Revised Manuscript *09 October 2017*

Energy Levels of Light Nuclei
$A = 20$

F. Ajzenberg-Selove [a] and T. Lauritsen [b]

[a] *University of Pennsylvania, Philadelphia, Pennsylvania 19104-6396*
[b] *California Institute of Technology, Pasadena, California*

Abstract: An evaluation of $A = 5$–24 was published in *Nuclear Physics* 11 (1959), 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.

(References closed December 1, 1958)

The original work of Fay Ajzenberg-Selove was supported by the US Department of Energy [DE-AC02-76-ER02785]. Later modification by the TUNL Data Evaluation group was supported by the US Department of Energy, Office of High Energy and Nuclear Physics, under: Contract No. DEFG05-88-ER40441 (North Carolina State University); Contract No. DEFG05-91-ER40619 (Duke University).

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}O

(Not illustrated)

GENERAL:

Mass of ^{20}O: The mass excess of ^{20}O is estimated as 13.3 ± 2 MeV by extrapolation from heavier $A = 4$n isobars (see (1954SH28, 1955AJ61)). ^{20}O is then stable to neutron emission by ≈ 4 MeV.

^{20}O has not been observed. A recent attempt to detect its β-decay was unsuccessful: (1956KA1E) bombarded ^{18}O with 40-MeV α-particles (^{18}O(α, 2p)^{20}O, $Q_{\rm m} = -20.3$) and found that $\tau_{1/2}$ is not in the range 10 min to 150 years. If $\tau_{1/2}$ is between 1 sec and 10 min, the cross section for the (α, 2p) reaction is less than a few milibarns.

Two possible reactions leading to ^{20}O are ^{18}O(t, p)^{20}O ($Q_{\rm m} = -0.5$) and ^{22}Ne(n, ^{3}He)^{20}O ($Q_{\rm m} = -22$).

^{20}F

(Fig. 44)

GENERAL:

Theory: See (1957RA1C).

1. ^{20}F(β^-)^{20}Ne $\quad Q_{\rm m} = 7.050$

See ^{20}Ne.

2. ^{17}O(α, p)^{20}F $\quad Q_{\rm m} = -5.659$

Not observed.

3. ^{18}O(d, n)^{19}F $\quad Q_{\rm m} = 5.737$ $\quad E_{\rm b} = 12.343$

See ^{19}F.

4. ^{18}O(d, p)^{19}O $\quad Q_{\rm m} = 1.731$ $\quad E_{\rm b} = 12.343$

The proton yield has been measured from $E_{\rm d} = 0.79$ to 0.88 MeV (1956AH1A). See also (1959ZI16) and ^{19}O.

Table 20.1: Energy levels of ^{20}F

E_x (MeV $\pm$ keV)	J^π	$\tau_{1/2}$ or Γ (keV)	Decay	Reactions
0	$2^+, 3^+$	$\tau_{1/2} = 11.4 \pm 1$ sec	β^-	1, 6, 9, 15, 23, 24
0.652 ± 8	$1^+, 2^+, 3^+$		γ	15, 23
0.828 ± 8	$1^+, 2^+, 3^+$			15
0.988 ± 8	$1^+, 2^+, 3^+$			15
1.059 ± 8	$0^+, 1^+$		γ	15
1.309 ± 8				15
1.970 ± 8				15
2.048 ± 8	$1^+, 2^+, 3^+$			15
2.195 ± 8	$1^+, 2^+, 3^+$			15
2.870 ± 8	$2^-, 3^-, 4^-$			15
2.966 ± 8	$0^-, 1^-, 2^-$			15
3.491 ± 8	$0^+, 1^+$			15
3.528 ± 8	$0^+, 1^+$			15
3.586 ± 8				15
3.681 ± 8				15
3.961 ± 9				15
4.079 ± 9	$0^+, 1^+$			15
4.275 ± 9				15
4.310 ± 9	$0^+, 1^+$			15
5.04 ± 20	$0^-, 1^-, 2^-$			15
5.19 ± 20	$0^-, 1^-, 2^-$			15
5.27 ± 20	$0^-, 1^-, 2^-$			15
5.72 ± 20				15
5.87 ± 20	$0^-, 1^-, 2^-$			15
5.95 ± 20	$0^-, 1^-, 2^-$			15
6.25 ± 20				15
6.52 ± 20	$0^-, 1^-, 2^-$			15
6.63 ± 10	2^-	0.36 ± 0.08	n, γ	9, 10, 15
6.65 ± 10	1^-	1.4	n, γ	9, 10
6.70 ± 10	1^-	11 ± 2	n, γ	9, 10

Table 20.1: Energy levels of ^{20}F (continued)

E_x (MeV $\pm$ keV)	J^π	$\tau_{1/2}$ or Γ (keV)	Decay	Reactions
6.87 ± 15		24 ± 10	n, γ	9, 10, 11
6.93 ± 25		190 ± 95	n, (γ)	9, 10
7.01 ± 15		24 ± 14	n, (γ)	9, 10, 11
7.09 ± 15		24 ± 14	n, γ	9, 10, 11
7.17 ± 15		24 ± 10	n, γ	9, 10, 15
7.35			n, (γ)	9, 11
7.39			n	11
7.44			n, (γ)	9, 11
7.51 ± 20			n, (γ)	9, 10, 11
7.65 ± 20			n, (γ)	9, 10
7.79 ± 20			n, γ	9, 10
8.18 ± 20			n, γ	9, 10
8.55 ± 20			n	10
8.74 ± 20			n	10
9.8 ± 100			n, α	14
10.04 ± 50			n, α	14
10.11 ± 50			n, α	14
10.19 ± 50			n, α	14
10.53 ± 50			n, α	14
10.81 ± 50			n, α	14
11.22 ± 50			n, α	14
11.39			n, α	14
11.74			n, α	14
11.92			n, α	14
12.21 ± 100			n, α	14
12.38			n, α	14
13.60		450	d, α	5
13.92		360	d, α	5
14.28		270	d, α	5
14.95		540	d, α	5

5. ^{18}O(d, α)^{16}N $Q_m = 4.237$ $E_b = 12.343$

The cross section has been measured for $E_d = 0.5$ to 3.0 MeV. Resonances are observed at $E_d = 1.40$, 1.75, 2.15, and 2.90 MeV, with widths of 500, 400, 300, and 600 keV, respectively, corresponding to ^{20}F*(13.60, 13.92, 14.28, and 14.95 MeV) (1957BO04). See also ^{16}N.

6. ^{18}O(t, n)^{20}F $Q_m = 6.085$

See (1956SH1A).

7. ^{18}O(^{3}He, p)^{20}F $Q_m = 6.850$

Not reported.

8. ^{18}O(α, d)^{20}F $Q_m = -11.501$

Not reported.

9. ^{19}F(n, γ)^{20}F $Q_m = 6.606$

The thermal capture cross section is 9.4 ± 2 mb (1947SE33). The γ-spectrum has been measured by (1957CA28) who find transitions with E_γ (corrected for recoil) of 6.600 ± 0.011, 6.019 ± 0.011, 5.54 ± 0.02, 5.28 ± 0.02, and 5.10 ± 0.02 MeV, with intensities of 30, 16, 24, 27, and 14 photons per 100 captures, respectively. The 6.60 MeV line is the ground state transition; the other transitions are not uniquely determined. Upper limits for transitions to ^{20}F*(0.65, 0.83, and 0.99 MeV) are 1, 3, and 7 photons per capture, respectively. The γ-rays of energy 5.54 and 5.28 MeV may result from transitions to ^{20}F*(1.06 and 1.31) (1957CA28). Two resonances for ^{20}F production are observed at $E_n = 280$ and 590 keV, with widths ≈ 20 keV and peak cross sections of 1.2 and 1.3 mb, respectively; $\omega\Gamma_\gamma \approx 15$ eV (1950HE92). A number of additional resonances appear in the range $E_n = 25$ to 2000 keV: see (1958HU18). See also (1951KI35).

10. ^{19}F(n, n)^{19}F $E_b = 6.606$

The coherent scattering cross section is 3.8 ± 0.3 b; the total cross section (epithermal, bound) is 4.0 ± 0.1 b (1958HU18). The cross section is approximately constant at ≈ 3.7 b from 0.02 eV to 20 keV (1958HU18). Resonances in the total cross section are listed in Table 20.2. The J^{π} assignments indicated for the first three levels (p-wave) are based on elastic scattering distributions and total cross sections (1958BL54).

Total cross sections have been measured to $E_{\rm n} = 5$ MeV by (1958WI36), from $E_{\rm n} = 3$ to 14 MeV by (1954NE03), from $E_{\rm n} = 3.8$ to 8.1 MeV by (1957BO13), from $E_{\rm n} = 4.4$ to 5.6 MeV by (1956BE98) and from $E_{\rm n} = 7$ to 14 MeV by (1958BR16). The cross section shows structure at least as high as $E_{\rm n} \approx 7.5$ MeV: see (1956BE98, 1957BO13, 1958WI36). For the presentation of the data as a whole, see (1958HU18). Angular distributions have been measured and phase shifts determined at five energies in the range $E_{\rm n} = 0.66$ to 2.92 MeV by (1958WI36). See also (1955PA1B, 1957LA14) and (1956NE1C; theor.).

11. ^{19}F(n, n′)^{19}F* $E_{\rm b} = 6.606$

Observed resonances in the yield of 0.1 and 0.2 MeV γ-radiation (see ^{19}F) for $E_{\rm n} < 1$ MeV are exhibited in Table 20.3. A satisfactory fit to the excitation function for $E_{\rm n} < 300$ keV is obtained on the assumption for p-wave resonances at $E_{\rm n} = 100$ and 260 keV. The excitation functions for 0.1, 0.2, 1.24, and 1.37 MeV γ-rays have been measured to $E_{\rm n} = 2.2$ MeV (1955FR1B).

The cross section for excitation of ^{19}F*(2.79) has been studied from $E_{\rm n} = 3$ to 3.6 MeV. The very slow rise for the first 300 keV above threshold suggests a large spin difference between the 2.79 MeV level and the ground state (1957FR57). See also (1955AJ61, 1956VA29).

