Energy Levels of Light Nuclei
$A = 18$

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Abstract: An evaluation of $A = 5$–24 was published in *Nuclear Physics* 11 (1959), p. 1. This version of $A = 18$ differs from the published version in that we have corrected some errors discovered after the article went to press. 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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^{18}O

(Fig. 37)

GENERAL:

Theory: See (1955EL1B, 1955RE1D, 1956TH1B, 1957RA1C, 1958RE1B).

1. ^{14}C(α, γ)^{18}O $\qquad Q_{\rm m} = 6.243$

Three resonances are reported, at $E_\alpha = 1.13$, 1.79, and 2.33 MeV (1958GO69, 1958PH37): see Table 18.2. Angular distribution measurements of the capture radiation at the resonances permit the assignments $J = 0^+$, 2^+, 4^+ for the first three states of ^{18}O and $J = 4^+$, 1^- and 1^- to the resonance levels, ^{18}O*(7.12, 7.64, 8.06) (1958GO69, 1958PH37). The branching ratios for the upper two levels do not agree with values estimated from a simple collective model (1958PH37). The ground state transition from ^{18}O*(3.55) is less than 3% of the transition $3.55 \rightarrow 1.98$ (1958GO69).

2. ^{14}C(α, n)^{17}O $\qquad Q_{\rm m} = -1.825 \qquad E_{\rm b} = 6.243$

$E_{\rm thresh.} = 2.340 \pm 0.003$;

$Q_0 = -1.820 \pm 0.002$ (1956SA06).

Observed resonances in the $0°$ yield curve for $E_\alpha = 2.3$ to 3.6 MeV are shown in Table 18.3. The angular distribution of the neutrons at the 2.64 MeV resonance indicates $J = 1^-$ or 3^- for the 8.29 MeV state of ^{18}O (1956SA06).

3. ^{14}C(α, α)^{14}C $\qquad E_{\rm b} = 6.243$

Observed anomalies in the scattering for $E_\alpha = 2$ to 3.9 MeV are shown in Table 18.3. The resonances at $E_\alpha = (2.8)$, 3.3, and 3.5 MeV appear to have $\Gamma_{\rm n} \gg \Gamma_\alpha$ (1958WE29).

4. ^{14}C(α, p)^{17}N $\qquad Q_{\rm m} = -9.75 \qquad E_{\rm b} = 6.238$

See (1951SU1A).

5. ^{15}N(t, p)^{17}N $\qquad Q_{\rm m} = -0.15 \qquad E_{\rm b} = 15.842$

Table 18.1: Energy levels of ^{18}O

E_x (MeV $\pm$ keV)	J^π	Γ (keV)	Decay	Reactions
0	0^+		stable	1, 7, 10, 12, 13, 14, 15, 16, 18
1.982 ± 4	2^+		γ	1, 10, 12, 13, 16, 18
3.55 ± 20	4^+		γ	1, 10, 13, 18
3.929 ± 40				18
5.007 ± 40				18
5.170 ± 40				18
5.311 ± 40				18
5.456 ± 40				18
6.190 ± 40				18
6.328 ± 40				18
7.12	4^+		γ, α	1
7.638 ± 15	1^-	< 3	γ, α	1
8.057 ± 15	1^-	< 3	γ, α	1, 3
8.229 ± 15	2^+	1.3 ± 0.8	α, n	2, 3
8.302 ± 15	3^-	8 ± 1	α, n	2, 3
(8.42 ± 20)		17 ± 8	α, n	2
8.84 ± 20		80 ± 16	α, n	2
8.971 ± 15	$\geq 2^+$	42 ± 2	α, n	2, 3
$9.0 - 9.2$ (two levels)	$\left\{ \begin{array}{l} 2^+,\ 3^- \\ 4^+,\ 3^- \end{array} \right.$ or	> 150	α	3

Table 18.2: Resonances in ^{14}C(α, γ)^{18}O (1958GO69, 1958PH37)

E_{res} (MeV $\pm$ keV)	Γ (keV)	E_x in ^{18}O (MeV)	J^π	Γ_s [a] (eV) (g.s.)	(1.98)	(3.55)	(3.93)
1.13		7.12	4^+		0.01		
1.794 ± 6	< 3	7.638	1^-	0.12	0.24	< 0.02	< 0.02
2.334 ± 6	< 3	8.058	1^-	0.09	0.23	< 0.05	< 0.05

[a] $\Gamma_\alpha \Gamma_\gamma / \Gamma$ for γ-transitions leading to the states indicated.

