were compared with calculations involving the coupling to higher orders between elastic and α-transfer channels. Differential cross sections were measured at $E(^{16}{\rm O}) = 71.4$ MeV by (1995FUZW). The effect of the dynamic α-transfer polarization potential is discussed in (1989FI03).

74. ^{28}Si(α, ^{12}C)^{20}Ne $\qquad$ $Q_{\rm m} = -12.026$

See (1983AJ01).

75. ^{28}Si(^{16}O, ^{24}Mg)^{20}Ne $\qquad Q_{\rm m} = -5.255$

This reaction was studied at $E_{\rm cm} = 31.57$ MeV by (1989PO1J).

^{20}Na

(Figs. 4 and 5)

GENERAL: See Table 20.32.

$$\mu = 0.3694 \pm 0.0002 \text{ nm (1975SC20, 1989RA17)}$$

1. ^{20}Na$(\beta^+)^{20}$Ne $\qquad Q_m = 13.887$

^{20}Na decays by positron emission to ^{20}Ne* (1.63) and to a number of other excited states of ^{20}Ne: see Table 20.31 and reaction 59 in ^{20}Ne. The half-life of ^{20}Na is 447.9 ± 2.3 ms [weighted mean of values quoted in (1978AJ03, 1983CL01, 1989CL02)]; $J^\pi = 2^+$: see (1987AJ02). See also (1992KUZO, 1992KUZQ) and (1993BL10; instrumentation). The beta delayed alpha decay of ^{20}Na has been studied by (1989CL02) [see reaction 2]. See also (1993XU06).

2. ^{12}C(^{10}B, nn)^{20}Na $\qquad Q_m = -10.936$

Extensive measurements of the decay of ^{20}Na nuclei produced in the ^{12}C(^{10}B, nn) reaction were reported by (1989CL02). Measurements included β^+ spectra, β delayed alphas, $\beta\nu\alpha$ triple correlation coefficients, branching ratios, ^{20}Ne level energies and the ^{20}Na half-life. Isospin mixing and the weak-vector coupling constant were deduced.

3. ^{12}C(^{14}N, ^{6}He)^{20}Na $\qquad Q_m = -21.576$

An 82-MeV ^{14}N beam was used by (1993BAZX) to study ^{20}Na states up to $E_x = 4.5$ MeV. The cross section for the $E_x = 2.646$ MeV level was determined and the results suggest that state is not the mirror of the 1^+ 3.173 MeV state in ^{20}F as had been proposed. The results are consistent with the suggestion that the 2.646 MeV level is the mirror of the 2.966 MeV $J^\pi = 3^+$ state in ^{20}F. See, however, reactions 5 and 8.

4. ^{19}F(p, π^-)^{20}Na $\qquad Q_m = -140.611$

Angular distributions and analyzing powers have been studied at $E_p = 199.6$ MeV to ^{20}Na* (0.74, 1.85, 3.01, 4.11) [probably unresolved]: it is suggested that the latter two have $J = 6$ or 7 (1987CA05).