12. ^{19}F(n, 2n)^{18}F $Q_{\rm m} = -10.414$ $E_{\rm b} = 6.606$

The cross section at $E_{\rm n} = 14.1$ MeV is 62 mb (1958AS63); at $E_{\rm n} = 14.5$ MeV it is 60 mb (1953PA1C). See also (1952AJ38, 1958RA1H).

13. ^{19}F(n, p)^{19}O $Q_{\rm m} = -4.006$ $E_{\rm b} = 6.606$

The excitation function has been measured from $E_{\rm n} = 4.7$ to 8.0 MeV; it shows a single broad maximum at 7.5 MeV. For $E_{\rm n} < 8$ MeV, the (n, α) cross section is at least twice as large as the (n, p) cross section (1955MB01). At $E_{\rm n} = 14.5$ MeV, σ(n, α)/σ(n, p) $= 1.2 \pm 0.4$ (1958KO03); σ(n, p) $= 135$ mb (1953PA1C). See (1958HU18).

14. ^{19}F(n, α)^{16}N $Q_{\rm m} = -1.500$ $E_{\rm b} = 6.606$

Table 20.2: Resonances in $^{19}F(n, n)^{19}F$

E_n (keV)	Γ_{lab} (keV)	σ_{max} (b)	$^{20}F^*$ (MeV)	J^π
27 [a]	0.38 ± 0.08 [a]	23.7 [e]	6.63	2^- [e]
49.5 [b]	1.4 [e]	22.7	6.65	1^- [e]
99.5 [b]	11 ± 2 [b,e]	22.7	6.70	1^- [e]
280 ± 10 [c]	25 ± 10	10.0	6.87	
340 ± 20 [c]	200 ± 100	8.0	6.93	
420 ± 10 [c]	25 ± 15	8.8	7.01	
510 ± 10 [c]	25 ± 15	5.7	7.09	
590 ± 10 [c]	25 ± 10	6.0	7.17	
950 [d]		4.0	7.51	
1100 [d]		3.5	7.65	
1240 [d]		4.2	7.79	
1660 [d]		3.6	8.18	
2040 [d]		3.3	8.55	
2250 [d]		3.0	8.74	

[a] (1958HU18).
[b] (1955HI1C, 1958HU18).
[c] (1950BO95, 1958HU18).
[d] (1951WI1A, 1958WI36).
[e] (1957CR65, 1957ME1E, 1958BL54).

Observed resonances are listed in Table 20.4 (1955BO98, 1955MB01: see graph in (1958HU18)). See also (1937WI1A, 1955BO1C, 1955GR18, 1958KO03).

15. $^{19}F(d, p)^{20}F$

$Q_m = 4.379$
$Q_0 = 4.383 \pm 0.015$ (1957KH16);
$Q_0 = 4.38 \pm 0.03$ (1956EL1A).

Energy levels of ^{20}F derived from the proton groups are listed in Table 20.5 (1952WA1A, 1956EL1A, 1957KH16). The J^π assignments given in the table result from analysis of angular distributions by stripping theory. The angular distribution of the ground state protons has been studied at a number of energies (1953BR1C, 1956TA1D, 1956VA17, 1957ON1A, 1957SE1D). The pattern varies strongly with energy, suggesting compound nucleus interaction rather than stripping: it

Table 20.3: Resonances in ^{19}F(n, n$'\gamma$)^{19}F (1955FR1B)

E_n (0.1) (keV)	σ [a] (0.1-MeV γ) (b)	E_n (0.2) (keV)	σ [a] (0.2-MeV γ) (b)	^{20}F* (MeV)
(100)				(6.70)
270	4.6	(300)	0.8	6.87
(390)	1.4	420	2.1	(7.01)
(500)	1.1			(7.08)
(780)	0.6	780	0.8	7.35
830	0.9			7.39
880	0.8			7.44
950	0.7	950	1.3	7.51

[a] Cross sections $\pm 40\%$.

is concluded that an earlier assignment of $J = 1^+$ (1953BR1C) is not supported (1957SE1D). See also (1956OK1A, 1956TO1C; theor.). At $E_d = 1.05$ MeV, γ rays are observed with $E_\gamma = 0.64$ and 1.06 MeV (1954TH1B).

It is of interest to note that among the levels of ^{20}F there occur seven groups with equal spacings of 165n keV, where n is an integer for each group (1952WA1A, 1956EL1A). Above $E_x = 5$ MeV, only odd parity levels appear; below this value, even parities predominate. The levels appear in groups of the same parity, separated by ≈ 0.6 MeV (1956EL1A).

16. ^{20}Ne(n, p)^{20}F $\qquad Q_m = -6.267$

Not observed.

17. ^{20}Ne(t, ^{3}He)^{20}F $\qquad Q_m = -7.032$

Not observed.

18. ^{21}Ne(n, d)^{20}F $\qquad Q_m = -10.797$

Not observed.

Table 20.4: Resonances in ^{19}F(n, α)^{16}N

E_n [a] (MeV)	E_n [b] (MeV)	σ_{max} [a] (mb)	σ_{max} [c] (mb)	^{20}F* (MeV)
3.4				9.8
3.61 ± 0.05		48		10.04
3.69 ± 0.05		55		10.11
3.77 ± 0.05		44		10.19
4.11 ± 0.05	4.17	90	11.1	10.53
4.42 ± 0.05		167		10.81
	4.68		11.7	
4.86 ± 0.05		186		11.22
	5.04		12.2	11.39
	5.40		12.3	11.74
	5.59		11.9	11.92
5.9 ± 0.1	5.90	268	11.4	12.21
	6.08		10.6	12.38

[a] (1955MB01): cross sections $\pm 40\%$.
[b] (1955BO98).
[c] (1955BO98, 1958WA1C).

Table 20.5: Proton groups from ^{19}F(d, p)^{20}F

E_x (MeV $\pm$ keV)	E_x (MeV)	E_x (MeV)	$(2J+1)\theta^2$ (%)	l_n	J^π
(1952WA1A)	(1957KH16) [a]	(1956EL1A) [b]	(1956EL1A)	(1956EL1A)	
0					
0.652 ± 8	0.66		8.0	2 [c]	$1^+, 2^+, 3^+$
0.828 ± 8	0.81		0.5	2	$1^+, 2^+, 3^+$
0.988 ± 8			0.5	2	$1^+, 2^+, 3^+$
1.059 ± 8	1.08		0.1	0	$0^+, 1^+$
1.309 ± 8	1.34			iso.	
1.970 ± 8					
2.048 ± 8			8.1	2	$1^+, 2^+, 3^+$

Table 20.5: Proton groups from $^{19}F(d, p)^{20}F$ (continued)

E_x (MeV ± keV)	E_x (MeV)	E_x (MeV)	$(2J+1)\theta^2$ (%)	l_n	J^π
(1952WA1A)	(1957KH16) [a]	(1956EL1A) [b]	(1956EL1A)	(1956EL1A)	
2.195 ± 8	2.15		2.8	2	$1^+, 2^+, 3^+$
2.870 ± 8			5.7	3	$2^-, 3^-, 4^-$
2.966 ± 8			0.6	1	$0^-, 1^-, 2^-$
	3.11				
3.491 ± 8			7.1	0	$0^+, 1^+$
3.528 ± 8			7.1	0	$0^+, 1^+$
3.586 ± 8	3.58				
3.681 ± 8	3.77				
3.961 ± 9					
4.079 ± 9	4.09		2.1	0	$0^+, 1^+$
4.275 ± 9					
4.310 ± 9	4.37		3.6	0	$0^+, 1^+$
	(4.73)				
(5.062 ± 11)	4.86	5.04	0.7	1	$0^-, 1^-, 2^-$
	5.16	5.19	1.0	1	$0^-, 1^-, 2^-$
		5.27	1.8	1	$0^-, 1^-, 2^-$
	5.41				
	5.54				
		5.72			
		5.87	4.4	1	$0^-, 1^-, 2^-$
		5.95	9	1	$0^-, 1^-, 2^-$
	6.07				
	6.17	6.25			
	6.36				
	6.47	6.52	9	1	$0^-, 1^-, 2^-$
	6.65	6.63	5	1	$0^-, 1^-, 2^-$
	6.74				
		6.81	7	1	$0^-, 1^-, 2^-$
		6.98			

Table 20.5: Proton groups from ^{19}F(d, p)^{20}F (continued)

E_x (MeV ± keV)	E_x (MeV)	E_x (MeV)	$(2J+1)\theta^2$ (%)	l_n	J^π
(1952WA1A)	(1957KH16) [a]	(1956EL1A) [b]	(1956EL1A)	(1956EL1A)	
		7.20	4	1	$0^-, 1^-, 2^-$

(1952WA1A): $E_d = 1.8$ MeV.
(1956EL1A): $E_d = 8.9$ MeV.
[a] $E_d = 3.3$ to 4.0 MeV; errors ± 20-25 keV (1957KH16).
[b] Levels 1-19 of (1952WA1A) identified, but not measured; errors on remaining levels ±20 keV (1956EL1A).
[c] See also (1956TA1D, 1957ON1A, 1957SE1D).

19. ^{21}Ne(d, ^{3}He)^{20}F $\qquad Q_m = -7.530$

Not observed.

20. ^{21}Ne(t, α)^{20}F $\qquad Q_m = 6.789$

Not observed.

21. ^{22}Ne(n, t)^{20}F $\qquad Q_m = -14.905$

Not observed.

22. ^{22}Ne(p, ^{3}He)^{20}F $\qquad Q_m = -15.670$

Not observed.

23. ^{22}Ne(d, α)^{20}F $\qquad Q_m = 2.681$

Alpha particle groups have been observed at $E_d = 7.8$ MeV corresponding to the ground state and to a level at 0.57 ± 0.13 MeV (1951MI1A).

24. ^{23}Na(n, α)^{20}F $\qquad Q_m = -3.888$

See (1950JE1A).

^{20}Ne

(Fig. 45)

GENERAL:

Theory: See (1955GA1C, 1955HE1E, 1956MO1D, 1957BA1H, 1957RA1C).

1. ^{9}Be(^{14}N, t)^{20}Ne $\qquad Q_{\rm m} = 6.323$

See (1958GO71).