Table 18.3: Resonances in $^{14}C(\alpha, n)^{17}O$ and $^{14}C(\alpha, \alpha)^{14}C$

E_{res} (MeV ± keV)	Γ_{lab} (total) (keV)	θ^2_α (%)	θ^2_n (%)	E_x (MeV)	J^{π} [c]
2.331 ± 5 [a]	$< 6 \pm 3$ [a, d]	< 2.8		8.056	$0^+, 1^-$ [d]
2.553 ± 4 [a, b]	1.6 ± 1 [b]	0.90	6.2×10^{-4}	8.229	2^+
2.642 ± 3 [a, b]	10 ± 1 [b]	20	0.16	8.302	3^-
(2.798 ± 11) [b]	22 ± 10 [b]			(8.419)	
3.335 ± 15 [a, b]	100 ± 20 [b]			8.837	
3.508 ± 4 [a, b]	54 ± 3 [b]			8.971	$\geq 2^+$
$3.6 - 3.9$ [a]	> 200 [a]			$9.0 - 9.2$ (two levels)	$\left\{ \begin{array}{l} 2^+,\ 3^- \\ 4^+,\ 3^- \end{array} \right.$ or

[a] (1958WE29): $^{14}C(\alpha, \alpha)^{14}C$; measurements at several back angles.
[b] (1956SA06): $^{14}C(\alpha, n)^{17}O$; 0°.
[c] From analysis of (α, α) and (α, n) data (1958WE29).
[d] Compare $^{14}C(\alpha, \gamma)^{18}O$.

See (1956SH1A).

6. $^{15}N(\alpha, p)^{18}O$ $\quad Q_m = -3.971$

Not observed.

7. $^{16}O(t, p)^{18}O$ $\quad Q_m = 3.730$

See (1953CU1D).

8. $^{17}O(n, p)^{17}N$ $\quad Q_m = -7.93$ $\quad E_b = 8.069$

See (1949CH1A).

9. $^{17}O(n, \alpha)^{14}C$ $\quad Q_m = 1.825$ $\quad E_b = 8.069$

The thermal neutron cross section is 0.4 ± 0.1 b (1958HU18).

10. ^{17}O(d, p)^{18}O $\qquad Q_m = 5.842$

$Q_0 = 5.821 \pm 0.010$ (1954AH37, 1954AH47).

Proton groups have been observed corresponding to excited states at 1.986 ± 0.013 (1954AH37, 1954AH47: based on Q_0), 1.981 ± 0.02 MeV, at 2.449 ± 0.02 MeV (1955HO28: based on Q_m) and at 3.56 ± 0.02 MeV (1956BA1L: based on Q_0). The reported level at 2.45 MeV is not found by (1956BA1L): an upper limit of $0.2 - 0.3$ is given for the relative intensity of groups leading to states in the range $E_x = 2$ to 3.5 MeV compared to the ground-state group; see also ^{18}O(p, p′)^{18}O*and ^{19}F(t, α)^{18}O. At $E_d = 7.77$ MeV, angular distributions of protons to the first three states of ^{18}O are fitted by $l_n = 2$, 0 and 2, respectively. Assignments of $J^\pi = 0^+$, 2^+, 4^+ are indicated for ^{18}O*(0, 1.98, and 3.56 MeV). Derived coefficients for the first excited state wave function are in good agreement with the theories of (1954RE1B and 1955EL1B) (1957BI80).

11. ^{18}O(γ, p)^{17}N $\qquad Q_m = -15.99$

See (1955AJ61) and (1955RE1C).

12. ^{18}O(p, p′)^{18}O*

At $E_p = 4.6$ to 5.3 MeV, a group is reported corresponding to ^{18}O*(1.981 ± 0.004). No evidence is found for a level at 2.45 MeV reported in ^{17}O(d, p)^{18}O: intensity less than 0.1 of 1.98 MeV group (1957YO04). A 1.9 MeV γ-ray is reported by (1956NA1C), presumably arising from the decay of the first excited state.

13. ^{18}O(d, d′)^{18}O*

At $E_d = 7.8$ MeV, deuteron groups are reported to states at 0, 1.98 and 3.551 ± 0.019 MeV. Upper limits of 3 to 8% are given for other possible groups in the range $E_x = 2$ to 3.5 MeV (1956BA1L). At $E_d = 4.98$ MeV, the $Q = -1.98$ MeV group is < 3% of the ground-sate group (1957YO04).

14. ^{18}F(β^+)^{18}O $\qquad Q_m = 1.667$

See ^{18}F.

15. ^{19}F(γ, p)^{18}O $\qquad Q_{\rm m} = -7.964$

See ^{19}F.

16. ^{19}F(n, d)^{18}O $\qquad Q_{\rm m} = -5.737$

$Q_0 = -5.79 \pm 0.08$ (1957RI44).

At $E_{\rm n} = 14.1$ MeV, deuteron groups are observed to the ground state, to an excited state at 1.9 ± 0.1 MeV and , possibly, to others near 3 to 4 MeV. Angular distributions indicate $l_{\rm p} = 0$ for the ground state transition, consistent with $J = 0^+$ or 1^+, and most probably $l_{\rm p} = 2$ for the 1.9 MeV state ($J = 1^+$, 2^+, 3^+). The ratio of reduced widths $\theta^2_{\rm p}(1.9)/\theta^2_{\rm p}(0) = 0.87$, in good agreement with shell model calculations of (1955EL1B and 1957RI44).

17. ^{19}F(d, ^{3}He)^{18}O $\qquad Q_{\rm m} = -2.470$

Not observed.