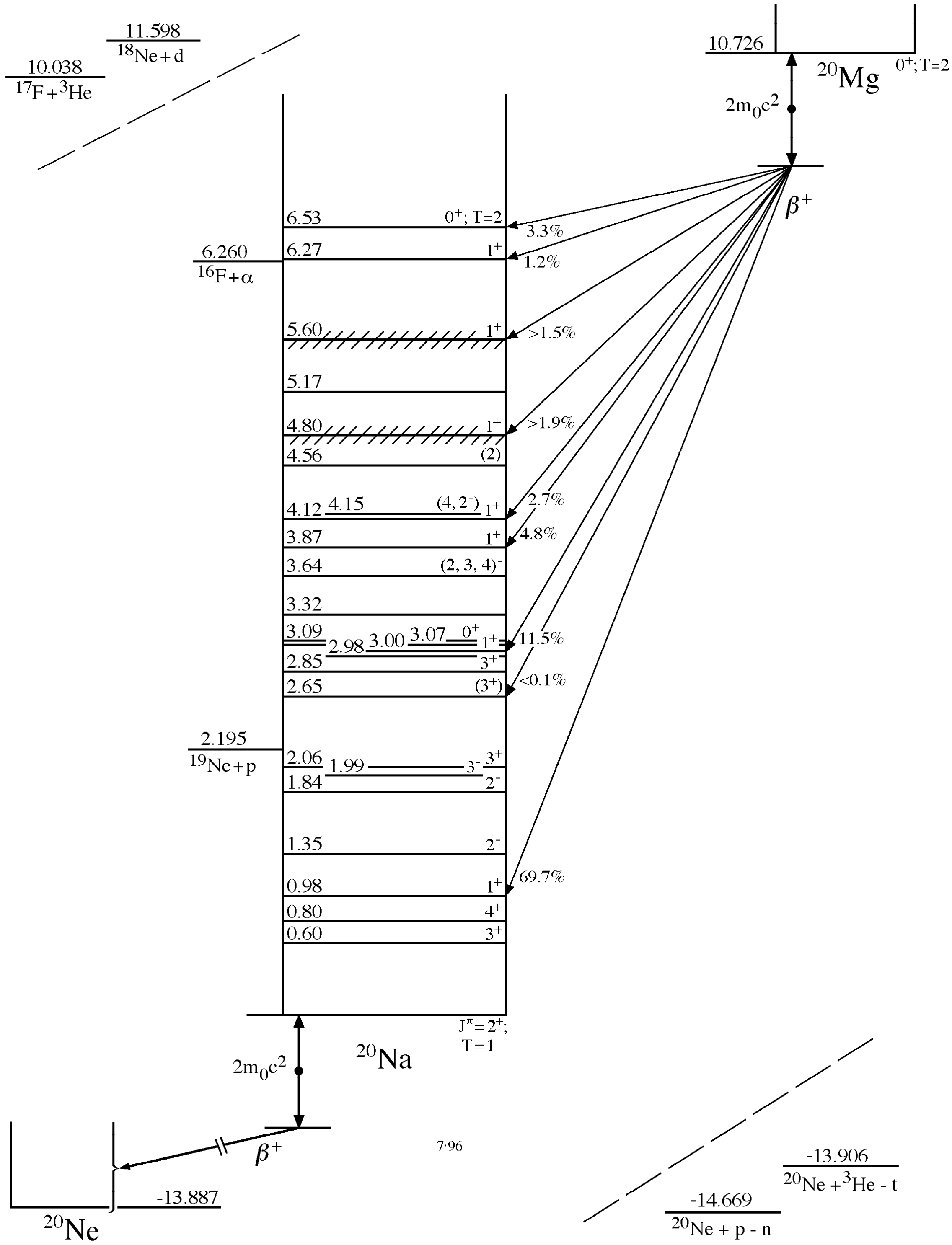

FIgure 4: Energy levels of ^{20}Na. For notation see Fig. 1.

Table 20.32: ^{20}Na – General

Reference	Description
Review:	
1987RA1D	Nuclear processes and accelerated particles in solar flares
1989RA17	Compilation of exp. data on nuclear moments for ground & excited states of nuclei
Other articles:	
1987BA1T	Spin-isospin excitations in nuclei with relativistic heavy ions
1989KU15	Exp. determination of ^{19}Ne(p, γ)^{20}Na reaction rate; breakout problem from hot CNO cycle
1990DE34	^{20}F & ^{20}Na nuclei and the ^{19}Ne(p, γ)^{20}Na reaction in a microscopic three-cluster model
1990PO04	New method of determining masses & quantum characteristics of light nuclei
1992AV03	The proton neutron interaction and mass calcs. for nucl. with $Z > N$
1993BR12	Nature of the ^{20}Na 2646-keV level and the stellar reaction rate for ^{19}Ne(p, γ)^{20}Na
1995SU18	Neutron skin of Na isotopes studied via their interaction cross sections
1996BR15	Neutron halos in the Na isotopes; Hartree-Fock calcs.
1996KR1A	Nucl. matter radii calc. for $A = 20$ nucl.; evidence found for proton & neutron skins

