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Energy Levels of Light Nuclei
$A = 20$

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Abstract: An evaluation of $A = 18$–20 was published in *Nuclear Physics A*190 (1972), p. 1. This version of $A = 20$ differs from the published version in that we have corrected some errors discovered after the article went to press. Figures and introductory tables have been omitted from this manuscript. Reference key numbers have been changed to the NNDC/TUNL format.

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Table of Contents for $A = 20$

Below is a list of links for items found within the PDF document. Figures from this evaluation have been scanned in and are available on this website or via the link below.

^{20}C

(Not illustrated)

^{20}C has not been observed: see (1960ZE03).

^{20}N

(Not illustrated)

^{20}N has been observed in the bombardment of ^{232}Th by 122 MeV ^{18}O ions (1969AR13, 1970AR1D) and in the 3 GeV proton bombardment of ^{197}Au (1970RA1A): it is particle stable. See also (1960ZE03, 1961BA1C, 1971BU1E).

^{20}O

(Figs. 9 and 13)

GENERAL:

Model calulations: (1959BR1E, 1960TA1C, 1962TA1B, 1963PA03, 1964CO24, 1964MO1E, 1964PA1D, 1964TR1A, 1965DE1H, 1965FE02, 1966AR10, 1966BR04, 1966TR02, 1967FE01, 1967FL13, 1967LA1H, 1967PI1B, 1968AR02, 1968BE1U, 1968CO1N, 1968FL1C, 1968GU1E, 1968HA17, 1968HA1P, 1968MO1G, 1968PA1Q, 1969FE1A, 1969KU1G, 1969SO08, 1971AR25).

Other theoretical calculations: (1961JA1E, 1966KE16, 1967ST1N, 1968SU1C, 1969SC14, 1971LA1D, 1971LE1H).

General experimental work: (1969AR13, 1971AR02, 1971AR1P).

1. ^{20}O(β^-)^{20}F $\quad Q_{\rm m} = 3.815$

^{20}O decays to ^{20}F*(1.06) [$J^\pi = 1^+$] with a half-life of 13.57 ± 0.1 sec (1970MA42), 13.6 ± 1.0 sec (1960SC01). Using E_β(max) $= 2.76$ MeV and $\tau_{1/2} = 13.57 \pm 0.1$ sec, $\log ft = 3.73$. Upper limits for the branching to other states of ^{20}F are shown in Table 20.2 (1970MA42). See also (1959AM13) and (1957TH14, 1970AN27, 1970MC23; theor.).

2. ^{18}O(t, p)^{20}O $\quad Q_{\rm m} = 3.079$

$Q_0 = 3.086 \pm 0.015$ (1960JA13);

$Q_0 = 3.076 \pm 0.010$ (1962HI06).

Table 20.1: Energy levels of ^{20}O

E_x (MeV ± keV)	$J^\pi; T$	$\tau_{1/2}$ (sec)	Decay	Reactions
0	0^+; 2	13.57 ± 0.1	β^-	1, 2, 3
1.672 ± 5	2^+		γ	2
3.568 ± 5	4^+		(γ)	2
4.065 ± 5	2^+		(γ)	2
4.446 ± 7	0^+		(γ)	2
4.838 ± 7			(γ)	2
4.997 ± 7			(γ)	2
5.220 ± 7			(γ)	2
5.298 ± 7			(γ)	2
5.382 ± 7			(γ)	2
5.603 ± 7			(γ)	2
(5.83 ± 20)			(γ)	2

Table 20.2: Branching in ^{20}O(β^-)^{20}F (1970MA42)

Decay to ^{20}F* (MeV)	J^π	Branch (%)	log ft
0.98	$1^+(2^+, 3^+)$	< 0.6	> 6.0
1.06	1^+	100.0	3.73
1.31	2^+	< 0.8	> 5.7
1.84	2, 1^+	< 1.9	> 4.8
1.97		< 1.4	> 4.8
2.04	2^+	< 2.0	> 4.6
2.19	2^+	< 1.0	> 4.7

Table 20.3: Energy levels of ^{20}O from ^{18}O(t, p)^{20}O

E_x (MeV ± keV)		L	J^π
(1960JA13)	(1962HI06)		
0	0	0 [a,b]	0^+
1.682 ± 20	1.672 ± 5	2 [a,b]	2^+
	3.568 ± 5	4 [a]	4^+
4.091 ± 25	4.065 ± 5	2 [a,b]	2^+
4.449 ± 25	4.446 ± 7	0 [a]	0^+
	4.838 ± 7		
	4.997 ± 7		
	5.220 ± 7		
	5.298 ± 7		
	5.382 ± 7		
	5.603 ± 7		
	(5.83 ± 20)		

[a] (1964MI05): $E_t = 10.0$ MeV.
[b] (1965MO19): $E_t = 5.55$ MeV.

Observed proton groups are displayed in Table 20.3: angular distributions lead to the L and J^π values shown (1960JA13, 1962HI06, 1964MI05, 1965MO19). The $J = 2$ assignment for ^{20}O*(1.67) is confirmed by the angular correlation of the 1.67 MeV γ-rays (1970NI03). See also (1959JA01, 1967CH1L, 1969BA1Z) and (1964TR1A, 1966TR02, 1967DO1B; theor.).

3. ^{18}O(^{18}O, ^{16}O)^{20}O $\qquad Q_m = -0.628$

See (1970MA42).

^{20}F

(Figs. 10 and 13)

GENERAL:

Model calculations: (1959BR1E, 1963KU19, 1964MO1E, 1965DE1H, 1965DE1M, 1966CH1G, 1966PI1B, 1967BO09, 1967GU05, 1967GU1D, 1968AR02, 1968CO11, 1968GU1E, 1968HA17, 1968HA1P, 1969HO32, 1970AN27, 1970BA66, 1971AR25, 1971JO01, 1971WI01).

Other theoretical calculations: (1967ST1N, 1968CE1A, 1968DW1A, 1969SC14, 1971LE1H, 1971TE06).

General experimental work: (1970FA01, 1971AR02).

Ground state: $\mu = +2.0935 \pm 0.009$ nm (1967GU14; see also (1963TS01, 1969FU11).

See also (1963KU19, 1964LI14, 1964ST1B, 1967SH14, 1969PE1D, 1971AR25).

1. ^{20}F(β^-)^{20}Ne $\qquad Q_{\rm m} = 7.026$

^{20}F decays principally to ^{20}Ne*(1.63) with a half-life of 11.03 ± 0.06 sec [see Table 20.5]: see ^{20}Ne.

2. ^{17}O(t, p)^{19}O $\qquad Q_{\rm m} = 3.521 \qquad E_{\rm b} = 14.159$

See (1962MO08).

3. ^{17}O(α, p)^{20}F $\qquad Q_{\rm m} = -5.656$

Not reported.

4. ^{18}O(d, n)^{19}F $\qquad Q_{\rm m} = 5.768 \qquad E_{\rm b} = 12.369$

An excitation function has been measured for $E_{\rm d} = 0.95$ to 3.30 MeV (1969HE1P). See also ^{19}F.

5. ^{18}O(d, p)^{19}O $\qquad Q_{\rm m} = 1.732 \qquad E_{\rm b} = 12.369$

The proton yield has been measured for $E_{\rm d} = 0.79$ to 0.88 MeV (1956AH1A). See also ^{19}O.

Table 20.4: Energy levels of ^{20}F [a]

E_x (MeV $\pm$ keV)	$J^\pi; T$	τ or Γ_{cm} (keV)	Decay	Reactions
0	$2^+; 1$	$\tau_{1/2} = 11.03 \pm 0.06$ sec	β^-	1, 8, 11, 19, 20, 21, 23, 28, 29, 30
0.65595 ± 0.15	3^+	$\tau_m = 0.40 \pm 0.05$ psec	γ	7, 8, 10, 11, 19, 29
0.8229 ± 0.2	4^+, 2^+	79 ± 6 psec	γ	7, 8, 10, 11, 19, 29
0.9838 ± 0.2	$(1^+$, 2^+,, $3^+)$	1.6 ± 0.3 psec	γ	8, 11, 19, 29
1.05693 ± 0.16	1^+	45 ± 13 fsec	γ	8, 11, 19, 22, 29
1.30922 ± 0.16	2^+	0.9 ± 0.2 psec	γ	8, 11, 19, 23
1.8244 ± 1.3	(3^-)		γ	8, 28, 29
1.8434 ± 0.3	2, 1^+	30 ± 20 fsec	γ	8, 11, 19, 29
1.9706 ± 0.3			γ	8, 11
2.0439 ± 0.3	2^+	37 ± 16 fsec	γ	8, 11, 19
2.1946 ± 0.5	2^+	< 12 fsec	γ	8, 11, 19
2.865 ± 1.5	$(2, 3, 4)^-$		γ	8, 11, 19
2.9662 ± 0.4	2^+, 3^+	60 ± 40 fsec	γ	8, 11, 19
3.1746 ± 1.2			γ	19
3.4884 ± 0.2	1^+	44 ± 11 fsec	γ	8, 11, 19, 29
3.5259 ± 0.4	0^+	30 ± 15 fsec	γ	11, 19, 29
3.5871 ± 0.3	$(1, 2, 3)^+$	30 ± 30 fsec	γ	8, 11, 19
3.6810 ± 0.4			γ	8, 11, 19
3.761 ± 2			(γ)	8, 19, 29
3.9662 ± 1.4			γ	8, 11, 19
4.0824 ± 0.4	1^+		γ	8, 11, 19
4.1989 ± 2.7			(γ)	19, 29
4.2077 ± 2.6			(γ)	19
4.2766 ± 0.5	1^+, 2^+		γ	11, 19
4.3115 ± 2.6	0^+, 1^+		(γ)	19
4.5838 ± 3.0			(γ)	19
4.5922 ± 2.9			(γ)	19
4.7302 ± 2.9			(γ)	19
4.7638 ± 2.7			(γ)	19
4.8916 ± 2.8			(γ)	19
4.8982 ± 2.8			(γ)	19
5.0402 ± 3.1	$(0, 1, 2)^-$		(γ)	11, 19

Table 20.4: Energy levels of ^{20}F [a] (continued)

E_x (MeV $\pm$ keV)	$J^\pi; T$	τ or Γ_{cm} (keV)	Decay	Reactions
5.0655 ± 3.1			(γ)	19
5.2240 ± 3.1	$(0, 1, 2)^-$		(γ)	19
5.2810 ± 3.3	$(0, 1, 2)^-$		(γ)	19
5.3171 ± 2.7			(γ)	19
5.3445 ± 3.3			(γ)	19
5.4131 ± 0.6			γ	11
5.4503 ± 3.8			(γ)	19
5.4554 ± 3.2			(γ)	19
5.4634 ± 3.3			(γ)	19
5.5547 ± 0.6			γ	11
5.6203 ± 3.3			(γ)	19
(5.713 ± 2)			γ	11
5.7628 ± 3.4			(γ)	19
5.8091 ± 2.9	$(0, 1, 2)^-$		(γ)	19
5.9361 ± 0.3	$1^-, 2^-$		γ	11, 19
6.0173 ± 0.3	$1^-, 2^-$		γ	11, 19
6.0446 ± 0.4			γ	11, 19
6.25 ± 20			(γ)	9
6.513 ± 33	$0^+; 2$		(γ)	19, 28
6.6013 ± 0.3	$0^+, 1^+$		γ	11
6.616			n	12
6.627	2^-	$\Gamma = 0.29$ keV	γ, n	11, 12, 19
6.632			n	12
6.634			n	12
6.637			n	12
6.648	1^-	1.62	γ, n	11, 12
6.668			n	12
6.685	0^-	3.80	n	12
6.692	1^-	5.23	(γ), n	11, 12, 13
6.696	2^-	1.05	(γ), n	11, 12
6.699	1^+	2.85	(γ), n	11, 12
6.709	0^-	1.14	n	12
6.717	0^-	0.95	n	12

Table 20.4: Energy levels of ^{20}F [a] (continued)

E_x (MeV ± keV)	$J^\pi; T$	τ or Γ_{cm} (keV)	Decay	Reactions
6.729	(0^-)		n	12
6.732	(0^-)		n	12
6.737	(0^-)		n	12
6.742	(0^-)		n	12
6.746	(0^-)		n	12
6.791	0^+	1.9	n	12
6.835	1^+	1.7	n	12
6.837	1^+	0.4	n	12
6.856	1^+	1.3	n	12
6.858	1	19	γ, n	11, 12, 13
7.005	$0^{(-)}$	24	γ, n	11, 12, 13, 19
7.076	(1^+)	24	γ, n	11, 12, 13
7.171	(2^+)	14	γ, n	11, 12
7.311	(1)	33	γ, n	11, 12
(7.355)	(1)	19	n	12, 13
7.410	(2^+)	10	γ, n	11, 12, 13
7.489	(2)	57	n	12
7.503	(0)	85	γ, n	11, 13
7.670	(2^+)	60	γ, n	11, 12
7.80	(1, 2)	100	γ, n	11, 12
8.05 ± 100	2^+; 2			28
8.15	(1)	190	γ, n	11, 12
8.50		140	n	12
8.74		≤ 30	n	12
8.77		76	n	12
8.99		140	n	12
9.69		140	n	12
9.85		120	n, α	12, 18
10.024 ± 10		200	n, α	12, 18
10.10 ± 50			n, α	18
10.228 ± 10	0^-, 1	≈ 200	n, α	12, 18
10.480 ± 10		≈ 10	n, α	12, 18
(10.641 ± 10)	1, 2	≈ 60	n	12

Table 20.4: Energy levels of ^{20}F [a] (continued)

E_x (MeV ± keV)	$J^\pi; T$	τ or Γ_{cm} (keV)	Decay	Reactions
10.807 ± 10	$0^-, 1$	≈ 330	n, α	12, 18
(10.89)			n, α	18
(11.045 ± 10)		≈ 30	n	12
(11.130 ± 10)		< 25	n	12, 18
(11.244 ± 10)		< 25	n	12, 18
11.49 ± 50			n, α	18
(11.73)			n, α	18
12.0			n, α	18
12.2			n, α	18
12.39			n, α	18
12.82			n, α	18
13.2			n, α	18
13.66			n, α	18
14.0			n, α	18

[a] See also Tables 20.6, 20.9 and 20.14.

6. ^{18}O(d, α)^{16}N $\qquad Q_m = 4.245 \qquad E_b = 12.369$

Excitation functions have been measured for $E_d = 0.9$ to 2.0 MeV (1960AM03; α_0, α_1, α_2, α_3), 0.5 to 3.0 MeV (1957BO04; α) and 9.6 to 11.5 MeV (1970BO08; α_4, α_5, α_6, α_{7+8}, α_{16}, α_{17}). At the lower energies a number of sharp structures are reported: see (1957BO04, 1960AM03). At the higher energies, there is no substantial resonant structure with widths less than a few hundred keV (1970BO08).

7. ^{18}O(t, n)^{20}F $\qquad Q_m = 6.112$

The lifetime of ^{20}F*(0.82), $\tau_m = 79 \pm 6$ psec and $J = 2$, 4. The 167-keV γ-ray from this state to ^{20}F*(0.63) is observed to have a multipole mixing ratio near zero for both of the above J values. The results are consistent with ^{20}F*(0.82) having $J^\pi = 4^+$ and being the third member of the ground state rotational band (1971PR10).

Table 20.5: The half-life of ^{20}F [a]

$\tau_{1/2}$ (sec)	Ref.
12.5 ± 2	(1959VA10)
11.2 ± 0.1	(1960SC01)
11.56 ± 0.05	(1962MA38)
11.36 ± 0.07	(1963GL01)
10.81 ± 0.11	(1967FL16)
10.31 ± 0.07	(1967YU01)
11.03 ± 0.06	(1970WI05)
11.03 ± 0.06	"best" value

[a] See also (1952AJ38).

8. ^{18}O(^{3}He, p)^{20}F $\quad Q_m = 6.876$
$Q_0 = 6.8752 \pm 0.0015$ (1970RO06).

Proton groups have been observed to states of ^{20}F with $E_x < 4.1$ MeV (1970RO06): see Table 20.7. Directional correlation and branching ratio measurements [see Table 20.6] lead to the J^π assignments shown in Table 20.7 (1970QU04). See also (1967BI01, 1967QU01). Angular distributions of the protons corresponding to ^{20}F*(1.06, 3.49) are very similar at $E(^3\text{He}) = 18$ MeV: both show an $L = 0 + 2$ pattern, and therefore both are $J^\pi = 1^+$ states. This implies that ^{20}F*(3.53) which is only weakly excited has $J^\pi = 0^+$: see the discussion in (1971FO14) and in reaction 19 [see also (1971BE19)]. See also (1969BA1Z).

9. ^{18}O(α, d)^{20}F $\quad Q_m = -11.478$

Not reported.

10. (a) ^{18}O(^{6}Li, α)^{20}F $\quad Q_m = 10.895$
(b) ^{18}O(^{7}Li, αn)^{20}F $\quad Q_m = 3.645$

$\tau_m \approx 1$ psec for ^{20}F*(0.66) and 76 ± 20 psec for ^{20}F*(0.82): see Table 20.14 (1969NI09).

Table 20.6: Radiative transitions in ^{20}F

E_i (MeV)	J^π_i	E_f (MeV)	J^π_f	Branching (%)	Refs.
0.66	3^+	0	2^+	100	(1968SP01, 1970HO05, 1970QU04)
0.82 [a]	4^+, 2^+	0	2^+	36 ± 10	(1970QU04)
				42 ± 4	(1969HE20)
		0.66	3^+	64 ± 10	(1970QU04)
				58 ± 6	(1969HE20)
0.98 [b]	(1^+, 2^+, 3^+)	0	2^+	90 ± 10	(1970QU04)
				≥ 95	(1969HE20)
		0.66	3^+	10 ± 10	(1970QU04)
				≤ 5	(1969HE20)
				< 1	(1968SP01)
		0.82	4^+, 2^+	< 1	(1968SP01)
1.06	1^+	0	2^+	100	(1968SP01, 1970QU04)
		0.66	3^+	< 1	(1968SP01)
		0.82	4^+, 2^+	< 1	(1968SP01)
1.31	2^+	0	2^+	100	(1968SP01, 1969HO20, 1970QU04)
				≥ 86	(1969HE20)
		0.66	3^+	≤ 14	(1969HE20)
		0.82	4^+, 2^+	< 2	(1968SP01)
		0.98	(1^+, 2^+, 3^+)	< 1	(1968SP01)
		1.06	1^+	< 1	(1968SP01)
1.82	(3^-)	0	2^+	< 20	(1970QU04)
		0.82	4^+, 2^+	> 80	(1970QU04)
1.84 [c]	2, 1^+	0	2^+	> 95	(1970QU04)
		0.82	4^+, 2^+	< 5	(1970QU04)
1.97 [d]		0	2^+	20 ± 10	(1970QU04)
		0.82	4^+, 2^+	50 ± 15	(1970QU04)
		1.31	2^+	30 ± 10	(1970QU04)
2.04 [e]	2^+	0	2^+	20 ± 5	(1970QU04)
		0.66	3^+	80 ± 5	(1970QU04)
2.19 [f]	2^+	0	2^+	45 ± 10	(1970QU04)

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

E_i (MeV)	J^π_i	E_f (MeV)	J^π_f	Branching (%)	Refs.
		0.82	$4^+, 2^+$	55 ± 10	(1970QU04)
2.87		0	2^+	(100)	(1970QU04)
2.97 [c]	$2^+, 3^+$	0	2^+	24 ± 3	(1969HE20)
				45 ± 10	(1970QU04)
		0.66	3^+	14 ± 2	(1969HE20)
		0.82	$4^+, 2^+$	62 ± 6	(1969HE20)
				55 ± 10	(1970QU04)
3.17 [g]		0	2^+	< 5	(1970QU04)
		0.98	$(1^+, 2^+, 3^+)$	> 95	(1970QU04)
3.49 [h]	1^+	0	2^+	68 ± 4	(1969HO20)
		0.98	$(1^+, 2^+, 3^+)$	7 ± 1	(1969HO20)
		1.06	1^+	7 ± 1	(1969HO20)
		1.31	2^+	10 ± 2	(1969HO20)
		1.84	$2, 1^+$	8 ± 2	(1969HO20)
3.53 [b]	0^+	1.06	1^+	100	(1968SP01, 1969HO20)
3.59	$(1, 2, 3)^+$	0	2^+	66	(1968SP01)
				60	(1969HO20)
		2.04	2^+	34	(1968SP01)
				40	(1969HO20)
3.68		0	2^+	33	(1968SP01)
		0.66	3^+	67	(1968SP01)
3.97		0	2^+	77	(1969HA04)
		0.98	$(1^+, 2^+, 3^+)$	6	(1969HA04)
		1.31	2^+	17	(1969HA04)
4.08 [i]	1^+	0	2^+	35 ± 5	(1969HO20)
		1.06	2^+	65 ± 5	(1969HO20)
4.28	$(1, 2)^+$	1.06	1^+	100	(1968SP01)
5.41		2.04	2^+	100	(1968SP01)
5.55		0	2^+	24	(1968SP01)
		1.31	2^+	76	(1968SP01)

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

E_i (MeV)	J_i^π	E_f (MeV)	J_f^π	Branching (%)	Refs.
5.71		1.06	1^+	60	(1969HA04)
		4.28	$(1, 2)^+$	40	(1969HA04)
5.94 [j]	$(1, 2)^-$	0	2^+	7	(1968SP01)
		0.66	3^+	35	(1968SP01)
		0.98	$(1^+, 2^+, 3^+)$	4	(1968SP01)
		1.31	2^+	1	(1968SP01)
		1.84	$2, 1^+$	7	(1968SP01)
		1.97		31	(1968SP01)
		2.19	2^+	5	(1968SP01)
		3.49	1^+	10	(1968SP01)
6.02 [j]	$(1, 2)^-$	0	2^+	29	(1968SP01)
				40	(1968BL1C)
		0.66	3^+	3	(1968SP01)
		0.98	$(1^+, 2^+, 3^+)$	19	(1968SP01)
				23	(1968BL1C)
		1.06	1^+	1	(1968BL1C)
		1.31	2^+	2	(1968BL1C)
		1.84	$2, 1^+$	6	(1968SP01)
				6	(1968BL1C)
		2.19	2^+	3	(1968SP01)
		2.97		8	(1968SP01)
		3.49	1^+	19	(1968SP01)
				18	(1968BL1C)
		3.59	$(1, 2, 3)^+$	10	(1968BL1C, 1968SP01)
		4.08	1^+	3	(1968SP01)
6.04		1.31	2^+	46	(1968SP01)
		1.84	$2, 1^+$	54	(1968SP01)
6.60	$0^+, 1^+$	see Table 20.9			
6.63	2^-	see Table 20.9			
6.65	1^-	see Table 20.9			

[a] See also (1967BE36, 1968SP01, 1969HO20, 1970HO05, 1971PR10).
[b] See also (1967BE36).
[c] See also (1968SP01, 1970HO05).
[d] See also (1967BE36, 1968SP01).
[e] See also (1967BE36, 1968SP01, 1969HA04, 1970HO05).
[f] See also (1968SP01, 1969HO20).
[g] See also (1969HO20).
[h] See also (1967BE36, 1968SP01, 1969HA04).
[i] See also (1968SP01).
[j] See also (1969HA04).