18. ^{19}F(t, α)^{18}O $\qquad Q_{\rm m} = 11.849$

At $E_{\rm t} = 1.8$ MeV, α-groups are reported to levels at 1.989 ± 0.024, 3.504 ± 0.034, 3.929 ± 0.040, 5.007 ± 0.040, 5.170 ± 0.040, 5.311 ± 0.040, 5.456 ± 0.040, 6.190 ± 0.040 and 6.328 ± 0.040 MeV. No other states below $E_{\rm x} = 6.8$ MeV are observed (1956JA31).

19. ^{21}Ne(n, α)^{18}O $\qquad Q_{\rm m} = 0.704$

Not observed.

^{18}F

(Fig. 38)

GENERAL:

Theory: See (1954RE1B, 1955EL1A, 1955EL1B, 1956NE1B, 1957GR1D, 1959WA16).

1. ^{18}F(β^+)^{18}O $\qquad Q_{\rm m} = 1.677$

The positron end point is 635 ± 15 (1949BL26), 649 ± 9 keV (1951RU24). The spectrum is simple (see (1956DR38)). The half-life is 112 ± 1 min (1949BL26), 111 ± 1 min (1955JA1A), 110 ± 1 min (1958BE74): $\log ft = 3.62$. The fact that the β transition to the ground state of ^{18}O is allowed indicates $J = 1^+$ for ^{18}F (assumed $T = 0$) (MO54). The ratio $\epsilon_{\rm K}/\beta^+ = 0.030 \pm 0.002$ (1956DR38). See also (1956DZ1A) and (1958RE1B; theor.).

2. ^{12}C(^{7}Li, n)^{18}F $\qquad Q_{\rm m} = 5.963$

See (1957NO17).

3. ^{14}N(α, γ)^{18}F $\qquad Q_{\rm m} = 4.421$

Resonances have been observed at $E_\alpha = 1.53$, 1.62, 2.35, and 2.88 MeV, corresponding to ^{18}F* $= 5.61$, 5.68, 6.25, and 6.651 MeV (1955PR1A, 1958AL03, 1958BR29, 1958PH37): see Table 18.5.

The 5.61 MeV state decays to the ^{18}F ground state (16%), and to states at 1.08 MeV (41%) and 3.06 MeV (45%). Gamma rays with $E_\gamma = 2.12$ and 0.94 MeV are also observed (1958AL03): see Fig. 39. The radiative widths $\omega\Gamma_{\rm s}$ to the ground state and ^{18}F*(1.08) are 0.7 and 2.2 eV, respectively; all others amount to 3 eV (1955PR1A). The branching ratios favor $J = 1^-$; $T = 0$ for ^{18}F*(5.61) and $T = 1$ for ^{18}F*(1.08 and 3.06). Angular distributions of the cascade γ-rays are consistent with $J = 0^+$ and 2^+ for the states at 1.08 and 3.06 MeV. Angular correlations rule out $J = 0$ for the 0.94 MeV state. The 3.06 MeV state shows a 25% ground-state branch and a 75% cascade through the 0.94 MeV level (1958AL03: see also (1958KU81)). Delayed coincidence measurements on the γ-decay of the 0.94 MeV state show $\tau \leq 5 \times 10^{-9}$ sec. This implies $1 \leq J \leq 3$ when taken together with the results of the ^{16}O(^{3}He, pγ)^{18}F reaction (1958BR29).

The 5.68 MeV state decays to the 1.08 MeV state $(1.075 \pm 0.010$ MeV) with $\omega\Gamma_\gamma = 2.2 \pm 0.3$ eV. The ground-state transition is < 0.2 eV; others amount to about 2 eV (1955PR1A). The strength of the transition $5.68 \rightarrow 1.08$ suggests dipole radiation, $J(5.68) = 1$; $T = 0$ (1959WA16).

Table 18.4: Energy levels of ^{18}F

E_x (MeV $\pm$ keV)	$J^\pi; T$	$\tau_{1/2}$ or Γ (keV)	Decay	Reactions
0	$1^+; 0$	$\tau_{1/2} = 111 \pm 1$ min	β^+	1, 2, 3, 8, 13, 14, 15, 16, 17, 19, 22, 23, 24, 25, 26, 27, 28, 29, 32, 34
0.940 ± 10	$(2^+, 3^+; 0)$	$\tau_m \leq 5 \times 10^{-9}$ sec	γ	3, 14, 22, 27, 28, 29
1.043 ± 10	(0; 0)			3, 14, 22, 29, 32
1.085 ± 10	$0^+; 1$	$\tau_m < 3 \times 10^{-13}$ sec	γ	3, 14, 27, 28, 29
1.127 ± 10	$(4^+, 5^+)$			14, (22), 29
1.700 ± 10	$1^+; 0$		γ	3, 14, 27, 29, 32
2.104 ± 10	(1, 2); 0		γ	14, 29, 32
2.525 ± 10	(1, 2, 3); 0		γ	14, 29, 33
3.063 ± 10	$(2^+; 1)$		γ	3, 14, 29
3.133 ± 10				14, 29, 33
3.354 ± 10				14, 27, 29, 33
3.725 ± 10				14, 29
3.790 ± 10				14, 29
3.839 ± 10				14, 27, 29, 32
4.115 ± 10	$3^+; 0$			14, 27, 29, 32
4.226 ± 10				14, 29
4.360 ± 10				14, 29
4.400 ± 10				29, 32
4.649 ± 10				29
4.741 ± 10				29
4.840 ± 10				29
4.965 ± 13				29, 32
5.292 ± 10				29
5.500 ± 10				29
5.608 ± 15	$(1^-); 0$	< 1.5	α, γ	3, 29
5.670 ± 10	$(1^-; 0)$	< 1.0	α, γ	3, 29
5.785 ± 10				29
6.093 ± 10				29