5. ^{19}Ne(p, γ)^{20}Na $\qquad Q_{\rm m} = 2.195$

The dominant process for the breakout from the HCNO cycle during hot hydrogen burning in stars in considered to be ^{15}O(α, γ)^{19}Ne(p, γ)^{20}Na [see references in the following discussion]. Thus the ^{19}Ne(p, γ)^{20}Na reaction rate at stellar temperatures is of considerable importance. The nuclear levels above the ^{19}Ne(p, γ) threshold are critical for calculation of the reaction rates and have been the object of several experimental studies by the ^{20}Ne(^{3}He, t) reaction (1988LAZY, 1989KU1D, 1989KU15, 1989SMZZ, 1990LA05, 1992SM03, 1995HO1G, 1995HO25, 1995GO16) as well as by ^{20}Ne(p, n)^{20}Na (1989KU15). See reactions 7, 8, 10 and Table 20.35.

The ^{20}Na state at $E_{\rm x} = 2.646$ MeV is presumed to be the strongest (p, γ) resonance and it has been the object of several studies [see refs. mentioned above as well as (1992GO10, 1992KU07, 1990DE34). See also (1995MI29). Work by (1993BAZX, 1993BR12, 1993CL09) strongly suggests that the state has $J^{\pi} = 3^{+}$ (the analog of the ^{20}F 3^{+} state at $E_{\rm x} = 2.966$ MeV) rather than 1^{+} as had been assumed in earlier work. More recent work described in (1994PA42, 1995HU13, 1995PA1K) determined a 90% confidence-level upper limit of 18 meV for the resonance strength of this level and provides arguments against the $J^{\pi} = 3^{+}$ assignment.

6. ^{19}Ne(p, p)^{19}Ne

Resonances in ^{20}Na above the proton threshold were studied with radioactive ^{19}Ne beams scattered off polyethelene targets by (1994CO12). Analysis by extended Breit Wigner, R-matrix and K-matrix formalism is described. Results are summarized in Table 20.34.

Table 20.33: Energy Levels of ^{20}Na [a]

E_x (MeV ± keV)	$J^\pi; T$	$\tau_{1/2}$ or Γ_{cm}	Decay	Reactions
0	$2^+; 1$	$\tau_{1/2} = 447.9 \pm 2.3$ ms	β^-	1, 7, 8
0.596 ± 8	3^+		(γ)	7, 8
0.802 ± 7	4^+		(γ)	7, 8
0.98425 ± 0.10	1^+		(γ)	7, 8, 10
1.346 ± 8	2^-		(γ)	7, 8
1.837 ± 7	2^-		(γ)	7, 8
1.992 ± 8	3^-		(γ)	7, 8
2.057 ± 12	3^+		(γ)	8
2.645 ± 6	$(3^+,\ 1^+)$		$(\gamma$, p)	3, 5, 7, 8
2.849 ± 6	3^+			7, 8
2.983 ± 7	> 3			8
3.001 ± 2	1^+	$\Gamma = 19.8 \pm 2$ keV [b]	p	5, 6, 10
3.067 ± 2	(0^+)			5, 7, 8
3.086 ± 2	0^+	$\Gamma = 35.9 \pm 2$ keV [b]	p	6
3.315 ± 9				8
3.642 ± 16	(2, 3, 4)$^-$			7, 8
3.871 ± 9	1^+		p	7, 8, 10
4.123 ± 16	1^+		p	10
4.150 ± 60	(4, 2^-)			8
4.560 ± 60	(2)			8
≈ 4.800	1^+		p	10
5.170 ± 60				8
≈ 5.600	1^+			8, 10
6.266 ± 30	1^+		p	10
6.534 ± 13	0^+		p	10

[a] See also Tables 20.35 and 20.36.

[b] From (1994CO12). See Table 20.34.