2. ^{16}O(α, γ)^{20}Ne $\qquad Q_{\rm m} = 4.753$

An unsuccessful attempt has been made to observe the isobaric spin-forbidden transition between the $T = 0$ states at 7.19 MeV ($J = 3^-$) and 1.63 MeV ($J = 2^+$). The radiative width is $< 6 \times 10^{-3}$ eV, indicating an admixture of $T = 1$ of $< 1.3 \times 10^{-3}$ in ^{20}Ne*(7.19) (1957TO1B). The relevance of alpha capture in ^{16}O to element synthesis has been discussed by (1956CA1F, 1956HA1C, 1956HA1D, 1957BU66, 1957LI1A, 1957SA1B).

3. ^{16}O(α, n)^{19}Ne $\qquad Q_{\rm m} = -12.158 \qquad E_{\rm b} = 4.753$

See (1947TE01).

4. ^{16}O(α, p)^{19}F $\qquad Q_{\rm m} = -8.119 \qquad E_{\rm b} = 4.753$

See ^{19}F.

5. ^{16}O(α, pn)^{18}F $\qquad Q_{\rm m} = -18.533 \qquad E_{\rm b} = 4.753$

See (1947TE01).

6. ^{16}O(α, α)^{16}O $\qquad E_{\rm b} = 4.753$

The elastic scattering has been studied in the range $E_\alpha = 0.9$ to 4.0 MeV by (1953CA44) and from $E_\alpha = 3.9$ to 5.5 MeV by (1958MC61): see Table 20.7. See also (1940FE01, 1957CO1H, 1958CO59) and ^{16}O.

Table 20.6: Energy levels of ^{20}Ne

E_x (MeV $\pm$ keV)	$J^\pi; T$	τ_m or Γ (keV)	Decay	Reactions
0	0^+; 0	–	stable	1, 9, 13, 20, 21, 22, 25
1.632 ± 4	2^+; 0	$\tau_m = (7.6 \pm 3.3) \times 10^{-13}$ sec	γ	9, 13, 16, 20, 21, 22, 25
4.248 ± 6	; 0		γ	13, 20, 22, 25
4.969 ± 6	≥ 1; 0		γ	9, 20, 22, 25
5.631 ± 6	; 0			13, 20, 22, 25
6.745 ± 10	0^+; 0	19	α	6
7.189 ± 10	3^-; 0	8	α	6, 13, 22
7.225 ± 10	0^+; 0	4	α	6, 13, 20
7.457 ± 10	2^+; 0	8	α	6, 20
7.861 ± 10	2^+; 0	2	α	6, 13, 20
≈ 8.6	0^+; 0	≈ 1300	α	6
8.76	1^-; 0	4	α	6
≈ 8.8	2^+; 0	≈ 1200	α	6
8.84	(5^-); 0	≤ 4	α	6
8.91	1^-; 0	20	α	6
9.11	4^+; 0	8	α	6, 13, 20
9.34 ± 100	$(\leq 2^-)$		γ	13, 20
9.97 ± 100	; (1)		(γ), (α)	13, 20
(10.61 ± 100)	; (1)		(γ)	13
11.11			γ	13
11.19			γ	13
11.33			γ	13
11.42			γ	13
11.69			γ	13
11.87	; (1)		(γ), α	13
12.27			γ	13
12.51			γ	13
13.086 ± 8		1.0	p, α	11
13.196 ± 8	1^+	3.1 ± 0.2	p, α	11
13.253	1^-	100	p, α	11

Table 20.6: Energy levels of ^{20}Ne (continued)

E_x (MeV ± keV)	$J^\pi; T$	τ_m or Γ (keV)	Decay	Reactions
13.253	0^+	100	p, α	11
13.332 ± 8		0.9	p, α	11
13.440 ± 8	(2^-)	28 ± 3	p, α	11
13.491	1^-	190	p, α	11
13.511 ± 8	1^+	5.8 ± 0.7	p, α, γ	9, 10, 11
13.548 ± 10	1^-	33	p, α	11
13.569 ± 10	2^+	63	p, α	11
13.613 ± 10	2^+	≈ 10	p, α	10, 11
13.667 ± 8		6.2 ± 1	p, α	10, 11
13.673 ± 10	$0^+, 2^+$	20	p, α	10, 11
13.690 ± 10	1^-	110	p, α	11
13.703 ± 8	2^-	5.1 ± 0.3	p, α, γ	9, 10, 11
13.730 ± 8		4.8 ± 1	p, α	10, 11
13.757 ± 10	0^+	≈ 170	p, α	11
13.761 ± 8	1^+	8.2 ± 0.5	p, α, γ	9, 10, 11
13.80			p, γ	9
13.899 ± 10	1^-	≈ 200	p, α	11
13.909 ± 8		0.7 ± 0.3	p, α, γ	9, 10, 11
13.932 ± 10	2^+	45	p, α	11
13.956 ± 8		3	p, α	10, 11
13.975 ± 10	0^+	≈ 70	p, α	11
14.003 ± 8		100 ± 20	p, α	11
14.046 ± 10	1^-	≈ 60	p, α	11
14.061 ± 10	2^+	≈ 100	p, α	10, 11
14.092 ± 8	(3^+)	17.5 ± 1	p, α, γ	9, 10, 11
14.13		3.8	p, γ	9
14.154 ± 8	2^-	5.2 ± 0.5	p, α, γ	9, 10, 11
14.167 ± 10	2^+	40	p, α	11
14.179 ± 8	2^-	10.5 ± 1	p, α, γ	9, 10, 11
14.224 ± 10	1^+	14 ± 1	p, γ	9, 10

Table 20.6: Energy levels of ^{20}Ne (continued)

E_x (MeV $\pm$ keV)	$J^\pi; T$	τ_m or Γ (keV)	Decay	Reactions
14.380 ± 8		5.7 ± 1	p, α	10, 11
14.436 ± 60		55	p, α	10, 11
14.482 ± 8		33 ± 3	p, α	10, 11
14.497 ± 10	0^+	130 ± 5	p, α	11
14.633 ± 10	1^-	125 ± 5	p, α	11
14.725 ± 8	0^+, 1^+	38 ± 10	p, α	10, 11
14.802 ± 8		110 ± 20	p, α	11
14.91	(4^+)	70 ± 25	p, α	11
15.07	(2^+)	75 ± 25	p, α	11
15.08		80	p, α	11
15.26		27	p, α	11
15.34	(0^+)	285 ± 25	p, α	11
15.37		85	p, α	11
15.42		75	p, α	11
15.53		55	p, α	11
15.55		120	p, α	11
15.67			p, α	11
15.74		28	p, α	11
15.84		150	p, α	11
15.90		78	p, α	11
16.05		100	p, α	11
16.19		38	p, α	11
(16.20)		(75)	p, α	11
(16.28)		(110)	p, α	11
16.37		(100)	p, α	11
16.54			p, α	11
16.60		28	p, α	11
16.61		190	p, α	11
16.65		130	p, α	11
16.67		105	p, α	11

Table 20.6: Energy levels of ^{20}Ne (continued)

E_x (MeV ± keV)	$J^\pi; T$	τ_m or Γ (keV)	Decay	Reactions
16.80		95	p, α	11
16.95		45	p, α, n	11, 12
17.02		95	p, α	11
17.11		85	p, α, n	11, 12
17.14		25	p, α, n	11, 12
17.22		25	p, α, n	11, 12
17.26		57	p, n	12
17.33		60	p, α	11
17.35		25	p, α, n	11, 12
17.41		35	p, α, n	11, 12
17.53		85	p, α	11
17.61		35	p, α	11
17.61		19	p, α, n	11, 12
17.69		30	p, α, n	11, 12
17.79		210	p, α	11
17.81		67	p, α	11
17.86		67	p, n	11, 12
18.01			p, n	12
18.34			p, n	12
18.66			p, n	12
19.02			p, n	12

7. ^{17}O(α, n)^{20}Ne $\qquad Q_m = 0.608$

Not observed.

8. ^{18}O(^{3}He, n)^{20}Ne $\qquad Q_m = 13.117$

Not observed.

Table 20.7: Resonances in ^{16}O(α, α)^{16}O

E_α (MeV)	$\Gamma_{c.m.}$ (keV)	θ^2 (%)	J^π	^{20}Ne* (MeV)	Reference
2.490	19	22	0^+	6.745	(1953CA44)
3.045	8	36	3^-	7.189	(1953CA44)
3.090	4	1.1	0^+	7.225	(1953CA44)
3.380	8	4.7	2^+	7.457	(1953CA44)
3.885	2	0.6	2^+	7.861	(1953CA44)
≈ 4.8	≈ 1300	≈ 70	0^+	≈ 8.6	(1958MC61) [a]
5.01	4	0.23	1^-	8.76	(1958MC61) [a]
≈ 5.1	≈ 1200	≈ 95	2^+	≈ 8.8	(1958MC61) [a]
5.11	≤ 4		(5^-)	8.84	(1958MC61) [a]
5.19	20	1.0	1^-	8.91	(1958MC61) [a]
5.44	8	3.9	4^+	9.11	(1958MC61) [a]
5.6			(1^-)	9.2	(1940FE01)
6.7			(1^-)	10.1	(1940FE01)

[a] Preliminary results.

9. ^{19}F(p, γ)^{20}Ne $\qquad Q_m = 12.873$

Resonances for capture radiation are listed in Table 20.8 (1954SI07, 1955FA1A). The level formed at $E_p = 0.67$ MeV decays predominantly to the 1.63 MeV state: $\Gamma_\gamma = 2.2$ eV (1951CA1A, 1952JO1D, 1955CL1B). The angular distribution of the hard radiation is isotropic within two per cent (1955FA1A). The γ-γ angular correlation shows that the transition to the 1.63 MeV state is predominantly M1. The direct ground state transition is < 0.02 eV which implies different nucleon configurations for the ground and first excited states of ^{20}Ne (1955CL1B). At $E_p = 0.67$ and 1.09 MeV, cascades through the 4.97 MeV state have been observed. The 4.97 MeV level decays with $> 95\%$ probability through the 1.63 MeV state. Triple γ-correlations (C $\rightarrow 4.97 \rightarrow 1.63 \rightarrow 0$) show $J \neq 0$ for the 4.97 MeV state. Since a cascade takes place to it from the $J = 1^+$ state at the 0.67 MeV resonances, $J \leq 3$ (1958GO03). See also (1953WI1F, 1957WA1B, 1958BR1D).