11. ^{19}F(n, γ)^{20}F

$Q_{\rm m} = 6.601$
$Q_0 = 6.6013 \pm 0.0010$ (1967RA24);
$Q_0 = 6.602 \pm 0.002$ (1967BL04, 1968BL1C);
$Q_0 = 6.011 \pm 0.0003$ (1968SP01);
$Q_0 = 6.6020 \pm 0.0006$ (1969HA04).

The thermal capture cross section is 9.8 ± 0.7 mb (1963GL01: see (1964ST25)). At $E_{\rm n} = 30$ keV it is reported to be 4.5 ± 1.0 mb (1963MA1F). A number of resonances have been observed for $E_{\rm n} \leq 1.65$ MeV: see Table 20.8 (1959GA08). The primary γ-rays resulting from capture at thermal energies (^{20}F*(6.60); $J^\pi = 0^+$, 1^+) and at $E_{\rm n} = 27$ and 48 keV (^{20}F*(6.63, 6.65); $J^\pi = 2^-$ and 1^-, respectively) have been studied by several groups: see Table 20.9 (1965BI03, 1967BE36, 1967VA08, 1968BL1C, 1968SP01, 1969HA04). See also (1962BI1C, 1963NA08). There is some disagreement between the results of the various groups but it appears that the decay of ^{20}F*(6.60) is dominated by two intense transitions (probably E1) to ^{20}F*(5.94, 6.02) [thus $J^\pi = 1^-$, 2^-]. If the ground state transition is mainly M1, these two E1 transitions are (in terms of W.u.) about 150 times stronger than the M1 transition (1968SP01). It appears also that at ^{20}F*(6.63, 6.65) [$J^\pi = 2^-$ and 1^-, respectively] the E1 transitions to the ground state are very weak, even though other E1 transitions in the decay of these two states have approximately normal strengths (1965BI03, 1967BE36). Branching ratios for other ^{20}F states involved in this reaction are shown in Table 20.6 (1967BE36, 1968BL1C, 1968SP01, 1969HA04).

Table 20.10 displays excitation energies for ^{20}F states involved in cascade and in primary γ-transitions (1968SP01, 1969HA04). (1968BL1C) suggest 4^+ for ^{20}F*(0.83) since neither ^{20}F*(6.60) nor ^{20}F*(6.02) [$J^\pi = 0^+$, 1^+, and $J^\pi = 1^-$, respectively] decays to it and 3^+ for ^{20}F*(0.66) since the 6.60 MeV state decays to it and ^{20}F*(6.02) does not. See also (1958GR1B, 1961WA03, 1963GI1D) and (1964ST25).

12. ^{19}F(n, n)^{19}F

$E_{\rm b} = 6.601$

Table 20.7: States in ^{20}F from ^{18}O(^{3}He, p)^{20}F

E_x [a] (keV)	J^{π} [c]
0	2^+ [d]
657.2 ± 1.3	3^+
823.5 ± 1.5	2^+, 4^+
982.9 ± 1.3	1^+, 2^+, 3^+
1058.1 ± 1.4	1^+
1309.1 ± 1.4	$(1^+, 2^+)$
1824.4 ± 1.6 [b]	1, 2, 3, 5
1843.0 ± 1.7 [b]	2, 1^+, 3^+
1971.9 ± 1.6	
2044.0 ± 1.6	2^+
2195.5 ± 2.0	3^+, 2^+, 1^+
2868.2 ± 2.3	
2967.1 ± 2.0	2^+, 3^+
3487.8 ± 2.2	1^+ [d]
3586.3 ± 2.2	
3681.0 ± 2.5	
3761.0 ± 3.1	
3966.9 ± 2.8	
4083.7 ± 2.9	

[a] (1970RO06).
[b] (1967QU01) find $E_x = 1824.4 \pm 2.1$ and 1843.0 ± 2.2 keV.
[c] From (p, γ) correlation measurements (1970QU04). See also (1967BI01, 1967QU01).
[d] Known from β-decay: see reaction 29 in ^{20}Ne.

Table 20.8: Resonances in ^{19}F(n, γ)^{20}F [a]

E_n [b] (keV)	σ(n, γ) [c] (mb)	Γ_γ (eV)	Γ (keV)	J^π	E_x (MeV)
27	308	1.1 [e]	0.4 [f]	2^-	6.627
48	36	1.6	1.5 [f]	1^-	6.647
100	4.4	2.2	12 [f]	1^-	6.696
177					6.769
270 [d]	1.4	3.9	20	1	6.858
308					6.894
388					6.970
425	0.31	1.5	25	0	7.005
500	0.30	1.9	25	0, 1	7.076
600 [d]	1.8	8.1	15	1	7.171
760	0.11	2.9	60	1	7.323
865	0.11		60		7.423
950	0.06	2.8	95	0	7.503
1125	0.09	3.9	80	1	7.670
1290	0.27	8.6	75	1, 2	7.826
1635	0.07	7.5	180	1	8.154

[a] (1959GA08). See also Tables 20.6 and 20.9.

[b] (1963MA1G) report a resonance at $E_n = 15.5$ keV which (1967BL1J) do not observe. However (1967BL1J) report a narrow resonance at $E_n = 84$ keV.

[c] At resonance after correction for resolution.

[d] See also (1950HE1A).

[e] $\Gamma_n = 0.38 \pm 0.10$ keV, $\Gamma_\gamma = 0.55 \pm 0.15$ keV (1963MA1G).

[f] From σ_t measurements.

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

Final state ^{20}F* (MeV)	I_γ [b] from ^{20}F*(6.60)		I_γ [b] from ^{20}F*(6.63)		I_γ [b] from ^{20}F*(6.65)	
	(1968SP01)	(1969HA04)	(1965BI03)	(1967BE36)	(1965BI03)	(1967BE36)
0	11	10	< 1		< 1	5 ± 3
0.66	< 0.1		4	6 ± 2	5	9
0.82	< 0.1				(2)	
0.98	1.5	2			5	13
1.06 [c]	5	6				
1.31	3	3	25	32 ± 2	5	12
1.84	2	2				
1.97	0.1		22	50 ± 2	5	
2.04	6	6	25		20	42 ± 2
2.19			4		6	
2.87			3			
2.97	< 0.2				11	
3.49	2.5	2				
3.53	2		5	8 ± 1	10	20 ± 2
3.59	4.4	4				
3.68	1	1				
3.97		1				
4.08		1	4	5 ± 2	4	
4.28	1	1				
5.04			3			
5.41	0.5					
5.55	3					
5.94	17	13				
6.02 [c]	38	48				
6.04	2					

[a] See also Tables 20.6 and 20.8 and (1968BL1C).

[b] In units of photons/100 captures.

[c] E_γ for the transitions (6.60 $\rightarrow$ 0), (6.60 $\rightarrow$ 1.06) and (6.60 $\rightarrow$ 6.02) are, respectively, 6599.8 ± 3.0, 5534.9 ± 2.0 and 583.6 ± 0.5 keV (1967VA08).

Table 20.10: States of ^{20}F involved in ^{19}F(n, γ)^{20}F [a]

E_x (keV)	
(1968SP01)	(1969HA04)
0	0
656.3 ± 0.3	656 ± 1
822.9 ± 0.3	
983.8 ± 0.3	984 ± 1
1057.2 ± 0.3	1057 ± 1
1309.1 ± 0.3	1309 ± 1
1843.4 ± 0.3	1843 ± 1
1970.6 ± 0.3	
2044.2 ± 0.4	2044 ± 1
2194.5 ± 0.6	2194 ± 2
2965.8 ± 0.5	2966 ± 2
3488.3 ± 0.3	3488 ± 2
3526.0 ± 0.5	
3587.3 ± 0.3	3588 ± 2
3681.0 ± 0.4	3681 ± 2
	3967 ± 2
4082.2 ± 0.5	4085 ± 2
4276.7 ± 0.5	4275 ± 2
5413.1 ± 0.6	
5554.7 ± 6	
	5713 ± 2
5936.0 ± 0.3	5937 ± 1
6017.3 ± 0.3	6018 ± 1
6044.6 ± 0.4	
6601.1 ± 0.3	6602.0 ± 0.6

[a] For measurements of I_γ, see (1968SP01, 1969HA04).

The scattering amplitude (bound) is $a = 5.74 \pm 0.09$ fm (1963BA1F). The coherent scattering cross section is 3.9 ± 0.1 b (1964ST25). See also (1961WI1A, 1969BA1P).

The total cross section has been measured for $E_n = 1$ to 300 keV (1964HI04), 0.2 to 2.2 MeV (1964EL02), 0.45 to 1.20 MeV (1966CA14), 2.5 to 15 MeV (1971FO1A), 2.61 to 2.83 MeV (1965SO1A), 3.35 to 5.07 MeV (1960TS02), 7 to 14 MeV (1957PE1B), 13.70 to 14.60 MeV (1968HU1E), 14.5 MeV (1970AN1F), and 17.7 to 29.1 MeV (1960PE1B). See also (1966GA1K, 1969AN1E). For earlier measurements see (1959AJ76). Observed resonances in the total cross section are shown in Table 20.11 (1958WI36, 1960TS02, 1964HI04, 1964ST25, 1966CA14). The level density may be appreciably greater than that shown in Table 20.11: see (1964HI04) and (1964EL02).

Angular distributions and polarization measurements have been carried out over the range $E_n = 0.2$ to 2.2 MeV (1964EL02). The results have been interpreted in terms of doorway states: see (1967AF01, 1967MO1M, 1968LE1P). Angular distributions have also been measured at $E_n = 14.1$ MeV (1970CL03) and for $E_n = 0.66$ to 2.92 MeV (1958WI36). See also (1970GA1A). Polarization measurements are reported by (1962OT01) at $E_n = 3.5$ MeV. See also (1959MA1C, 1965WY1B, 1966EL1C, 1967EL1F) and (1964ME1B, 1967FE1F, 1971BU02, 1971GI05; theor.).

13. ^{19}F(n, n′)^{19}F* $E_b = 6.601$

The excitation function for 0.110, 0.197, 1.24 and 1.37 MeV γ-rays has been measured from threshold to 2.2 MeV by (1955FR1B). See also (1966VE1B, 1971BE1G). Resonances are reported at $E_n = (100)$, 270, 420, (500), 780, 830, 880 and 950 keV, corresponding to the excitation of ^{20}F states at $E_x = (6.70)$, 6.86, 7.00, (7.08), 7.34, 7.39, 7.44 and 7.50 MeV (1955FR1B). See also (1966VE1B). The cross section for excitation of ^{19}F*(2.78) has been studied for $E_n = 3$ to 3.6 MeV. The very slow rise for the first 300 keV above threshold is consistent with the large spin difference between ^{19}F*(2.78) and the ground state [$J^\pi = \frac{9}{2}^+$ for the former, $\frac{1}{2}^+$ for the latter]. See also (1970CL03) and (1964ST25).

14. ^{19}F(n, 2n)^{18}F $Q_m = -10.431$ $E_b = 6.601$

Cross sections have been measured from $E_n = 10$ to 37 MeV (1961BR1A), 12.4 to 20.9 MeV (1965PI1A), 12.6 to 19.6 MeV (1965BO42), 12.7 to 19.4 MeV (1967ME1J), 13.5 to 15.0 MeV (1967BO24), 13.6 to 14.6 MeV (1968VO1B), 13.9 to 14.8 MeV (1964ST1F), 14.1 MeV (1962CE1B), 14.2 MeV (1965NA1C), 14.4 MeV (1961RA06, 1963RA1A) and at 14.7 MeV (1967PA1N). See (1959AJ76) for earlier reports. See also (1960MC05, 1961WI1C, 1963PI1B, 1964HE18, 1965GO1C, 1967CS02), (1964ST25, 1966JE1B) and (1969CH1N; theor.).

15. ^{19}F(n, p)^{19}O $Q_m = -4.036$ $E_b = 6.601$

Cross sections have been measured for $E_n = 12.6$ to 19.6 MeV (1965BO42), 14.4–14.8 MeV

Table 20.11: Resonances in ^{19}F(n, n)^{19}F

E_n (keV)	Γ_{lab} (keV)	J^π	^{20}F* (MeV)	Refs.
15.25			6.616	(1964HI04)
27.35	0.30	2^-	6.627	(1964HI04)
31.9			6.632	(1964HI04)
34.0			6.634	(1964HI04)
38.0			6.637	(1964HI04)
49.7	1.70	1^-	6.648	(1964HI04)
70.5			6.668	(1964HI04)
87.8	4.00	0^-	6.685	(1964HI04)
96.0	5.50	1^-	6.692	(1964HI04)
100.0	1.10	2^-	6.696	(1964HI04)
102.4	3.00	1^+	6.699	(1964HI04)
113.2	1.20	0^-	6.709	(1964HI04)
121.7	1.00	0^-	6.717	(1964HI04)
134.0		(0^-)	6.729	(1964ST25)
138.0		(0^-)	6.732	(1964ST25)
143.1		(0^-)	6.737	(1964ST25)
148.0		(0^-)	6.742	(1964ST25)
152.5		(0^-)	6.746	(1964ST25)
200.2	2.0	0^+	6.791	(1964HI04)
246.0	1.8	1^+	6.835	(1964HI04)
247.8	0.4	1^+	6.837	(1964HI04)
267.7	1.4	1^+	6.856	(1964HI04)
270	20	1	6.858	(1964ST25)
425	25	0	7.005	(1964ST25)
500	25	(1^+)	7.076	(1964ST25, 1966CA14)
600	15	(2^+)	7.171	(1964ST25, 1966CA14)
747	35	(1)	7.311	(1966CA14)
794	20	(1)	(7.355)	(1966CA14)
852	11	(2^+)	7.410	(1966CA14)
935	60	(2)	7.489	(1958WI36, 1964ST25, 1966CA14)
1100	50	(2^+)	7.65	(1958WI36, 1964ST25, 1966CA14)
1250	150		7.79	(1958WI36, 1964ST25)
1620	220		8.14	(1958WI36, 1964ST25)

Table 20.11: Resonances in ^{19}F(n, n)^{19}F (continued)

E_n (keV)	Γ_{lab} (keV)	J^π	^{20}F* (MeV)	Refs.
2000	150		8.50	(1958WI36, 1964ST25)
2250	≤ 30		8.74	(1958WI36, 1964ST25)
2280	80		8.77	(1958WI36, 1964ST25)
2520	150		8.99	(1958WI36, 1964ST25)
3250	150		9.69	(1958WI36, 1964ST25)
3420	130		9.85	(1958WI36, 1960TS02, 1964ST25)
3460 ± 10			(9.887)	(1960TS02)
3505 ± 10			(9.929)	(1960TS02)
3560 ± 10			(9.982)	(1960TS02)
3605 ± 10	200		10.024	(1958WI36, 1960TS02, 1964ST25)
3820 ± 10	≈ 200	0^-, 1	10.228	(1960TS02)
4085 ± 10	≈ 10		10.480	(1960TS02)
4255 ± 10	≈ 60	1, 2	10.641	(1960TS02)
4430 ± 10	≈ 330	0^-, 1	10.807	(1960TS02)
4680 ± 10	≈ 30		11.045	(1960TS02)
4770 ± 10	< 25		11.130	(1960TS02)
4890 ± 10	< 25		11.244	(1960TS02)
(4935)			(11.29)	(1960TS02)

(1962KA1A, 1966MI1J, 1966PR1A, 1967CS1A, 1967PA1N, 1968RE07) and for $E_n = 18.2$ to 21.0 MeV (1965PI1A). See also (1959AJ76), (1961DA16, 1963PI1B), (1960BU1C, 1963LE1D, 1964ST25, 1966JE1B, 1971CU1B, 1971PR09) and ^{19}O.

16. ^{19}F(n, d)^{18}O $\quad Q_m = -5.768 \quad E_b = 6.601$

See (1960VE06, 1967VA12, 1968RE07, 1969LI1F) and ^{18}O.

17. ^{19}F(n, t)^{17}O $\quad Q_m = -7.557 \quad E_b = 6.601$

See (1967VA12, 1968RE07) and ^{17}O in (1971AJ02).

18. ^{19}F(n, α)^{16}N $\quad Q_m = -1.523 \quad E_b = 6.601$

Table 20.12: Resonances in ^{19}F(n, α)^{16}N

E_n (MeV ± keV)			E_x (MeV)
(1955MA1D)	(1960SM03)	(1961DA16)	
3.4			9.8
3.61 ± 50			10.03
3.69 ± 50			10.10
3.77 ± 50	3.75 ± 50	3.85	10.17
4.11 ± 50	4.08 ± 50	4.1	10.49
4.42 ± 50	4.36 ± 50	4.35	10.77
	4.52 [a]		10.89
4.86 ± 50	4.79 ± 50	4.80	11.18
	5.15 ± 50		11.49
	5.40 [a]		11.73
		5.7	12.0
5.9 ± 100	5.9 [a]		12.2
		6.10	12.39
		6.55	12.82
		6.9	13.2
		7.44	13.66
		7.8	14.0

[a] Not resolved.

Observed resonances are shown in Table 20.12 (1955MA1D, 1960SM03, 1961DA16): see graph in (1964ST25). Excitation functions are reported from threshold to $E_n = 6$ MeV (1960SM03), $E_n = 8.2$ MeV (1961DA16) and for $E_n = 14.2$ to 21.0 MeV (1965PI1A). See also (1959AJ76), (1962KA1A, 1963PI1B, 1966BH05, 1966KN02, 1968RE07, 1969BR1F), (1960BU1C, 1963CH20, 1966JE1B), (1964GA1A; theor.) and ^{16}N in (1971AJ02).

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

$Q_0 = 4.3777 \pm 0.0009$ (1970RO06; see also (1967SP09)).