Table 20.34: Resonances in ^{1}H(^{19}Ne, ^{19}Ne)^{1}H [a]

J^π	Formalism	E_r (keV)	γ or g (MeV$^{1/2}$)	Γ (keV)	E_x (MeV)
1^+	BW	797		19.8	2.996
	R	797	0.92	19.8 [b]	
	K	797	15.6	19.8	
0^+	BW	887		35.9	3.086
	R	887	1.00	35.9 [c]	
	K	887	15.8	35.9	

[a] From Table I of (1994CO12). Resonance energies (E_r) and widths (Γ) of the ^{20}Na resonances in the cm system; E_r, E_x and Γ are affected by a ± 2 keV uncertainty; γ and g are, respectively, R-matrix and K-matrix reduced widths amplitudes; Γ_F is the R-matrix formal width.

[b] $\Gamma_F = 28.8$ keV ($R = 4.5$ fm).

[c] $\Gamma_F = 55.2$ keV ($R = 4.5$ fm).

7. ^{20}Ne(p, n)^{20}Na $\qquad Q_m = -14.669$

Early work on this reaction is described in (1987AJ02). More recently ^{20}Na levels up to $E_x = 3.636$ MeV were studied at $E_p = 35$ MeV by (1989KU15). See Table 20.35.

The ^{20}Ne(p, n) reaction at $E_p = 136$ MeV was used in measurements of Gamow Teller strength (1991AN01) and in a study of isovector stretched-state excitation (1992TA04). A $\Delta\ell = 2$ angular distribution measured at $E_p = 135$ MeV (1995AN18) for the ^{20}Na state at $E_x = 2.645$ MeV was determined to be consistent with $J^\pi = 3^+$.

A review of spin-isospin response in nuclei based on charge exchange reaction data is presented in (1989RA1G). See also (1987EL14). An analysis leading to total Gamow Teller strength is described in (1988MA53).

8. ^{20}Ne(^{3}He, t)^{20}Na $\qquad Q_m = -13.906$

Early work on this reaction is summarized in (1987AJ02). See also (1987EL14). More recent measurements include those at $E(^3\text{He}) = 55.33$ MeV (1988KU23, 1989KU15), at $E(^3\text{He}) = 25.5$ MeV (1988LAZY, 1990LA05), at $E(^3\text{He}) = 29.7$ MeV (1989SMZZ, 1992SM03) and at $E(^3\text{He}) = 33.4$ MeV (1990CL06, 1993CL09). Energy levels and spin parity assignments obtained from these experiments are displayed in Table 20.35. See also (1989AR1H, 1989KU1D). A major concern of this work was the ^{20}Na level at $E_x = 2.645$ MeV, which is presumed to be the strongest (p, γ) resonance in ^{19}Ne(p, γ) [see reaction 5]. Detailed comparison of data on ^{20}Ne(^{3}He, t)^{20}Na and the analogue reaction ^{20}Ne(t, ^{3}He)^{20}F by (1993BR12) and (1993CL09) has led to the conclusion that the 2.645 MeV state in ^{20}Na is to be identified with the $J^\pi = 3^+$ state at

Table 20.35: Levels in ^{20}Na from ^{20}Ne(p, n) and ^{20}Ne(^{3}He, t)

