Energy Levels of Light Nuclei
$A = 14$

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Abstract: An evaluation of $A = 5$–24 was published in *Nuclear Physics* 11 (1959), p. 1. This version of $A = 14$ 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 $A = 14$

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.

^{14}C

(Fig. 25)

GENERAL:

Theory: See (1954JA1A, 1955SH84, 1956EL1B, 1956GO1P, 1956ST1D, 1957CA1F, 1957GO1G, 1957SH1B, 1957VI1A, 1958BA1A, 1958SU1C).

1. ^{14}C(β^-)^{14}N $\quad Q_m = 0.155$

The mean of reported end points is 156 ± 1 keV (1957LI51). The weighted mean half-life is 5568 ± 30 years (1955LI1D: see (1958ST50)): $\log ft = 9.03$. The spectrum does not deviate from the allowed shape down to 3 keV (1954MO84); see also (1954FO29, 1955PO04).

It appears that the long lifetime of ^{14}C may be due to chance cancellation in the matrix element for the decay, brought about by a small tensor force (1954JA1A, 1955SH84, 1956ST1D, 1957VI1A); see, however, (1958BA1A). See also (1955SM1A, 1957ST1G).

2. (a) ^{7}Li(^{7}Li, p)^{13}B $\quad Q_m = 5.97 \quad E_b = 26.797$
   (b) ^{7}Li(^{7}Li, d)^{12}B $\quad Q_m = 3.311$
   (c) ^{7}Li(^{7}Li, ^{8}Be)^{6}He $\quad Q_m = 7.247$

These reactions have been studied for $E(^7\text{Li}) \approx 1.3$ to 2.0 MeV: see (1957NO14, 1957NO17).

3. ^{9}Be(^{6}Li, p)^{14}C $\quad Q_m = 15.130$

At $E(^6\text{Li}) = 2$ MeV, the ground state proton group, and proton groups corresponding to the known levels between $E_x = 6.1$ and 8.5 MeV have been observed (1958LI42).

4. ^{11}B(α, p)^{14}C $\quad Q_m = 0.780$
   $Q_0 = 0.788 \pm 0.017$ (W.J. Fader, quoted in (1957VA11)).

See (1951FR1B, 1953MA42) and ^{15}N.

5. ^{12}C(t, p)^{14}C $\quad Q_m = 4.634$

Table 14.1: Energy levels of ^{14}C

E_x in ^{14}C (MeV $\pm$ keV)	$J^\pi; T$	τ or Γ (keV)	Decay	Reactions
0	$0^+; 1$	$\tau_{1/2} = 5568 \pm 30$ y	β^-	1, 3, 4, 5, 6, 9, 12, 13, 15, 16, 18
6.091 ± 15	1^-	$\tau_m < 3 \times 10^{-13}$ sec	γ	3, 5, 9
6.589 ± 20	$(1^-, 2^\pm, 3^-)$	sharp		3, 9
6.723 ± 15	$(3^-, 2^-)$	$\tau_m > 3 \times 10^{-13}$ sec	γ	3, 9
6.894 ± 15	$0^{(-)}$	$\tau_m < 3 \times 10^{-13}$ sec	γ	3, 9
7.346 ± 20	$(2^-, 3^-)$	sharp	γ	3, 9
8.321 ± 20		sharp		3, 9
9.800 ± 20		$\Gamma = 24$	n	7, 9
10.433 ± 20		14	n	7, 9
10.505 ± 20		14	n	7, 9
11.9 ± 300		950		9
12.601 ± 20		110		9
12.854 ± 20		sharp		9
12.958 ± 20		sharp		9

See (1951PO1A, 1955CU17, 1956BA1E, 1956JA31, 1956MA09).

6. ^{13}C(n, γ)^{14}C $\qquad Q_m = 8.174$

The thermal capture cross section is 0.5 ± 0.2 mb, 0.9 ± 0.3 mb (1955HU1B).

7. ^{13}C(n, n)^{13}C $\qquad E_b = 8.174$

The thermal scattering cross section is 4.7 ± 0.09 b (1955HU1B: free atoms); see also (1952KO1A). In the range $E_n = 0.2$ to 3 MeV, resonances are observed at $E_n = 1.75$ MeV ($\Gamma = 25$ keV), 2.43 and 2.45 MeV. The latter levels, whose widths are of the order of 15 keV, interfere strongly. The non-resonant cross section decreases smoothly from about 3 b at 0.2 MeV to 1 b at 3 MeV (1958WI01).

8. ^{13}C(n, α)^{10}Be $Q_m = -3.843$ $E_b = 8.174$

See (1954SA68) and (1947HU03).

9. ^{13}C(d, p)^{14}C $Q_m = 5.947$

The weighted mean of seven Q-values is 5.943 ± 0.003 MeV (1957VA11: see also (1954AH47, 1954SP01)).

Proton groups reported by (1954SP01) and (1955MC75) are displayed in Table 14.2. No other groups have been observed for $E_x = 0$ to 8.1 MeV with an intensity greater than 0.2 of the group corresponding to the 6.1 MeV state (1954SP01: $\theta = 90°$). See also (1953KO42, 1956EL1A, 1956KO26, 1956VA17).