Measurements of proton spectra and γ-rays have led to the identification of a number of states of ^{20}F: see Table 20.13 (1969HE20, 1969HO20, 1970RO06). Angular distributions have been studied at $E_d = 0.6$ MeV (1970SC14), 0.8 to 2.5 MeV (1964EL01), 1.32 to 2.03 MeV (1959ON26),

Table 20.13: States in ^{20}F from ^{19}F(d, p)^{20}F

E_x (keV) [a]			l_n [d]	J^π [e]	$(2J_f+1)S$ [j]
(1970RO06) [b]	(1969HO20) [c]	(1969HE20) [c]			
0			2	$1^+, 2^+, 3^+$	≤ 0.06
654.9 ± 1.0	655.9 ± 0.2	655.4 ± 0.5	2	$1^+, 2^+, 3^+$	2.59
821.6 ± 1.0	823.0 ± 0.3	822.6 ± 0.7	2	$1^+, 2^+, 3^+$	$\lesssim 0.3$
983.3 ± 1.0	983.9 ± 0.3	983.4 ± 0.7	2	$1^+, 2^+, 3^+$	$\lesssim 0.3$
1056.3 ± 1.0	1057.0 ± 0.2	1055.2 ± 0.6	0	$0^+, 1^+$	0.019
1310.8 ± 1.1	1309.3 ± 0.2	1308.0 ± 0.9	iso., 2 [g]	$(1^+, 2^+, 3^+)$	$\lesssim 0.02$
1843.4 ± 1.2	1843.5 ± 0.7				$\lesssim 0.11$
	2043.7 ± 0.5		2	$1^+, 2^+, 3^+$	2.32
2195.1 ± 1.5	2194.5 ± 0.6		2	$1^+, 2^+, 3^+$	0.50
2863.7 ± 1.6			3 [h]	$2^-, 3^-, 4^-$	$\lesssim 0.01$
2966.6 ± 1.7	2966.8 ± 0.6	2964.5 ± 2.0	1	$0^-, 1^-, 2^-$	0.36
3171.8 ± 2.2	3175.6 ± 1.3				$\lesssim 0.2$
	3488.5 ± 0.3		0	$0^+, 1^+$	1.20
3525.5 ± 2.6	3525.9 ± 0.5		0	$0^+, 1^+$	0.28
3586.4 ± 2.7	3586.5 ± 0.6		2 [g]	$1^+, 2^+, 3^+$	0.36
3681.0 ± 2.5					$\lesssim 0.04$
3760.8 ± 2.7					
3964.5 ± 2.5					$\lesssim 0.04$
4080.9 ± 2.5	4082.5 ± 0.8		0	$0^+, 1^+$	0.18
4198.9 ± 2.7					
4207.7 ± 2.6					
4276.3 ± 2.8			2 [g]	$1^+, 2^+, 3^+$	0.07
4311.5 ± 2.6			0	$0^+, 1^+$	0.27
4583.8 ± 3.0					
4592.2 ± 2.9					
4730.2 ± 2.9					
4763.8 ± 2.7					
4891.6 ± 2.8					
4898.2 ± 2.8					
5040.2 ± 3.1			1	$0^-, 1^-, 2^-$	
5065.5 ± 3.1					

Table 20.13: States in ^{20}F from ^{19}F(d, p)^{20}F (continued)

E_x (keV) [a]			l_n [d]	J^π [e]	$(2J_f+1)S$ [j]
(1970RO06) [b]	(1969HO20) [c]	(1969HE20) [c]			
5224.0 ± 3.1			1	$0^-, 1^-, 2^-$	
5281.0 ± 3.3			1	$0^-, 1^-, 2^-$	
5317.1 ± 2.7					
5344.5 ± 3.3					
5450.3 ± 3.8					
5455.4 ± 3.2					
5463.4 ± 3.3					
5620.3 ± 3.3					
5762.8 ± 3.4					
5809.1 ± 2.9			(1)	$(0^-, 1^-, 2^-)$	
5933.9 ± 3.3 [f]			1	$0^-, 1^-, 2^-$	
6015.0 ± 3.8 [f]			1 [i]	$0^-, 1^-, 2^-$	
6043.3 ± 3.7					
		(1956EL1A)			
		6.25 ± 20			
		6.52 ± 20			
		6.63 ± 20	1	$0^-, 1^-, 2^-$	
		6.81 ± 20	1	$0^-, 1^-, 2^-$	
		6.98 ± 20	1	$0^-, 1^-, 2^-$	
		7.20 ± 20	1	$0^-, 1^-, 2^-$	

[a] See also (1959AJ76, 1960RI05, 1964LO1A).

[b] From measurements of proton groups.

[c] From measurements of γ-rays.

[d] (1956EL1A): see also (1963RO21, 1964EL01, 1964LO1A, 1966SC09, 1968BI1A, 1970FO1J, 1970SC14, 1970ZA02, 1971LA1F, 1971RO06, 1972LA1N).

[e] J^π derived from I_n measurements only. Unique assignments derived from (p-γ) correlation work are discussed in the text and displayed in Table 20.6.

[f] (1971RO06) find $E_x = 5.932 \pm 0.005$ and 6.013 ± 0.005 MeV, respectively.

[g] (1963RO21): $E_d = 2$ MeV.

[h] (1963RO21) find $l_n = 1$.

[i] (1971RO06).

[j] (1970FO1J) and H.T. Fortune, private communication.

1.35 to 2.00 MeV (1969BA2M), 1.5 MeV (1964LO1A), 2 MeV (1963RO21, 1968BI1A), 2.6 to 4.0 MeV (1970ZA02), 3 MeV (1971LA1F, 1972LA1N), 8.9 MeV (1956EL1A, 1971RO06), 9 and 13 MeV (1966SC09) and 16 MeV (1970FO1J). See also (1959AJ76).

Branching ratio and angular correlation measurements, together with lifetime determinations [see Table 20.14] permit a unique choice of J^π in many cases, from among the J^π values stemming from direct interaction analyses of angular distributions [see Table 20.13]. These J^π values are displayed in Table 20.6 (1969HE20, 1969HO20, 1970HO05, 1970RO06). See also (1964CH21, 1965NE07).

(1970QU1A), using polarized deuterons, have looked at the protons corresponding to ^{20}F*(0.66, 2.04). These two states are found to be populated by a $j = \frac{5}{2}$ neutron transfer. This result, togther with (p-γ) correlation data, provides a unique $J^\pi = 3^+$ assignment for ^{20}F*(0.66) and is in agreement with 2^+ for ^{20}F*(2.04). Transitions to ^{20}F*(2.19, 2.97) appear to be admixed $j = \frac{3}{2}, \frac{5}{2}$ transfer implying $J = 2$ for both these states (1970QU1A). See also (1972HA2H). Comparison of the results of this reaction and of the ^{18}O(^{3}He, p)^{20}F and ^{22}Ne(d, α)^{20}F reactions leads to assignments of $J^\pi = 1^+$ and 0^+ for ^{20}F*(3.49, 3.53) (1971FO14).

See also (1959GO1C, 1960RA23, 1963BO1C, 1967HE1D, 1968CA1E) and (1958SA1A, 1959BO1C, 1959HO1D, 1959SI1A, 1960NA1A, 1962DA06, 1963RO13, 1966NE1C, 1971BU02; theor.).

20. ^{19}F(t, d)^{20}F $\qquad Q_m = 0.344$

See (1963HU1C).

21. ^{19}F(^{19}F, ^{18}F)^{20}F $\qquad Q_m = -3.833$

See (1971GA13).

22. ^{20}O(β^-)^{20}F $\qquad Q_m = 3.815$

See ^{20}O.

23. ^{20}Ne(n, p)^{20}F $\qquad Q_m = -6.244$

See (1971KA18).

24. ^{20}Ne(t, ^{3}He)^{20}F $\qquad Q_m = -7.008$

Table 20.14: Lifetime measurements of some ^{20}F states

^{20}F* (MeV)	τ_m	Refs.
0.66 [a]	0.36 ± 0.07 psec	(1969HE20)
	0.37 ± 0.06 psec	(1970HO05)
	0.42 ± 0.05 psec	A
0.82 [b]	76 ± 20 psec	(1969NI09)
	≥ 4.4 psec	(1969HE20)
	$0.9^{+0.9}_{-0.4}$ psec	(1970HO05)
	79 ± 6 psec	(1971PR10)
0.98	$1.3^{+0.6}_{-0.4}$ psec	(1969HE20)
	1.8 ± 0.4 psec	(1970HO05)
1.06	≤ 92 fsec	(1969HE20)
	45 ± 13 fsec	(1970HO05)
1.31	$1.1^{+0.4}_{-0.3}$ psec	(1969HE20)
	0.8 ± 0.3 psec	(1970HO05)
1.84	30 ± 20 fsec	(1970HO05)
2.04	≤ 38 fsec	(1969HE20)
	37 ± 16 fsec	(1970HO05)
2.19	≤ 46 fsec	(1969HE20)
	< 12 fsec	(1970HO05)
2.97	≤ 62 fsec	(1969HE20)
	60 ± 40 fsec	(1970HO05)
3.49	≤ 47 fsec	(1969HE20)
	44 ± 11 fsec	(1970HO05)
3.53	≤ 32 fsec	(1969HE20)
	30 ± 15 fsec	(1970HO05)
3.59	30 ± 30 fsec	(1970HO05)

A: E.K. Warburton, J.W. Olness, G.A.P. Engelbertink and T.K. Alexander, private communication.

[a] See also (1969NI09).

[b] See also (1971PR10).

Not reported.

25. (a) ^{21}Ne(n, d)^{20}F $\quad Q_{\rm m} = -10.780$
(b) ^{21}Ne(d, ^{3}He)^{20}F $\quad Q_{\rm m} = -7.511$

Not reported.

26. ^{21}Ne(t, α)^{20}F $\quad Q_{\rm m} = 6.809$

Not reported.

27. ^{22}Ne(n, t)^{20}F $\quad Q_{\rm m} = -14.888$

Not reported.

28. ^{22}Ne(p, ^{3}He)^{20}F $\quad Q_{\rm m} = -15.652$

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]. The experimental cross-section ratio, R, for the transitions to ^{20}Ne*(10.28) and ^{20}F(0) [2^{+}; $T = 1$] is 2.00 ± 0.20; R for the transitions to ^{20}Ne*(12.25 ± 0.03) and ^{20}F*(1.82) [(3^{-}); $T = 1$] is 1.40 ± 0.15 (1969HA19). Angular distributions for the ^{3}He ions and the tritons corresponding to the first $T = 2$ states $(J^{\pi} = 0^{+})$ [^{20}Ne*(16.722 ± 0.025) and ^{20}F*(6.513 ± 0.033)] have also 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 18.5 MeV in ^{20}Ne (estomated errors ± 0.1 MeV)] (1964CE05, 1969HA38). See also (1970OL1B).

29. ^{22}Ne(d, α)^{20}F $\quad Q_{\rm m} = 2.701$

At $E_{\rm d} = 10$ MeV, α-particle groups are observed to a number of states below $E_{\rm x} = 6.0$ MeV. ^{20}F*(1.82) was more strongly excited than ^{20}F*(1.84) (1970FO1H). The angular distributions (at $E_{\rm d} = 10$ MeV) of the α-particles corresponding to ^{20}F*(3.49, 3.53) have been measured. ^{20}F*(3.49) is strongly populated and the angular distribution shows direct interaction features while ^{20}F*(3.53) is weakly populated and the angular distribution is roughly symmetric about $90°$. These results are consistent with the assignments $J^{\pi} = 1^{+}$ and 0^{+} for ^{20}F*(3.49, 3.53), respectively (1971FO14): see reactions 8 and 19. See also (1966LA14).

30. ^{23}Na(n, α)^{20}F $Q_{\rm m} = -3.867$

See (1960VA15, 1961WI1B, 1962KA12, 1962KA26, 1963CS1B, 1966WO03) and (1964FA04, 1964MA1N, 1964SA1B; theor.).

^{20}Ne

(Figs. 11 and 13)

GENERAL: (See also (1959AJ76):

Shell model: (1959BR1E, 1960SO1A, 1960TA1C, 1962TA14, 1963FL1A, 1963KE1B, 1963LE1C, 1963SA07, 1964BA1J, 1964BA1K, 1964IN03, 1964KE06, 1964MO1E, 1964PA1D, 1964TA1D, 1965BA1J, 1965DA1D, 1965DE1H, 1965YU1A, 1965ZA1B, 1966BA2E, 1966BA2H, 1966BA2C, 1966BO17, 1966IN01, 1966LO07, 1966RI1F, 1966ZA1E, 1967BA1W, 1967BA1K, 1967BA1V, 1967BO09, 1967EN01, 1967FE01, 1967FL13, 1967GU05, 1967HA1M, 1967LA1H, 1967MU02, 1967PA1P, 1967PA10, 1967PA12, 1967PI1B, 1967ST02, 1967ST1N, 1967ST25, 1967ST26, 1967ST1L, 1967SV1A, 1968AN1G, 1968AR02, 1968BA1L, 1969BO1Y, 1968CO11, 1968DR1B, 1968EL1C, 1968GU1E, 1968GU1C, 1968GU1G, 1968HA17, 1968HA26, 1968HA1P, 1968HE1H, 1968HI1H, 1968MO1G, 1968SA1J, 1968SA10, 1968ST06, 1968WO1A, 1969AB05, 1969AK02, 1969BA2G, 1969BA2J, 1969BA2K, 1969BE1V, 1969CO1M, 1969FA06, 1969FO1E, 1969FO04, 1969GU1E, 1969HA1Z, 1969HA45, 1969JA10, 1969KE1B, 1969KU1H, 1969LA26, 1969LE1Q, 1969MA1T, 1969PA13, 1969SA19, 1969SA1F, 1969SA1A, 1969SV1A, 1969TE04, 1969WO1G, 1969WO06, 1970AN27, 1970AR21, 1970AS1F, 1970BO1J, 1970CA24, 1970EI06, 1970FA1F, 1970FR14, 1970GI1F, 1970GI11, 1970HA49, 1970KH01, 1970KR1D, 1970KU16, 1970MC1J, 1970MC23, 1970NG01, 1970PA15, 1970PA27, 1970RO1B, 1970RU1A, 1970ST1D, 1970SV1B, 1970TE1A, 1970TU01, 1970WA39, 1970WO12, 1971AR05, 1971AR25, 1971AR1R, 1971BO29, 1971FA08, 1971FO19, 1971GU08, 1971GU1N, 1971HA1U, 1971HO23, 1971JE02, 1971KE10, 1971LA13, 1971MA22, 1971RA16, 1971SC01, 1971ST01, 1971WI01, 1971WO13, 1971ZO03, 1972LE1L, 1972RE03).

Collective and deformed models: (1959BE1A, 1960BE1A, 1962TA14, 1963FL1A, 1963KE1B, 1963LE1C, 1964BA1J, 1964BA1K, 1964KE06, 1966AB04, 1966BO17, 1967BA1V, 1967BE1V, 1967DA1G, 1967FE01, 1967KE1H, 1967KR1E, 1967LA1G, 1967PA12, 1967PA1M, 1967RI1B, 1967ST25, 1967ST1L, 1968CO11, 1968HO1G, 1968RI1M, 1968SA10, 1968ST06, 1968UN1A, 1969AB05, 1969AK02, 1969BA2G, 1969BE1V, 1969DA14, 1969HA45, 1969LE1Q, 1969VO1E, 1969WO06, 1970FA1F, 1970FR14, 1970GO1Q, 1970KH01, 1970NG01, 1970PA15, 1970RI1C, 1970SV1B, 1970VO01, 1971AR1R, 1971BO29, 1971CH22, 1971DE1R, 1971HO19, 1971HO23, 1971KE10, 1971MI02, 1971PI02, 1971ST01, 1971ZO03, 1971ZO01, 1972AB1C, 1972LE1L).

Cluster and α-particle models: (1959BE1A, 1960BE1A, 1960SH1A, 1962BO23, 1962VA1D, 1964MA1G, 1965IN1A, 1965NE1C, 1966HA33, 1966KA1A, 1968AB1B, 1968PI1A, 1968TA1G, 1969AB1B, 1969BA2E, 1969BA2L, 1969CH1P, 1969HI1B, 1969SM1A, 1969WE1J, 1970BA2B, 1970BA2H, 1970BR35, 1970EI06, 1971CH22, 1971FR06, 1971HA44, 1971KH06, 1971MC1F, 1972AB1C).

Astrophysical questions: (1961GO1G, 1963DU1C, 1970BA1M).

Giant resonances (See also reactions 30 and 32.): (1963MI1B, 1965DA1D, 1965GR1H, 1966BA2F, 1967BE1V, 1969HA1Y, 1969HO1W).

Table 20.15: Energy levels of ^{20}Ne [a]

E_x (MeV ± keV)	$J^\pi; T$	K^π	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
0	0^+; 0	0^+		stable	1, 2, 3, 4, 5, 6, 8, 13, 14, 16, 19, 20, 26, 27, 28, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 45, 46, 47, 48, 49, 50, 51
1.6338 ± 0.4	2^+; 0	0^+	$\tau_m = 1.20 \pm 0.15$ psec	γ	3, 4, 8, 13, 14, 15, 16, 18, 19, 20, 26, 27, 28, 29, 36, 37, 39, 40, 42, 43, 44, 45, 46, 47, 50
4.2473 ± 1.8	4^+; 0	0^+	$\tau_m = 93 \pm 9$ fsec	γ	3, 4, 8, 13, 14, 16, 18, 19, 20, 26, 27, 28, 36, 37, 39, 40, 44, 45, 46, 47, 50
4.9682 ± 0.8	2^-; 0	2^-	$\tau_m = 4.8 \pm 0.5$ psec	γ	3, 4, 13, 19, 20, 26, 27, 28, 29, 36, 40, 44, 45, 47, 50
5.6217 ± 2.0	3^-; 0	2^-	$\tau_m = 200 \pm 50$ fsec	γ, α	3, 4, 8, 13, 14, 18, 19, 20, 26, 27, 28, 36, 37, 40, 45, 47, 50
5.785 ± 3	1^-; 0	0^-	$\Gamma > 1.3 \times 10^{-2}$	γ, α	3, 8, 13, 14, 18, 19, 20, 27, 28, 37, 40, 45, 50
6.722 ± 3	0^+; 0	0^+	15 ± 7	γ, α	3, 8, 9, 13, 19, 26, 27, 28, 45
7.0055 ± 2.8	4^-; 0	2^-	$\tau_m = 440 \pm 90$ fsec	γ	3, 4, 13, 27, 28
7.166 ± 4	3^-; 0	0^-	$\Gamma = 8$	α	3, 9, 13, 14, 27, 28, 40
7.196 ± 4	0^+; 0		4	γ, α	3, 8, 9, 13, 14, 27, 28, 37
7.424 ± 4	2^+; 0	0^+	8	α	3, 9, 26, 27, 36, 43
7.834 ± 4	2^+; 0		2	α	3, 9, 19, 26, 36, 43
8.447 ± 3	5^-; 0	2^-		γ, α	3, 8
≈ 8.6	0^+; 0		> 800	α	9
8.72 ± 20	1^-; 0		2.5	α	3, 9, 43
8.7750 ± 2.2	6^+; 0	0^+	0.110 ± 0.025	γ, α	3, 8, 9, 13, 19, 36

Table 20.15: Energy levels of ^{20}Ne [a] (continued)

E_x (MeV ± keV)	$J^\pi; T$	K^π	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
≈ 8.8	2^+; 0		> 800	α	9
8.82	(5^-); 0		< 1	α	9
8.850 ± 5	1^-; 0		19	α	3, 9
9.040 ± 5	4^+; 0	0^+	≤ 3	γ, α	3, 8, 9, 19
9.117 ± 5	3^-; 0		3.2	α	3, 9, 26, 36
(9.34 ± 30)					3, 26
9.489 ± 9	2^+; 0		29 ± 15	γ, α	3, 8, 9, 43
9.950 ± 6	(1^+)		$\tau_m < 35$ fsec	γ	3, 19
9.99 ± 10	4^+; 0		$\Gamma = 150 \pm 50$	γ, α	8, 9, 19, 26, 36
10.257 ± 5	5^-; 0	0^-	141	α	9
10.26 ± 20	2^+; 1		$\lesssim 2$	γ, α	3, 8, 19, 26, 43
10.401 ± 5	3^-; 0		81	α	9
10.548 ± 5	4^+; 0		16	α	3, 9
10.579 ± 10	2^+; 0		24	α	3, 9
10.609 ± 7	6^-; 0	2^-	$\tau_m = 23 \pm 7$ fsec	γ	3
10.79 ± 100	4^+; 0		$\Gamma = 350$	α	9
10.836 ± 5	2^+; 0		13	α	9, 43
10.836	3^-; 0		45	α	9
10.853 ± 10	(1, 2, 3)$^+$; 1				19, 26
10.920 ± 7			$\tau_m < 30$ fsec	γ	3
10.97 ± 150	0^+; 0		$\Gamma = 580$	α	9
11.015 ± 10	4^+; 0		24	α	9
11.08 ± 20	(4^+; 1)		$\lesssim 3$	γ, α	8, 26
11.23 ± 30	1^-; 0		172	α	9
11.233 ± 10	1^+; 1			γ	20, 26, 34, 45
11.27 ± 30	2^+		$\lesssim 4$	γ, α	8, 43
11.324 ± 10	2^+; 0		53	α	9
11.528 ± 6	≤ 4		$\tau_m < 30$ fsec	γ, α	3, 8, 19
11.549 ± 10	($T = 1$)				26, 34
11.871 ± 20	2^+; 0		$\Gamma = 46$	α	9

Table 20.15: Energy levels of ^{20}Ne [a] (continued)

E_x (MeV $\pm$ keV)	$J^\pi; T$	K^π	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
11.925 ± 5	4^+; 0		0.44 ± 0.15	α	9, 26
11.948 ± 5	8^+; 0	0^+	$(35 \pm 10) \times 10^{-3}$	α	3, 8, 9, 13
11.953 ± 10	1^-; 0		24	α	9
11.971 ± 8	1^-; 0		29 ± 8	α	9
12.086 ± 10	$(T = 1)$			(α)	9, 26
12.150 ± 10	6^+; 0		< 40		3, 26
(12.200 ± 10)	$(T = 1)$				26
12.224 ± 10	4^+; 0		142	α	9
12.245 ± 15	(2^+); 1		40 ± 16	γ, α	8, 20, 26
12.35 ± 100	2^+; 0			α	9
12.367 ± 10	3^-; 0		46 ± 16	α	9, 26
12.410 ± 5	0^+; 0		≤ 8	α	9, 19, 26
12.559 ± 10	6^+; 0		101	α	3, 9
12.61 ± 100				α	9
12.682 ± 15	5^-; 0		97	α	9
12.77 ± 100	4^+; 0		100	α	9
12.83 ± 30			55	α	9, 19
12.98 ± 75	$(4^+; 0)$		60	α	9
13.060 ± 4	2^-		1.0	p, α	32
13.086 ± 15	$(4^+; 0)$		70	α	9, 26
13.168 ± 1	1^+; (1)		2.3 ± 0.2	γ, p, α	20, 21, 22, 26
13.18 ± 75	$(4^+; 0)$		60	α	9
13.224	1^-		95	p, α	22
13.224	0^+		95	p, α	22
13.304 ± 1	1^+		0.9 ± 0.1	γ, p, α	20, 21, 22
13.333 ± 6	7^-; 0	2^-	$(80 \pm 30) \times 10^{-3}$	α	3, 9
13.342	4^+; 0		20	α	9
13.411	2^-		35	γ, p, α	9, 20, 21, 22
13.42 ± 140	$(4^+; 0)$		110	α	9
13.462 ± 20	1^-		190	p, α	22