(p, n) [a]		(^{3}He, t) [a]		(^{3}He, t) [b]		(^{3}He, t) [c]		(^{3}He, t) [d]
E_x (MeV ± keV)	J^π	E_x (MeV ± keV)	J^π	E_x (MeV ± keV)	J^π	E_x (MeV ± keV)	J^π	E_x (MeV ± keV)
0.0	2^+	0.0	$(1,2,3)^+$			0.0	2^+	
0.580 ± 15	3^+	0.600 ± 15	$(3,4,5)^+$	0.606 ± 13	3^+	0.595 ± 20	3^+	
0.790 ± 15	4^+	0.802 ± 15	$(3,4,5)^+$	0.808 ± 11	4^+	0.801 ± 20	4^+	
0.993 ± 15	1^+	0.990 ± 15	$(1,2,3)^+$	0.996 ± 12	1^+	0.996 ± 20	$(1^\pm)$	
1.353 ± 15	(2^-)	1.347 ± 15	$(2,3,4)^-$	1.338 ± 14	2^-	1.350 ± 20	2^-	
1.843 ± 15	(2^-)	1.832 ± 15	$(2,3,4)^-$	1.841 ± 11	$2^\pm$	1.819 ± 26	2^-	
2.016 ± 20	(3^-)	1.967 ± 20	$(2,3,4)^-$	1.993 ± 12	3^-	1.992 ± 20	$(3^\pm, 2^-)$	
		2.034 ± 20	$(3,4,5)^+$	2.064 ± 16	$(2,3)^+$	2.10 ± 40	$(3,4,5^\pm)$	
2.651 ± 20	1^+	2.637 ± 15	$(0,1)^+$	2.649 ± 16	1^+	2.64 ± 20	$(1^\pm)$	2.646 ± 9
2.852 ± 20	$(2,3)^+$	2.842 ± 15	$(3,4,5)^+$	2.836 ± 12	3^+	2.86 ± 20	$(3,4^\pm)$	2.857 ± 9
		2.967 ± 20		2.972 ± 13				2.986 ± 9
3.053 ± 20		3.046 ± 20	$(1,2,3)^+$	3.035 ± 15		3.01 ± 20	$(> 3^-, > 4^+)$	3.056 ± 9
				3.100 ± 14				
		3.302 ± 30	$(4,5,6)^-$	3.324 ± 11	$(1,2)^+$	3.29 ± 20	$(2,3,4^\pm)$	
3.636 ± 20		3.644 ± 30	$((2,3,4)^-)$			3.69 ± 60	$(2,3^-,4^\pm)$	
						4.15 ± 60	$(4^\mp, 2^-)$	
						4.56 ± 60	$(2^\pm)$	
						5.17 ± 60		
						5.43 ± 60		

[a] (1989KU15).
[b] (1990LA05).
[c] (1990CL06).
[d] (1992SM03).

$E_x = 2.966$ MeV in ^{20}F. This conclusion is supported by the work of (1993BAZX) [see however the discussion of reaction 5]. Measurements described in (1995HO1G, 1995HO25) have determined the γ branching ratio for this state to be $\Gamma_\gamma/\Gamma \approx 0.1$. A reanalysis by (1995GO16) of earlier (^{3}He, t) data has resolved conflicting values of excitation energies for levels above the proton threshold.

9. ^{20}Ne(^{12}C, ^{12}B)^{20}Na $\qquad Q_m = -27.256$

A study of the response of nuclei to spin-isospin excitation displayed through charge exchange reactions such as ^{20}Ne(^{12}C, ^{12}B)^{20}Na is described in (1988RO17).

10. ^{20}Mg$(\beta^+)^{20}$Na $\qquad Q_m = 10.726$

The ^{20}Mg decay to ^{20}Na has been studied through β-delayed proton and γ-ray measurements. For the earlier work see (1979MO02, 1987AJ02). More recent studies are described in (1992KU07, 1992GO10, 1993PIZZ, 1995PI03). Half-lives measured for this decay are 95 ± 3 ms (1995PI03), 82 ± 4 ms (1992GO10), 114 ± 17 ms (1992KU07), 95^{+80}_{-50} ms (1979MO02). See Table 20.36 for β-decay branching ratios and $\log ft$ values. A compilation of ^{20}Na levels as observed in beta decay and other experiments is provided in (1995PI03), and serves as the basis for Table 20.33 here.

11. ^{27}Al(^{20}Ne, ^{27}Mg)^{20}Na $\qquad Q_m = -16.497$

The Δ resonance is very strongly excited in this reaction at $E(^{20}\text{Ne}) = 950$ MeV/A (1986BA16).