Observed γ-radiation assigned to ^{14}C is exhibited in Table 14.3. The internally-formed positron distribution suggests that the 6.1 MeV line is E1 and hence that the level has $J = 1^-$ and is the analog to the 8.06 MeV level of ^{14}N (1952TH24, 1958CH1A, 1958GO81). The 0.81 MeV cascade transition from the 6.89 MeV state shows a Doppler shift ($\tau_m < 3 \times 10^{-13}$ sec) and hence is predominantly dipole. The angular correlation of 6.1 and 0.8 MeV γ-rays is consistent with $J = 0$ and excludes $J = 1$ or 2. $J = 0$ is also suggested by the absence of the direct ground state transition for the 6.89 MeV level (1958WA02). The 6.89 MeV level is probably the analog of the $J = 0^-$ level of ^{14}N at 8.71 MeV. Assuming that the 6.1 MeV radiation is E1, the relative intensities of external and internal pairs for the 6.1 and 6.7 MeV γ-rays are consistent with E2, E1, M1 or E3 for the 6.7 MeV transition (1955BE1G). The mean lifetime of the 6.72 MeV state is greater than 3×10^{-13} sec, suggesting E3 or M2 (1958WA02). The 0.61 MeV γ-ray is in coincidence with the 6.7 MeV γ-ray and has an intensity roughly equal to that of the 7.35 MeV γ-ray (within a factor of 5). The strength of the cascade then suggests $J = 2^-$ or 3^- for the 7.35 MeV state (1958WA02): see also (1955AU1A; theor.). Comparison of reduced widths and calculation of level shifts suggests the following associations of ^{14}C and ^{14}N levels: $6.09 - 8.06$, $6.72 - 8.91$, $6.89 - 8.71$ and $7.35 - 9.50$ (1959WA04).

10. ^{13}C(t, d)^{14}C $Q_m = 1.915$

Not observed.

11. ^{13}C(α, ^{3}He)^{14}C $Q_m = -12.404$

Not observed.

Table 14.2: Proton groups from ^{13}C(d, p)^{14}C

(1954SP01)	(1955MC75)				(1958WA02)	
E_x (MeV ± keV)	E_x (MeV ± keV)	$d\sigma/d\Omega$ [b] (mb/sr)	l_n [c]	J^π	J^π	θ_n^2 [h]
0	0	10	1	$0^+, 1^+, 2^+$	0^+	0.10 $(J = 0^+)$
6.091 ± 10	6.09	62	0 [g]	$0^-, 1^-$	1^-	0.40 $(J = 1^-)$
	6.589 ± 20	1.6	1, 2, 3 [d]	$(1^-, 2^\pm, 3^-)$		$\lesssim$ 0.01
6.723 ± 10 [a]	6.72	74	2	$1^-, 2^-, 3^-$	$3^-, (2^-)$	0.11 $(J = 3^-)$
6.894 ± 10 [a]	6.89	22	0, 1 [d]	$0^\pm, 1^\pm, 2^+$	0^- [d]	0.39 $(J = 0^-)$
	7.346 ± 20	56	2	$1^-, 2^-, 3^-$	$2^-, 3^-$	0.11 $(J = 2^-)$
	8.321 ± 20	2.2				
	9.800 ± 20	7.1				
	10.433 ± 20	≈ 1.9				
	10.505 ± 20	≈ 1.4				
	11.9 ± 300 [e]	90				
	12.601 ± 20 [f]	6.3				
	12.854 ± 20	1.0				
	12.958 ± 20	1.9				

[a] The spacing of these two levels is 171 ± 3 keV (1954SP01).
[b] Differential cross section at the first maximum or in the forward direction, ±25% (1955MC75: $E_d = 14.8$ MeV).
[c] See also (1952BR1C, 1953BE1D, 1956EL1A).
[d] See footnotes 18 and 31 in (1958WA02).
[e] $\Gamma_{lab} = 1.10 \pm 0.30$ MeV.
[f] $\Gamma_{lab} = 0.130 \pm 0.020$ MeV.
[g] With $J = 1^-$, $\theta^2 = 0.32$ (1956EL1A).
[h] E. Baranger, private communications: see (1959WA04).

Table 14.3: Gamma rays from ^{13}C(d, p)^{14}C

(1955MA36)	(1955BE62)		(1958RA13)		(1958WA02)
E_γ (MeV $\pm$ keV)	E_γ (MeV $\pm$ keV)	Total σ [d] (mb)	E_γ (MeV $\pm$ keV)	Total σ [e] (mb)	E_γ (MeV $\pm$ keV)
6.090 ± 25 [a]	6.11 ± 30 [a,b]	52	6.090 ± 20 [a]	131	6.09
6.730 ± 40 [f]	6.720 ± 30 [b,f]	26	6.738 ± 25 [f]	68	6.72
	(7.30 ± 50) [b]		7.323 ± 25 [a]	12	7.35
0.811 ± 3 [c]					0.813 ± 8 [c]
$(6.89 \rightarrow 6.09)$					$(6.89 \rightarrow 6.09)$
					0.621 ± 7
					$(7.35 \rightarrow 6.72)$

[a] Corrected for Doppler shift: see (1958WA02).
[b] Average of values at $E_{\rm d} = 2.0$ and 4.0 MeV.
[c] A Doppler shift of $0.5 - 1.0$ % applies (1958WA02).
[d] Average value, $E_{\rm d} = 3.4$ to 4.0 MeV.
[e] $E_{\rm d} = 4.5$ MeV.
[f] No Doppler shift: $\tau > 3 \times 10^{-13}$ sec (1958WA02). See also (1955BE62).