Table 18.4: Energy levels of ^{18}F (continued)

E_x (MeV $\pm$ keV)	$J^\pi; T$	$\tau_{1/2}$ or Γ (keV)	Decay	Reactions
6.137 ± 10				29
6.240 ± 10	$(2^\pm; 1)$	< 1.0	α, γ	3, 6, 29
6.264 ± 10	(1^+)	< 3	α	6, 29
6.374 ± 10				29
6.470 ± 10				29
6.560 ± 10	$(3^+, 4^+, 5^+)$	< 0.8	α	6, 29
6.640 ± 10		< 2.0	p, α, γ	3, 6, 18, 29
6.653 ± 10	1^-	93 ± 5	α	5, 6
6.765 ± 10				29
6.790 ± 10				29
6.817 ± 10	2^-	101 ± 5	α, p	5, 6, 18
6.857 ± 10				29
7.190 ± 10	(4^+)	< 4	α, p	6, 29
7.29 ± 20	(1^+)	45	α, p	5, 6, 18
7.313 ± 10	(3^-)	53	α, p	5, 6, 18, 29
7.50 ± 20	(3^-)	25	α, p	5, 6, 18, 29
7.56 ± 20		75	α, p	5, 6, 18
7.62 ± 20		40	α, p	5, 6
7.71 ± 20		11	α, p	18
7.74 ± 20		110	α, p	5, 6, 18
7.91 ± 20	(2^-)	≈ 25	α, p	5, 6, 18
7.96 ± 20	(1^+)	70	α, p	5, 6
8.10 ± 20		≈ 40	d, p, α	10, 18
8.22 ± 20		≈ 15	α, p	18
8.24 ± 20		≈ 10	α, p	18
8.38 ± 20		≈ 50	α, p	6, 18
$9.19 - 13.8$	29 levels reported in ^{16}O + d: see Table 18.6			

The 6.25 MeV state decays mainly to ^{18}F*(1.7): $E_\gamma = 4.45 \pm 0.05$ MeV ($\omega\Gamma_\gamma = 7.9 \pm 1.0$ eV), and ^{18}F*(0.94): $E_\gamma = 5.30 \pm 0.10$ MeV ($\omega\Gamma_\gamma = 0.8 \pm 0.15$ eV). Transitions to the ground state and to levels at ≈ 3 MeV have upper limits of 5% and 20%. The 1.7 MeV state decays through

Table 18.5: Resonances in ^{14}N + α

E_α (MeV $\pm$ keV)	Particle Out	$\Gamma_{\text{c.m.}}$ (keV)	$J^\pi; T$	θ^2_α	E_x (MeV)	References
1.530 ± 3	γ	< 1.5	(1^-); 0		5.611	(1955PR1A, 1958AL03, 1958PH37)
1.617 ± 3	γ	< 1.0	$(1^-; 0)$		5.679	(1955PR1A, 1958PH37, 1959WA16)
2.351 ± 3	γ, α	< 1.0	$2^\pm$; 1		6.250	(1958HE54, 1958HE56, 1958PH37, 1959WA16)
2.370 ± 4	α	< 3	(1^+)	< 0.033	6.264	(1958HE54, 1958HE56)
2.767 ± 4	α	(< 0.8)	$(3^+, 4^+, 5^+)$		6.573	(1958HE54, 1958HE56)
2.868 ± 4	γ, p_0	< 2.0			6.651	(1958HE54, 1958HE56, 1958PH37)
2.870 ± 6	α	93 ± 5	1^-	0.715	6.653	(1958HE54, 1958HE56, 1958KA32)
3.080 ± 6	α, p_0	101 ± 5	2^-	0.50	6.817	(1953HE58, 1958HE54, 1958HE56, 1958KA32)
3.576 ± 4	α	< 4	(4^+)		7.202	(1958HE54, 1958HE56, 1958KA32)
3.67	α	45 ± 10	(1^+)		7.28	(1958HE54, 1958HE56, 1958KA32)
3.72	α, p_0	53 ± 6	(3^-)		7.32	(1958HE54, 1958HE56, 1958KA32)
4.00	α, p_0	35	(3^-)		7.53	(1958KA32)
4.05	α, p_0	60			7.57	(1958KA32)
4.11	α, p_0	40			7.62	(1958KA32)
4.28	α, p_0	120			7.75	(1958KA32)
4.50	α, p_0	30	(2^-)		7.92	(1958KA32)
4.55	α, p_0	70	(1^+)		7.96	(1958KA32)
5.2	α				8.5	(1939BR1A, 1939DE1A)

^{18}F*(1.05). The $(6.25 \to 1.7)$ and $(1.05 \to 0)$ γ-γ correlation is isotropic within 10%, consistent with $J = 0^+$ for the 1.05 MeV state. The 1.7 MeV state is most likely to be $1^\pm$ or (2^+), and is assumed to be $T = 0$ from the ^{18}O level structure (compare ^{20}Ne(d, α)^{18}F). The 6.25 MeV state is then $2^\pm$ or 3^- (1958PH37). If the 1.7 MeV state is 1^+, $J(6.25)$ is 2^+ or 2^-; the strength of the transition $(6.25 \to 1.7)$ indicates $T = 1$ for ^{18}F*(6.25) (1959WA16).