Table 20.15: Energy levels of ^{20}Ne [a] (continued)

E_x (MeV $\pm$ keV)	$J^\pi; T$	K^π	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
13.479 ± 1.5	$1^+; 1$		7.1	γ, p, α	19, 20, 21, 22, 26
13.523	(1^-)		30	p, α	21, 22
13.541	2^+		63	p, α	22
13.584	2^+		≈ 10	p, α	21, 22
13.63 ± 30			7.9	p	19, 21
13.650 ± 15	$0^+; 1$		22	p, α	21, 22, 26
(13.66)	1^-		115	p, α	22
13.673 ± 1	2^-		4.5 ± 0.2	γ, p, α	20, 21, 22
13.699			4.6	p	21
13.7 ± 400	$(3, 7)^-$		320	α	9
(13.73)	0^+		170	p, α	22
13.733 ± 1.5	1^+		7.7 ± 0.5	γ, p, α	20, 21, 22
13.775				γ, p	20
(13.87)	(1^-)		190	p, α	22
13.88 ± 30	(6^+)		100	α	9, 13
13.882 ± 15			≈ 1	γ, p	20, 21, 26
13.903	2^+		48	p, α	32
13.924			3.5	p	21
13.946	0^+		≈ 70	p, α	22
14.017	1^-		≈ 70	p, α	21, 22
14.03	2^+		≈ 140	p, α	22
14.065			18	γ, p	20, 21
14.098			3.8	γ, p	20
14.124 ± 1.2	2^-		4.7 ± 0.7	γ, p, α	9, 20, 21, 22
14.134	2^+		51	p, α	22
14.148 ± 1.2	2^-		11.8 ± 1.0	γ, p, α	20, 21, 22
14.197	1^+		13.9 ± 1	γ, p	20, 21
14.3 ± 300	6^+		240	α	9, 13
14.373			≈ 5	p	21
14.421				p	21

Table 20.15: Energy levels of ^{20}Ne [a] (continued)

E_x (MeV ± keV)	$J^\pi; T$	K^π	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
14.453 ± 2			33 ± 3	p, α	21, 22
14.467	0^+		135	p, α	22
14.6 ± 300	(4^+)		240	α	9
14.604	1^-		125	p, α	22
14.695 ± 2.6	(1^+)		38 ± 10	p, α	21, 22
14.772 ± 3.0			95 ± 20	p, α	21, 22
14.85 ± 150	$(2^+, 4^+)$		≈ 100	p, α	9, 22
15.03 ± 150	(2^+)		≈ 90	p, α	9, 22
15.18 ± 40	9^-				3
15.23			28	p, α	22
15.26	(1^-)		285	p, α	13, 22
15.30	(0^+)		285	p, α	22
15.39			76	p, α	22
15.44			57	p, α	22
15.52			150	p, α	22
15.59				α	9
15.618	(8^-)	2^-			3
15.71			28	α	9, 22
15.9 ± 40	5^-			(α)	3, 9, 22
15.9 ± 40	8^+			(α)	3, 9, 22
16.02			100	p, α	22
16.24				α	9
16.34			(100)	p, α	9, 22
16.49				p, α	9, 22
16.59			125	p, α	9, 22
16.728 ± 4	$0^+; 2$		2.0 ± 0.5	γ, p, α	19, 20, 21, 22, 45
16.77			100	p, α	22
16.98			100	n, p, α	22, 23
17.08 [b]			90	n, p, α	22, 23

Table 20.15: Energy levels of ^{20}Ne [a] (continued)

E_x (MeV ± keV)	$J^\pi; T$	K^π	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
17.30			60	n, p, α	22, 23
17.50			86	n, p, α	22, 23
17.58			38	n, p, α	22, 23
17.76			180	p, α	9, 22
18.08 ± 180	(6^+, 7^-)		140	n, p, α	3, 9, 23
18.31 ± 300	(6^+)		240	n, p, α	9, 23
18.426 ± 5	$2^+; T = 2$		10 ± 3	γ, n, p, α	20, 21, 22, 23, 45
18.7	(6^+)		600	α	9
19.16 ± 250	(6^+)		200	α	9
19.40 ± 350	6^+		280	α	9
19.84 ± 350	6^+		280	α	9
20.16 ± 120	7^-		250	α	9
20.4 ± 180	6^+		360	α	9
20.4 ± 100	7^-		200	α	9
20.68 ± 60	9^-		120	α	9
20.9				α	9
21.0	7^-		200	α	9
21.08 ± 40	9^-		80	α	9
21.3	7^-		300	α	9
21.8 ± 200	7^-		300	α	9
22.3 ± 200	7^-		500	α	9
22.7 ± 250	9^-		500	α	9
22.84 ± 125	9^-		250	α	9
23.4 ± 250	8^+		500	α	9
24.11 ± 150	8^+		350	α	9
25.0 ± 300	8^+		600	α	9
25.7 ± 200			400	α	9
27.2 ± 350			700	α	9
28.	8^+		1600	^{3}He, α	9, 17
28.2 ± 350			700	α	9

[a] See also Tables 20.17 and 20.18.

[b] Additional states with $E_{\rm x} > 17.1$ MeV are reported in reaction 23: see Table 20.30.

Electromagnetic transitions: (1965GR1H, 1965NE1C, 1965ST22, 1967GU1D, 1967HS1A, 1967KA06, 1967KU1E, 1968AN1G, 1968EL1C, 1968GU1G, 1968HA17, 1969AB05, 1969AK02, 1969BE1V, 1969CU07, 1969FO1E, 1969HA1Y, 1969HA1Z, 1969HA1F, 1969HI1B, 1969JA10, 1969LA26, 1970AN27, 1970HA49, 1971AR05, 1971AR25, 1971FO19, 1971GU1N, 1971HA44).

Special levels: (1960SH1A, 1961BA1D, 1961TR1B, 1964BA1J, 1964BA1K, 1964EN1A, 1964MI16, 1964TA1D, 1966BA42, 1966BO17, 1966BR1H, 1966LO07, 1966ZA1E, 1967EN01, 1968AN1G, 1968AR02, 1968HA1P, 1968SA1J, 1969AK02, 1969BO1Z, 1969HA1Y, 1969HA1G, 1969HA1F, 1969JA10, 1969ST1J, 1969TE04, 1969WO06, 1970AN27, 1970AR21, BA70W, 1970GO1Q, 1970HO17, 1970RO1B, 1970RU1A, 1970TE1A, 1971AR1R, 1971BO1F, 1971FA08, 1971GU08, 1971LE30, 1971SE1C, 1971ST36).

Special reactions: (1960AN1A, 1960LE1A, 1970BE1D, 1970HU07, 1971AR02).

Pion and kaon capture and reactions: (1970GA1K).

Other topics: (1960EV1A, 1960SO1A, 1961BA1D, 1962CH12, 1963DA1C, 1963EV01, 1964AB1A, 1964BR1H, 1964EN1A, 1964IN03, 1964KA1A, 1964MO1E, 1965DE1H, 1965YO1A, 1966DA1E, 1966GI1A, 1966IN01, 1966SU1D, 1966YO1B, 1967AB03, 1967BA1W, 1967BR1G, 1967FL13, 1967GU05, 1967GU1D, 1967KA06, 1967KE1H, 1967PA1P, 1967ST02, 1967ST1N, 1967ST25, 1967ST26, 1968DA1P, 1968DR1B, 1968DW1A, 1968FL1C, 1968GU1E, 1968GU1C, 1968GU1G, 1968HE1H, 1968MO1G, 1968PA1Q, 1968SA10, 1968TA1G, 1968WO1A, 1969BA2G, 1969BA2J, 1969BA2K, 1969BO1Z, 1969DE15, 1969KE1B, 1969LA26, 1969MA1T, 1969RU04, 1969SH1E, 1969SO08, 1969WO06, 1970BO1J, 1970DA13, 1970FO1K, 1970GM1A, 1970GO1R, 1970PA15, 1970RU1A, 1970RU1B, 1970ST19, 1970TU01, 1970VO01, 1971FA13, 1971FO04, 1971FR1B, 1971GO36, 1971HA14, 1971HO19, 1971HO23, 1971JE02, 1971LA13, 1971MI02, 1971SC01, 1971SE1C, 1971ST01, 1971ZO03, 1972LE1L, 1972RE03).

Ground state: $J = 0$ (1960LU06);

$\mu < 4 \times 10^{-4}$ nm (1960LU06); see also (1964LI14).

See also (1967BA1V, 1967GU1D, 1967LA1G, 1967SH14, 1967ST26, 1968EL1C, 1968RI1M, 1969BA2J, 1969CO1M, 1969FO1E, 1969FO04, 1969FU11, 1969HI1B, 1969KE1B, 1969LA26, 1969SA19, 1969SA1F, 1970GO1R, 1970KH01, 1970RU1B, 1970ST19, 1970TU01, 1970VO01, 1971AR25, 1971BO29, 1971FO19, 1971GU1N, 1971LA13, 1971RA16, 1971SC01, 1971ST01, 1971TE1C, 1971WI01, 1971ZO03, 1972LE1L).

$Q(^{20}\mathrm{Ne}^*(1.63)) = -0.24 \pm 0.03$ b (1970NA07);

$B(\mathrm{E2})(0^+ \rightarrow 2^+) = 0.048 \pm 0.007\ e^2 \cdot \mathrm{b}^2$ (1970NA07).

1. ^{9}Be(^{14}N, t)^{20}Ne $Q_{\rm m} = 6.304$

See (1958GO71).

2. ^{10}B(^{14}N, α)^{20}Ne $Q_{\rm m} = 19.534$

See (1970IS1A).

3. ^{12}C(^{12}C, α)^{20}Ne $Q_{\rm m} = 4.618$

Particle group and γ-ray energy measurements have been made for many states of ^{20}Ne: see Table 20.16 (1961AL12, 1964PE02, 1966KU03, 1967KU04, 1970PA08, 1971HA26, 1971MI09, 1971MI1J, 1971PA1C, 1971SC12). Angular correlation (1961GO12, 1962KU03, 1964KU03, 1966KU03, 1967KU04, 1967SM04, 1971SC12) and γ-ray branching measurements [see Table 20.17] (1964BR18, 1967BR22, 1967SM04, 1971HA26) lead to the J^{π} assignments shown in Table 20.16, which also show level assignments to rotational bands. See also (1962BR35, 1964AL15, 1966BR1T).

At $E(^{12}\text{C}) = 22.0$ to 35.0 MeV the α-spectra are dominated by the group corresponding to the 2^{+} state at $E_{\rm x} = 7.83$ MeV. Both ^{20}Ne*(7.83) and ^{20}Ne*(7.20) [$J^{\pi} = 0^{+}$] are much more strongly excited than the 0^{+} and 2^{+} states at $E_{\rm x} = 6.72$ and 7.42 MeV. At $E(^{12}\text{C}) = 25$ and 27 MeV, the distributions of the α-particles to ^{20}Ne*(7.83) is barely oscillatory and is strongly forward peaked, indicating a direct interaction, while the distributions to ^{20}Ne*(7.42) are compound nuclear in character. This is consistent with the hypothesis that ^{20}Ne*(7.20, 7.83) are quartet states of the configuration (220) [two sd-shell α-particles outside a ^{12}C core], populated via a "semi-direct" mechanism that proceeds through the formation of doorway states in the incident channel (1971MI09). See also (1970AR21, 1971MI1J, 1971MI11). At $E(^{12}\text{C}) = 50$ MeV, compound nucleus formation dominates (1971HA1D). Angular distributions are also reported at $E(^{12}\text{C}) = 5.6$ to 6.2 MeV (1963AL07; $\alpha_0 \rightarrow \alpha_3$, α_{4+5}), 10.6 to 12.4 MeV (1963KU05; α_0), 12.5 MeV (1961PO13; α_0, α_1), ≈ 20.0 to ≈ 28.4 MeV (1964BO35; α_0), 20.3 to 25.6 MeV (1964AL17, 1964VO03; α_0, α_1), 21.5 to 28.3 MeV (1964BO35; α_1) and 50 MeV (1970PA08, 1971PA1C; α_0, α_5, α_{10}). See also (1972NO01; theor.).

(1969PA22) have studied the yield of this reaction to permit predictions of the cross section in the energy region of interest in stellar carbon burning. The importance of this reaction for astrophysical work is discussed by (1969AR1F). See also ^{24}Mg in (1973ENVA).

For lifetime measurements, see Table 20.18 (1962BR35, 1965EV03, 1971HA26). See also (1961CL06).

See also (1959AL1H, 1960AL05, 1961LI07, 1961LI17, 1961SE1C, 1968JA1F, 1970MA1D, 1971HA1D, 1971MA1E), (1966KU1D) and (1961LI06, 1965BO1H, 1966ER1A, 1967VO1B, 1968GA1J).

Table 20.16: Excited states of ^{20}Ne from ^{12}C(^{12}C, α)^{20}Ne

E_x (MeV ± keV)							$\Gamma_{c.m.}$	J^{π} [e]	K^{π}
(1961AL12) [a]	(1964PE02) [a]	(1967KU04) [a]	(1971HA26) [b]	(1971MI09) [a,c]	(1971PA1C) [a,d]	(1971SC12) [a]	(keV)		
			1.6329 ± 1.0					2^+	0^+
4.25 ± 20	4.25 ± 20		4.2456 ± 2.5					4^+	0^+
4.97 ± 20	4.97 ± 20		4.9663 ± 2.5					2^-	2^-
5.64 ± 20	5.62 ± 20		5.618 ± 4					3^-	2^-
5.81 ± 20	5.79 ± 20							1^-	0^-
6.17 ± 20									
6.74 ± 20	6.71 ± 20			6.722 ± 4				0^+	
6.87 ± 20									
7.05 ± 20	7.02 ± 20		7.004 ± 4	7.007 ± 4				4^-	2^-
7.19 ± 20	7.17 ± 20			7.159 ± 4		7.15 ± 60		3^-	0^-
7.25 ± 20	7.21 ± 20			7.195 ± 4				0^+	
7.46 ± 20	7.43 ± 20			7.421 ± 4				2^+	
7.65 ± 20									
7.86 ± 20	7.85 ± 20			7.833 ± 4		7.83 ± 60		2^+	
7.93 ± 20									
8.52 ± 20	8.46 ± 20		8.446 ± 9					5^-	2^-
	8.71 ± 20					8.73 ± 60		1^-	
	8.79 ± 20								
8.92 ± 20	8.87 ± 20								
	9.04 ± 20								
	9.11 ± 20								
	(9.31 ± 20)								
	9.48 ± 20								
			9.950 ± 6						

Table 20.16: Excited states of ^{20}Ne from ^{12}C(^{12}C, α)^{20}Ne (continued)

E_x (MeV $\pm$ keV)							$\Gamma_{c.m.}$	J^{π} [e]	K^{π}
(1961AL12) [a]	(1964PE02) [a]	(1967KU04) [a]	(1971HA26) [b]	(1971MI09) [a,c]	(1971PA1C) [a,d]	(1971SC12) [a]	(keV)		
	10.24 ± 20							(1^+)	
		10.57 ± 40					< 40	4^+	
		(10.65)	10.609 ± 7					6^-	2^-
			10.920 ± 7						
			11.528 ± 6						
		11.99 [f,g]						8^+	0^+
		12.19 ± 40					< 40	6^+	
						12.5 ± 300		6^+	
		13.39 ± 40				13.43 ± 60	< 40	7^-	2^-
					15.18 ± 40			9^-	
					15.62 ± 30		≤ 23	(8^-)	2^-
					15.9 ± 40			5^-	
					15.9 ± 40			8^+	
					17.4		≤ 23	$8 < J < 12$	
					18.15 ± 40		≤ 40	7^-	

[a] From measurements of particle groups.

[b] From measuremenets of γ-rays.

[c] See also (1971MI1J).

[d] A.D. Panagiotou, private communication; see also (1970PA08).

[e] From work done with this reaction.

[f] (1966KU03).

[g] See also (1971MA23).

Table 20.17: Radiative decays in ^{20}Ne [a]

E_i (MeV)	$J^{\pi}_i; T$	E_f (MeV)	Branch (%)	Γ_γ (meV)	$\|M\|^2$ (W.u.)	Refs.
1.63	$2^+; 0$	0	100		17.8 ± 2.5	(1971HA26)
4.25	$4^+; 0$	1.63	≈ 100		21.9 ± 2.1	(1971HA26)
4.97 [d]	$2^-; 0$	0	0.6 ± 0.2		2×10^{-3}	(1967BR22)
					$(2.5 \pm 0.9) \times 10^{-3}$	(1971HA26)
		1.63	99			(1967BR22)
					$(1.7 \pm 0.7) \times 10^{-2}$ [b]	(1971HA26)
					$(7.0 \pm 1.0) \times 10^{-6}$ [c]	(1971HA26)
5.62 [e]	$3^-; 0$	0	7.6 ± 1.0			(1964BR18)
					10.6 ± 2.7	(1971HA26)
		1.63	87.6 ± 1.0			(1964BR18)
					$(6.6 \pm 1.5) \times 10^{-6}$	(1971HA26)
		4.97	4.8 ± 1.6		35 ± 9	(1971HA26)
5.79 [f]	$1^-; 0$	0	18 ± 5		7.2×10^{-6}	(1965VA14)
		1.63	82 ± 5	4.0	9.2×10^{-5}	(1965VA14)
6.72	$0^+; 0$	1.63	100	33	3.8	(1965VA14)
7.01 [g]	$4^-; 0$	1.63	0.5 ± 0.2			(1967BR22)
		4.25	63.5			(1967BR22)
					$(1.7 \pm 0.4) \times 10^{-5}$	(1971HA26)
		4.97	11			(1967BR22)
					10.4 ± 1.8	(1971HA26)
		5.62	25			(1967BR22)
					24 ± 5	(1971HA26)
7.20	$0^+; 0$	1.63				(1969GR03)
8.45	$5^-; 0$	5.62	100	13 ± 3	26 ± 6	(1971RO33)
8.78 [h]	$6^+; 0$	4.25	100	100 ± 15	20.4 ± 2.4	(1971DI08, 1971RO13)
9.04	$4^+; 0$	1.63	(100)	0.38 ± 0.05	7.0	(1964PE05)
9.49	$2^+; 0$	0		$\lesssim 0.06$	$\lesssim 0.3$	(1964PE05)
		1.63	(100)	0.26 ± 0.1	3.2 (E2), 0.03 (M1)	(1964PE05)
9.95	$(1^+); 0$	1.63	> 90			
9.99	$4^+; 0$	0		$\lesssim 0.07$		(1964PE05)
		1.63	(100)	0.9 ± 0.4	6.9	(1964PE05)
10.26	$2^+; 1$	0		0.19 ± 0.05	0.6	(1964PE05)

Table 20.17: Radiative decays in ^{20}Ne [a] (continued)

E_i (MeV)	$J^\pi_i; T$	E_f (MeV)	Branch (%)	Γ_γ (meV)	$\lvert M\rvert^2$ (W.u.)	Refs.
		1.63		5.6 ± 0.6	0.41 (M1), 0.017 (E2)	(1964PE05)
		4.97		$\lesssim 0.44$	$\lesssim 0.006$	(1964PE05)
10.61 [i]	$6^-; 0$	7.01	95.5 ± 1.2		17^{+7}_{-4}	(1971HA26)
		8.45	4.5 ± 1.2		10 ± 4	(1971HA26)
10.92		1.63	25 ± 5			(1971HA26)
		4.25	75 ± 5			(1971HA26)
11.08	$(4^+; 1)$	1.63		$\lesssim 0.08$	$\lesssim 0.4$	(1964PE05)
		4.25	(100)	4.8 ± 0.5	0.72 (M1), 7.3 (E2)	(1964PE05)
		7.01		$\lesssim 1.4$	$\lesssim 0.04$	(1964PE05)
11.23	$1^+; 1$	0	(100)			(1964PE05)
11.53	≤ 4	4.25	34 ± 6			(1971HA26)
		4.97	66 ± 6			(1971HA26)
11.95	$8^+; 0$	8.78	100		7.5 ± 2.5	(1972AL05)
12.25	$(2^+); 1$	1.63	(100)			(1964PE05, 1968LA1H)
13.48	$1^+; 1$	1.63	95			(1961GO21)
		4.97	5			(1961GO21)
13.88		1.63	20			(1961GO21)
		4.97	80	[k]		(1961GO21)
16.73	$0^+; 2$	11.23	(100)	≈ 5000		(1967KU06)
18.43	$2^+; 2$	12.25	(100)	≈ 300		(1968LA1H)

[a] See also (1961CL06, 1962EI04, 1965EV03).
[b] If M2.
[c] If E2.
[d] See also (1960KA18, 1961GO21).
[e] See also (1964AL15, 1965VA14).
[f] See also (1964AL15).
[g] See also (1962BR35, 1966BR1T, 1967SM04).
[h] See also (1967LI07).
[i] See also (1967SM04).
[j] See also (1964PE05). Note: this footnote is not labeled in the tablular.
[k] See Table 20.23.