^{20}Mg
(Fig. 20.5)

^{20}Mg has been populated in the ^{24}Mg(α, ^{8}He) reaction at $E_\alpha = 127$ and 156 MeV, in the ^{20}Ne(^{3}He, 3n) reaction at $E(^3\text{He}) = 70$ MeV, and more recently in projectile fragmentation reactions. Reviews of proton rich nuclei and methods of production are presented in (1989AYZU, 1993SO13). See also (1990PO04). The super-allowed decay of ^{20}Mg to the first $T = 2$ $(J^\pi = 0^+)$ state of ^{20}Na [$E_x = 6.534 \pm 0.013$ MeV (1995PI03)] has been reported in early work (1979MO02, 1987AJ02) and more recently by (1992KU07, 1992GO10, 1993PIZZ, 1995PI03), who also observed β decay to other proton-unstable ^{20}Na states [see ^{20}Na, reaction 10]. Lifetime measurements for ^{20}Mg have given $\tau_{1/2} = 95^{+80}_{-50}$ ms (1979MO02), 114 ± 17 ms (1992KU07), 82 ± 4 ms (1992GO10), and 95 ± 3 ms (1995PI03). High-energy interaction cross sections of ^{20}Mg on carbon

Table 20.36: Branching in ^{20}Mg(β^+)^{20}Na [a]

E_x(^{20}Na) (keV)	Branch (%) [b]	$\log ft$	B(GT) [c]	J^π
984.25 ± 0.10	69.7 ± 1.2	3.83 ± 0.02	0.579 ± 0.030	1^+
2645	≤ 0.1	≥ 6.24	≤ 0.002	?
3001 ± 2	11.5 ± 1.4	4.08 ± 0.06	0.33 ± 0.05	1^+
3874 ± 15	4.8 ± 0.6	4.17 ± 0.06	0.27 ± 0.04	1^+
4123 ± 16	2.7 ± 0.3	4.33 ± 0.06	0.18 ± 0.03	1^+
≈ 4800 [d]	≥ 1.9 $[3.6 \pm 0.5]$	≤ 4.23 $[3.95 \pm 0.06]$	≥ 0.23 $[0.45 \pm 0.07]$	1^+
≈ 5600 [d]	≥ 1.5 $[2.8 \pm 0.4]$	≤ 3.97 $[3.70 \pm 0.06]$	≥ 0.42 $[0.79 \pm 0.10]$	1^+
6266 ± 30	1.2 ± 0.1	3.72 ± 0.06	0.75 ± 0.11	1^+
6521 ± 30	3.3 ± 0.4	3.13 ± 0.06	B(F) 4.57 ± 0.68	0^+
6770 ± 100	≥ 0.03	≤ 5.01	≥ 0.04	(1^+)
6920 ± 100	≥ 0.01	≤ 5.39	≥ 0.03	(1^+)
7440 ± 100	≥ 0.01	≤ 4.99	≥ 0.04	(1^+)

[a] From Table 4 of (1995PI03).

[b] It is noted in (1995PI03) that these branching ratios refer to the number of implanted ^{20}Mg atoms as 100%. For details on branching of the proton decay into ^{19}Ne levels see (1995PI03).

[c] Gamow-Teller strength.

[d] Unresolved levels. These are broad or unresolved states, for which the branching percentage could be determined only from proton emission to excited ^{19}Ne levels. The numbers in square brackets indicate the estimated branch, $\log ft$ and B(GT) values under inclusion of the 3% branching to the ^{19}Ne ground state.

have been measured by (1996CH24, 1996KR1A). Nuclear matter radii obtained from these data show evidence for a proton skin for ^{20}Mg.

In related theoretical work, shell model calculations for isospin-forbidden β delayed proton emission are described in (1990BR26); also see the mass calculation (1992AV03). Coulomb displacement energies analyzed by (1996CH04) show some evidence for a proton halo. Ground state properties have been studied using relativistic mean field theory (1996RE03, 1996RE10) and deformed Hartree-Fock-Bogoliubov calculations (1996GR21).

^{20}Al, etc.