The 6.65 MeV state decays with $E_\gamma = 5.80 \pm 0.10$ (7%), $\omega\Gamma_\gamma = 0.25$ eV and 4.90 ± 0.05 MeV (70%), $\omega\Gamma_\gamma = 2.1$ eV to the 0.94 and 1.70 MeV states, respectively. Transitions with relative intensity $\approx 23\%$ are also reported to states with $E_x \approx 3$ MeV (1958PH37). See also (1958BA59, 1958BR1D, 1958HE1F) and ^{16}O(^{3}He, p)^{18}F.

4. ^{14}N(α, n)^{17}F $\qquad Q_m = -4.747 \qquad E_b = 4.421$

See (1938FU01).

5. ^{14}N(α, p)^{17}O $\qquad Q_m = -1.197 \qquad E_b = 4.421$

Observed resonances are displayed in Table 18.5 (1953HE58, 1958HE54, 1958KA32). Absolute cross sections are given by (1958HE54) for $E_\alpha = 2.7$ to 3.6 MeV. The yield of protons to ^{17}O*(0.7) is at least a factor of 10 smaller than the ground-state yield. See also (1954MA1F, 1955GR1F) and (1952AJ38).

6. ^{14}N(α, α)^{14}N $\qquad E_b = 4.421$

Observed anomalies in the elastic scattering are exhibited in Table 18.5 (1939BR1A, 1939DE1A, 1953HE58, 1958HE54, 1958HE56, 1958KA32). The indicated assignments to the narrow resonances at $E_\alpha = 2.35$, 2.37, 2.77, 2.88, and 3.58 MeV are obtained from qualitative analysis of the excitation functions. The two broad resonances at $E_\alpha = 2.870$ and 3.080 MeV have been analyzed in detail: both are formed with p-waves, $J = 1^-$ and 2^-, respectively. For the former, $\Gamma_\alpha/\Gamma = 0.85$. See also (1958KA32). A broad anomaly at $E_\alpha = 3.7$ MeV requires two levels, and possible admixture of higher l-values (1958HE56, 1958KA32).

7. ^{15}N(α, n)^{18}F $\qquad Q_m = -6.420$

Not reported.

8. ^{16}O(d, γ)^{18}F $\qquad Q_m = 7.538$

At $E_d = 1.7$ MeV, the capture cross section is ≈ 10 μb (1955BU1C). See also (1954SI07).

9. ^{16}O(d, n)^{17}F $\qquad Q_m = -1.631 \qquad E_b = 7.538$

Observed resonances in the forward yield of neutrons are displayed in Table 18.6 (1955MA85). See also (1952AJ38) and (1955BU1C).

10. ^{16}O(d, p)^{17}O $\qquad Q_m = 1.919 \qquad E_b = 7.538$

The yield shows strong variations with energy, suggesting compound nucleus formation (1948HE1C, 1955BE1J, 1955ST1A, 1956RO1A, 1956VA17): see Table 18.6. On the other hand, angular distribution measurements show strong stripping peaks for both p_0 and p_1, for $E_d = 0.5$ to 4.1 MeV (1955AL1E, 1955BE1J, 1955JU1C, 1955ST1A, 1956GR1F, 1956JU1G, 1956KO26, 1957BA14, 1957JU1A). See also ^{17}O.

11. ^{16}O(d, d)^{16}O $\qquad E_b = 7.538$

Observed maxima in the $\theta = 135°$ and $97°$ cross section are listed in Table 18.6 (1956BE1B). Structure in the yield of elastically scattered deuterons is also reported by (1957BA14). See also (1955KH31, 1955KH35).

12. ^{16}O(d, α)^{14}N $\qquad Q_m = 3.116 \qquad E_b = 7.538$

Two resonances are reported for ground-state α-particles at $E_d = 3.85$ MeV, $\Gamma = 35$ keV, and 4.0 MeV, $\Gamma = 100$ keV (1957BA14): see Table 18.6. Yield curves if the α_0, α_1 and α_2 groups are reported for $E_d = 5.5$ to 7.5 MeV by (1956BR36). The α_1-group, leading to the $T = 1$, 2.31 MeV state of ^{14}N, is greatly inhibited: the average intensity is only a few per cent of the average yield of the α_0 group. Broad resonances are observed in the yields of all three α groups. The resonances in the α_1-yield occur at ≈ 6.2, 6.6, and 7.0 MeV; they are presumably due to predominantly $T = 1$ states at $E_x \approx 13.0$, 13.4, and 13.8 MeV (1956BR36). At $E_d = 7.2$ MeV, the intensity ratio α_1/α_0 is 16% ($\theta = 35°$), at 6.8 and 7.1 MeV, $\alpha_1/\alpha_0 < 6\%$, and at 8.9 MeV, $< 2\%$ (1958DA16). The observations are consistent with expected isobaric spin impurities in the states involved (1956BR36). Angular distributions for α_0, α_2 may give evidence of compound nucleus effects (1958DA16): see also ^{14}N.