Table 20.18: Lifetime measurements of some ^{20}Ne states [a]

^{20}Ne* (MeV)	$\tau_{\rm m}$	Refs.
1.63 [b]	1.23 ± 0.12 psec	(1965EV03)
	1.15 ± 0.20 psec	(1971HA26)
	1.20 ± 0.15 psec	'best' value (1971HA26)
4.25 [c]	134 ± 12 fsec	(1965EV03)
	150 ± 25 fsec	(1969AN08, 1969AN1J)
	93 ± 9 fsec	(1971HA26)
	93 ± 9 fsec	'best' value
4.97 [c]	$2.8^{+2.4}_{-0.9}$ psec	(1969AN08, 1969AN1J)
	$4.8^{+1.7}_{-1.1}$ psec	(1965EV03)
	4.8 ± 0.5 psec	(1971HA26)
	4.8 ± 0.5 psec	'best' value
5.62	350 ± 75 fsec	(1965EV03)
	200 ± 50 fsec	(1971HA26)
	200 ± 50 fsec	'best' value
7.01	405^{+110}_{-90} fsec	(1962BR35)
	470 ± 90 fsec	(1971HA26)
	440 ± 90 fsec	mean value
9.95	< 35 fsec	(1971HA26)
10.61	23 ± 7 fsec	(1971HA26)
10.92	< 30 fsec	(1971HA26)
11.53	< 30 fsec	(1971HA26)

[a] See also (1964LI1B).
[b] See also (1956DE22, 1959AL91, 1961CL06, 1969AN08, 1969AN1J, 1969GR03, 1969TH01).
[c] See also (1961CL06).

4. ^{12}C(^{14}N, ^{6}Li)^{20}Ne $\qquad Q_{\rm m} = -4.182$

At $E(^{14}{\rm N}) = 52$ and 60 MeV the reaction appears to proceed via the direct transfer of eight nucleons. Angular distributions have been reported for the ^{6}Li ions corresponding to ^{20}Ne*(0, 1.63, 4.25, 4.97, 5.62, 7.01) (1971MA23). Assignment of observed states to rotational bands is discussed by (1971MA23, 1971NA17).

5. ^{12}C(^{16}O, ^{8}Be)^{20}Ne $\qquad Q_{\rm m} = -2.637$

See (1963GO27, 1971GO1M).

6. ^{12}C(^{19}F, ^{11}B)^{20}Ne $\qquad Q_{\rm m} = -3.112$

See (1967BO1P, 1971BO1V). See also (1969VO1D).

7. (a) ^{14}N(^{6}Li, p)^{19}F $\qquad Q_{\rm m} = 11.148 \qquad E_{\rm b} = 23.994$
(b) ^{14}N(^{6}Li, d)^{18}F $\qquad Q_{\rm m} = 2.943$
(c) ^{14}N(^{6}Li, α)^{16}O $\qquad Q_{\rm m} = 19.263$
(d) ^{14}N(^{6}Li, αn)^{15}O $\qquad Q_{\rm m} = 3.594$

Yield curves have been measured for $E(^{6}{\rm Li}) = 4.1$ to 6.3 MeV for the protons to ^{19}F*(2.78), and the d_0 and α_0 groups: no structure is apparent (1968RI13). See also (1961NO05).

8. ^{16}O(α, γ)^{20}Ne $\qquad Q_{\rm m} = 4.730$

Observed resonances in the yield of capture γ-rays over the range $E_\alpha = 0.8$ to 10 MeV are displayed in Table 20.19 (1964PE05, 1965VA14, 1967LI07, 1969GR03, 1972AL05, 1971DI08, 1971RO13, 1971RO33, 1971TO06, 1971TO1C). Information on the character of the radiative decay is shown in Table 20.17.

No resonances have been observed below $E_\alpha = 1$ MeV: for $E_{\rm res} < 0.85$ MeV, $(2J+1)\Gamma_\alpha\Gamma_\gamma/\Gamma \leq 0.044$ eV, and $(2J+1)\Gamma_\alpha\Gamma_{\gamma_1}/\Gamma \leq 0.031$ eV; for $E_{\rm res} < 1.00$ MeV, $\omega\gamma \leq 0.036$ eV and $\omega\gamma_1 \leq 0.024$ eV (1971TO06, 1971TO1C). The astrophysical implications of this reaction are discussed in (1970TO1F, 1971TO06, 1971TO1C). See also (1957BU1B) and (1965ME10, 1967WI1B).

The $J^\pi = 5^-$ states at $E_{\rm x} = 8.45$ MeV [$E_\alpha = 4.65$ MeV] decays by an E2 transition [$|M|^2 =$

Table 20.19: Resonances in $^{16}O(\alpha, \gamma)^{20}Ne$ [a]

E_α (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	$\omega\gamma$ [a] (eV)	E_x (MeV)	$J^\pi; T$	Refs.
1.116 ± 4	2.6×10^{-6} [b]	$(1.7 \pm 0.3) \times 10^{-3}$	5.623	$3^-; 0$	(1965VA14, 1971TO06, 1971TO1C)
1.319 ± 3	$> 1.3 \times 10^{-2}$ [b]	$(14 \pm 3) \times 10^{-3}$	5.785	$1^-; 0$	(1965VA14, 1971TO06, 1971TO1C)
2.490 ± 8	15 ± 7 [b]	$(38 \pm 10) \times 10^{-3}$	6.722	$0^+; 0$	(1965VA14, 1971TO06, 1971TO1C)
3.09			7.20	$0^+; 0$	(1969GR03)
4.647 ± 3			8.447	$5^-; 0$	(1971RO33)
5.06	< 3	1.35 ± 0.15	8.775 ± 0.0032	$6^+; 0$	(1967LI07, 1971DI08, 1971RO13)
5.374 ± 9	$\lesssim 3$	3.4 ± 0.4	9.028	$4^+; 0$	(1964PE05)
5.94 ± 30	29 ± 15	1.3 ± 0.5	9.48	$2^+; 0$	(1964PE05)
6.61 ± 30	155 ± 30	8 ± 3	10.02	$(4^+); 0$	(1964PE05)
6.930 ± 10	≤ 2	28 ± 3	10.272	$2^+; 1$	(1964PE05)
7.94 ± 20	≤ 3	46 ± 5	11.08	$(4^+; 1)$	(1964PE05)
8.17 ± 30	≤ 4	0.9 ± 0.4	11.26	$(1^-$ or $2^+)$	(1964PE05)
8.54 ± 40		0.5 ± 0.3	11.56	≤ 4	(1964PE05)
[c]		0.104 ± 0.035	11.948	$8^+; 0$	(1972AL05)
9.40 ± 40	40 ± 16	7 ± 3	12.25	≤ 4	(1964PE05)

[a] See also Table 20.17.

[b] This is also Γ_α.

[c] $E(^{16}O) \approx 36.05$ MeV.

26 ± 6 W.u.] to the 3^- state at $E_x = 5.62$ MeV (1971RO33). The $J^\pi = 6^+$ state at $E_x = 8.78$ MeV [$E_\alpha = 5.06$ MeV] decays by an E2 transition [$|M|^2 = 20.4 \pm 2.4$ W.u.] to the 4^+ state at $E_x = 4.25$ MeV (1971DI08, 1971RO13). The $J^\pi = 8^+$ state at $E_x = 11.95$ MeV decays by an E2 transition to the $E_x = 8.78$ MeV [$J^\pi = 6^+$] state which then decays via the 4^+ and 2^+ members of the ground state rotational band. The transition probability of the $8^+ \to 6^+$ transition is 7.5 ± 2.5 W.u. which establishes ^{20}Ne*(11.95) as the 8^+ member of the ground state band. The experimental E2 transition probabilities in the ground state band deviate strongly from those predicted by the pure rotational model but agree reasonably well with simple shell model predictions (1972AL05).

The lifetime of ^{20}Ne*(1.63), τ_m, is 0.84 ± 0.20 psec (1969GR03): see also Table 20.18.

9. (a) ^{16}O(α, α)^{16}O — $E_b = 4.730$
(b) ^{16}O(α, 2α)^{12}C — $Q_m = -7.162$
(c) ^{16}O(α, ^{8}Be)^{12}C — $Q_m = -7.254$

Excitation functions have been measured over a wide energy range for elastically scattered α-particles and γ-rays from the decay of ^{16}O*(6.13, 6.92, 7.12): see Table 20.20. See also (1964BO1E, 1965CA02) and (1963DA1D). Angular distributions of various α-particle groups are reported for $E_\alpha = 5.0$ to 104 MeV: see Table 16.27 in (1971AJ02).

A number of anomalies are observed in the elastic scattering. Phase shift analyses lead to the results shown in Table 20.21 (1953CA44, 1960MC09, 1964PE05, 1965MC02, 1967HU06, 1967ME10, 1969JO18, 1971BE17, 1972HA07, 1971TA05). At higher energies, a prominent 2 MeV wide resonance is observed corresponding to ^{20}Ne*(28.) with $J^\pi = 8^+$ (1969CO19, 1970CO13). In the range $E_\alpha = 37$ to 51 MeV, the cross section for elastic scattering appears to decrease monotonically (1965VA11). Identifying various of the observed states as members of different rotational bands is discussed by (1967HU06, 1972HA07): see also Table 20.15. The $J^\pi = 6^+$, 8^+ and 7^+ states at $E_x = 8.78$, 11.95 and 13.33 MeV are probable members of the lowest rotational bands with $K^\pi = 0^+$ and $K^\pi = 2^+$. The known reduced widths in both bands are small, indicating that the bands should be describable in terms of the spherical shell model. The reduced widths within each band are found to decrease sharply with increasing spin (1972HA07). See also (1963NO1C, 1968CE1B, 1969AG06) and (1968SH1G, 1969PI02, 1971MC03; theor.).

Reaction (b) can be described in terms of both sequential and one-step knockout processes. A state at $E_x \approx 24$ MeV in ^{20}Ne may be involved (1968PA12). Reaction (c) to ^{12}C*(0, 4.4) has been studied for $E_\alpha = 35.5$ to 41.9 MeV. The results are qualitatively consistent with the statistical theory of compound nuclear reactions, with an average width of 1.1 MeV for the compound states (1965BR13). See also (1971GO1U). For spallation reactions see (1968JA1J, 1969JU03).

10. ^{16}O(α, n)^{19}Ne — $Q_m = -12.135$ — $E_b = 4.730$

See (1962GO1J, 1963GO1J, 1965TS1A) and ^{19}Ne.

Table 20.20: Summary of ^{16}O(α, α)^{16}O and ^{16}O(α, ^{8}Be)^{12}C excitation function measurements

E_α (MeV)	Detected	Refs.
0.9 – 4.0	α_0	(1953CA44)
3.7 – 6.5	α_0	(1960MC09)
5.0 – 11.0	α_0	(1972HA07)
5.8 – 10	α_0	(1967HU06) [a]
7.2 – 8.4	α_0	(1965MC02)
8.9 – 9.9	$\gamma_{6.13}$	(1964PE05)
10.0 – 19.0	α_0, $\gamma_{6.13}$, $\gamma_{6.92+7.12}$	(1967ME10) [a]
13.0 – 17.4	^{8}Be	(1971GO1U)
13.5 – 30.5	α_0	(1963LU08)
14.5 – 22.7	α_0	(1962JO14)
18.9 – 30.0	α_0, α_{1+2}	(1971BE17)
20 – 24	α_0	(1968CE1B, 1969AG06, 1969FE10)
20 – 24.5	α_0	(1971TA05)
25 – 32	α_0	(1969CO19, 1970CO13)
35.5 – 41.9	^{8}Be	(1965BR13)
37 – 51	α_0	(1965VA11)

[a] See also (JO68C, 1968ME1H).

11. ^{16}O(α, p)^{19}F $\quad Q_m = -8.115 \quad E_b = 4.730$

See (1961YA02).

12. ^{16}O(α, pn)^{18}F $\quad Q_m = -18.546 \quad E_b = 4.730$

See (1961FU01).

13. ^{16}O(^{6}Li, d)^{20}Ne $\quad Q_m = 3.257$

Deuteron groups have been observed to all ^{20}Ne states below 7.2 MeV (1968HE08, 1968RO1K,

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

E_α (MeV $\pm$ keV)	$\Gamma_{\mathrm{c.m.}}$ (keV)	Outgoing particles	θ^2 (%)	E_x (MeV)	J^π	Refs.
2.490 ± 10	19	α_0	22	6.721	0^+	(1953CA44)
3.045 ± 10	8	α_0	36	7.165	3^-	(1953CA44)
3.090 ± 10	4	α_0	1.1	7.201	0^+	(1953CA44)
3.380 ± 10	8	α_0	4.7	7.433	2^+	(1953CA44)
3.885 ± 10	2	α_0	0.6	7.837	2^+	(1953CA44)
≈ 4.9	> 800	α_0	≈ 70	≈ 8.6	0^+	(1960MC09)
5.002	2.5	α_0	0.23	8.730	1^-	(1960MC09)
5.058 ± 3	$(110 \pm 25) \times 10^{-3}$	α_0	8.5 ± 1.5	8.775	6^+	(1972HA07)
≈ 5.1	> 800	α_0	≈ 95	≈ 8.8	2^+	(1960MC09)
5.11	< 1	α_0		8.82	(5^-)	(1960MC09)
5.152 ± 5	19	α_0	1.1	8.850	1^-	(1960MC09, 1969JO18)
5.395 ± 5	3	α_0	3.9	9.044	4^+	(1960MC09, 1969JO18)
5.486 ± 5	3.2	α_0	0.49	9.117	3^-	(1960MC09, 1969JO18)
5.955 ± 10	24	α_0	1.4	9.492	2^+	(1960MC09, 1967HU06, 1969JO18)
6.569 ± 10	97	α_0	17	9.983	4^+	(1967HU06, 1969JO18)
6.912 ± 5	141	α_0	66	10.257	5^-	(1967HU06, 1969JO18)
7.092 ± 5	81	α_0	4.8	10.401	3^-	(1967HU06, 1969JO18)
7.276 ± 5	16	α_0	1.8	10.548	4^+	(1969JO18)
7.314 ± 10	24	α_0	0.85	10.579	2^+	(1965MC02, 1967HU06, 1969JO18)
7.580 ± 100	349	α_0	33	10.79	4^+	(1967HU06, 1969JO18)
7.635 ± 5	13	α_0	0.42	10.836	2^+	(1965MC02, 1967HU06, 1969JO18)
7.636	45	α_0	2.1	10.836	3^-	(1969JO18)
(7.75)	80	α_0		(10.93)		(1967HU06)
7.80 ± 150	576	α_0	14	10.97	0^+	(1969JO18)

Table 20.21: Resonances in ^{16}O(α, α)^{16}O [a] (continued)

E_α (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Outgoing particles	θ^2 (%)	E_x (MeV)	J^π	Refs.
7.860 ± 10	24	α_0	2.0	11.015	4^+	(1965MC02, 1967HU06, 1969JO18)
8.132 ± 30	172	α_0	4.2	11.233	1^-	(1969JO18)
8.246 ± 10	53	α_0	1.5	11.324	2^+	(1965MC02, 1967HU06, 1969JO18)
(≈ 8.6)	≈ 500	α_0		(≈ 11.6)	(2^+)	(1967HU06)
8.930 ± 20	46	α_0	1.1	11.871	2^+	(1969JO18)
8.997 ± 5	0.44 ± 0.15	$\alpha_0, \gamma_{6.13}$	0.04 ± 0.01	11.925	4^+	(1972HA07)
9.026 ± 5	$(35 \pm 10) \times 10^{-3}$	α_0	1.0 ± 0.3	11.948	8^+	(1972HA07)
9.033 ± 10	24	α_0	1.4	11.953	1^-	(1969JO18)
9.055 ± 8	29 ± 8	α_0		11.971	1^-	(1967HU06, 1972HA07)
(9.25 ± 40) [b]		α		(12.13)		(1964PE05)
9.365 ± 20	142	α_0	6.6	12.219	4^+	(1964PE05, 1967HU06, 1969JO18)
9.530 ± 100		α_0		12.35	2^+	(1969JO18)
9.550 ± 10 [b,c]	46 ± 16	α_0	1.2	12.367	3^-	(1964PE05, 1969JO18)
9.605 ± 5	≤ 8	α_0	< 0.15	12.411	0^+	(1969JO18)
9.790 ± 10	101	α_0	23	12.559	6^+	(1967HU06, 1969JO18)
9.860 ± 100		α_0		12.61		(1969JO18)
9.944 ± 15	97	α_0	7.3	12.682	5^-	(1969JO18)
10.050 ± 100 [d]	100	α_0		12.77	4^+	(1967ME10, 1969JO18)
10.14 ± 70	55	$\alpha_0, \gamma_{6.13}$		12.84		(1967ME10)
10.32 ± 75	60	$\alpha_0, \gamma_{6.13}$		12.98	(4^+)	(1967ME10)
10.43 ± 90	70	$\alpha_0, \gamma_{6.13}$		13.07	(4^+)	(1967ME10)
10.57 ± 75	60	$\alpha_0, \gamma_{6.13}$		13.18	(4^+)	(1967ME10)
10.759 ± 6	$(80 \pm 30) \times 10^{-3}$	α_0		13.333	7^-	(1972HA07)
10.770 [e]	20	$\alpha_0, \gamma_{6.13}$		13.342	4^+	(1967ME10, 1972HA07)

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

E_α (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Outgoing particles	θ^2 (%)	E_x (MeV)	J^π	Refs.
10.83 ± 50	40	$\gamma_{6.13}$		13.39		(1967ME10)
10.87 ± 140	110	α_0, $\gamma_{6.13}$		13.42	(4^+)	(1967ME10)
11.20 ± 400	320	α_0, $\gamma_{6.13}$		13.7	$(3, 7)^-$	(1967ME10)
11.51 ± 125	400	α_0, $\gamma_{6.13}$		13.93	(6^+)	(1967ME10)
11.77		α_0, $\gamma_{6.9+7.1}$		14.14		(1967ME10)
11.97 ± 300	240	α_0, $\gamma_{6.13}$, $\gamma_{6.9+7.1}$		14.3	6^+	(1967ME10)
(12.06)		α_0, $\gamma_{6.9+7.1}$		(14.37)		(1967ME10)
12.31 ± 300	240	α_0, $\gamma_{6.9+7.1}$		14.6	(4^+)	(1967ME10)
12.66 ± 150	120	α_0, $\gamma_{6.13}$, $\gamma_{6.9+7.1}$		14.85		(1967ME10)
12.86 ± 150	120	α_0, $\gamma_{6.13}$, $\gamma_{6.9+7.1}$		15.01		(1967ME10)
13.165 ± 150	120	α_0, $\gamma_{6.13}$		15.26		(1967ME10)
13.22		α_0		15.30		(1967ME10)
13.37 ± 470	380	α_0, $\gamma_{6.13}$, $\gamma_{6.9+7.1}$		15.4	7^-	(1967ME10)
13.58		α_0, $\gamma_{6.13}$, $\gamma_{6.9+7.1}$		15.59		(1967ME10)
13.73		α_0, $\gamma_{6.13}$, $\gamma_{6.9+7.1}$		15.71		(1967ME10)
14.05		α_0, $\gamma_{6.13}$, $\gamma_{6.9+7.1}$		15.96		(1967ME10)
14.26		$\gamma_{6.13}$, $\gamma_{6.9+7.1}$		16.13		(1967ME10)
14.40		$\gamma_{6.13}$		16.24		(1967ME10)
14.53		α_0, $\gamma_{6.13}$, $\gamma_{6.9+7.1}$		(16.35)		(1967ME10)
14.69		α_0, $\gamma_{6.9+7.1}$		16.48		(1967ME10)
14.782		α_0, $\gamma_{6.13}$, $\gamma_{6.9+7.1}$		16.58		(1967ME10)
(14.91)		α_0		(16.65)	(1^-)	(1967ME10)
15.18 ± 400	320	α_0, $\gamma_{6.9+7.1}$		16.9	6^+	(1967ME10)
15.673 ± 340	270	α_0, $\gamma_{6.13}$, $\gamma_{6.9+7.1}$		17.3	2^+	(1967ME10)

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

E_α (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Outgoing particles	θ^2 (%)	E_x (MeV)	J^π	Refs.
16.01 ± 230	180	$\alpha_0, \gamma_{6.13}, \gamma_{6.9+7.1}$		17.3		(1967ME10)
16.30 ± 230	180	$\alpha_0, \gamma_{6.13}, \gamma_{6.9+7.1}$		17.76		(1967ME10)
(16.3)		α_0		(17.95)		(1967ME10)
16.70 ± 180	140	$\alpha_0, \gamma_{6.13}$		18.08	6^+	(1967ME10)
16.98 ± 300	240	$\alpha_0, \gamma_{6.13}, \gamma_{6.9+7.1}$		18.31	(6^+)	(1967ME10)
17.45	600	$\alpha_0, \gamma_{6.13}$		18.7	(6^+)	(1967ME10)
18.05 ± 250	200	$\alpha_0, \gamma_{6.9+7.1}$		19.16	(6^+)	(1967ME10)
18.35 ± 350	280	α_0		19.40	6^+	(1967ME10)
18.90 ± 350	280	α_0		19.84	6^+	(1967ME10)
19.30 ± 120	250	α_0		20.16	7^-	(1971BE17)
19.6 ± 180	360	α_0		20.4	6^+	(1971BE17)
19.6 ± 100	200	α_0		20.4	7^-	(1971BE17)
19.95 ± 60	120	α_0		20.68	9^-	(1971BE17)
20.18		α_0		20.9		(1971BE17)
20.4 ± 100	200	α_0		21.0	7^-	(1971BE17)
20.45 ± 40	80	α_0		21.08	9^-	(1971BE17)
20.70	300	α_0		21.3	7^-	(1962JO14, 1971BE17, 1971TA05)
21.3 ± 200	300	α_0		21.8	7^-	(1971BE17, 1971TA05)
22.0 ± 200	500	α_0		22.3	7^-	(1971BE17, 1971TA05)
22.5 ± 250	500	α_0		22.7	9^-	(1971BE17)
22.65 ± 125	250	α_0		22.84	9^-	(1971BE17)
23.3 ± 250	500	α_0		23.4	8^+	(1971BE17, 1971TA05)
24.24 ± 150	350	α_0		24.11	8^+	(1971BE17, 1971TA05)
25.4 ± 300	600	α_0		25.0	8^+	(1971BE17)

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

E_α (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Outgoing particles	θ^2 (%)	E_x (MeV)	J^π	Refs.
26.2 ± 200	400	α_0		25.7		(1971BE17)
28.1 ± 350	700	α_0		27.2		(1971BE17)
29.	1600	α_0		28.	8^+	(1969CO19, 1970CO13)
29.4 ± 350	700	α_0		28.2		(1971BE17)

[a] See also (1959AJ76).