(Not observed)

See (1972AJ02, 1983ANZQ, 1986AN07).

Table 20.37: Isospin triplet components ($T = 1$) in $A = 20$ nuclei [a]

^{20}F		^{20}Ne			^{20}Na		
E_x (MeV)	J^π	E_x (MeV)	$J^\pi; T$	ΔE_x (MeV) [b]	E_x (MeV)	J^π	ΔE_x (MeV) [c]
0	2^+	10.273	2^+;1	—	0	2+	—
0.656	3^+	10.884	3^+;1	-0.045	0.596	3^+	-0.060
0.823	4^+	11.090	4^+;1	-0.006	0.802	4^+	-0.021
0.984	1^-	11.270	1^-;1	0.013			
1.057	1^+	11.262	1^+;1	-0.068	0.984	1^+	-0.073
1.309	2^-	11.601	2^-;1	0.019	1.346	2^-	0.037
1.824	5^+						
1.844	2^-	12.098	2^-;1	-0.019	1.837	2^-	-0.007
1.971	(3^-)	12.256	3^-;1	0.012	1.992	3^-	0.021
2.044	2^+	12.221	2^+;1	-0.096			
2.194	3^+				2.057	3^+	-0.137
2.865	(3^-)						
					2.645	$(3^+, 1^+)$ [d]	
2.966	3^+				2.849	3^+	-0.117
2.968	(4^-)						
3.172	$(0^-,1^+)$						
3.488	1^+	13.484	1^+;1	-0.278	3.001	1^+	-0.487
3.526	(0^+)	13.642	0^+;1	-0.157	3.086	0^+	-0.440
3.587	(2)	13.881	2^+;1	0.021			

[a] As taken from Tables 20.5, 20.17, 20.33.
[b] Defined as $E_x(^{20}\mathrm{Ne}) - E_x(^{20}\mathrm{F}) - 10.273$.
[c] Defined as $E_x(^{20}\mathrm{Na}) - E_x(^{20}\mathrm{F})$.
[d] The 2.645-MeV state in ^{20}Na is of astrophysical interest and has been associated with the 3^+ level in ^{20}F at 2.966 MeV (1993BR12). The justification for this correspondence is based on the similar cross sections and angular distributions observed in (^{3}He, t)/(t, ^{3}He studies (1993CL09) and on the expected large s-wave Coulomb shift. However, the ^{19}Ne(p, γ) resonance strength that follows from this assignment is larger than the observed upper limit. More recently, the ^{20}Na level at 2.849 MeV has been assigned $J^\pi = 3^+$ (1995PI03). If this state is in fact the analog to the 2.966-MeV state in ^{20}F, then the 2.645-MeV state would have to be linked with one of the ^{20}F states at 2.865 (3^-), 2.968 (4^-), or 3.172 $(0^-, 1^+)$ MeV (B.A. Brown, private communication, September 1997). In view of the astrophysical significance of the 2.645-MeV state, further study is warranted.