13. ^{16}O(t, n)^{18}F $\qquad Q_m = 1.280$

Table 18.6: Maxima in the yield of (^{16}O + d) reactions

$E_{\rm d}$ (MeV)	Particle Out	$E_{\rm x}$ in ^{18}F (MeV)	References
(0.68)	p_0	(8.14)	(1956VA17)
1.86	p_0, p_1	9.19	(1948HE1C, 1955BE1J, 1956RO1A)
2.06	p_1	9.37	(1955BE1J, 1956RO1A)
2.14	p_1	9.44	(1956RO1A)
2.22	n	9.51	(1955MA85)
2.34	n, p_1	9.62	(1955MA85, 1956RO1A)
2.42 [a]	n	9.69	(1955MA85)
2.55	p_1	9.81	(1955ST1A, 1956RO1A)
2.75	p_1	9.98	(1956RO1A)
2.92	n, p_0, p_1	10.13	(1948HE1C, 1955MA85, 1955ST1A, 1956RO1A)
3.10	n, p_1	10.29	(1955MA85, 1956RO1A)
3.22	n	10.40	(1955MA85)
3.36	n, p_0, p_1	10.53	(1955MA85, 1955ST1A, 1956RO1A)
(3.43)	p_1	(10.59)	(1956RO1A)
3.65	n, p_0, p_1	10.78	(1955MA85, 1955ST1A, 1956RO1A)
(3.75)	p_1	(10.87)	(1956RO1A)
3.84 [b]	p_1, α_0	10.95	(1956RO1A, 1957BA14)
3.94	n, p_1	11.04	(1955MA85, 1956RO1A)
4.00 [c]	p_1, α_0	11.09	(1956RO1A, 1957BA14)
4.10	n, p_1	11.18	(1955MA85, 1956RO1A)
4.35	p_1	11.41	(1956RO1A)
4.79	d_0	11.80	(1956BE1B)
5.08	d_0	12.05	(1956BE1B)
5.617	d_0	12.53	(1956BE1B)
5.78	d_0	12.68	(1956BE1B)
6.10	d_0	12.96	(1956BE1B)
6.2 [d]	α_1	13.0	(1956BR36)
6.40	d_0	13.23	(1956BE1B)
6.57 [d]	d_0, α_1	13.38	(1956BE1B, 1956BR36)
6.74	d_0	13.53	(1956BE1B)
7.0 [d]	α_1	13.8	(1956BR36)

[a] $J^\pi = 2^+$ or 3^+.
[b] $\Gamma \approx 100$ keV (1957BA14).
[c] $\Gamma \approx 35$ keV (1957BA14).
[d] $(T = 1)$.

See (1951PO1A, 1955BA1Q, 1956SH1A).

14. ^{16}O(^{3}He, p)^{18}F $\qquad Q_{\rm m} = 2.045$

$Q_0 = 2.052 \pm 0.015$ (1959HI67).

Seventeen proton groups corresponding to excited states of ^{18}F from 0 to $E_{\rm x} = 4.36$ MeV are reported by (1959HI67: E(^{3}He) $= 5.7$ to 5.9 MeV): see Table 18.7. See also (1958KU81). Angular distributions for the first five states, analyzed by direct interaction theory, indicate $J = 1^+$, 2^+ or 3^+, 0^+, (?), and 4^+ or 5^+ for ^{18}F*(0, 0.94, 1.04, 1.08 and 1.13), respectively (1959HI67: tentative assignments). Gamma transitions to ^{18}F(0) have been observed from the levels at 0.94, 1.04 and 1.08 MeV; the decay of the 1.13 MeV level has not been detected (1958KU81). Proton-gamma coincidence techniques have been used to determine branching ratios and angular correlations involving ^{18}F states at 0.94, 1.08, 1.7, 2.1, 2.5, and 3.07 MeV (1958KU1D: see also (1956BU1F)): see Fig. 39. All of these states show at least one anisotropic radiation except for ^{18}F*(1.04 and 1.08), excluding $J = 0$ for all but these two ((1958KU1D) and E. Almqvist, private communication).