10. (a) ^{19}F(p, p)^{19}F $\qquad E_b = 12.873$
(b) ^{19}F(p, p$'$)^{19}F*

Table 20.8: Resonances in ^{19}F(p, γ)^{20}Ne

E_p (keV)	Γ (keV)	Yield [a] (%)	^{20}Ne* (MeV)
669 [b, c]	7.5	1.80 ± 0.36	13.511 [f]
874 [c]		0.03 ± 0.01 [e]	13.703 [f]
935 [c]		0.03 ± 0.01	13.761 [f]
980 [c]		0.22 ± 0.04 [d]	13.80
1091 [b, c]	< 1.2	0.34 ± 0.07	13.909 [f]
1280 [c]		0.06 ± 0.01	14.092 [f]
1320 [b, c]	4.0	0.90 ± 0.18 [d]	14.13
1350 [c]		0.12 ± 0.02	14.154 [f]
1370 [c]		0.08 ± 0.02	14.179 [f]
1420 [b, c]	15.7	0.35 ± 0.07 [d]	14.224 [g]

[a] Relative to ^{19}F(p, $\alpha\gamma$)^{16}O.
[b] (1954SI07: resonances for $E_\gamma = 12$ MeV).
[c] (1955FA1A: resonances for $E_\gamma > 8$ MeV).
[d] Resonance not observed for ^{19}F(p, $\alpha\gamma$)^{16}O.
[e] $E_\gamma < 2$ eV (1953WI1F).
[f] Excitation energies from ^{19}F(p, $\alpha\gamma$): see Table 20.13.
[g] Excitation energy from ^{19}F(p, p′): see Table 20.10.

The elastic scattering has been studied in the range $E_p = 500$ to 2000 keV by (1954DE1A, 1954PE1A, 1955BA1C, 1955WE44, 1956DE33). Parameters for the observed resonances are exhibited in Table 20.9, taken mainly from (1955BA1C); values given by (1956DE33) are in good agreement with these. Orbital angular momentum assignments derive from angular distributions; J^π from the anomaly shape, and Γ_p/Γ from σ(p, p), σ(p, p′) and σ(p, α) cross sections. At $E_p = 340$ keV, 480 keV (1955WE44), and 598 keV (1956DE33), the elastic scattering anomaly is too small to be detected: it is concluded that Γ_p/Γ is small for these resonances. Some unresolved structure is observed at $E_p = 900$, 1092, and 1137 keV, in addition to a broad structure near $E_p = 1700$ keV (1955WE44). It is of interest to note that two of the resonances, at $E_p = 669$ and 843 keV have comparatively large proton reduced widths (1955BA1C). For high-energy scattering, see ^{19}F.

Resonances for inelastic scattering involving the 110 keV, $J = \frac{1}{2}^-$ and 197 keV, $J = \frac{5}{2}^+$, states of ^{19}F are listed in Table 20.10 (1955BA94). Resonance structure in the yield of 109, 197, 1240, and 1360 keV γ-radiation is reported by (1958RA15) up to $E_p = 4.5$ MeV. In general, the resonances observed are identical with those reported from other ^{19}F + p reactions, although the

Table 20.9: Levels of ^{20}Ne from ^{19}F(p, p)^{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	$1^{+\ b}$	0.016	3.8	13.196
598	37	1	$2^{-\ b}$	0.0012	0.38	13.441
669	7.5	0	1^+	0.98	9.6	13.509
843	23	0	0^+	0.996	10.8	13.674
873	5.2	1	$2^{-\ a}$	0.21	1.5	13.702
935	8.0	0	1^+	0.17	0.44	13.761
1346	4.5	1	$2^{-\ a}$	0.067	0.07	14.152
1372	15	1	$2^{-\ a}$	0.17	0.52	14.176
1422	14.6	0	1^+	0.85	0.92	14.224
1694 [c]						14.482
1940 [c]		(0)	$(0^+, 1^+)$			14.716
2030 [c]						14.802

[a] 1^- not excluded by elastic scattering alone.
[b] not determined by (p, p): see ^{19}F(p, α)^{16}O.
[c] (1956DE33).

relative intensities differ greatly. The nonresonant yield of the 197 keV radiation appears to be mainly due to Coulomb excitation, while that of the 110 keV radiation suggests contributions from broad, unresolved s-wave resonances (1954PE1A, 1955BA94). See also (1954PE1C) and ^{19}F.

11. ^{19}F(p, α)^{16}O $\quad Q_m = 8.119 \quad E_b = 12.873$

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 ($J = 0^+$); the next longest (α_π) results in the formation of the $J = 0^+$ nuclear pair-emitting state at 6.06 MeV, while the three remaining groups (α_1, α_2, α_3) lead to γ-ray emitting states at 6.14 ($J = 3^-$), 6.91 ($J = 2^+$), and 7.12 MeV ($J = 1^-$). At $E_p > 3$ MeV, excitation of higher ^{16}O levels occurs: see ^{16}O. Resonances for α_0 and α_π (Tables 20.11 and 20.12) are generally identical and different from those for α_1, α_2, α_3 (Table 20.13). The resonances for α_0 and α_π are required to have even J, even π or 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.

Table 20.10: 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		13.196
483		2.2	< 1.5	< 1.5			13.332
598	2^-	37	< 500	< 500	< 28	< 145	13.441
669	1^+	7.5	46	< 0.5	0.6	< 0.4	13.509
720		≈ 30	< 10000	< 10000			13.557
780 [b]		≈ 10	< 400	≈ 9000			13.614
831		8.3	< 6	≈ 2300			13.662
845	0^+	23	≈ 50	< 10	≈ 0.14	< 0.92	13.676
873	2^-	5.2	< 2	570	< 0.07	2.7	13.702
900		4.8	< 30	≈ 2200			13.728
935	1^+	8.0	3000	< 20	5.0	< 0.8	13.761
1092		< 1.2					13.910
1137 [c]		3.7	< 40	≈ 2100			13.953
≈ 1250		≈ 80	≈ 70000	< 4000			14.061
1290		19	< 600	≈ 900			14.099
1346	2^-	4.5	300	600	0.92	0.24	14.152
1372	2^-	15	700	1400	1.93	0.56	14.176
1422	1^+	14.6 ± 1	2200	≤ 35	0.56	≤ 0.11	14.224
1610		≈ 5					14.403
1660							14.450
1700							14.488

[a] (1955BA1C).
[b] (1955HU1A) find $E_p = 780.3 \pm 0.8$ keV, $\Gamma = 7.6 \pm 1.0$ keV but assignment to this reaction is uncertain.
[c] (1955HU1A) find 1123 ± 2.0 keV, $\Gamma = 22 \pm 5$ keV, but assignment is uncertain.

Table 20.11: Resonances for ground state α-particles (α_0) in $^{19}F(p, \alpha_0)^{16}O$

E_p (keV)	Γ_{lab} (keV)	σ (mb)	t [f]	θ^2_α [a] (%)	J^π	$^{20}Ne^*$ (MeV)
400 [g]	100	0.04	0		1^-	13.253
400	100	0.005	0		0^+	13.253
650	200	0.2	∞		1^-	13.491
710 [a, g]	35	< 0.5		0.6	(1^-)	13.548
733	66	1.4	0.2	1.0	2^+	13.569
778	≈ 10	> 0.5	1.6	0.02	2^+	13.612
843	23	3.7	1.38	0.16	2^+ [e]	13.674
≈ 860	120	1.0	10.6	2.1	1^-	13.690
≈ 930	≈ 180	0.5		2.9	0^+	13.757
≈ 1080	≈ 200	3.4	5.1	3.4	1^-	13.899
1115	50	2.4	2.2	0.55	2^+	13.932
1160	≈ 70	5.1		1.1	0^+	13.975
1235 [a, b]	≈ 70	5.2	0.11	1.2	1^-	14.046
≈ 1250 [a]	≈ 150	0.26	0.6	2.7	2^+	14.061
1358 [a, b, c]	54	43 [d]	2.6	0.49	2^+	14.163
1640 [b]	< 115					14.431
1709 [b, c]	140	53	0		0^+	14.497
1853 [b, c]	132	76	0.4		1^-	14.633
2110 [b, c]	75	9			(4^+)	14.878
2310 [b, c]	80	29			(2^+)	15.067
(2530) [b]						(15.28)
2590 [b, c]	300	51 ± 10			(0^+)	15.33
2680 [b]	80					15.42
(2820)						(15.55)
2940						15.67
3120	170					15.84
3340	105					16.05
3680	(100)					16.37
3860						16.54
3980	135					16.65
4130	100					16.80

Table 20.11: Resonances for ground state α-particles (α_0) in ^{19}F(p, α_0)^{16}O (continued)

E_p (keV)	Γ_{lab} (keV)	σ (mb)	t [f]	θ^2_α [a] (%)	J^π	^{20}Ne* (MeV)
4360	100					17.02
4460	95					17.11
4690	65					17.33
4900	90					17.53
4990	40					17.62

[a] (1958IS10, 1958IS11): quoted cross sections in these references are resonant cross sections, derived from analysis of angular distributions.
[b] (1958RA15).
[c] (1957CL42).
[d] See also (1958FR03).
[e] $J = 0^+$ from ^{19}F(p, p)^{19}F; possibly $T = 1$ (1955BA94, 1955BA1C).
[f] $t = \Gamma(J_c = 1)/\Gamma(J_c = 0)$.
[g] (1958BR1K).