[b] ^{20}Ne*(12.11, 12.37) decays by α_2 to ^{16}O*(6.13) with $\omega\Gamma_\alpha\Gamma'_\alpha/\Gamma = 100 \pm 50$ eV and $\omega\Gamma_\alpha\Gamma'_\alpha/\Gamma = 3 \pm 1$ keV, respectively (1964PE05).

[c] $\omega\gamma \lesssim 1$ and $\lesssim 4$ eV to ^{20}Ne*(0, 1.63), respectively; $\omega\Gamma_\alpha\Gamma'_\alpha/\Gamma = 3 \pm 1$ keV (1964PE05).

[d] Values quoted are taken preferentially from the elastic scattering results (1967ME10).

[e] $\theta_0^2 = 0.7 \pm 0.2$, $\theta_1^2 = 6 \pm 3$ % (1972HA07).

1969GO18). (1969BE1X) report the strong excitation of ^{20}Ne*(8.78, 10.30, 12.64, 13.96, 14.35, 15.34) while ^{20}Ne*(11.95), the 8^+ member of the ground state rotational band is comparitively weakly populated. Angular distributions have been measured at $E(^6\text{Li}) = 5.50$, 5.70 and 6.22 MeV (1968GR22; α_0, α_1–the latter is isotropic), 20.0 MeV (1968HE08: all states below $E_x = 7$ MeV), 25.8 MeV (1969GO18, 1970OG1A: $E_x = 0$, 1.6, 4.3, 5.8, 7.2, 8.8, 10.3, 12.7, 15.6). The reaction proceeds to a large extent by compound nucleus formation. Even at $E(^6\text{Li}) = 34$ MeV, a large compound nuclear contribution is reported (1971HA1D). This is consistent also with $d_1 - \gamma$ angular correlation work at $E(^6\text{Li}) = 15$ MeV (1971BA24).

The lifetime of ^{20}Ne*(1.63), τ_m, is 1.27 ± 0.24 psec, as determined in this reaction and in reaction 14 (1969TH01). See also (1968OG1A) and (1965ZE1B, 1969CH1K, 1969CH1Q, 1969JA08, 1969SM1A, 1970DO07; theor.).

14. ^{16}O(^{7}Li, t)^{20}Ne $\qquad Q_m = 2.264$

At $E(^7\text{Li}) = 16$ MeV, this reaction excites only those rotational states which are allowed by the selection rules in the SU_3 scheme. The reaction appears to proceed mainly by a direct stripping mechanism. Relative maximum cross sections for formation of ^{20}Ne*(0, 1.63, 4.25, 5.62, 5.79) are 100, 272, 171, 39, 82 while the unresolved ^{20}Ne*(7.17, 7.20) states are formed with a relative cross section of 486 (1968MI01). Angular distributions are also reported at $E(^7\text{Li}) = 15.0$ MeV (1970MI1E, 1970NE18; $t_0 \rightarrow t_2$), 20.0 MeV (1970NE18; t_2) and 30.3 MeV (1969GO18, 1970OG1A: same states as in reaction 13). Angular correlation work [$t_1 - \gamma$ and $t_2 - \gamma$ at $E(^7\text{Li}) = 13$, 14 MeV] shows some indication of competition between an α-particle transfer process and either multistep or compound nuclear processes (1971BA24). See also (1968OG1A, 1971HA1D) and (1969DA14, 1970DO07, 1971AR1R; theor.).

15. ^{16}O(^{9}Be, αn)^{20}Ne $\qquad Q_m = 3.159$

The lifetime of ^{20}Ne*(1.63), τ_m, is ≈ 1 psec: see Table 20.18 (1969NI09).

16. (a) ^{16}O(^{12}C, 2α)^{20}Ne $\qquad Q_m = -2.544$

(b) ^{16}O(^{16}O, ^{12}C)^{20}Ne $\qquad Q_m = -2.432$

See (1971BA33) and ^{24}Mg in (1973ENVA) for reaction (a). See (1971VA1H) for reaction (b).

17. ^{17}O(^{3}He, α)^{16}O $\qquad Q_m = 16.435 \qquad E_b = 21.166$

Table 20.22: States of ^{20}Ne from ^{18}O(^{3}He, n)^{20}Ne [a]

E_x (MeV ± keV)	L	J^π; T	E_x (MeV ± keV)	L	J^π; T
0	0	0^+	11.27 ± 50		
1.63 ± 160	2	2^+	11.59 ± 40		
4.22 ± 150	4	4^+	12.20 ± 30	2	2^+
4.96 ± 150			12.41 ± 30	0	0^+
5.73 ± 120			12.83 ± 30		
6.72 ± 100			13.10 ± 30	0	0^+
7.86 ± 100			13.34 ± 30		
8.79 ± 60			13.48 ± 30		
9.05 ± 60			13.63 ± 30		
9.98 ± 50			13.88 ± 30		
10.25 ± 50	2	2^+; (1)	14.22 ± 30		
10.88 ± 50			16.730 ± 6 [b]	0	0^+; 2

[a] (1970GU08). See also (1970TA08).
[b] $\Gamma < 20$ keV. This state is reported by (1969AD02).

The ground state excitation function has been measured for $E(^{3}\text{He}) = 7.0$ to 10.0 MeV: it shows a resonance corresponding to ^{20}Ne*(28.). This resonance is also observed in the ^{16}O(α, α) elastic scattering. It is interpreted in terms of a quasi-molecular α-particle cluster model (1969CO19). See also (1965WA1D).

18. ^{17}O(α, n)^{20}Ne $\qquad Q_m = 0.588$

Angular distributions have been measured at $E_\alpha = 9.8$ to 12.3 MeV by (1967HA14; n_1, n_2, n_{4+5}). See (1970CL1C) for astrophysical implications.

19. ^{18}O(^{3}He, n)^{20}Ne $\qquad Q_m = 13.119$

Neutron groups have been observed to a number of ^{20}Ne states: see Table 20.22 (1969AD02, 1970GU08). In particular the first $T = 1$ state in ^{20}Ne is reported at $E_x = 10.25 \pm 0.05$ MeV ($J^\pi = 2^+$) (1970GU08) and the first $T = 2$ state is found at $E_x = 16.730 \pm 0.006$ MeV ($J^\pi = 0^+$) (1969AD02). See also (1969BA1Z).

Table 20.23: Resonances in ^{19}F(p, γ)^{20}Ne [a]

E_p (keV)	Γ_{lab} (keV)	$\Gamma_{\gamma 0}$ (eV)	$\Gamma_{\gamma 1}$ (eV)	^{20}Ne* (MeV)	Refs.
340		< 0.07	0.28 ± 0.06	13.167	(1962KE03)
484		≈ 0.05	0.42	13.304	(1963BE19)
597		< 0.6	12	13.411	(1963BE19)
668	7.5	1.0×10^{-2}	2.2 [e]	13.479	(1954SI07, 1955FA1A, 1959KU79, 1960KA18 [f], 1961ET01, 1961GO21)
874				13.674	(1955FA1A)
935				13.732	(1955FA1A)
980				13.775	(1955FA1A)
1091	≈ 1			13.881	(1954SI07, 1955FA1A, 1961ET01, 1961GO21)
1280				14.060	(1955FA1A)
1320 [b]	4.0			14.098	(1954SI07, 1955FA1A)
1350				14.126	(1955FA1A)
1370				14.145	(1955FA1A)
1420	15.7			14.198	(1954SI07, 1955FA1A, 1961ET01)
4090 ± 5 [c]		$\Gamma_\gamma \approx 5$ eV		16.728	(1967KU06)
5878 ± 5 [d]	11 ± 3	$\Gamma_\gamma \approx 0.3$ eV		18.426	(1968LA1H)

[a] See also Table 20.17.
[b] See also (1961ET01).
[c] $J^\pi = 0^+$; $T = 2$.
[d] $J^\pi = 2^+$; $T = 2$.
[e] Γ_γ to ^{20}Ne*(4.97) $= 0.12$ eV (1961GO21), 0.24 eV (1960KA18).
[f] Assignment to this reaction probable but not certain.

Angular distributions have been measured at $E(^3\text{He}) = 2.80$ to 4.64 MeV (1971DI12), 3.1 MeV (1970GU08), 4 MeV (1970TA08) and 5.70 and 7.33 MeV (1969AD02). See also (1964DI1C, 1967AD01, 1967BE1W) and (1969TO1E; theor.).

20. ^{19}F(p, γ)^{20}Ne $\qquad Q_\text{m} = 12.845$

Over the range $E_\text{p} = 2.9$ 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 structure is observed with a characteristic $\Gamma \approx 175$ 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 (1967SE02). See also (1959GE34, 1960BR35, 1964TA05, 1965TA1E, 1966ME1H, 1966PA1K).

The yield curve for 11.2 MeV γ-rays [from the decay of ^{20}Ne*(11.23), $J^\pi = 1^+$; $T = 1$, to the ground state] displays a resonance at $E_\text{p} = 4.090 \pm 0.005$ 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: $\Gamma_\text{p}\Gamma_\gamma/\Gamma \approx 0.5$ eV. Since Γ_p/Γ (from the elastic scattering) is ≈ 0.1, $\Gamma_\gamma \approx 5$ eV (1967KU06). For $E_\text{p} = 5.65$ to 6.21 MeV, the γ_0, γ_1, γ_2, γ_3, γ_4 and γ_5 yields are not resonant but the yield of 10.6 MeV γ-rays is resonant at 5.878 ± 0.005 MeV [$\Gamma_\text{lab} = 11 \pm 3$ keV; $\Gamma_\text{p}\Gamma_\gamma/\Gamma \approx 0.055$ 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*(12.25), to the 2^+ state at 1.63 MeV (1968LA1H). See also (1968HA1T, 1968HA1U, 1969HA1Y).

These and other resonances observed at lower energies are displayed in Table 20.23 (1954SI07, 1955FA1A, 1960KA18, 1961ET01, 1961GO21, 1962KE03, 1963BE19). ^{20}Ne*(13.48) ($E_\text{p} = 0.67$ MeV) decays predominantly to ^{20}Ne*(1.63). [See Table 20.17 for branching ratios.] The radiation is M1 and the angular distribution of the 11.9 MeV γ-rays is approx. isotropic: $J^\pi = 1^+$ (1955FA1A, 1960KA18, 1961GO21). ^{20}Ne*(13.88) [$E_\text{p} = 1.09$ MeV] decays predominantly to ^{20}Ne*(4.97) (1961GO21). See also (1959AJ76) and (1969HO1W; theor.). For astrophysical considerations see (1969BA71).

21. (a) ^{19}F(p, p)^{19}F $\qquad E_\text{b} = 12.845$
(b) ^{19}F(p, p$'$)^{19}F*

The elastic scattering has been studied in the range $E_\text{p} = 500$ to 2000 keV by (1954DE1A, 1954PE1A, 1955BA1C, 1955WE1A, 1956DE33, 1963BE19). Parameters for the observed resonances are exhibited in Tables 20.24 and 20.25 taken mainly from (1955BA1C). Some unresolved structure is observed at $E_\text{p} = 900$, 1092 and 1137 keV, in addition to a broad structure near $E_\text{p} = 1700$ keV (1955WE1A). A sharp anomaly is observed in the elastic scattering at $E_\text{p} = 4.096 \pm 0.003$ MeV (1967BL19), 4.090 ± 0.005 MeV (1967KU06). It is an s-wave resonance corresponding to the 0^+; $T = 2$ state at $E_\text{x} = 16.73$ MeV (1967BL19, 1967KU06). There is

Table 20.24: Levels of ^{20}Ne from ^{19}F(p, p_0)^{19}F (1955BA1C)

E_p (keV)	Γ_{lab} (keV)	l	J^π	Γ_p/Γ	θ_p^2 (%)	^{20}Ne* (MeV)
340	2.9	0	1^+	0.016	3.8	13.167
483 [b]			1^+			13.303
598	37	1	2^-	0.0012	0.38	13.412
669	7.5	0	1^+	0.98	9.6	13.480
843	23	0	0^+	0.996	10.8	13.645
873	5.2	1	2^- [a]	0.21	1.5	13.674
935	8.0	0	1^+	0.17	0.44	13.732
1346	4.5	1	2^- [a]	0.067	0.07	14.123
1372	15	1	2^- [a]	0.17	0.52	14.147
1422	14.6	0	1^+	0.85	0.92	14.195
1694 [c]						14.453
1940 [c]		(0)	(0^+, 1^+)			14.687
2030 [c]						14.772
4094 [d]	2.1 ± 0.5	0	0^+	0.062 ± 0.004		16.732
5880 [e]	11 ± 3	2	2^+	≈ 0.2		18.427

[a] 1^- not excluded by elastic scattering alone.
[b] (1963BE19).
[c] (1956DE33).
[d] (1967BL19, 1967KU06); $T = 2$.
[e] (1968LA1H); $T = 2$.

Table 20.25: Resonance parameters in ^{19}F + p [c] (1955BA1C)

E_p (keV)	J^π	θ^2 [a] (%)					
		p_0	p_1	p_2	α_1	α_2	α_3
340	1^+	3.8	< 15		18.8	1.0	7.2
598	2^-	0.38	< 28	< 145	31	< 0.5	< 5.1
669	1^+	9.6	0.6	< 0.4	0.26	0.005	0.27
843	0^+	10.8	≈ 0.14	< 0.92			
873	2^-	1.5	< 0.07	2.7	1.05 [b]	1.45 [b]	3.4
935	1^+	0.44	5.0	< 0.8	3.3	0.34	2.3
1260	3^+						
1346	2^-	0.07 [b]	0.92	0.24	0.36	0.21 [b]	2.1
1372	2^-	0.52 [b]	1.93	0.56	1.7 [b]	0.34 [b]	0.86
1422	1^+	0.92	0.56	< 0.11	total < 0.034		

[a] p_0, p_1, p_2 represent transitions to ^{19}F(0), (0.1), (0.2). α_1, α_2, α_3 represent transitions to ^{16}O(6.1), (6.9), (7.1).

[b] Assuming lowest possible values of l; see (1957MA1A).

[c] See also (1958IS11).

no indication of this resonance in the p_3, p_4 or p_5 yields (1967KU06). The amplitude of the $T = 1$ or $T = 0$ impurity in this state is $\approx 1.5\%$ (1967BL19). In the range $E_p = 5.65$ to 6.21 MeV, a single anomaly is seen in the elastic scattering at $E_p = 5.880 \pm 0.005$ MeV. The interference patterns show that the scattering is d-wave, corresponding to the excitation of the $J^\pi = 2^+; T = 2$ state at $E_x = 18.43$ MeV (1968LA1H). The parameters of these two $T = 2$ states are shown in Table 20.24. The elastic scattering has also been studied for $E_p = 4.2$ to 7.5 MeV by (1967TH06), and the polarization has been determined at $E_p = 10.2$ MeV by (1961RO05). The total reaction cross section is reported for $E_p = 24.6$ to 46.0 MeV by (1969MC1A).

Resonances for inelastic scattering involving ^{19}F*(0.11) ($J^\pi = \frac{1}{2}^-$) and ^{19}F*(0.197) ($J^\pi = \frac{5}{2}^+$) [p_1 and p_2] are listed in Table 20.26 (1955BA94, 1963BE19). See also (1958RA15). In general the resonances observed are identical with those reported from other ^{19}F + p reactions, although the relative intensities differ greatly. The p_2 scattering has been measured at $E_p = 5.6$ to 6.3 MeV (1967TH06). For a spallation study, see (1969EP1B). See also (1959TR1A, 1969LE08), (1969HA1Y, 1969MC1C, 1969TE1A), (1963MI1D, 1966AM1B, 1967AF01; theor.), (1959AJ76) and ^{19}F.

22. ^{19}F(p, α)^{16}O $\qquad Q_m = 8.114 \qquad E_b = 12.845$

Table 20.26: Resonances in ^{19}F(p, p′)^{19}F* (1955BA94)

E_p (keV)	J^π	Γ_{lab} (keV)	Γ_{p_1} (eV)	Γ_{p_2} (eV)	$\theta^2_{p_1}$ [a] (%)	$\theta^2_{p_2}$ [a] (%)	E_x in ^{20}Ne (MeV)
340	1^+	2.9	< 0.5	< 0.1	< 15		13.167
483 [b]	1^+	2.2	< 1.3	< 1.2			13.303
598 [b]	2^-	37	< 100	< 60	< 28	< 145	13.412
669	1^+	7.5	46	< 0.5	0.6	< 0.4	13.480
720		≈ 30	< 10000	< 10000			13.528
780		≈ 10	< 400	≈ 9000			13.585
831		8.3	< 6	≈ 2300			13.634
845	0^+	23	≈ 50	< 10	≈ 0.14	< 0.92	13.647
873	2^-	5.2	< 2	570	< 0.07	2.7	13.674
900		4.8	< 30	≈ 2200			13.699
935	1^+	8.0	3000	< 20	5.0	< 0.8	13.732
1092		< 1.2					13.881
1137		3.7	< 40	≈ 2100			13.924
≈ 1250		≈ 80	≈ 70000	< 4000			14.03
1290		19	< 600	≈ 900			14.069
1346	2^-	4.5	300	600	0.92	0.24	14.123
1372	2^-	15	700	1400	1.93	0.56	14.147
1422	1^+	14.6 ± 1	2200	≤ 35	0.56	≤ 0.11	14.195
1610		≈ 5					14.373
1660							14.421
1700							14.459

[a] (1955BA1C).
[b] (1963BE19).

Table 20.27: Resonances for ground-state α-particles (α_0) in ^{19}F(p, α_0)^{16}O

E_p (keV)	Γ_{lab} (keV)	θ^2_α [a] (%)	J^π	^{20}Ne* (MeV)
400 [b]	100		1^-	13.224
400 [b]	100		0^+	13.224
650 ± 20 [b]	200		1^-	13.462
710 [a,b]	35	0.6	(1^-)	13.519
733	66	1.0	2^+	13.541
778	≈ 10	0.02	2^+	13.583
843	23	0.16	2^+ [g]	13.645
≈ 860	120	2.1	1^-	13.66
≈ 930	≈ 180	2.9	0^+	13.73
≈ 1080	≈ 200	3.4	1^-	13.87
1115	50	0.55	2^+	13.903
1160	≈ 70	1.1	0^+	13.946
1235 [a,c]	≈ 70	1.2	1^-	14.017
≈ 1250 [a]	≈ 150	2.7	2^+	14.03
1358 [a,c,d]	54	0.49	2^+	14.134
1640 [c]	< 115			14.402
1709 [c,d]	140		0^+	14.467
1853 [c,d]	132		1^-	14.604
2110 [c,d,e]	75		$(2^+, 4^+)$	14.85
2310 [c,d,e]	90		(2^+)	15.04
2550 [e]	300		(1^-)	15.26
2590 [c,d,h]	300		(0^+)	15.30
2680 [c,h]	80			15.39
2730 [e]	60			15.44
2820 [e]	160			15.52
2940 [h]				(15.64)
3120 [h]	170			(15.81)
3340	105			16.02
3680	(100)			16.34
3860				16.51
3980	135			16.62

Table 20.27: Resonances for ground-state α-particles (α_0) in ^{19}F(p, α_0)^{16}O (continued)

E_p (keV)	Γ_{lab} (keV)	θ^2_α [a] (%)	J^π	^{20}Ne* (MeV)
4090 [i]			$0^+; T = 2$	16.73
4130	100			16.77
4360	100			16.98
4460	95			17.08
4690	65			17.30
4900	90			17.50
4990	40			17.58
5880 ± 5 [f]	11 ± 3		$2^+; T = 2$	18.427

[a] (1958IS10, 1958IS11).
[b] (1959BR67).
[c] (1958RA15).
[d] (1957CL42).
[e] (1964BR12).
[f] (1968LA1H). [g] $J = 0$ from ^{19}F(p, p)^{19}F; possibly $T = 1$ (1955BA1C, 1955BA94).
[h] See, however, (1964BR12).
[i] (1967KU06). See blue Note in Erratum.