The mean life of the 0.94 MeV state is $\leq 5 \times 10^{-9}$ sec, indicating $J \leq 3$ (1958BR29). The polarization of the γ-radiation indicates positive parity for the state (1958LI41). The strong transition from ^{18}F*(3.07: $T = 1$) suggests $T = 0$. For the 1.04 MeV state, $J = 0^+$ is indicated by the proton angular distributions (1959HI67); $J = 0^-$; $T = 0$ is suggested by the γ-branching (E. Almqvist, private communication). The 1.08 MeV state appears to have $J = 0^+$; $T = 1$ (see ^{14}N(α, γ)^{18}F). The absence of the ground-state transition from ^{18}F*(1.12) is consistent with its expected $J = 5^+$ character. The 1.7 MeV state is fixed as $J = 1^+$ from the present reaction and ^{19}F(p, d)^{18}F. For ^{18}F*(2.1 and 2.54) assignments of $J = 1$, 2 and 1, 2, 3 are indicated by the branching ratios (E. Almqvist, private communication). See also (1958BR1D, 1958BR86).

15. ^{16}O(α, pn)^{18}F $\qquad Q_{\rm m} = -18.533$

See (1947TE01).

16. ^{16}O(^{6}Li, α)^{18}F $\qquad Q_{\rm m} = 6.067$

See (1957NO17).

17. ^{17}O(p, γ)^{18}F $\qquad Q_{\rm m} = 5.619$

A resonance in the capture cross section may be indicated near 1.24 MeV ($E_{\rm x} = 6.79$ MeV), $\sigma \approx 1$ mb (1956NI1C).

Table 18.7: Energy levels of ^{18}F from ^{16}O(^{3}He, p)^{18}F, ^{19}F(^{3}He, α)^{18}F and ^{20}Ne(d, α)^{18}F

(1959HI67) [a]		(1958KU81) [b]	(1951MI1A) [c]	Assignment [d]	
(^{3}He, p) (MeV)	(^{3}He, α) (MeV)	(^{3}He, p) (MeV)	(d, α) (MeV $\pm$ keV)	l_p	$J^\pi; T$
0	0	0	0	$0+2$	1^+; 0
0.941	0.940	0.940		2	$2^+, 3^+$; (0)
1.044	1.042	1.045	1.05 ± 30	0	$0^{(+)}$ [e]; (0)
1.084	1.087	1.080 [g]			0^+; 1 [h]
1.126	1.129	1.125		(4)	$(4^+, 5^+)$
1.704	1.699		1.83 ± 30		1^+; 0
2.104	2.105		2.20 ± 60		1, 2; 0
2.525	2.525		2.61 ± 50		1, 2, 3; 0
3.064	3.063				2^+; 1
3.135	3.131		3.23 ± 80		
3.357	3.352				
3.723	3.727				
3.791	3.790				
3.837	3.841				
4.115	4.116		3.92 ± 40		
4.226	4.227				
4.361	4.358				
	4.400		4.42 ± 100		
	4.649				
	4.741				
	4.840				
	4.965 [f]		5.01 ± 90		
	5.292				
	5.500				
	5.603 [f]		5.61 ± 100		
	5.666				
	5.785				
	6.093				

Table 18.7: Energy levels of ^{18}F from ^{16}O(^{3}He, p)^{18}F, ^{19}F(^{3}He, α)^{18}F and ^{20}Ne(d, α)^{18}F (continued)

(1959HI67) [a]		(1958KU81) [b]	(1951MI1A) [c]	Assignment [d]	
(^{3}He, p) (MeV)	(^{3}He, α) (MeV)	(^{3}He, p) (MeV)	(d, α) (MeV $\pm$ keV)	l_p	$J^{\pi}; T$
	6.137				
	6.232				
	6.264 [f]				
	6.374				
	6.470				
	6.551				
	6.633				
	6.765				
	6.790				
	6.857				
	7.183				
	7.313				
	7.495				

[a] $E(^{3}\text{He}) = 5.7$ and 5.9 MeV: energies ± 10 keV.
[b] $E(^{3}\text{He}) = 2.4$ to 2.9 MeV.
[c] $E_d = 7.8$ MeV.
[d] l_p from proton distributions (1959HI67).
[e] $J = 0^{-}$, $T = 0$ suggested by γ-branching.
[f] ± 13 keV.
[g] ± 10 keV.
[h] Assignment from γ-branching, proton group weak but suggests odd parity (1959HI67).

18. ^{17}O(p, α)^{14}N $\qquad Q_m = 1.197 \qquad E_b = 5.619$

Resonances in the yield of ground state α-particles are displayed in Table 18.8 (1957AH20).

19. ^{17}O(d, n)^{18}F $\qquad Q_m = 3.392$

Table 18.8: Resonances in ^{17}O(p, α_0)^{14}N (1957AH20)

E_p (MeV)	$\Gamma_{c.m.}$ (keV)	E_x (MeV)
1.110	9	6.667
1.273	90	6.821
1.786	≈ 65	7.306
2.021	11	7.528
2.048	90	7.553
2.218	11	7.714
2.235	100	7.730
2.406	≈ 25	7.891
2.435	≈ 25	7.919
2.623	≈ 40	8.096
2.753	≈ 15	8.219
2.775	≈ 10	8.240
2.928	≈ 50	8.384

See ^{19}F.

20. ^{17}O(^{3}He, d)^{18}F $\quad Q_m = 0.125$

Not reported.

21. ^{17}O(α, t)^{18}F $\quad Q_m = -14.194$

Not reported.