12. ^{14}C(d, t)^{13}C $\qquad Q_{\rm m} = -1.915$

Reduced widths derived from pick-up angular distributions at $E_{\rm d} = 14.8$ MeV are listed in Table 14.4 (1958MO97). The observation of strong contributions from ^{13}C excited states indicates considerable configuration mixing in the ground state of ^{14}C. An admixture of 2s^2 and 2d^2 consistent with these results also permits a satisfactory account of the cancellation in the ^{14}C-^{14}N beta decay matrix element without recourse to tensor forces (1958BA1A). See also ^{14}C(β^-)^{14}N.

13. ^{14}N(n, p)^{14}C $\qquad Q_{\rm m} = 0.628$

The weighted mean of five Q-value determinations is 0.626 ± 0.001 MeV (1957VA11). See also (1951ST1D, 1952LI24, 1958DO63) and ^{15}N.

14. ^{14}N(t, ^{3}He)^{14}C $\qquad Q_{\rm m} = -0.137$

Not observed.

Table 14.4: ^{14}C ground-state widths from ^{14}C(d, t)^{13}C (1958MO97)

^{13}C* (MeV)	l_n	J^{π} [a]	θ^2 [b]
0	1	$\frac{1}{2}^-$	1
3.08	0	$\frac{1}{2}^+$	0.03
3.68	1	$\frac{3}{2}^-$	0.5
3.86	2	$\frac{5}{2}^+$	0.19

[a] See ^{13}C.

[b] Relative to ground state value.

15. ^{15}N(γ, p)^{14}C $Q_m = -10.214$

See ^{15}N.

16. ^{15}N(n, d)^{14}C $Q_m = -7.987$

See (1956FR1A).

17. (a) ^{15}N(d, ^{3}He)^{14}C $Q_m = -4.720$
(b) ^{15}N(t, α)^{14}C $Q_m = 9.581$
(c) ^{16}O(n, ^{3}He)^{14}C $Q_m = -14.607$

Not observed.

18. ^{17}O(n, α)^{14}C $Q_m = 1.825$

See ^{18}O.

^{14}N
(Fig. 26)

GENERAL:

Theory: See (1955AD1A, 1955OT1B, 1956EL1B, 1956FR1A, 1957BA1H, 1957GR1D, 1957VI1A, 1958FA1A, 1958MA1K, 1958MO17, 1958SK1A, 1959WA16).

1. ^{9}Be(^{6}Li, n)^{14}N $Q_{\rm m} = 14.503$

See (1957NO17).

2. ^{10}B(α, n)^{13}N $Q_{\rm m} = 1.065$ $E_{\rm b} = 11.615$

Resonances are reported at $E_\alpha = 1.51$, 1.64, 2.16, 2.26, 2.95, 4.53, 4.85, and 5.36 MeV: see Table 14.6 (1953SH64, 1955SH46, 1956BO61, 1958MA1J, 1959GI47). Angular distributions have been measured at $E_\alpha = 1.51$ and 2.16 MeV (1955SH46).

3. ^{10}B(α, p)^{13}C $Q_{\rm m} = 4.070$ $E_{\rm b} = 11.615$

Observed resonances in the yields of γ-rays (from ^{13}C*) and of various proton groups are given in Table 14.6. Studies of the angular distributions of protons (1953SH64), γ-ray angular distributions, and (p-γ) correlations (1954ST20) lead to the J^π assignments given in the table. Angular distributions of the protons at the $E_\alpha = 1.51$ and 2.16 MeV resonances are identical with those of the neutrons at the same resonances. However, the reduced neutron width at $E_\alpha = 1.51$ MeV is 5.7 ± 0.5 times the proton width, while at $E_\alpha = 2.16$ MeV the ratio is near unity. It is suggested that strong isobaric spin mixing must occur for the $E_\alpha = 1.51$ MeV state: ^{14}N*(12.70) (1955SH46: see also (1957BA1K, 1958MC63)).

4. ^{10}B(α, d)^{12}C $Q_{\rm m} = 1.351$ $E_{\rm b} = 11.615$

Observed resonances are exhibited in Table 14.6 (1953SH64).

5. ^{10}B(α, α)^{10}B $E_{\rm b} = 11.615$

See ^{10}B.