Studies of the α_0 yield and of angular distributions have been made by (1957CL42, 1957TA1D, 1958BR1K, 1958FR03, 1958IS10, 1958IS11, 1958RA15): see Table 20.11. Assignments of (1958IS11) and (1957CL42) are based on detailed analysis of angular distributions. It is of interest that the reduced widths of these levels, where known, are generally less than a few per cent of the single-particle limit. There is some disagreement on the assignment of the prominent $E_p = 843$ keV resonance (compare ^{19}F(p, p)^{19}F). The 1358 keV resonance reported here appears to be distinct from the $E_p = 1372$ keV ($J = 2^-$) resonance seen in ^{19}F(p, p)^{19}F and ^{19}F(p, $\alpha\gamma$)^{16}O. (1958BR1K) find from angular distribution studies that the 720 keV resonance has $J = 2^+$, and is formed in channel spin 0. Near $E_p = 400$ keV, two resonances are required, with $J^\pi = 1^-$ and 0^+, both with $\Gamma \approx 100$ keV, $J_c = 0$. A third resonance occurs at $E_p = 650$ keV, with $J = 1^-$, $\Gamma = 200$ keV (1958BR1K).

A special study has been made to detect a possible resonance for ^{19}F(p, α_0)^{16}O at the $E_p = 340$ keV, $J = 1^+$, resonance. An upper limit of 2% resonant/nonresonant yield is found, indicating a maximum admixture of 2×10^{-4} of odd-parity component in the wave functions involved (1957TA1D: see also (1958WI41)).

Resonances in the ^{19}F(p, α_π)^{16}O yield have been investigated by (1950CH53, 1951PH1A, 1954DE36, 1955IS1A, 1956IS1A, 1958IS11, 1958RA15): see Table 20.12. 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 23 (p, α_0) resonances have no clear counterpart in σ(p, α_π). For resonances at $E_p = 1.35$, 1.72, 1.88, and 2.33 MeV, $\theta^2_{\alpha_0} = \theta^2_{\alpha_\pi}$ within about 10%; at $E_p = 2.17$ MeV, a large difference occurs, possibly to be ascribed to superposition

Table 20.12: Nuclear pair resonances (α_π) in ^{19}F(p, α_π)^{16}O

E_p (keV)	Γ (keV)	σ [c] (mb)	θ^2_α [c] (%)	J^π	^{20}Ne* (MeV)
710 [a]	35	≈ 0.2	2	1^-	13.548
780	≈ 10	≈ 0.2	0.15	2^+	13.614
842	23	3.4	0.27	2^+	13.673
1115	50	1.5	3.6	2^+	13.932
1236 [a,b]	≈ 70	3	1.0	1^-	14.047
1367 [a,b]	30	6.0	0.29	2^+	14.172
1630 [b]	60				14.42
1720	95	≈ 18			14.51
1880	170				14.66
2170	95				14.94
2330	≈ 100				15.09
2600	100				15.34
2680	100				15.42
2820	125				15.55
3120	145				15.84
3340	100				16.05
(3500)	(80)				(16.20)
(3590)	(115)				(16.28)
3960	200				16.64
4360	95				17.02
4690	< 150				17.33
4900	115				17.53
4990	40				17.61
5170	220				17.79

[a] (1950CH53, 1951PH1A, 1954DE36, 1958IS11).
[b] (1958RA15).
[c] (1958IS11): resonant cross sections derived from analysis; see also (1950CH53).

of several resonances (1958RA15). Below $E_p = 1.3$ MeV, several fairly large differences occur (1958IS11).

Resonances in the yield of $6 - 7$ MeV γ-rays have been studied by (1948BO21, 1949HE1A, 1950AR1A, 1950BA1A, 1950CH1A, 1950CH53, 1952HU1C, 1952WI27, 1953FA18, 1953HU18, 1953WI1F, 1955BU1A, 1955HU1A, 1955KI28, 1956BU27): see Table 20.13.

Table 20.13: Resonances for $6 - 7$ MeV γ-rays (α_1, α_2, α_3) in ^{19}F(p, α)^{16}O

E_p (keV)	Γ (keV)	σ [g] (mb)	Γ_{α_1} [j] (eV)	Γ_{α_2} [j] (eV)	Γ_{α_3} [j] (eV)	J^π	^{20}Ne* (MeV)
224.4 [d]	1.0	> 0.2					13.086
340.5 ± 0.3 [a]	3.3 ± 0.2	160	2800	16	75	1^+ [h]	13.196
483.6 [d]	0.9 ± 0.1	> 32	≈ 1700	≈ 30	≈ 450		13.332
596.8 ± 1.0 [b]	30.0 ± 3	7.1	37000	< 100	< 100	(2^-) [i]	13.440
671.6 ± 0.7 [b]	6.0 ± 0.7	57	110	0.4	25	1^+	13.511
834.8 ± 0.9 [b]	6.5 ± 1.0	19	total ≈ 5400				13.667
874.0 ± 1.0 [c]	5.0 ± 0.3	540	2400	850	300	2^-	13.703
902.3 ± 0.9 [b]	5.1 ± 1.0	23	≈ 2500	< 130			13.730
935.1 ± 0.9 [b]	8.6 ± 0.5	180	2800	110	780	1^+	13.761
1090 ± 1.0 [b]	0.7 ± 0.3	> 13					13.909
(1123 ± 2.0) [b]	22 ± 5						(13.94)
1140 ± 1.0 [b]	2.5 ± 5	15	total ≈ 1600				13.956
1189 ± 7.0 [b]	110 ± 20	19					14.003
1283 ± 1.4 [b]	18.6 ± 1.0	29	≈ 13000	≈ 1300	≈ 3200	(3^+)	14.092
1348 ± 1.3 [b,e]	5.6 ± 0.5	89	1800	450	1050	2^-	14.154
1375 ± 1.4 [b,e]	11.0 ± 1.0	300	9100	840	520	2^-	14.179
(1607 ± 1.6) [b]	6.0 ± 1.0						14.380
1694 ± 1.7 [b,f]	35.0 ± 3.0						14.482
1949 ± 2.5 [b,f]	40 ± 10						14.725
2030 ± 3.0 [b,f]	120 ± 20						14.802
2320 [f]	85						15.08
2510	30						15.26
2630	90						15.37
2800	60						15.53
3020	30						15.74
3190	80						15.90

Table 20.13: Resonances for $6-7$ MeV γ-rays (α_1, α_2, α_3) in ^{19}F(p, α)^{16}O (continued)

E_p (keV)	Γ (keV)	σ [g] (mb)	Γ_{α_1} [j] (eV)	Γ_{α_2} [j] (eV)	Γ_{α_3} [j] (eV)	J^π	^{20}Ne* (MeV)
3490	40						16.19
3920	30						16.60
4000	110						16.67
4290	50						16.95
4490	30						17.14
4570	30						17.22
4710	30						17.35
4780	35						17.41
4990	20						17.61
5070	35						17.69
5200	70						17.81

[a] (1955BU1A, 1956BU27): see also (1949MO1A, 1952HU1C). (1958BO76 find $\Gamma = 2.4 \pm 0.3$ keV).
[b] (1955HU1A; assignment to this reaction probable but not certain).
[c] Observed values are 872.5 ± 1.8 (1953FA18), 871.3 ± 0.4 (1955BU1A, 1956BU22), 873.5 ± 0.8 (1949HE1A), 872.4 ± 0.4 keV (1958BO76), 874.5 ± 0.9 keV (1955HU1A).
[d] (1952HU1C, 1953HU18, 1958BO76).
[e] (1955KI28).
[f] (1952WI27); these values should be reduced by about 0.2%: see (1955KI28).
[g] (1950CH53): see also (1948BO21).
[h] (1950AR1A, 1950BA1A, 1950CH1A).
[i] (1950CH1A, 1953WI1F).
[j] (1955BA94).

At $E_p = 224$ keV, the angular distribution of 6 MeV radiation is anisotropic (1954NE1C). The $6-7$ MeV radiation produced at the $E_p = 340$, 483, 669, and 935 keV resonances is isotropic or nearly so (1949DE1A, 1951DA1B, 1952SA1A, 1953SA1B, 1957GA1B, 1957GO1E). (1958RE24) finds a 3.5% anisotropy at $E_p = 340$ keV, indicating a 1% admixture of d-waves: $\theta_d^2 \approx \theta_s^2$. At $E_p = 340$, 669, and 935 keV, the α_1-γ correlations establish that $J = 1^+$ for the corresponding ^{20}Ne levels (1950AR1A, 1950BA1A, 1952SE1C, 1957MA1A): this assignment is confirmed for the 935 keV resonance by the α_1 angular distribution (1954PE1C). Correlations and angular distributions at the $E_p = 874$ keV resonance establish $J = 2^-$ for this level (1952SE1C, 1954PE1C, 1957MA1A), and the observed polarization of the γ rays is consistent with this assignment (1953FA1B). The level corresponding to $E_p = 598$ keV is assigned $J = 2^-$

Table 20.14: 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).

by (1950CH1A) on the basis of γ-ray angular distributions: $W(\theta) = 1 + 0.17 \cos^2 \theta$ (1958RE24): see also (1953WI1F). Levels corresponding to resonances at $E_p = 1283$ and 1348 keV are assigned $J = 3^+$ by (1950CH1A). Angular distributions of the α groups at $E_p = 1283$ keV are not inconsistent with $J = 3^+$, but lead to $J = 2^-$ for the 1348 keV resonance (1954PE1C). Gamma-ray angular distributions at $E_p = 1375$ keV indicate a pronounced anisotropy and are consistent with $J = 2^-$ (1953SA1B: see also ^{19}F(p, p)^{19}F). This is evidently not the same as the 1.36 MeV α_0 resonance. $(\alpha_1$-$\gamma_1)$ angular correlations have been studied by (1957MA1A) at $E_p = 873$, 935, 1250, 1280, 1346, and 1372 keV. For the $J = 2^-$ resonances at $E_p = 873$, 1346, and 1372 keV, the p-wave and f-wave proton reduced widths are comparable in magnitude: for the first and last, g-wave α_1-emission has a surprisingly large probability.

An analysis of certain ^{20}Ne levels into partial widths, based on information from ^{19}F(p, p), (p, p′), (p, γ) and (p, α) is given by (1955BA1C, 1955BA94, 1958IS11): see Table 20.14. It is noted that a number of $T = 1$ levels may be expected in this region (compare ^{20}F).

12. ^{19}F(p, n)^{19}Ne $\qquad Q_m = -4.039 \qquad E_b = 12.873$

Observed resonances are listed in Table 20.15 (1951BL1A, 1952WI27, 1955MA84). See also (1958TA03, 1959GI47).