22. ^{18}O(p, n)^{18}F $\quad Q_m = -2.450$

$E_{thresh.} = 2.590 \pm 0.004$ (1950RI59);
$E_{thresh.} = 2.584 \pm 0.010$ (1956MA18);
$E_{thresh.} = 2.577 \pm 0.008$ (1956HI35).

Slow neutron thresholds are reported corresponding to $E_x = 960 \pm 10$, 1065 ± 15, and, possibly, 1245 ± 10 keV; no others appear with $E_x < 1.65$ MeV (1956NA1B). Gamma rays are observed with $E_\gamma = 940 \pm 20$ and 1040 ± 20 keV at $E_p = 4.3$ and 4.4 MeV: the 1040 keV γ-ray exhibits a Doppler shift ($\tau < 3 \times 10^{-13}$ sec, consistent with $J = 0^+$), the 940 keV γ-ray does not, which is consistent with $J = 3^+, 5^+$. No γ-ray is observed from the 1245 keV state (1956NA1C, 1956RO1C). See also ^{16}O(^{3}He, p)^{18}F and ^{19}F.

23. ^{18}O(^{3}He, t)^{18}F $\quad Q_m = -1.685$

See (1953KU08).

24. ^{18}Ne(β^+)^{18}F $\quad Q_m = 4.227$

See ^{18}Ne.

25. ^{19}F(γ, n)^{18}F $\quad Q_m = -10.414$

See ^{19}F.

26. ^{19}F(n, 2n)^{18}F $\quad Q_m = -10.414$

See ^{20}F.

27. ^{19}F(p, d)^{18}F $\quad Q_m = -8.187$

$Q_0 = -8.12 \pm 0.2$ (1956RE04).

At $E_p = 18$ MeV, angular distributions have been measured to the ground state of ^{18}F (1956RE04, 1958BE28) and to levels at 0.94, 1.05, 1.7, 3.4 and 4.1 MeV (1958BE28). The results indicate $J = 0^+$ or 1^+ for the ground state (1956RE04), even parity for the 0.94, 1.04, 1.7 and 4.1 MeV states; probably assignments are stated to be 3^+, 0^+, 0^+ and 2^+, respectively, and odd parity, $J \leq 2$ for the 3.4 MeV state (1958BE28). The reduced width for the ground state reaction is $\theta^2 = 0.009$ (1956RE04). According to (1959WA16), the distributions permit $J = 0^+$ or 1^+ for ^{18}F*(1.7); $J = 0$ is excluded by the observed γ-decay to ^{18}F*(1.04). See also ^{19}F and (1958EL1A; theor.).

28. ^{19}F(d, t)^{18}F $\quad Q_m = -4.155$
$Q_0 = -4.17 \pm 0.02$ (1957EL12).

At $E_d = 8.9$ MeV proton groups are observed to the ground state and to states at 0.94 ± 0.02 and 1.07 ± 0.02 MeV. The angular distributions are consistent with $l_n = 0$, 1 and 0, respectively (1957EL12). The $l_n = 1$, odd parity assignment for the 0.94 MeV state is not in accord with other experiments (see, e.g., ^{16}O(^{3}He, p)^{18}F and ^{19}F(p, d)^{18}F). See also (1950BO1A, 1951SH1B).

29. ^{19}F(^{3}He, α)^{18}F $\quad Q_m = 10.164$
$Q_0 = 10.162 \pm 0.015$ (1959HI67).

At $E(^3\text{He}) = 5.9$ MeV, 41 α-particle groups have been observed, corresponding to the ground state of ^{18}F and to excited states with $E_x < 7.5$ MeV (1959HI67): see Table 18.7.

30. ^{20}Ne(n, t)^{18}F $\quad Q_m = -14.802$

Not reported.

31. ^{20}Ne(p, ^{3}He)^{18}F $\quad Q_m = -15.567$

Not reported.

32. ^{20}Ne(d, α)^{18}F $\quad Q_m = 2.784$
$Q_0 = 2.791 \pm 0.009$ (1954MI61).

Observed alpha-particle groups are listed in Table 18.7 (1951MI1A).

33. ^{21}Ne(p, α)^{18}F $\quad Q_m = -1.746$

Not reported.

34. ^{25}Mg(p, 2α)^{18}F $\quad Q_m = -11.636$

See (1954CO72).

^{18}Ne

(Not illustrated)

GENERAL:

Theory: see (1957RA1C).

1. ^{18}Ne(β^+)^{18}F $\quad Q_{\rm m} = 4.227$

The maximum energy of the positrons is 3.2 ± 0.2 MeV, the half-life is 1.6 ± 0.2 sec: $\log ft = 2.9 \pm 0.2$ (1954GO17). See also (1956DZ1A).

2. ^{16}O(^{3}He, n)^{18}Ne $\quad Q_{\rm m} = -2.966$

See (1953KU08).

3. ^{19}F(p, 2n)^{18}Ne $\quad Q_{\rm m} = -15.424$

See (1954GO17).

4. ^{20}Ne(p, t)^{18}Ne $\quad Q_{\rm m} = -19.812$

Not reported.

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(Closed 01 December 1958)

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