Table 14.5: Energy levels of ^{14}N

E_x in ^{14}N (MeV $\pm$ keV)	$J^\pi; T$	τ_m or Γ (keV)	Decay	Reactions
0	1^+; 0	–	stable	1, 6, 13, 15, 18, 21, 22, 24, 25, 26, 27, 28, 29, 30, 31, 36
2.312 ± 1.2	0^+; 1	$< 2 \times 10^{-13}$ sec	γ	6, 13, 15, 18, 22, 25, 28, 29, 30, 31, 36
3.945 ± 5	1^+; 0		γ	6, 13, 15, 18, 28, 29, 36
4.910 ± 9	(0^-); 0		γ	6, 13, 15, 18, 28
5.104 ± 10	2; 0	$> 3 \times 10^{-13}$ sec	γ	13, 15, 28, 29, 36
5.685 ± 7	1; 0		γ	15, 18, 28
5.832 ± 12	$3^{(-)}$	$0.5 < \tau < 6.5 \times 10^{-13}$ sec	γ	15, 18, 28, 29
(5.98)				18, 28
6.23 ± 20	$1^{(-)}$; 0		γ	15, 18, 28
6.44 ± 30	(3); 0		γ	15, 18, 28, 29
(6.60 ± 40)				28
7.03 ± 30	(2); 0		γ	18, 28, 29
7.40 ± 50			(γ)	18, 28
7.60 ± 20				18, 28
7.962 ± 10	; (0)		p, γ	15, 29
8.060 ± 6	1^-; 1	30 ± 1	p, γ	15, 16, 18, 24
(8.45)	; (0)			29
8.62	0^+; 1	5.5 ± 2	p, γ	15, 16
8.71	0^-; 1	460	p, γ	15, 16
8.903 ± 6	3^-; (1)	15 ± 2	p, γ	15, 16
8.99	(1^+)	7	p, γ	15, 16
9.17 ± 10	$2^+, 1^+$; 1	0.075	p, γ	15, 24
9.40 ± 20	1^-	≈ 20	p	16
9.504 ± 6	2^-; 1	41 ± 2	p, γ	15, 16
9.71 ± 20	1^+	14 ± 3	p, γ	16, 24
(10.05 ± 70)	; (0)			29
10.24 ± 40		75 ± 30	p	16
10.43 ± 10	2; 1	28 ± 3	p, γ	15, 16

Table 14.5: Energy levels of ^{14}N (continued)

E_x in ^{14}N (MeV ± keV)	$J^\pi; T$	τ_m or Γ (keV)	Decay	Reactions
(10.57)			d, p	8
11.07	$1^+; 0$	120	d, p, n	8, 16, 17
11.23	; 1	25	d, p, n	8, 17
11.26	$2^-; 0$	200	d, p, (n)	8
11.38	$3^+; 0$	55	d, p, n	8, 16, 17
11.50	3^+	13	d, p	8
11.66		17	d, p	8
11.73		130	p, n	16, 17
11.95			p, n	17
12.05			p, n	17
12.20			p, n	17
12.29			p, α	3
12.41 ± 10	4^-	41 ± 3	p, α, d	3, 8, 9
12.51 ± 10		36 ± 5	p, α, d	3, 8
12.61 ± 10	3^+	48 ± 3	p, α, d	3, 8, 9
12.69 ± 10	3^-	16 ± 4	n, p, α, d	2, 3, 4, 8, 9
12.80 ± 10	4^+	15 ± 4	n, p, α, d	2, 3, 4, 8, 9
12.82 ± 10	4^-	7 ± 3	p, α, d, n	3, 4, 8, 9
12.93 ± 10	4^+	22 ± 4	p, α, d	3, 4, 8, 9
13.16 ± 10	0^-, 1^-	35 ± 15	n, p, α, d	2, 3, 8, 9
13.23		140	n, p, α	2, 3, 17
13.71	3	135	n, p, α, d	2, 3, 8
14.22		290	p, α, d	3, 8
14.43		≈ 140	p, α, d	3, 8
14.84		≈ 140	n, p, α, d	2, 3, 8
15.09		≈ 35	n, p, α, d	2, 3, 8
15.44		≈ 70	n, p, α	2, 3

Table 14.6: Resonances in ^{10}B + α

E_α (MeV ± keV)	$\Gamma_{\rm c.m.}$ (keV)	Outgoing [a] particle (x)	$\sigma_{\rm x}$ (mb)	$\Gamma_{\rm x}$ (keV)	$\theta^2_{\rm x}$	^{14}N* (MeV)	J^{π} [b]	References
0.95		p_0				12.29		(1953MA42)
1.09		p_0						(1953MA42)
1.13 ± 10	43 ± 4	p_0, p_3, d				12.42	4^-	(1953SH64, 1954ST20)
1.20		p_0						(1953MA42)
1.24 ± 10	36 ± 5	p_0				12.50		(1953SH64)
1.39 ± 10	50 ± 5	p_1, p_3				12.61		(1953SH64)
1.518 ± 4	14 ± 4	α		1.7	6.0	12.70	3^-	(1953SH64, 1953TA06, 1954ST20, 1957BR18)
		p_0	4.7	0.62	0.012			
		p_1	1.3	0.17	0.29			
		p_2	5.3	0.70	0.31			
		p_3	42	5.6	0.47			
		d	7.0	0.93	0.26			
		n	32	4.3	0.19			
1.64 ± 10	14 ± 4	α		1.0	8.2	12.79	4^+	(1953SH64, 1953TA06, 1954ST20)
		p_0	0.98	0.18	0.012			
		p_1	0.46	0.085	2.7			
		p_2	2.4	0.44	3.0			
		p_3	52	9.6	4.9			
		d	11	2.0	3.9			
		n	3.2	0.59	0.16			
1.68 ± 10	5 ± 2	p_1, p_2, p_3, d				12.82	4^-	(1953SH64, 1953TA06, 1954ST20)
1.83 ± 10	21 ± 4	p_0, p_1, p_2, p_3, d				12.92	4^+	(1953SH64, 1953TA06, 1954ST20)
2.16	20	p_0, γ, n				13.16		(1953TA06, 1955SH46)
2.26	140	p_0, γ, n				13.23		(1953TA06, 1955SH46)
2.95	≈ 100	p_0, γ, n				13.72		(1953TA06, 1956BO61, 1958MA1J, 1959GI47)
3.6	290	γ				14.2		(1956BO61, 1959GI47)
3.94	≈ 140	γ				14.43		(1956BO61)
4.53	140	n, γ				14.85		(1956BO61, 1958MA1J, 1959GI47)
4.85	≈ 35	n, γ				15.08		(1956BO61, 1958MA1J, 1959GI47)
5.36	≈ 70	n, γ				15.44		(1956BO61)