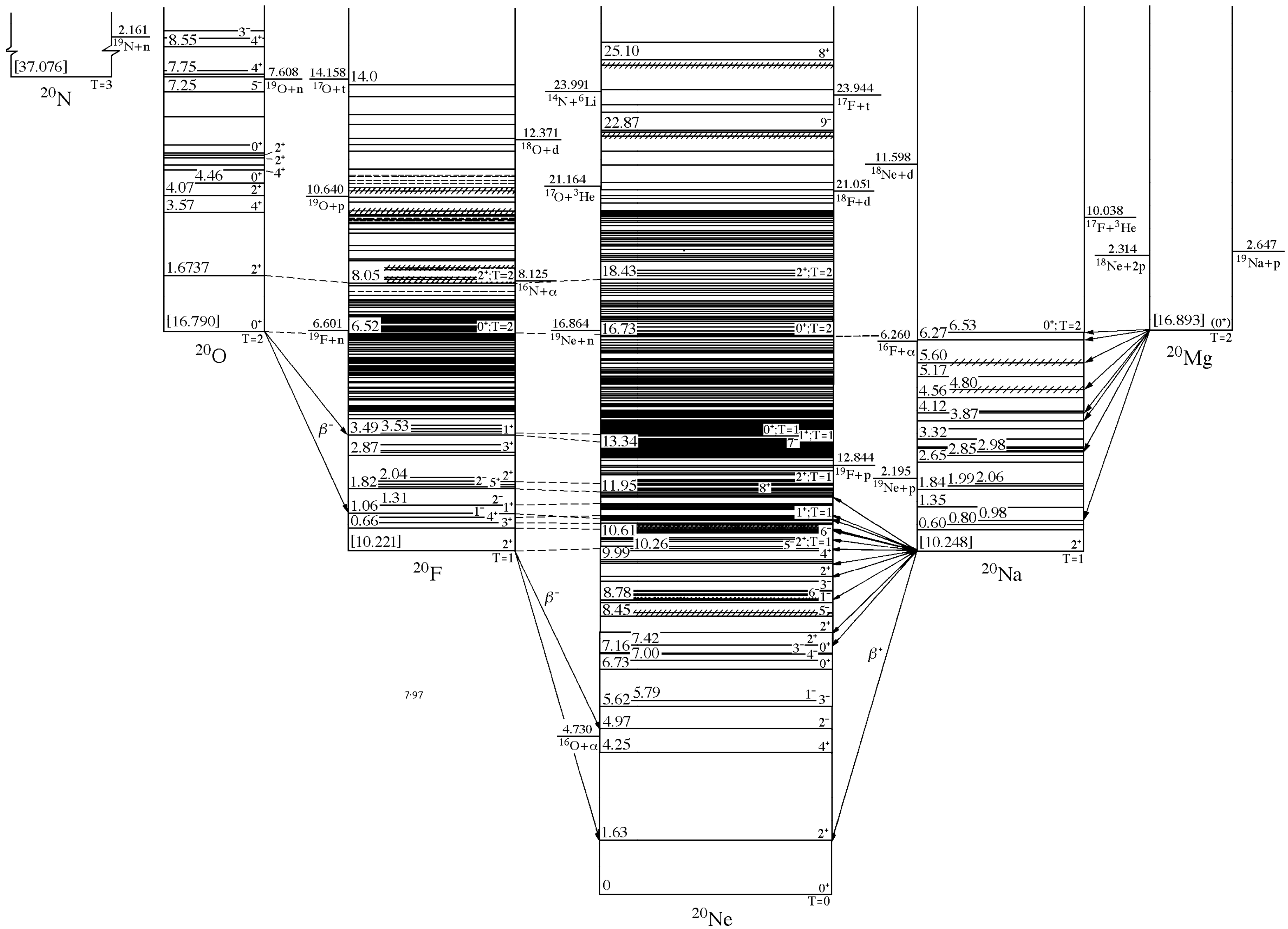

Figure 5: Isobar diagram, $A = 20$. The diagrams for individual isobars have been shifted vertically to eliminate the neutron-proton mass difference and the Coulomb energy, taken as $E_{\rm C} = 0.60Z(Z-1)/A^{1/3}$. Energies in square brackets represent the (approximate) nuclear energy, $E_{\rm N} = M(Z,A) - ZM({\rm H}) - NM({\rm n}) - E_{\rm C}$, minus the corresponding quantity for ^{20}Ne: here M represents the atomic mass excess in MeV. Levels which are presumed to be isospin multiplets are connected by dashed lines.

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(Closed 21 April 1997)

References are arranged and designated by the year of publication followed by the first two letters of the first-mentioned author's name and then by two additional characters. Most of the references appear in National Nuclear Data Center files and have NNDC key numbers ending in two numeric or two alphabetic characters. Otherwise, TUNL key numbers were assigned with the last two characters of the form 1A, 1B, etc. In response to many requests for more informative citations, we have, when possible, included up to 10 authors per paper and added the initials of all authors.

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