Table 20.15: Resonances in ^{19}F(p, n)^{19}Ne

E_p (MeV)	Γ (keV)	^{20}Ne* (MeV)
4.29 [a]	45	16.95
4.46 [a]	80	17.11
4.49 [a]	20	17.14
4.57 [a]	20	17.21
4.62 [a]	60	17.26
4.71 [a]	25	17.35
4.78 [a]	45	17.41
4.99 [a]	20	17.61
5.07 [a]	30	17.69
5.25 [a, b]	70	17.86
5.41 [b, c]		18.01
5.75 [b, c]		18.34
6.09 [c]		18.66
6.47 [c]		19.02

[a] (1952WI27): these values should be decreased by about 0.2%: see (1955KI28).
[b] (1955MA84).
[c] (1951BL1A): broad resonances, stacked-foil method.

13. ^{19}F(d, n)^{20}Ne $\qquad Q_m = 10.646$

Levels of ^{20}Ne derived from reported neutron groups are listed in Table 20.16: see also (1956BA1F, 1956TO1C). The earlier reported 2.2 MeV state appears to be spurious. The g.s. and 1.6 MeV groups show a clear stripping pattern, with $l_p = 0$ and 2, respectively. No clear evidence is found for the 4.2 and 5.4 MeV levels at $E_d = 9$ MeV (1955CA1F). Levels at $E_x = 9.7$ MeV (1950FR1C) (9.97 ?), and $E_x = 11.85$ MeV (1952WA1A) decay by α-particle emission.

Thresholds for production of γ radiation with $E_\gamma \approx 10 - 12$ MeV, are listed in Table 20.17 (1955BU1E, 1958BU12). Observed γ-ray energies are exhibited in Table 20.18 (1951TE1B, 1955BE81, 1957KR1B)[†] . It is noted that levels yielding appreciable γ-radiation must be presumed not to decay by α-emission. The 9.97 and 10.61 MeV levels may be the $T = 1$ levels

[†] *Note added in proof:* Recent studies of the γ-spectra at $E_d = 3.6$ MeV confirm the work of (1955BE81) and are not consistent with the fine structure reported in Table 20.17 (T.W. Bonner, private communication).

Table 20.16: Neutron groups from ^{19}F(d, n)^{20}Ne

E_x [a] (MeV)	E_x [b] (MeV)	l_p	J^π	$\frac{\Lambda}{2J+1}$ [d]
0	0	0	0^+, 1^+	0.07
1.5	1.6	2	1^+, 2^+, 3^+	0.44
4.2				
5.4				
7.3	7.3 [c]	(0)	$(0^+, 1^+)$	0.039
		(2)	$(1^+, 2^+, 3^+)$	1.0
9.0	9.2	1	0^-, 1^-, 2^-	0.054
10.1				

[a] (1940BO1A).
[b] (1955CA1F; $E_d = 9$ MeV).
[c] Unresolved levels; the angular distribution shows a composite of $l_p = 0$ and 2.
[d] Proton capture probability, in c.g.s. units, $\times 10^{48}$.

corresponding to ^{20}F(0) and *(0.65). The 10.6 MeV level has not been reported in any other reaction.

14. ^{19}F(^{3}He, d)^{20}Ne $\qquad Q_m = 7.379$

Not reported.

15. ^{19}F(α, t)^{20}Ne $\qquad Q_m = -6.940$

Not reported.

16. ^{20}F(β^-)^{20}Ne $\qquad Q_m = 7.050$

The decay is to the 1.6 MeV state of ^{20}Ne: E_β(max) $= 5.413 \pm 0.013$ MeV. The energy of the subsequent γ-ray is 1.629 ± 0.005 MeV (1952AL26, 1952AL30, 1954WO23). The relative intensity of the ground-state transition is $< 3.2 \times 10^{-4}$ (1954WO23). The Fermi plot is straight from the end point to $E_\beta = 1$ MeV. With a half-life of 11.4 sec, $\log ft$ (1.63 MeV state) $= 4.99$, $\log ft$ (ground state) $\gtrsim 9$ (1954WO23). A search for γ-γ coincidences from the cascade decay of

Table 20.17: Levels of ^{20}Ne from ^{19}F(d, n)^{20}Ne thresholds (1955BU1E, 1958BU12)

$E_{\text{thresh.}}$ (keV)	^{20}Ne* (MeV)
510	11.11
600	11.19
760	11.33
850	11.42
1150	11.69
1350	11.87
1790	12.27
2060	12.51

Table 20.18: Gamma radiation from ^{19}F(d, n)^{20}Ne

E_γ (MeV)			Assignment
A	B	C	C
6.7 ± 0.3			
	7.2		
8.1 ± 0.4	8.4		$9.97 \rightarrow 1.6$
9.3 ± 0.3	9.4	9.34 ± 0.1	$9.34 \rightarrow$ g.s.
	10.1	9.97 ± 0.1	$9.97 \rightarrow$ g.s.
	10.6	10.61 ± 0.1	$10.61 \rightarrow$ g.s. or $12.2 \rightarrow 1.6$
11.5 ± 0.4		11.51 ± 0.2	$11.4 \rightarrow$ g.s. or $11.7 \rightarrow$ g.s.

A: (1951TE1B): $E_{\text{d}} = 1.56$ MeV.
B: (1957KR1B).
C: (1955BE81): $E_{\text{d}} = 3.6$ MeV. Corrected for Doppler shift.

the 4.97 MeV state was unsuccessful: $\log ft > 6.5$ (1958KA14). The (β-γ) angular correlation has the form $W(\theta) = 1 + a\cos^2\theta$, where $a = (0.94 \pm 0.28) \times 10^{-2}$. The anisotropy is attributed to a "weak magnetic" interaction associated with the anomalous nucleon moments. The sign of a indicates $J = 2^+$ for ^{20}F (1958BO65, 1958GE1C).

17. ^{20}Ne(γ, n)^{19}Ne $\qquad Q_m = -16.912$

A giant resonance is observed at $E_\gamma = 21.5$ MeV with $\Gamma = 6.6$ MeV and σ(max) $= 7.3$ mb (1954FE16). See also (1957BA1H; theor.).

18. ^{20}Ne(γ, p)^{19}F $\qquad Q_m = -12.873$

See (1956AT1A, 1957KO1C, 1957WA1G).

19. ^{20}Ne(γ, α)^{16}O $\qquad Q_m = -4.753$

See (1953ER1B, 1956AT1A, 1957KO1C, 1957WA1G).

20. ^{20}Ne(p, p′)^{20}Ne*

^{20}Ne levels derived from observations of proton groups are listed in Table 20.19 (1954FR43, 1956SC1F). A 2.6 MeV γ-ray has been observed in coincidence with the p_2 group (4.2 MeV state) at $E_p = 5.85$ MeV (1957KR1B). At $E_p = 185$ MeV, inelastic peaks corresponding to levels near 5 and 20 MeV are observed (1958TY1D).

Elastic scattering angular distributions have been studied in the range $E_p = 1.8$ to 4.3 MeV by (1955HA1F), for $E_p = 4.7$ to 5.5 MeV by (1958KO58), at 9.5 MeV by (1954FR43, 1956BU95, 1957GI14). Angular distributions of inelastic groups are reported by (1954FR43, 1956SC1F, 1957GI14, 1958KO58). See also (1957BU52; theor.).

21. ^{20}Ne(d, d′)^{20}Ne*

At $E_d = 7.8$ MeV, an inelastic deuteron group is observed corresponding to a state at 1.66 ± 0.02 MeV (1951MI1A). The angular distribution, analyzed by the direct interaction theory (of (1952HU1B)), indicates $l = 2$, $J = 1, 2, 3^+$; the observed distributions can also be ascribed to electric excitation, but the required moments are about two orders of magnitude too large (1958VA06). See also (1952MI1B).

Table 20.19: Levels of ^{20}Ne from ^{20}Ne(p, p′)^{20}Ne*, ^{20}Ne(α, α')^{20}Ne* and ^{23}Na(p, α)^{20}Ne

E_x [a] (MeV ± keV)	E_x [b] (MeV)	E_x [c] (MeV)	E_x [d] (MeV ± keV)
0	0	0	0
1.58 ± 10	1.63	1.63	1.635 ± 6 [e]
4.20 ± 10	4.26	4.25	4.248 ± 6
4.95 ± 20	4.97	4.97	4.969 ± 6
5.62 ± 20	5.81	5.81	5.631 ± 6
		7.2	
	7.45		
	7.85		
	9.2		
	10.0		

[a] ^{20}Ne(p, p′): (1954FR43), $E_p = 9.5$ MeV.
[b] ^{20}Ne(p, p′): (1956SC1F), $E_p = 18$ MeV; energies for identification only.
[c] ^{20}Ne(α, α'): (1958SE51), $E_\alpha = 18$ MeV; energies for identification only.
[d] ^{23}Na(p, α): (1957BU36), $E_p = 7.0$ to 7.5 MeV.
[e] 1.634 ± 4 (1953DO04).

22. ^{20}Ne(α, α')^{20}Ne*

At $E_\alpha = 18.0$ MeV, inelastic groups are observed to ^{20}Ne states at 1.63, 4.25, 4.97, 5.81, and 7.2 MeV: see Table 20.19. Angular distributions for α_0(g.s.) and α_1 show sharp diffractions maxima characteristic of direct interaction (1958SE51). See also (1957MO1C; theor.) and (1957EN01).

23. ^{22}Ne(p, t)^{20}Ne $\qquad Q_m = -8.638$

Not reported.

24. ^{20}Na(β^+)^{20}Ne $\qquad Q_m = 15.333$

The decay proceeds to excited states of ^{20}Ne between 6.8 and 10.8 MeV which decay by α-particle emission (1950AL57). The half-life is 0.23 ± 0.08 sec (1951SH38), 0.385 ± 0.01 sec (1953HO01). See also (1957EN01).

25. ^{23}Na(p, α)^{20}Ne

$Q_{\rm m} = 2.379$
$Q_0 = 2.370 \pm 0.008$ (1957BU36);
$Q_0 = 2.379 \pm 0.003$ (1953DO04);
$Q_0 = 2.372 \pm 0.008$ (1952VA1A).