[a] p_0, p_1, p_2, p_3 correspond respectively to the ground state and the 3.1, 3.7, and 3.9 MeV states of ^{13}C; γ-rays are presumably also from ^{13}C*.

[b] From angular distributions and (p-γ) correlations (1953SH64, 1954ST20).

6. ^{11}B(α, n)^{14}N $\qquad Q_m = 0.152$

Evidence is reported for levels of ^{14}N at 0, 2.0, 3.15, 3.85 and 4.8 MeV (± 0.3 MeV) (1956QU1A). See also (1944PE1A, 1955BR1A) and (1955AJ61).

7. ^{12}C(d, γ)^{14}N $\qquad Q_m = 10.265$

At $E_d = 1.50$ MeV, the cross section is less than 1 μb (1955AL16).

8. (a) ^{12}C(d, n)^{13}N $\qquad Q_m = -0.286 \qquad E_b = 10.265$

(b) ^{12}C(d, p)^{13}C $\qquad Q_m = 2.719$

Resonances in the yields of protons and neutrons are displayed in Table 14.7: see (1955MA76, 1956BO08, 1956KO26, 1956MC88, 1956VA17, 1957JA37, 1957SA01, 1958MC63). See also (1948BA02, 1949BO67, 1950PH1A, 1957DE22).

Angular distributions of protons for $E_d < 1$ MeV are reported to be strongly influenced by stripping effects (1956JU1E, 1956KO26, 1956VA17, 1957JU1A); the same influence is seen for $E_d > 2$ MeV (1956MC88: see ^{13}C). In the region $E_d = 0.8$ to 1.7 MeV, however, (1957SA01) find no stripping contribution and analyze the observed distributions in terms of 5 resonances: see Table 14.7. Although the J^π assignments listed are determined in part by choosing $\gamma_n^2 \approx \gamma_p^2$, neutron reduced widths seem generally to be nearly a factor of 10 low (1957SA01). A detailed analysis for the region $E_d = 2.5$ to 3 MeV has been made by (1958MC63). Both stripping and compound nucleus formations are involved. See also (1955AL1D, 1955AL1E).

For $E_d = 5$ to 30 MeV, the course of the cross section indicates predominance of stripping over compound nucleus effects (1955WI43).

9. ^{12}C(d, d)^{12}C $\qquad E_b = 10.265$

Reported resonances are given in Table 14.7 (1956MC88, 1958MC63). A detailed analysis of the resonances at $E_d = 2.502$ and 2.735 MeV has been made by (1958MC63). See also (1954CA1C, 1956CA1J) and (1955AJ61).

10. ^{12}C(d, t)^{11}C $\qquad Q_m = -12.463 \qquad E_b = 10.265$

The cross section rises from ≈ 0.1 mb at $E_d = 16$ MeV to ≈ 10 mb at 20 MeV. The magnitude of the cross section is indicative of the pick-up character of the reaction (1955WI43).

Table 14.7: Resonances in $^{12}C + d$ [e]

E_d (MeV)	$\Gamma_{c.m.}$ (keV)	Particle out [a]	$^{14}N*$ (MeV)	$J^{\pi}; T$	References
0.335		p	10.57		(1956KO26, 1956VA17)
0.94	140	p_0, n	11.07	$1^+; 0$	(1948BA02, 1950PH1A, 1957SA01)
1.13	33	p_0	11.23	; 1	(1948BA02, 1950PH1A, 1957SA01)
1.16	200	p_0, n	11.26	$2^-; 0$	(1948BA02, 1950PH1A, 1957SA01)
1.30	55	p_0, n	11.38	$3^+; 0$	(1948BA02, 1950PH1A, 1957SA01)
1.435	13	p_0, p_1	11.50	3^+	(1948BA02, 1950PH1A, 1957SA01)
1.62	17	p	11.66		(1950PH1A)
1.73	170	p, n	11.76		(1948BA02, 1950PH1A)
2.3		p, n			(1948BA02)
2.502 ± 0.007 [d]	40 ± 3	p_0, p_1, d, n	12.41	4^- [b]	(1948BA02, 1956BO08, 1956MC88, 1958MC63)
2.62 ± 0.012	22 ± 15	p_0, p_1, n	12.51		(1948BA02, 1956BO08, 1956MC88, 1958MC63)
2.735 ± 0.006	47 ± 3	p_0, p_1, d	12.61	3^+ [b]	(1956BO08, 1956MC88)
2.81 ± 0.010	22 ± 7	d	12.67		(1956MC88)
2.954 ± 0.007	17 ± 8	d	12.80		(1956MC88)
2.986 ± 0.006	11 ± 3	p, n, d	12.82		(1956BO08, 1956MC88)
3.123 ± 0.0065	28 ± 10	p, d	12.94		(1956MC88)
3.39 ± 0.012	47 ± 15	d, p, n	13.17	$0^-, 1^-$ [c]	(1956BO08, 1956MC88)
4.004	130	p, n	13.70	3	(1956BO08)
4.61		p, n	14.22		(1956BO08)
4.8		p	14.4		(1956BO08)
5.336		p	14.84		(1956BO08)
5.635	300	p	15.10		(1956BO08)