For $E_p \approx 1$ to 3 MeV, five α-particle groups are reported. All show resonance effects with relative intensities varying greatly with bombarding energy. The long range group (α_0) leaves ^{16}O in the ground state ($J^\pi = 0^+$); the next longest (α_π) results in the formation of the $J^\pi = 0^+$ nuclear pair-emitting state at 6.05 MeV, while the three remaining groups (α_1, α_2, α_3) lead to γ-ray emitting states at 6.13 ($J^\pi = 3^-$), 6.92 ($J^\pi = 2^+$) and 7.12 MeV ($J^\pi = 1^-$). At $E_p > 3$ MeV, excitation of higher ^{16}O levels occurs: see ^{16}O. Resonances for α_0 and α_π (Tables 20.27 and 20.28) are generally identical and different from those for α_1, α_2, α_3 (Table 20.29). The resonances for α_0 and α_π are required to have even J, even π of odd J, odd π while the α_1, α_2, α_3 resonances, insofar as their assignments are known, are all odd-even or even-odd.

Recent studies of the α_0 yield and of angular distributions have been carried out by (1959BR67: $E_p = 0.40$ to 0.72 MeV), (1964BR12: $E_p = 2.0$ to 3.3 MeV), (1966MO25: $E_p = 2.24$ to 3.35 MeV), (1963WA12: $E_p = 3.3$ to 12.2 MeV), (1965WA08: $E_p = 4.0$ to 12.0 MeV), (1960BR35: $E_p = 4.2$ to 8.8 MeV), (1968LA1H: $E_p \approx 5.9$ MeV), and (1959OG15: $E_p = 12.9$ to 14.1 MeV). See also (1969LE08). Resonances observed in the lower energy range are displayed in Table 20.27 (1957CL42, 1958IS10, 1958IS11, 1958RA15, 1959BR67, 1964BR12, 1968LA1H). Among these is a resonance at $E_p = 5.880 \pm 0.005$ MeV, $\Gamma_{lab} = 11 \pm 3$ keV which corresponds to the $J^\pi = 2^+$; $T = 2$ state at $E_x = 18.43$ MeV: the α_1 and α_2 channels also display it (1968LA1H). See also (1968HA1T, 1969HA1Y, 1969MC1C). (1965WA08) find that over the range $E_p = 4.0$ to 12.0

Table 20.28: Nuclear pair resonances (α_π) in ^{19}F(p, α_π)^{16}O

E_p (keV)	Γ_{lab} (keV)	σ [c] (mb)	θ^2_α [c] (%)	J^π	^{20}Ne* (MeV)
710 [a]	35	≈ 0.2	2	1^-	13.519
780	≈ 10	≈ 0.2	0.15	2^+	13.585
842	23	3.4	0.27	2^+ [d]	13.644
1115	50	1.5	3.6	2^+	13.903
1236 [a,b]	≈ 70	3	1.0	1^-	14.018
1367 [a,b]	30	6.0	0.29	2^+	14.143
1630 [b]	60				14.39
1720	95	≈ 18			14.48
1880	170				14.63
2170	95				14.91
2330	≈ 100				15.06
2600	100				15.31
2680	100				15.39
2820	125				15.52
3120	145				15.81
3340	100				16.02
(3500)	(80)				(16.17)
(3590)	(115)				(16.25)
3960	200				16.61
4360	95				16.98
4690	< 150				17.30
4900	115				17.50
4990	40				17.58
5170	220				17.75

[a] See (1950CH53, 1951PH1A, 1954DE36, 1958IS11).
[b] (1958RA15).
[c] (1958IS11): resonant cross sections derived from analysis: see also (1950CH53).
[d] See footnote [g] in Table 20.27.

MeV, direct interaction mechanisms are predominant although compound nuclear contributions cannot be ignored at certain energies. The continuing structure in the α_0 yield at the higher energies has been interpreted by (1964TE1F) in terms of fluctuations with a coherence energy $\Gamma = 160$ keV. See also (1966MO25).

Resonances in the ^{19}F(p, α_π)^{16}O yield have been investigated by (1950CH53, 1951PH1A, 1954DE36, 1958IS11, 1958RA15): see Table 20.28. Resonance locations and absolute reduced widths appear to correspond closely to those for (p, α_0), although some exceptions occur. In the work of (1958RA15) only 6 of the 23 (p, α_0) resonances have no clear counterpart in σ(p, α_π). For resonances at $E_{\rm p} = 1.35$, 1.72, 1.88 and 2.33 MeV, $\theta^2_{\alpha_0} = \theta^2_{\alpha_\pi}$ within about 10%; at $E_{\rm p} = 2.17$ MeV, a large difference occurs, possibly to be ascribed to superposition of several resonances (1958RA15). Below $E_{\rm p} = 1.3$ MeV, several fairly large differences occur (1958IS11).

Recent yield measurements of α-groups to excited states of ^{16}O and of the de-excitation γ-rays are reported by (1965AS07: $E_{\rm p} = 0.9$ to 2.6 MeV; α_1, α_2, α_3), (1969OS1B: $E_{\rm p} = 1.9$ to 4.2 MeV; $\sigma_{\rm t}$ for 6.13, 6.92, 7.12, 8.87 γ), (1963WA12: $E_{\rm p} = 10$ to 12 MeV; α_{1+2}, α_{3+4}) and (1971GO1U: $E_{\rm p} = 2$ to 6.2 MeV; α_0, α_1, α_2, α_3, α_4). See also (1961AS02). Resonances are displayed in Table 20.29 (1950AR1A, 1950BA1A, 1950CH1A, 1952WI1A, 1955BA94, 1955HU1A, 1955KI28, 1959BO14, 1959KU79, 1959LI51, 1960HU11, 1962KE03, 1962RY01, 1963BE19, 1964SE1A, 1965AS07, 1966MA60, 1967KU06). Anomalies are observed in the α_0, α_1, α_2, α_3 and α_4 yields at $E_{\rm p} = 4.09$ and 5.88 MeV, corresponding to the $T = 2$ state at $E_{\rm x} = 16.73$ and 18.43 MeV. [P. Gorodetzky, private communication.] See also (1967KU06).

A detailed discussion of the evidence leading to many of the J^π assignments shown in Table 20.29 is given in (1959AJ76).

The total cross section has been measured for $E_{\rm p} = 5.1$ to 6.5 MeV by (1960TE03). For spallation measurements see (1963VA1C). See also (1959TR1A, 1960GO12, 1961ET01, 1968KO05, 1970WI13, 1971GU23) and (1963MI1D; theor.). For astrophysical considerations, see (1969BA71). See also ^{16}O in (1971AJ02) and (1959AJ76).

23. ^{19}F(p, n)^{19}Ne $\qquad Q_{\rm m} = -4.021 \qquad E_{\rm b} = 12.845$

Yield measurements are reported for $E_{\rm p} = 4.23$ to 4.93 MeV (1959GI47; $\sigma_{\rm t}$), 4.23 to 6.01 MeV (1968RI08; $\sigma_{\rm t}$), 4.4 to 6.1 MeV (1969BL02; γ_1, γ_2), 4.9 to 11.0 MeV (1963JE04; $\sigma_{\rm t}$) and 6.2 to 6.9 MeV (1962FR09; n_0, n_{1+2}, n_3, n_4). See also (1965VA1E, 1968LA1H). Observed resonances are displayed in Table 20.30 (1952WI1A, 1963JE04, 1968RI08). A narrow anomaly is reported in the n_0 and n_1 yield at $E_{\rm p} = 5.879 \pm 0.004$ MeV corresponding to a state at $E_{\rm x} = 18.427$ MeV in ^{20}Ne, presumed to be the second $T = 2$ state in ^{20}Ne (1968AD1C). See also (1959AJ76) and ^{19}Ne.

24. ^{19}F(p, pn)^{18}F $\qquad Q_{\rm m} = -10.431 \qquad E_{\rm b} = 12.845$

See (1961GU1A, 1962GU10, 1963VA1C, 1965VA1E).

Table 20.29: Resonances for $6-7$ MeV γ-rays (α_1, α_2, α_3) in ^{19}F(p, α)^{16}O

$E_{\rm p}$ (keV)	$\Gamma_{\rm lab}$ (keV)	Γ_{α_1} (eV)	Γ_{α_2} (eV)	Γ_{α_3} (eV)	J^π	^{20}Ne* (MeV)
226.9 ± 3.4 [a,b]	1.0	1000	< 2.5	< 2.5	2^-	13.060
340.46 ± 0.04 [c,d]	2.4 ± 0.2	2800	16	75	1^+	13.168
483.8 ± 0.3 [e]	0.9 ± 0.1	700	19	190	1^+	13.304
872.11 ± 0.20 [f,g]	4.7 ± 0.2	2200	620	180	2^-	13.673
935.4 ± 1.3 [g]	8.1 ± 0.5	2900	110	720	1^+	13.733
1347.7 ± 1.0 [h]	4.9 ± 0.7	2250	650	1200	2^-	14.124
1373.0 ± 1.0 [i]	12.4 ± 1.0	6650	700	300	2^-	14.148
1694 ± 1.7 [j]	35 ± 3					14.453
1949 ± 2.5 [j]	40 ± 10					14.695
2030 ± 3.0 [j]	120 ± 20					14.772
2320 [k]	85					15.05
2510	30					15.23
2630	90					15.34
2800	60					15.50
3020	30					15.71
3190	80					15.87
3490	40					16.16
3920	30					16.57
4000	110					16.64
4090 [l]					$0^+; T = 2$	16.73
4290	50					16.92
4490	30					17.11
4570	30					17.18
4710	30					17.32
4780	35					17.38
4990	20					17.58
5070	35					17.66
5200	70					17.78

[a] (1959KU79; assignment to this reaction probable but not certain). See also (1959AJ76).
[b] (1962KE03). $\Gamma_{\alpha_0} < 100$ eV.
[c] (1955BA94, 1959BO14, 1964SE1A). See also (1959KU79, 1960HU11, 1962KE03) and (1959AJ76).
[d] (1950AR1A, 1950BA1A, 1950CH1A). Values listed for E_p and Γ are those recommended by (1966MA60).
[e] (1959BO14, 1959KU79, 1960HU11, 1963BE19). $\Gamma_{\alpha_0} < 25$ eV (1963BE19).
[f] Values listed for E_p and Γ are those recommended by (1966MA60). Other values are $E_{res} = 872.4 \pm 0.4$ keV (1959BO14), 873.5 ± 0.7 keV (1960HU11), 872.3 ± 0.5 keV (1961BE13), 871.80 ± 0.25 keV (1962RY01), 872.5 ± 1.1 keV (1965AS07). See also Table 20.13 in (1959AJ76) for earlier references.
[g] (1965AS07).
[h] Recently reported resonance energies are $E_p = 1344.5 \pm 1.0$ keV (1959LI51), 1347.7 ± 1.0 keV (1960HU11), 1347.7 ± 1.8 keV (1965AS07). See Table 20.13 in (1959AJ76) for earlier references.
[i] Recently reported resonance energies are $E_p = 1373.0 \pm 1.0$ keV (1959LI51), 1373.7 ± 1.2 keV (1960HU11), 1374.5 ± 1.8 keV (1965AS07). See Table 20.13 in (1959AJ76) for earlier references.
[j] (1952WI1A, 1955HU1A).
[k] (1952WI1A); these values should be reduced by about 0.2%: see (1955KI28).
[l] Resonance in α_2 yield: see text (1967KU06).

25. ^{19}F(p, ^{8}Be)^{12}C $\quad Q_m = 0.861 \quad E_b = 12.845$

The excitation curves show strong resonant behavior (cross sections up to 1.5 mb/sr) for $E_x = 15.3$ to 18.7 MeV, over which region 28 angular distributions have been measured. Twelve states with $J^\pi \leq 4^+$ have been observed.

The strongly populated states are in better agreement with those reported in the (p, α_1) yield to ^{16}O*(6.05) [$J^\pi = 0^+$] than those reported in the (p, α_0) yield (1969GO1B, 1971GO1U). It is suggested that most of the observed states are of 8p-4h and 12p-8h configurations (1971GO1U).

26. ^{19}F(d, n)^{20}Ne $\quad Q_m = 10.621$

Levels of ^{20}Ne derived from reported neutron groups are listed in Table 20.31 (1958MO02, 1963FE1B, 1964SA09, 1966RI05, 1968LA03, 1969RI01); those derived from threshold measurements are displayed in Table 20.32 (1960BU07). Gamma-ray measurements have been reported by (1960KR02, 1960RA23, 1965PE01) and angular correlation measurements by (1964SA09, 1966RI05). For a survey of the earlier work see (1959AJ76).

Angular distributions have been measured at $E_d = 0.5$ to 0.7 MeV (1964SA09; n to ^{20}Ne*(10.31)), 1.0 MeV (1966RI05; n to ^{20}Ne*(10.31, 11.03)), 1.0 to 1.3 MeV (1962FI02; n_0, n_1), 1.0 to 2.5 MeV (1966WA17; n_0, n_1), 2.17 MeV (1958MO02; $n_0 \rightarrow n_4$), 2.5 and 3.0 MeV (1963FE1B; n_0,

n_1 and n to ^{20}Ne*(5.80, 6.75, 8.76)), 2.51 to 3.31 MeV (1964SI09; $n_0 \rightarrow n_3, n_{4+5}, n_6$), 2.98 MeV (1968LA03: see Table 20.31), 3.06 to 6.07 MeV (1967BA40; n_0, n_1), 3.57 MeV (1961BE10; $n_0 \rightarrow n_3, n_{4+5}, n_6$) and 5.10 MeV (1969RI01: see Table 20.31). See (1959AJ76) for earlier references. See also (1963FE01, 1964AL14, 1964JO04, 1965BA1K), (1966WE1B) and (1966AR1D, 1966IN01, 1968WA1M, 1970BO1K; theor.).

Table 20.30: Resonances in ^{19}F(p, n)^{19}Ne

E_p (MeV)		Γ_{lab} (keV)	^{20}Ne* (MeV)
(1968RI08) [a]	(1963JE04) [b]	(1952WI1A)	
4.30		45	16.93
4.46		80	17.08
4.52		20	17.14
4.61		60	17.22
4.72		25	17.33
4.75		45	17.36
4.87			17.47
4.95	4.96	20	17.55
5.03	5.03		17.62
5.11	5.11		17.70
5.23			17.81
5.26	5.26 [c]		17.84
5.37	5.37		17.94
(5.44)			(18.01)
5.50			18.07
5.57			18.13
(5.62)			(18.18)
(5.69)			(18.25)
5.72	5.73		18.28
5.77			18.32
5.84			18.39
	5.879 ± 0.004 [d]	≈ 9 [d]	18.427
5.90			18.45
6.00	6.03		18.54
	6.15		18.68
	6.35 [e]		18.87

Table 20.30: Resonances in ^{19}F(p, n)^{19}Ne (continued)

E_p (MeV)		Γ_{lab} (keV)	^{20}Ne* (MeV)
(1968RI08) [a]	(1963JE04) [b]	(1952WI1A)	
	6.53		19.04
	6.81 [e]		19.31
	7.14		19.62
	7.27		19.75
	7.41		19.88
	7.52		19.98
	7.74		20.19
	8.02		20.46
	8.15		20.58
	8.28		20.71
	8.37		20.79
	8.70		21.10
	8.82		21.22
	9.08		21.47
	9.2		21.6
	9.5		21.9
	9.8		22.1
	10.2		22.5

[a] ± 5 keV.

[b] ± 20 keV, except for the last four values.

[c] See also (1969BL02).

[d] (1968AD1C): $T = 2$.

[e] See also (1962FR09).

27. ^{19}F(^{3}He, d)^{20}Ne $\qquad Q_m = 7.351$

At $E(^3\text{He}) = 9.5$ to 10.0 MeV, angular distributions have been measured for the deuterons corresponding to ^{20}Ne*(0, 1.63, 4.25, 4.97, 5.62, 5.79, 6.72, 7.01, $7.17+7.20$, 7.42). The distributions to ^{20}Ne*(0, 1.63, 5.79, 6.72, 7.42) have been fitted with $l = 0$, 2, 1, 0 and 2, respectively. Spectroscopic factors were also obtained. The results are consistent with the description of the states in terms of rotational bands (1965SI18). Angular distributions are also reported at $E(^3\text{He}) = 13.0$ MeV (1963JA01; d_0, d_1).

Table 20.31: Neutron groups from ^{19}F(d, n)^{20}Ne [a]

E_x (MeV ± keV)				l_p [a]	J^π; T
(1958MO02) [b]	(1963FE1B)	(1968LA03)	(1969RI01)		
0		[c]	[c]	0	0^+
1.74 ± 30				2	2^+
4.20 ± 40					
4.96 ± 50					
5.62 ± 40					
6.80 ± 10		[c]	[c]	0	0^+
7.16 ± 90					
7.41 ± 50					
7.90 ± 40					
(8.71 ± 10)					
9.15 ± 40	9.17 ± 30				
	9.37 ± 20				
(9.50 ± 40)	9.50 ± 20				
	9.60 ± 20				
	9.92 ± 30				
10.01 ± 30	10.00 ± 30		[c]		
	10.30 ± 30	[c]	[d,i]	[h]	[h]
			10.59 [c]		
	11.00 ± 20	10.853 ± 10 [j]	10.879 ± 40	2	$T = 1$ [f]
			11.03 ± 80 [i]		
	11.32 ± 20	11.233 ± 10	11.26 ± 40	0	1^+; (1) [e,f]
	11.66 ± 30	11.549 ± 10	11.568 ± 35	2	$(T = 1)$ [f]
			11.915 ± 30		
		12.086 ± 10		[g]	$(T = 1)$ [f]
		12.150 ± 10	12.179 ± 25	[g]	$(T = 0)$ [f]
		12.200 ± 10		[g]	$(T = 1)$ [f]
		12.245 ± 10		2	$T = 1$ [f]
		12.379 ± 10	12.397 ± 20	0	$T = 0$ [f]

Table 20.31: Neutron groups from ^{19}F(d, n)^{20}Ne [a] (continued)

E_x (MeV ± keV)				l_p [a]	$J^\pi; T$
(1958MO02) [b]	(1963FE1B)	(1968LA03)	(1969RI01)		
			13.086 ± 15		
			13.170 ± 15	0	1^+; (1)
			13.481 ± 15	0	1^+; 1 [e]
			13.650 ± 15	0	(0^+); 1 [e]
			13.882 ± 15		

[a] See also Table 20.16 in (1959AJ76).
[b] Evidence for some other states is also reported.
[c] Observed but no parameters reported.
[d] $E_x = 10.31 \pm 0.07$ MeV (1964SA09), $E_x = 10.33 \pm 0.05$ MeV (1966RI05).
[e] (1969RI01).
[f] (1968LA03).
[g] Weak group.
[h] See (1964SA09, 1966RI05).
[i] This state decays to ^{20}Ne*(1.63) (1966RI05).
[j] Data of (1968LA03) are adjusted downward by 26 keV: see (1969RI01).

Gamma-ray measurements lead to $E_x = 1635.3 \pm 1.8$, 4249 ± 2.5, 4968 ± 3, 5623 ± 3 and 7174 ± 4 keV and to $\tau_m = 1500^{+900}_{-400}$, 150 ± 25 and 2800^{+2400}_{-900} fsec, respectively, for ^{20}Ne*(1.63, 4.25, 4.97) (1969AN08, 1969AN1J: see also Table 20.18). See also (1964HE1D, 1966AR1D, 1966IN01, 1970BO1K; theor.).

28. ^{19}F(α, t)^{20}Ne $\qquad Q_m = -6.969$

At $E_\alpha = 28.5$ MeV, angular distributions are reported for the tritons to ^{20}Ne*(0, 1.63, 4.25, 4.97, $5.62 + 5.79$, $7.02 + 7.17 + 7.20$). All are typical of stripping reactions except that for ^{20}Ne*(4.97). The distributions have been analyzed by DWBA. ^{20}Ne*(6.72) is very weakly populated (1967HA23). Angular distributions have also been reported at $E_\alpha = 18.5$ MeV (1963JA01; t_0, t_1) and 28.4 MeV (1965KA14; t_0, t_1, t_2, t_3, t_{4+5}). See also (1964EL1B; theor.).

29. ^{20}F(β^-)^{20}Ne $\qquad Q_m = 7.026$

The decay is principally to ^{20}Ne*(1.63) with a half-life of 11.03 ± 0.06 sec: see Table 20.5 for a listing of half-life measurements and Table 20.33 for the branching to various ^{20}Ne states.

Table 20.32: Levels of ^{20}Ne from ^{19}F(d, n)^{20}Ne thresholds (1960BU07)

$E_{\text{thresh.}}$ (keV)	^{20}Ne* [a] (MeV)
510 ± 20	11.082
(600 ± 20)	(11.163)
760 ± 20	11.308
(850 ± 20)	(11.389)
1150 ± 20	11.660
1350 ± 20	11.841
1700 ± 20	12.157
1790 ± 20	12.239
2060 ± 20	12.483

[a] All these states are reported to decay principally to the ground state except for ^{20}Ne*(11.11, 11.19, 12.27) which decay to ^{20}Ne*(1.63). See, however, Table 20.15.

The 0.02% branching to ^{20}Ne*(4.97) [$J^{\pi} = 2^{-}$] is consistent with the assignment $J^{\pi} = 2^{+}$ to the ground state of ^{20}F (1969GA05), as are measurements of the $\beta - \gamma$ circularly polarized correlation (1961FR02, 1965MA28).