At $E_{\rm p} = 7.04$ to 7.45 MeV, five α-groups are observed, corresponding to the ground state and to levels at 1.635, 4.248, 4.969, and 5.631 MeV (1953DO04, 1957BU36): see Table 20.19. The first excited state decays with a mean life of $(7.6 \pm 3.3) \times 10^{-13}$ sec (1956DE22), emitting a γ-ray with $E_\gamma = 1.63 \pm 0.02$ (1954ST91), 1.629 ± 0.008 MeV (1954NE1D, 1955NE1B). Over 90% of the decays of the 4.25 and 4.97 MeV states are by cascades through the 1.63 MeV state (1957KR1B: see also (1958KR67)). At a resonance located at $E_{\rm p} = 1.255$ MeV, the α-γ correlation permits the unique assignment of $J = 1^+$ to the ^{24}Mg state and $J = 2^+$ to the 1.63 MeV state of ^{20}Ne (1953SE1C). See also (1954ST92, 1955RU1B, 1956SQ1A, 1957EN01).

References

(Closed 01 December 1958)

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.

1937WI1A Wilhelmy, Z. Phys. 107 (1937) 769

1940BO1A Bonner, Proc. Roy. Soc. A174 (1940) 339

1940FE01 A.J. Ferguson and L.R. Walker, Phys. Rev. 58 (1940) 666

1947SE33 L. Seren, H.N. Friedlander and S.H. Turkel, Phys. Rev. 72 (1947) 888

1947TE01 D.H. Templeton, J.J. Howland and I. Perlman, Phys. Rev. 72 (1947) 758

1948BO21 T.W. Bonner, J.E. Evans, Phys. Rev. 73 (1948) 666

1949DE1A Devons and Hine, Proc. Roy. Soc. A199 (1949) 56, 73

1949HE1A R.G. Herb, S.C. Snowdon and O. Sala, Phys. Rev. 75 (1949) 246

1949MO1A A.H. Morrish, Phys. Rev. 76 (1949) 1651

1950AL57 L.W. Alvarez, Phys. Rev. 80 (1950) 519

1950AR1A Arnold, Phys. Rev. 79 (1950) 170; Erratum Phys. Rev. 80 (1950) 34

1950BA1A Barnes, French and Devons, Nature 166 (1950) 145

1950BO95 C.K. Bockelman, Phys. Rev. 80 (1950) 1011

1950CH1A Chao, Phys. Rev. 80 (1950) 1035

1950CH53 C.Y. Chao, A.V. Tollestrup, W.A. Fowler and C.C. Lauritsen, Phys. Rev. 79 (1950) 108

1950FR1C French, Meyer and Treacy, Proc. Phys. Soc. (London) A63 (1950) 666

1950HE92 R.L. Henkel and H.H. Barschall, Phys. Rev. 80 (1950) 145

1950JE1A Jelley and Paul, Proc. Phys. Soc. (London) A63 (1950) 112

1951BL1A Blaser, Boehm, Marmier and Scherrer, Helv. Phys. Acta 24 (1951) 465

1951CA1A Carver and Wilkinson, Proc. Phys. Soc. (London) A64 (1951) 199

1951DA1B Day, Ph.D. Thesis, C.I.T. (1951)

1951KI35 B.B. Kinsey, G.A. Bartholomew and W.H. Walker, Phys. Rev. 83 (1951) 519

1951MI1A Middleton and Tai, Proc. Phys. Soc. (London) A64 (1951) 801

1951PH1A Phillips and Heydenburg, Phys. Rev. 83 (1951) 184

1951SH38 R.K. Sheline, Phys. Rev. 82 (1951) 954

1951TE1B J. Terrell and G.C. Phillips, Phys. Rev. 83 (1951) 703

1951WI1A Willard, Preston and Goodman, Phys. Rev. 81 (1951) 329A

1952AJ38 F. Ajzenberg and T. Lauritsen, Rev. Mod. Phys. 24 (1952) 321

1952AL26 D.E. Alburger, Phys. Rev. 88 (1952) 1257

1952AL30 D.E. Alburger, Physica 18 (1952) 1034

1952HU1B Huby and Newns, Phil. Mag. 42 (1952) 1442

1952HU1C Hunt, Proc. Phys. Soc. (London) A65 (1952) 982

1952JO1D Jones and Wilkinson, Proc. Phys. Soc. (London) A65 (1952) 1055

1952MI1B Middleton and Tai, Proc. Phys. Soc. (London) A65 (1952) 752

1952SA1A Sanders, Phil. Mag. 43 (1952) 630

1952SE1C J. Seed and A.P. French, Phys. Rev. 88 (1952) 1007

1952VA1A D.M. Van Patter, A. Sperduto, P.M. Endt, W.W. Buechner and H.A. Enge, Phys. Rev. 85 (1952) 142

1952WA1A Watson and Buechner, Phys. Rev. 88 (1952) 1324

1952WI27 H.B. Willard, J.K. Bair, J.D. Kington, T.M. Hahn, C.W. Snyder and F.P. Green, Phys. Rev. 85 (1952) 849

1953BR1C D.A. Bromley, J.A. Bruner and H.W. Fulbright, Phys. Rev. 89 (1953) 396

1953CA44 J.R. Cameron, Phys. Rev. 90 (1953) 839

1953DO04 D.J. Donahue, K.W. Jones, M.T. McEllistrem and H.T. Richards, Phys. Rev. 89 (1953) 824

1953ER1B Erdman and Barnes, Proc. Roy. Soc. Canada 47 (1953) 131A

1953FA18 K.F. Famularo and G.C. Phillips, Phys. Rev. 91 (1953) 1195

1953FA1B L.W. Fagg and S.S. Hanna, Phys. Rev. 92 (1953) 372

1953HO01 J.M. Hollander, I. Perlman and G.T. Seaborg, Rev. Mod. Phys. 25 (1953) 469

1953HU18 S.E. Hunt and W.M. Jones, Phys. Rev. 89 (1953) 1283

1953PA1C Paul and Clarke, Can. J. Phys. 31 (1953) 267

1953SA1B Sanders, Phil. Mag. 44 (1953) 1302

1953SE1C Seed, Phil. Mag. 44 (1953) 921

1953WI1F Wilkinson and Clegg, Phil. Mag. 44 (1953) 1322

1954DE1A Dearnaley, Phil. Mag. 45 (1954) 1213

1954DE36 S. Devons, G. Goldring and G.R. Lindsey, Proc. Phys. Soc. (London) A67 (1954) 134

1954FE16 G.A. Ferguson, J. Halpern, R. Nathans and P.F. Yergin, Phys. Rev. 95 (1954) 776

1954FR43 R.G. Freemantle, D.J. Prowse, A. Hossain and J. Rotblat, Phys. Rev. 96 (1954) 1270

1954NE03 N. Nereson and S. Darden, Phys. Rev. 94 (1954) 1678

1954NE1C Nelson, Lawrence and Carlson, Phys. Rev. 96 (1954) 825A

1954NE1D J.O. Newton, Phys. Rev. 96 (1954) 241

1954PE1A Peterson, Barnes, Fowler and Lauritsen, Phys. Rev. 94 (1954) 1075

1954PE1C R.W. Peterson, W.A. Fowler and C.C. Lauritsen, Phys. Rev. 96 (1954) 1250

1954SH28 R.K. Sheline, N.R. Johnson, P.R. Bell, R.C. Davis and F.K. McGowan, Phys. Rev. 94 (1954) 1642

1954SI07 R.M. Sinclair, Phys. Rev. 93 (1954) 1082

1954ST91 P.H. Stelson and W.M. Preston, Phys. Rev. 95 (1954) 974

1954ST92 P.H. Stelson, Phys. Rev. 96 (1954) 1584

1954TH1B L.C. Thompson, Phys. Rev. 96 (1954) 369

1954WO23 C. Wong, Phys. Rev. 95 (1954) 761

1955AJ61 F. Ajzenberg and T. Lauritsen, Rev. Mod. Phys. 27 (1955) 77

1955BA1C Baranger, Phys. Rev. 99 (1955) 145

1955BA94 C.A. Barnes, Phys. Rev. 97 (1955) 1226

1955BE81 R.D. Bent, T.W. Bonner, J.H. McCrary, W.A. Ranken and R.F. Sippel, Phys. Rev. 99 (1955) 710

1955BO1C Bostrom, Hudspeth and Morgan, Phys. Rev. 100 (1955) 973A

1955BO98 N.A. Bostrom, E.L. Hudspeth and I.L. MorganPhys. Rev. 99 (1955) 643, PA4

1955BU1A Bumiller, Ph.D. Thesis, Univ. of Zurich (1955)

1955BU1E Butler, Phys. Rev. 98 (1955) 241A

1955CA1F Calvert, Jaffe and Maslin, Proc. Phys. Soc. (London) A68 (1955) 1017

1955CL1B Clegg, Jones and Wilkinson, Proc. Phys. Soc. (London) A68 (1955) 538

1955FA1A Farney, Givin, Kern and Hahn, Phys. Rev. 97 (1955) 720

1955FR1B Freeman, Phys. Rev. 99 (1955) 1446

1955GA1C Gamba and Moncassoli, Nuovo Cim. 2 (1955) 1119

1955GR18 G.L. Griffith, Phys. Rev. 98 (1955) 579

1955HA1F Haeberli, Phys. Rev. 99 (1955) 640A

1955HE1E Herzenberg, Nuovo Cim. 1 (1955) 986, 1008

1955HI1C Hibdon and Langsdorf, Phys. Rev. 98 (1955) 223, B3

1955HU1A Hunt and Firth, Phys. Rev. 99 (1955) 786

1955IS1A Isoya, Goto and Momota, J. Phys. Soc. Jpn. 10 (1955) 1022

1955KI28 J.D. Kington, J.K. Bair, H.O. Cohn and H.B. Willard, Phys. Rev. 99 (1955) 1393

1955MA84 J.B. Marion, T.W. Bonner and C.F. Cook, Phys. Rev. 100 (1955) 91

1955MB01 J.B. Marion and R.M. Brugger, Phys. Rev. 100 (1955) 69

1955NE1B Newton, Proc. Glasgow Conf. (Pergamon Press, 1955)

1955PA1B Patterson, Newson and Merzbacher, Phys. Rev. 99 (1955) 1625, 10.