[a] p_0 and p_1 correspond, respectively to the ground- and first excited states of ^{13}C.
[b] (1958MC63).
[c] (1955MA76).
[d] There is some discrepancy between the energy scales of (1956BO08) and (1956MC88).
[e] See (1956BO08, 1956MC88, 1957JA37).

11. ^{12}C(d, α)^{10}B $Q_m = -1.351$ $E_b = 10.265$

See ^{10}B.

12. ^{12}C(t, n)^{14}N $Q_m = 4.007$

Not reported.

13. ^{12}C(^{3}He, p)^{14}N $Q_m = 4.772$

Proton groups have been observed corresponding to the first five states of ^{14}N. Angular distributions of the various proton groups have been measured for $E(^3\text{He}) = 1.30$ to 21 MeV (1957BR18: 1.30 to 2.66 MeV; p_0, p_1, p_2), (1958JO20: 2.0 to 5.0 MeV; p_0, p_1, p_2), (1958SW63: 6.05 MeV; p_0, p_1, p_2, p_{3+4}), and (1958WE1E: 21 MeV). At the lower energies, the distributions show both compound nucleus and direct interaction effects. At the higher energies, the forward peaking increases, and at 6.05 MeV the direct interaction character is well developed.

The de-excitation of the 3.95 MeV state has been studied; the direct ground-state decay is (3.7 ± 0.6)% of the total (1956GO42, 1957BR18); see also (1958MO17) and ^{13}C(p, γ)^{14}N. The angular distribution of the 2.31 MeV γ-rays is spherically symmetric while that of the 1.64 MeV γ-ray (from the $3.95 \rightarrow 2.31$ cascade transition) involves a 22% $P_2(\cos\theta)$ term, consistent with $J = 0^+$ and 1^+ for the 2.31 and 3.95 MeV states respectively (1956GO42, 1957BR18). The polarization of the 1.64 MeV γ-ray also indicates that the parity of these two states is the same (1958LI41). Since the J^π assignments permit M1 transitions for both the ground state and cascade transitions from the 3.95 MeV level, the ground state transition would be expected to dominate by a large factor. However, the M1 matrix element effectively cancels for $\Delta T = 0$, $T_z = 0$ (1957VI1A, 1958MO17, 1959WA16). The E2 transition is estimated to be 0.9%: the observed value of 3.7% must be ascribed to collective enhancement (1956EL1B, 1957VI1A). See also ^{14}C(β^-)^{14}N and ^{15}O.

14. ^{12}C(α, d)^{14}N $Q_m = -13.579$

This reaction has been observed at $E_\alpha = 42$ MeV. The deuteron angular distribution is similar to the α-particle distribution in the ^{14}N(d, α)^{12}C reaction at $E_d = 20$ MeV (1958BO71).

15. ^{13}C(p, γ)^{14}N $Q_m = 7.546$

Table 14.8: Levels of ^{14}N from ^{13}C(p, γ)^{14}N and ^{13}C(p, p)^{13}C

E_p (MeV ± keV)	Γ_{lab} (keV)	l_p	θ_p^2	σ_γ (mb)	$\omega\Gamma_\gamma$ (eV)	$J^\pi; T$	^{14}N* (MeV)	Refs.
0.448 ± 1				res	0.008		7.962	a
0.554 ± 2	32.5 ± 1	0	0.13	1.44	8.6	$1^-; 1$	8.060	b
1.16	6 ± 2	1	0.013	0.56	1.3	$0^+; 1$	8.62	b
1.25	500	0	0.23	0.062	12.8	$0^-; 1$	8.71	b
1.466 ± 6	16 ± 2	2	0.17	0.074	0.72	$3^-; (1)$	8.903	b,g
1.55	7	1	0.005	0.037	0.13	(1^+)	8.99	b
1.7473 ± 0.8	0.075			[340]	14.8	$2^+, 1^+; 1$	9.17	c
2.00 ± 20	≈ 20	2	0.08			1^-	9.40	d
2.112 ± 6	44 ± 2	2	0.14	0.20	6.2	$2^-; 1$	9.504	e
2.33 ± 20	15 ± 3	1	0.005			1^+	9.71	d
2.90 ± 40	80 ± 30						10.24	d
3.11 ± 10	30 ± 3		0.02	0.70	17	2; 1	10.43	f
3.12 ± 30	80 ± 10						10.44	d