E_{β^-}(max) $= 5.419 \pm 0.013$ MeV (1954WO23), 5.416 ± 0.015 MeV (1959AL06). The energy of the subsequent γ-ray is 1634.8 ± 0.6 keV (1967VA08), 1632.6 ± 0.8 keV (1966AL12). The γ-ray from the $(4.97 \rightarrow 1.63)$ transition has $E_{\gamma} = 3334.3 \pm 0.7$ keV. When recoil-corrected, $\Delta E = 3334.6 \pm 0.7$ keV, and using the E_{x} for ^{20}Ne*(1.63) shown in Table 20.15, E_{x} for ^{20}Ne*(4.97) $= 4968.4 \pm 0.8$ keV (1969GA05). See also (1960SC01, 1961OK1A, 1968SP01, 1971TO1K), (1959AJ76) and (1967YA04, 1968KR10, 1969BL1D, 1969SU12, 1970AN27, 1970MC23, 1970YA01, 1971LI1H, 1971WI18, 1971YA04; theor.).

30. ^{20}Ne(γ, n)^{19}Ne $\qquad Q_{\text{m}} = -16.866$

A giant resonance is observed at $E_{\gamma} = 21.5$ MeV, $\Gamma = 6.6$ MeV, σ(max) $= 7.3$ mb (1954FE16). See also (1962GO1E).

31. ^{20}Ne(γ, pn)^{18}F $\qquad Q_{\text{m}} = -23.275$

See (1959RE1A).

Table 20.33: Branching in ^{20}F(β^-)^{20}Ne

Decay to ^{20}Ne* (MeV)	J^π	Branch (%)	log ft [a]	Refs.
0	0^+	< 0.032		(1954WO23)
1.63	2^+	99.8	4.98	
4.25	4^+	< 0.015		(1969GA05)
4.97	2^-	0.017 ± 0.003	6.88	(1969GA05)
5.62	3^-	< 0.048		(1963GL01)
5.79	1^-	< 0.1		(1963GL01)
6.72	0^+	< 0.67		(1963GL01)
7.01	4^-	< 0.2		(1963GL01)

[a] I am grateful to B. Zimmerman for calculating these values.

32. ^{20}Ne(γ, p)^{19}F $\qquad Q_{\rm m} = -12.845$

For cross section measurements see (1969HO16, 1963FI1B). See also (1962DO1A, 1963HA1E), (1959AJ76, 1959HA1C, 1961DO08, 1962GO1E) and (1965SH1D; theor.).

33. ^{20}Ne(γ, α)^{16}O $\qquad Q_{\rm m} = -4.730$

See (1959HA1C).

34. (a) ^{20}Ne(e, e)^{20}Ne
(b) ^{20}Ne(e, ep)^{19}F $\qquad Q_{\rm m} = -12.845$

The ^{20}Ne charge radius, $r_{\rm rms} = 3.116 \pm 0.025$ fm (using a Born approx.) (1971MO15).

At $E_{\rm e} = 39$ and 56 MeV, the $180°$ inelastic scattering is dominated by the transitiion to a $J^\pi = 1^+$; $T = 1$ state at $E_{\rm x} = 11.22 \pm 0.05$ MeV with $\Gamma_{\gamma_0} = 11.2^{+2.1}_{-1.8}$ eV. A subsidiary peak is observed corresponding to $E_{\rm x} = 11.58 \pm 0.03$ MeV [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 $E_{\rm x} \approx 12.0$, 12.9, 13.9, 15.8, 16.9, 18.0 and 19.0 MeV (1971BE18). See also (1963BA19, 1963GO04) and (1971FO19, 1971HO20; theor.). A study of reaction (b) at $E_{\rm e} = 30$ MeV shows strong resonances (assuming ground state transitions) at $E_{\rm x} = 17.70$, 18.87, 19.87 and 21.02 MeV [$\Gamma = 0.50$, 0.58, 0.54 and

0.49 MeV, respectively], as well as some weaker structures (1962DO1A). See also (1961DO08) and (1970PA1H; theor.).

35. ^{20}Ne(n, n)^{20}Ne

See ^{21}Ne in (1973ENVA) and (1959CO82).

36. (a) ^{20}Ne(p, p)^{20}Ne
(b) ^{20}Ne(p, pα)^{16}O $\quad Q_{\rm m} = -4.730$

Angular distributions have been measured at $E_{\rm p} = 2.15$ and 2.72 MeV (1961SO02; p_1, γ_1), 3.65 to 4.35 MeV (1963HU1D; p_0, p_1), 4.95 to 5.50 MeV (1959OD08; p_0, p_1), 5.20 to 6.23 MeV (1962HU12; p_0, p_1), 6.86 to 7.15 MeV (1969MC14; p_0), 7.75 to 14.2 MeV (1960OD01; p_0, p_1), 17.4 MeV (1962SC12; p_1, p_2, p_3, and p to states with $E_{\rm x} = 5.63 \pm 0.07$, 7.45 ± 0.08, 7.85 ± 0.08, 9.20 ± 0.09, 10.0 ± 0.1 MeV), 18.03 MeV (1969LE1P; p_0), 24.5 MeV (1969DE15; p_0, p_1, p_2, p to ^{20}Ne*(8.78)) and 41.8 MeV (1970FA17; p_0). A large hexadecapole deformation, β_4, is needed to reproduce both the shapes and the intensities of the angular distributions to the 2^+, 4^+ and 6^+ members of the ground state rotational band [^{20}Ne*(1.63, 4.25, 8.78)] (1969DE15). Polarization measurements have been carried out at $E_{\rm p} = 3.8$ to 5.1 MeV (1967BE25; p_0), 8.0 MeV (1961RO13; p_0), 14.5 MeV (1966RO1R; p_0) and 24.5 MeV (1970BA2F, 1971BA1T; p_0, p_1, p_2, p_3).

37. ^{20}Ne(d, d)^{20}Ne

Angular distributions are reported at $E_{\rm d} = 10.95$ MeV (1960TA08; d_0), 11.6 MeV (1965JA13; d_0, d_1, d_2, d_{4+5}), 11.8 MeV (1966JA1J; d_0, d_1) and 52 MeV (1968HI09, 1968HI1B; d_0, d_1, d_2, d_{4+5}, and d to ^{20}Ne*(7.2, 10.5)). The second excited state has $E_{\rm x} = 4.250 \pm 0.008$ MeV (1960FR04). See also (1960EL09, 1966WE04, 1968ME1E, 1971DU12; theor.).

38. ^{20}Ne(t, t)^{20}Ne

The elastic scattering has been studied at $E_{\rm t} = 1.80$ and 2.00 MeV (1969HE08).

39. ^{20}Ne(^{3}He, ^{3}He)^{20}Ne

Angular distributions of elastically scattered ^{3}He particles have been measured at $E(^3\text{He}) = 10$ and 15 MeV (1969BA62), 15 MeV (1969ZU02), 17.83 MeV (1971KE11), 28 MeV (1960CA1C) and 35 MeV (1969AR08, 1969AR10). See also (1960CA10, 1962AG01). At $E(^3\text{He}) = 17.83$ MeV, angular distributions of the ^{3}He's corresponding to ^{20}Ne*(1.63, 4.25) [$J^\pi = 2^+$ and 4^+, respectively] have been analyzed by a coupled channels calculation. For ^{20}Ne*(1.63), β_2 is in the range 0.42 to 0.48; for ^{20}Ne*(4.25), $\beta_4 < 0.05$ (1971KE11). See also (1964VE1A, 1968HO1C; theor.).

40. (a) ^{20}Ne(α, α)^{20}Ne

(b) ^{20}Ne(α, ^{12}C)^{12}C $\qquad Q_\text{m} = -4.618$

Angular distributions have been measured at $E_\alpha = 12.7$ to 15.2 MeV (1967IV02, 1970BU25, 1970IV04; α_0, α_1, α_2, α_3, α_{4+5}), 16.8 MeV (1970FR1F; α_0, α_1, α_2), 18.0 MeV (1958SE51, 1966LU02; α_0, α_1), 20.2 to 23.3 MeV (1970AG08, 1970FE09, 1970PI1G; α_0, α_1), 20.5 to 23.2 MeV (1971TA20; α_0), 20.9 to 24.0 MeV (1966SE1G, 1967GH1A; α_0, α_1, α_2), 21.6 MeV (1968TA1Q; α_0), 22 MeV (1962EI04; α_0, α_1, α_2, α_3, α_{4+5}), 22.5 MeV (1970LA20; α_0, α_1), 27.3 MeV (1964KO02, 1965KO07, 1965KO1A, 1967KO1J; α_0, α_1, α_2. α_3, α_{4+5}), 31.8 MeV (1959MC1A; α_0, α_1, α_2), 33.0 MeV (1967RE1B, 1968RE1F; $\alpha_0 \rightarrow \alpha_5$ and α to ^{20}Ne*(7.17)), 44 MeV (1968FA1A; α_0), 50.9 MeV (1965SP02, 1965SP1E, 1967RE1B, 1968RE1F; α_0, α_1, α_2, α_3, α_4, α_5, α to ^{20}Ne*(7.17)), 80.8 MeV (1967RE1B, 1968RE1F; α_0, α_1, α_2, α_3, α_{4+5}) and 104 MeV (1969HA14, 1970SP01, 1971RE09; α_0, α_1, α_2). At $E_\alpha = 104$ MeV the quadrupole and hexadecapole deformation lengths have been determined (1969HA14, 1970SP01, 1971RE09). The γ-decay of several ^{20}Ne states is reported by (1962EI04): see Table 20.17. See also (1963CR01, 1963MI1C, 1968SP04) and (1959BL31, 1961EI1A, 1962HU1A, 1964GR1L, 1964VE1A, 1965FA1D, 1965SA1G, 1967RA1E, 1971GO28, 1971OB1A; theor.).

Reaction (b) has been studied for $E_\alpha = 12$ to 20 MeV (1963LA08). See also ^{24}Mg in (1973ENVA).

41. ^{20}Ne(^{16}O, ^{16}O)^{20}Ne

See (1961NE04).

42. ^{20}Ne(^{32}S, ^{32}S)^{20}Ne

The static quadrupole moment of ^{20}Ne*(1.63) has been determined to be $Q_0 = +0.94 \pm 0.38$ b (1969SC08).

Table 20.34: Decay of ^{20}Na [a]

Decay to ^{20}Ne* (MeV $\pm$ keV)	J^{π}	Branching ratio (%)	log ft
1.6332 ± 1	2^+	90.0	4.93
4.97	2^-	[b]	> 6.1
5.62	3^-	[b]	> 6.5
5.79	1^-	[b]	> 6.5
7.43 ± 10	2^+	8.1	4.48
7.84 ± 30	2^+	0.38	5.65
8.74 ± 30	1^-	0.024	6.46
9.48 ± 20	2^+	0.11	5.41
10.28 ± 10	$2^+; T = 1$	1.38	3.79 ± 0.05 [d]
10.86 ± 20	2^+	0.097	4.46
11.28 ± 40	2^+	0.032	4.50

[a] (1967PO11, 1967SU05). See also (1964MA44).
[b] Not observed. See discussion in (1967SU05).
[c] B. Zimmerman, private communication. Note: this footnote is not labeled in the tablular.
[d] (1971GO18).

43. ^{20}Na(β^+)^{20}Ne $\qquad Q_{\rm m} = 13.892$

^{20}Na decays to a number of states of ^{20}Ne: see Table 20.34 (1967PO11, 1967SU05, 1964MA44). The half-life of ^{20}Na is $\tau_{1/2} = 446 \pm 3$ msec [see ^{20}Na]. The ratio of the mirror decays ^{20}Na $\rightarrow$ ^{20}Ne*(1.63) and ^{20}F $\rightarrow$ ^{20}Ne*(1.63), $(ft)^+/(ft)^- = 1.054 \pm 0.023$. If this number is directly interpreted in terms of second-class currents, the induced tensor coupling constant $g_{\rm IT} = (1.5 \pm 0.6) \times 10^{-3}$ (1970WI05, 1971WI07).

The line shapes of the α-spectra from the decay of ^{20}Ne*(7.42, 10.26) are fitted by Gamow-Teller and by Fermi decay theory. The former indicates some evidence for longitudinal nuclear alignment of β-recoils (1971MA09). See also (1970OA01, 1971TO1K, 1971TO1L) and (1971HO1D, 1971LI1H; theor.).

44. ^{21}Ne(p, d)^{20}Ne $\qquad Q_{\rm m} = -4.536$

At $E_p = 20$ MeV, the angular distribution of the deuterons to ^{20}Ne*(1.63) [very strongly populated] is characterized by $l_n = 2$ while that of the d_2 group (to ^{20}Ne*(4.25)) is suggestive of a weak $l_n = 2$ component. All of the observed $l_n = 1$ pick up strength is associated with ^{20}Ne*(4.97) (1970HO1R). See also (1969HE1T).

45. ^{22}Ne(p, t)^{20}Ne $\qquad Q_m = -8.644$

Angular distributions have been reported at $E_p = 26.9$, 35.1 and 42.4 MeV (1971FA07; t_0, t_1, t_2, t_3, t_{4+5}, t_6) and at 43.7 MeV (1964CE05). At the higher energy the distributions of the tritons to the ground state of ^{20}Ne and to the first 0^+; $T = 2$ state [$E_x = 16.722 \pm 0.025$ MeV (1969HA38)] have been fitted by $L = 0$ and the tritons to ^{20}Ne*(18.5) by $L = 2$. The latter is the first 2^+; $T = 2$ state (1964CE05). The 0^+; $T = 2$ state [^{20}Ne*(16.73)] decays by α_0 [-6 ± 5%], $\alpha_1+\alpha_2$ [35 ± 12%], $\alpha_3+\alpha_4$ [29 ± 12%], $p_0+p_1+p_2$ [14 ± 9%], and $p_3+p_4+p_5$ [13 ± 8%] [measured branching ratios in percent are given in the brackets] to final states in ^{16}O and ^{19}F (1970MC04). The ratios of the cross section for formation of the analog states ^{20}Ne*(10.26)/^{20}F*(0) and ^{20}Ne*(12.25 ± 0.03)/^{20}F*(1.85) are 2.00 ± 0.20 and 1.40 ± 0.15, respectively, at $E_p = 45$ MeV (1969HA19). See also (1970OL1B) and (1969TO1E; theor.).

46. ^{22}Ne(α, ^{6}He)^{20}Ne $\qquad Q_m = -16.156$

Angular distributions have been obtained at $E_\alpha = 42$ MeV for the transitions to ^{20}Ne*(0, 1.63, 4.25) (1970AR1H).

47. ^{23}Na(p, α)^{20}Ne $\qquad Q_m = 2.377$

$Q_0 = 2.373 \pm 0.008$ (1967SP09).

Alpha-particle groups have been observed to the ground state and to ^{20}Ne states with $E_x = 1.634 \pm 0.004$ MeV (1953DO04), 1.635 ± 0.006, 4.248 ± 0.006, 4.969 ± 0.006 and 5.631 ± 0.006 MeV (1957BU36). An attempt has been made to see if ^{20}Ne*(4.97) could consist of unresolved states: the result was negative (1965ME10). Angular distributions have been measured at $E_p = 10.0$ MeV (1963WA10; $\alpha_0 \rightarrow \alpha_3$) and at 45.5 MeV (1969KO09; α_0).

The cross over transitions from ^{20}Ne*(4.25, 4.97) are ≤ 9% and ≤ 4%, respectively, of the cascade transition via ^{20}Ne*(1.63) (1959KR66, 1960KR02): see Table 20.17. See also (1960RA23). The lifetime, τ_m, of ^{20}Ne*(1.63) $= 0.76 \pm 0.33$ psec (1956DE22): see also Table 20.18. See also (1959AJ76) and (1961AD01).

For papers dealing with resonances in the compound nucleus, see (1963FI09, 1963KU24, 1964NO09, 1966VE09, 1967KU1L, 1968VA20, 1968VA21, 1969BR1M, 1970KR1K, 1970LU17).

48. ^{23}Na(^{3}He, ^{6}Li)^{20}Ne $\qquad Q_{\rm m} = -1.642$

At $E(^{3}\text{He}) = 40.7$ MeV, the ground state angular distribution has been measured by (1969OH1B).

49. ^{24}Mg(p, α)^{21}Na*(p)^{20}Ne $\qquad Q_{\rm m} = -9.315$

See (1970LI08).

50. ^{24}Mg(d, ^{6}Li)^{20}Ne $\qquad Q_{\rm m} = -7.840$

At $E_{\rm d} = 55$ MeV, ^{20}Ne*(0, 1.63, 4.25) [$J^{\pi} = 0^{+}$, 2^{+}, and 4^{+}, respectively] and ^{20}Ne*(4.97, 5.62) [$J^{\pi} = 2^{-}$ and 3^{-}, respectively] are strongly populated, while ^{20}Ne*(5.79) is weakly populated, as predicted by the SU_3 model. The results are similar to those from ^{16}O(^{7}Li, t)^{20}Ne (reaction 14) (1971MC04).

51. ^{25}Mg(d, ^{7}Li)^{20}Ne $\qquad Q_{\rm m} = -7.921$

See (1971MC04).

52. ^{26}Mg(p, t)^{24}Mg(α)^{20}Ne $\qquad Q_{\rm m} = -19.258$

See (1967MC06).

^{20}Na

(Figs. 11, 12 and 13)

Mass of ^{20}Na: From the threshold energy of the ^{20}Ne(p, n)^{20}Na reaction, $E_{\rm thresh.} = 15.419 \pm 0.006$ MeV, the atomic mass excess of ^{20}Na is 6.850 ± 0.006 MeV (1971GO18, 1971WI07). See also (1964GA1C, 1966GA25, 1966KE16, 1969HA38).

1. ^{20}Na(β^{+})^{20}Ne $\qquad Q_{\rm m} = 13.892$

Table 20.35: Energy levels of ^{20}Na

E_x (MeV $\pm$ keV)	$J^\pi; T$	$\tau_{1/2}$ or $\Gamma_{c.m.}$	Decay	Reactions
0	$2^+; 1$	$\tau_{1/2} = 446 \pm 3$ msec	β^-	1, 2, 3, 4
0.591 ± 12				2, 3
0.768 ± 8				2, 3
(0.85 ± 50)				3
0.958 ± 8				2, 3
(1.010 ± 14)				2
1.310 ± 10				2, 3
1.92 ± 40				3
2.89 ± 50		[a]		3
4.33 ± 100		[a]		3

[a] Broad or unresolved.

Table 20.36: States of ^{20}Na from ^{20}Ne(p, n)^{20}Na and ^{20}Ne(^{3}He, t)^{20}Na

E_x (MeV $\pm$ keV)	
^{20}Ne(p, n)^{20}Na (1971MO34)	^{20}Ne(^{3}He, t)^{20}Na (1965DO04, 1965PE04)
0	0
0.591 ± 12	0.65 ± 50 [a]
0.768 ± 8	0.75 ± 50 [a]
	0.85 ± 50 [a]
0.958 ± 8	0.95 ± 50 [a]
(1.010 ± 14)	
1.310 ± 10	1.27 ± 50
	1.92 ± 40
	2.89 ± 50
	4.33 ± 100

[a] These states are not fully resolved.

^{20}Na decays by positron emission to ^{20}Ne*(1.63) and to a number of excited states which decay by α-emission to the ground state of ^{16}O: see Table 20.34 (1967PO11, 1967SU05). The half-life of ^{20}Na is $\tau_{1/2} = 408 \pm 6$ msec (1967SU05), 448 ± 4 msec (1970OA01), 442 ± 5 msec (1971GO18, 1971WI07), 446 ± 8 msec (1972MO08). See also (1959AJ76) and reaction 43 in ^{20}Ne.

The character of the β^+ decay, which takes place by allowed transitions to 2^+ states of ^{20}Ne, sets $J^\pi = 2^+$ for the ground state of ^{20}Na.

2. ^{20}Ne(p, n)^{20}Na $\quad Q_\mathrm{m} = -14.674$

$Q_0 = -14.674 \pm 0.006$ (1971GO18).

Observed neutron groups at $E_\mathrm{p} = 22.9$ MeV are displayed in Table 20.36 (1971MO34). See also (1970OA01, 1971BE46, 1971RU1F, 1971WI07).

3. ^{20}Ne(^{3}He, t)^{20}Na $\quad Q_\mathrm{m} = -13.910$

$Q_0 = -14.04 \pm 0.08$ (1965PE04);

$Q_0 = -13.89 \pm 0.06$ (1965DO04).

At $E(^3\mathrm{He}) = 32$ MeV, triton groups are observed to nine states of ^{20}Na: see Table 20.36 (1965DO04, 1965PE04).

4. ^{24}Mg(p, αn)^{20}Na $\quad Q_\mathrm{m} = -23.989$

See (1967PO11, 1967SU05).

^{20}Mg

(Not illustrated)

^{20}Mg has not been observed [see, however, (1964MA44)]. The mass excess of ^{20}Mg is calculated to be 17.509 ± 0.002 MeV (using the senority scheme) and 17.510 ± 0.002 MeV (using the supermultiplet scheme). ^{20}Mg would then be stable with respect to breakup into ^{19}Na + p by 2.75 MeV (1969HA38). See also (1962GO1B, 1964GA1C, 1964GO1G, 1966GO1B, 1966GO1K, 1966KE16).

^{20}Al

(Not illustrated)

^{20}Al has not been observed: see (1966KE16).

References

(Closed 31 December 1971)

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

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