1955RU1B Rutherglen, Proc. Glasgow Conf. (Pergamon Press, 1955)

1955WE44 T.S. Webb, F.B. Hagedorn, W.A. Fowler and C.C. Lauritsen, Phys. Rev. 99 (1955) 138

1956AH1A Ahnlund, Ark. Fys. 10 (1956) 425

1956AT1A Atkinson, Crawford, Morisson, Preston and Wright, Physica 22 (1956) 1145A

1956BA1F Banta, Gibbons, Good and Neiler, ORNL 2076 (1956)

1956BE98 R.L. Becker and H.H. Barschall, Phys. Rev. 102 (1956) 1384

1956BU22 J.W. Butler, Bull. Amer. Phys. Soc. 1 (1956) 94

1956BU27 F. Bumiller, H.H. Staub and H.E. Weaver, Helv. Phys. Acta 29 (1956) 83

1956BU95 E.J. Burge, Y. Fujimoto and A. Hossain, Phil. Mag. 1 (1956) 19

1956CA1F Cameron, Bull. Amer. Phys. Soc. 1 (1956) 191

1956DE22 S. Devons, G. Manning and J.H. Towle, Proc. Phys. Soc. (London) A69 (1956) 173

1956DE33 G. Dearnaley, Phil. Mag. 1 (1956) 821

1956EL1A El-Bedewi, Proc. Phys. Soc. (London) A69 (1956) 221

1956HA1C Hayakawa, Hayashi, Imoto and Kikuchi, Prog. Theor. Phys. 16 (1956) 507

1956HA1D Hayashi and Nishida, Prog. Theor. Phys. 16 (1956) 613

1956IS1A Isoya, Goto and Momota, J. Phys. Soc. Jpn. 11 (1956) 899

1956KA1E Katcoff and Hudis, J. Inorganic Nucl. Chem. 3 (1956) 253

1956MO1D H. Morinaga, Phys. Rev. 101 (1956) 254

1956NE1C Newton, Can. J. Phys. 34 (1956) 804

1956OK1A Okai and Sano, Prog. Theor. Phys. 15 (1956) 203

1956SC1F Schrank and O'Neill, Bull. Amer. Phys. Soc. 1 (1956) 29

1956SH1A Sher and Floyd, Phys. Rev. 102 (1956) 242

1956SQ1A Squires, Bockelman and Buechner, Phys. Rev. 104 (1956) 413

1956TA1D Takemoto, Dazai, Chiba, Suganomata and Ito, Phys. Rev. 101 (1956) 772

1956TO1C W. Tobocman, Phys. Rev. 102 (1956) 588

1956VA17 F.P.G. Valckx, Ph.D. Thesis, Univ. of Utrecht (1956)

1956VA29 J.J. Van Loef and D.A. Lind, Phys. Rev. 101 (1956) 103

1957BA1H Barker, Phil. Mag. 2 (1957) 780

1957BO04 N.A. Bostrom, E.L. Hudspeth and I.L. Morgan, Phys. Rev. 105 (1957) 1545

1957BO13 R.O. Bondelid, K.L. Dunning and F.L. Talbott, Phys. Rev. 105 (1957) 193

1957BU36 W.W. Buechner and A. Sperduto, Phys. Rev. 106 (1957) 1008

1957BU52 S.T. Butler, Phys. Rev. 106 (1957) 272

1957BU66 E.M. Burbidge, G.R. Burbidge, W.A. Fowler and F. Hoyle, Rev. Mod. Phys. 29 (1957) 547

1957CA28 P.J. Campion and G.A. Bartholomew, Can. J. Phys. 35 (1957) 1361

1957CL42 R.L. Clarke and E.B. Paul, Can. J. Phys. 35 (1957) 155

1957CO1H Corelli, Bleuler and Tendam, Bull. Amer. Phys. Soc. 2 (1957) 34

1957CR65 P.W. Crutchfield, W. Haeberli and H.W. Newson, Bull. Amer. Phys. Soc. 2 (1957) 33, K8; Oral Report

1957EN01 P.M. Endt and C.M. Braams, Rev. Mod. Phys. 29 (1957) 683

1957FR57 J.M. Freeman, Phil. Mag. 2 (1957) 628

1957GA1B Gallmann, Ph.D. Thesis, Univ. of Strasbourg (1957)

1957GI14 W.M. Gibson, D.J. Prowse and J. Rotblat, Proc. Roy. Soc. A243 (1957) 237

1957GO1E S. Gorodetzky, A. Gallmann, M. Croissiaux and R. Armbruster, Nucl. Phys. 4 (1957) 112

1957KH16 L.M. Khromchenko, Zh. Eksp. Teor .Fiz. 32 (1957) 194; JETP (Sov. Phys.) 5 (1957) 231

1957KO1C Komar and Iavor, Zh. Eksp. Teor. Fiz. 32 (1957) 614

1957KR1B Kruse, Bent and Lidofsky, Bull. Amer. Phys. Soc. 2 (1957) 351

1957LA14 A. Langsdorf Jr., R.O. Lane and J.E. Monahan, Phys. Rev. 107 (1957) 1077

1957LI1A Livesey, Can. J. Phys. 35 (1957) 987

1957MA1A Martin, Fowler, Lauritsen and Lauritsen, Phys. Rev. 106 (1957) 1260

1957ME1E Merzbacher, Newson and Crutchfield, Bull. Amer. Phys. Soc. 2 (1957) 33

1957MO1C Morinaga and Peaslee, Nucl. Phys. 3 (1957) 115

1957ON1A Ono, Shimada, Kuroda and Tanaka, J. Phys. Soc. Jpn. 12 (1957) 745

1957RA1C G. Rakavy, Nucl. Phys. 4 (1957) 375

1957SA1B E.E. Salpeter, Phys. Rev. 107 (1957) 516

1957SE1D Seward, Slaus and Fulbright, Phys. Rev. 107 (1957) 159

1957TA1D N. Tanner, Phys. Rev. 107 (1957) 1203

1957TO1B Toppel, Bloom and Wilkinson, Phil. Mag. 2 (1957) 61

1957WA1B Wakatsuki, Hirao, Okada and Miura, J. Phys. Soc. Jpn. 12 (1957) 1178

1957WA1G Warren and Hay, Bull. Amer. Phys. Soc. 2 (1957) 178

1958AS63 V.J. Ashby, H.C. Catron, L.L. Newkirk and C.J. Taylor, Phys. Rev. 111 (1958) 616

1958BL54 R.C. Block, W. Haeberli and H.W. Newson, Phys. Rev. 109 (1958) 1620

1958BO65 F. Boehm, V. Soergel and B. Stech, Phys. Rev. Lett. 1 (1958) 77

1958BO76 R.O. Bondelid and C.A. Kennedy, NRL Rept. 5083 (1958)

1958BR16 A. Bratenahl, J.M. Peterson and J.P. Steering, Phys. Rev. 110 (1958) 927

1958BR1D Bromley, Proc. Rehovoth Conf. (North-Holland Pub. Co., Amsterdam, 1958)

1958BR1K Breuer and Neuert, Private Communication (1958)

1958BU12 J.W. Butler and H.D. Holmgren, Phys. Rev. 112 (1958) 461

1958CO59 J.C. Corelli, E. Bleuler and D.J. Tendam, Bull. Amer. Phys. Soc. 3 (1958) 200, P9

1958FR03 J.M. Freeman, R.C. Hanna and J.H. Montague, Nucl. Phys. 5 (1958) 148

1958GE1C M. Gell-Mann, Phys. Rev. 111 (1958) 362

1958GO03 H.E. Gove, A.E. Litherland and A.J. Ferguson, Bull. Amer. Phys. Soc. 3 (1958) 36, N1

1958GO71 C.D. Goodman and J.L. Need, Phys. Rev. 110 (1958) 676

1958HU18 D.J. Hughes and R.B. Schwartz, BNL-325, 2nd Ed. (1958); BNL-325, 2nd Ed., Suppl. I (1960)

1958IS10 A. Isoya, H. Ohmura and T. Momota, Nucl. Phys. 7 (1958) 116

1958IS11 A. Isoya, Nucl. Phys. 7 (1958) 126

1958KA14 R.W. Kavanagh, Bull. Amer. Phys. Soc. 3 (1958) 316, B7

1958KO03 E. Kondaiah, K.V.K. Iyengar and C. Badrinathan, Nucl. Phys. 5 (1958) 346

1958KO58 M. Kondo and T. Yamazaki, J. Phys. Soc. Jpn. 13 (1958) 771

1958KR67 T.H. Kruse, R.D. Bent and L.J. Lidofsky, Bull.Amer. Phys. Soc. 3 (1958) 200, P11

1958MC61 L.C. McDermott, K.W. Jones, H. Smotrich and R.E. Benenson, Bull. Amer. Phys. Soc. 3 (1958) 199, P6

1958RA15 W.A. Ranken, T.W. Bonner and J.H. McCrary, Phys. Rev. 109 (1958) 1646

1958RA1H Rayburn, Bull. Amer. Phys. Soc. 3 (1958) 337

1958RE24 T. Retz-Schmidt, Z. Naturforsch. A13 (1958) 833

1958SE51 L. Seidlitz, E. Bleuler and D.J. Tendam, Phys. Rev. 110 (1958) 682

1958TA03 Y.-K. Tai, G.P. Millburn, S.N. Kaplan and B.J. Moyer, Phys. Rev. 109 (1958) 2086

1958TY1D H. Tyren, G. Tibell and Th.A.J. Maris, Nucl. Phys. 7 (1958) 281

1958VA06 I.J. Van Heerden, Nucl. Phys. 6 (1958) 55

1958WA1C Way, Nucl. Data Cards, Natl. Res. Council, Washington, D.C. (1958)

1958WI36 J.E. Wills Jr., J.K. Bair, H.O. Cohn and H.B. Willard, Phys. Rev. 109 (1958) 891

1958WI41 D.H. Wilkinson, Phys. Rev. 109 (1958) 1610

1959GI47 J.H. Gibbons and R.L. Macklin, Phys. Rev. 114 (1959) 571

1959ZI16 W. Zimmermann Jr., Phys. Rev. 114 (1959) 837