[a] D. Hebbard, private communication.
[b] (1952SE01, 1953WO41, 1954MI05).
[c] (1952SE01, 1953WO41, 1956MA87, 1958BO76, 1958PA1D); $(2J + 2)\Gamma_\gamma = 29$ eV from inverse reaction (1957HA1K). Parity is even, according to (1958ST33).
[d] (1957ZI09, 1958ZI17).
[e] (1952SE01, 1953WO41, 1957ZI09, 1958ZI17, 1959WA04).
[f] (1957WI30): (possibly same as next entry).
[g] (1959WA04).

Resonances are observed at $E_p = 0.45$, 0.55, 1.16, 1.25, 1.47, 1.55, 1.75, 2.10, and 3.11 MeV; their parameters are displayed in Table 14.8; see also (1957JA37). The decay schemes of various levels of ^{14}N, as derived from the γ-spectra in this and other reactions are exhibited in Fig. 27 ((1953CL39, 1953WO41, 1956LE28, 1957BR33, 1957WI27) and D. Hebbard, private communication). At $E_p = 114$ and 126 keV, the capture cross sections are, respectively, $(5.1 \pm 2.0) \times 10^{-3}$ μb and $(8.2 \pm 2.5) \times 10^{-3}$ μb (1957LA15). The 0.45 MeV resonance involves both ground state decay and ≈ 4 MeV cascade radiation with about equal radiative widths (D. Hebbard).

The width of the $E_p = 0.55$ MeV resonance ($E_x = 8.06$ MeV) indicates s-wave formation $(J = 0^-, 1^-)$ (1953WO41). The observed isotropy of the radiation supports this assignment (1949DE1A). The level is established as $J = 1^-$ from ^{13}C(p, p)^{13}C. (1957BR33) find a 1% anisotropy, indicating a d-wave admixture of $\approx 6\%$, $\theta_p^2(\text{d}) = 0.45$; see, however, (1959WA04).

The γ-width for the ground-state radiation indicates an uninhibited E1 transition, and hence $T = 1$ for ^{14}N*(8.06) (1953CL39). The relative strength of the T-forbidden transition to ^{14}N*(2.3) is about 2% (1956LE28, 1956PI1B, 1957BR25, 1957WI27), indicating a strong $T = 0$ admixture in ^{14}N*(8.06). The fact that the 6.23 MeV state, $J = (1^-)$; $T = 0$ (see below) shows a similar contamination, suggests that these two states have a common parentage and contaminate each other (1957WI27): see, however, (1957BR25, 1957BR33, 1959WA04). The strength of the transition $8.06 \rightarrow 5.69$, $\Gamma_\gamma \approx 0.7$ eV, suggests E1 radiation and hence $J = 0^+, 1^+, 2^+$; $T = 0$ for ^{14}N*(5.69). The further transition $5.69 \rightarrow 2.3$ rules out $J = 0^+$. $J = 2^+$ is excluded by the strength of $8.62 \rightarrow 5.69$, $\Gamma_\gamma = 0.7$ eV (1956LE28, 1957WI27); see, however, (1957BR33). According to (1959WA04), the transition strength of $8.06 \rightarrow 5.69$ also admits M1, $\Delta T = 1$, and hence $J = 1^-$; $T = 0$ for ^{14}N*(5.69). The transition ^{14}N*(3.95) $\rightarrow$ g.s. is 5.5 ± 1.0 % of the cascade, $3.95 \rightarrow 2.3$ (1956LE28, 1956PI1B). See also (1954HI1B, 1956GR17) and ^{12}C(^{3}He, p)^{14}N.

The narrow $E_\mathrm{p} = 1.16$ MeV resonance, ^{14}N* $= 8.62$ MeV, $J = 0^+$ (from ^{13}C(p, p)^{13}C) shows strong transitions to the ground state and to ^{14}N*(3.95, 5.69): hence $T = 1$ (1959WA16). The strength of transition to ^{14}N*(6.23) indicates E1 radiation, $J = 1^-$; $T = 0$ for the 6.23 MeV state (1957WI27). However, the angular correlation in the cascade $8.62 \rightarrow 6.23 \rightarrow$ g.s. favors $J = 1^+$ or 2^+ for ^{14}N*(6.23) (1956GO1L, 1956GO39, 1957GA1B, 1957GO30). In this case, the transition strength still requires $J = 1$; $T = 0$ for ^{14}N*(6.23). The strong transition $8.62 \rightarrow 3.95$ requires dipole radiation and hence $J = 1$ for the latter (1959WA04).

The $E_\mathrm{p} = 1.25$ MeV resonance ($E_\mathrm{x} = 8.71$ MeV, $J = 0^-$ from ^{13}C(p, p)^{13}C) is established as due to s-waves by its width (1953WO41). Again the large γ-width is consistent with E1 radiation and $T = 1$ (1953WI1A). The γ-spectrum has been studied by (1957BR33) at $E_\mathrm{p} = 0.9$ and 1.0 MeV, where the main effects should be due to the $E_\mathrm{p} = 1.25$ MeV resonance: see, however, (1957JA37, 1959WA04). The results indicate relatively strong transitions to both the 4.9 and 5.7 MeV levels (see Fig. 27) and would appear to exclude the assignments $J = 0^-, 1^-$ respectively for these levels. An assignment $J = 1^+$ to ^{14}N*(5.10) is suggested. At $E_\mathrm{p} = 1.4$ MeV, (1959WA04) finds no evidence of transitions to the 5.10 MeV state. It is pointed out that some of the reported transitions may derive from the background or from other resonances.

The angular distribution of the ground-state γ-rays at the $E_\mathrm{p} = 1.75$ MeV resonance (^{14}N*(9.17)) indicates $J = 1^+, 2^+$ or 2^-; the relatively large γ-width, 13.3 eV, suggests an uninhibited E1 transition, $J = 2^-$; $T = 1$ (1951DA1A, 1951DA1B, 1953WO41, 1956MA87). However, the polarization is consistent with M1 or E2 but not E1 (1958ST33); see also (1959WA16). The total width is < 400 eV (1956MA87), < 150 eV (1958PA1D), 75 ± 50 eV (1958BO71). The resonant energy is 1746.9 ± 0.8 (1956MA87), 1747.6 ± 0.9 keV (1958BO76). If the transition $9.17 \rightarrow 6.44$ is dipole ($\omega\Gamma_\gamma = 1.3$ eV), and if $J(9.17)$ is 2, the angular distribution requires $J(6.44) = 3$ (1953WO41) and $T = 0$ (1959WA16). See also (1958ME77).

From elastic scattering work (see ^{13}C(p, p)^{13}C), the $E_\mathrm{p} = 1.47$ MeV resonance, ^{14}N* $= 8.90$ MeV, has $J = 2^-$, with 3^- and 1^- possible. The resonance at $E_\mathrm{p} = 2.11$ MeV, ^{14}N* $= 9.50$ MeV has $J = 3^-$, with 2^- and 1^- possible. A study of the gamma decay scheme and angular distributions confirms the assignments $J = 2^-$ ($T = 1$) and $J = 3^-$; $T = 1$ for these two levels. For the latter, the channel spin mixture is $(56 \pm 14)\% J_\mathrm{c} = 0$. Levels at ^{14}N* $= 5.83$ and 5.10 MeV are $J = 3^{(-)}$ and $J = 2$. The mean lives for these two levels, determined by Doppler shift, are

$0.5 < \tau < 6.5 \times 10^{-13}$ sec, and $\tau > 3 \times 10^{-13}$ sec, respectively. The 7.02 MeV level probably has $J = 2$, while the 6.44 MeV level has $J = 2$, 3 or 4. Shell-model assignments and the correlation with the levels of ^{14}C are discussed in some detail (1959WA04). See also (1956WI1G).

At the $E_{\rm p} = 3.11$ MeV resonance ($E_{\rm x} = 10.43$ MeV), the angular distribution of ground-state γ-rays is $1 - (0.40 \pm 0.02)P_2(\cos\theta)$, indicating $J = 2^-$, formed by d-waves with channel spin mixture $\sigma(J_{\rm c} = 0)/\sigma(J_{\rm c} = 1) = \frac{3}{2}$, followed by E1 radiation, or $J = 2^+$, f-wave formation, $J_{\rm c} = 1$, M1 radiation. The relatively large gamma width, 17 eV, suggests E1 radiation and $T = 1$ (1957WI30). According to (1959WA16), however, the assignment $J = 2^+$ (p or f) is equally satisfactory. The integrated cross section is 0.033 MeV-mb, in good agreement with the corresponding value for ^{14}N(γ, p)^{13}C (1957WI30).

16. (a) ^{13}C(p, p)^{13}C $\qquad E_{\rm b} = 7.546$

(b) ^{13}C(p, p$'$)^{13}C*

The elastic scattering has been studied for $E_{\rm p} = 0.15$ to 0.75 MeV by (1957HE1C), for $E_{\rm p} = 0.45$ to 1.60 MeV by (1954MI05) and for $E_{\rm p} = 1.5$ to 3.4 MeV by (1957ZI09, 1958ZI17): see Table 14.8. Assignments and level parameters for $E_{\rm p} < 2$ MeV are based in part on a qualitative analysis of the elastic scattering and in part on ^{13}C(p, γ)^{14}N (1952SE01, 1953WO41, 1954MI05). Near the 0.55 MeV resonance, the cross sections of (1957HE1C) are about 10% lower than those of (1954MI05). A close fit to the theory is obtained from $E_{\rm p} = 0.12$ to 0.65 MeV when the energy variation of Γ and E_0 are taken into account (1957HE1C: see also (1956CH1E)). Above $E_{\rm p} = 2$ MeV, the non-resonant background requires s, p and d waves. At the 9.51 MeV level, the channel spin mixture $\sigma(1)/\sigma(0) = \frac{2}{3}$ corresponds to ($\frac{5}{2}$, $\frac{1}{2}$) in j-j coupling (1957ZI09, 1958ZI17): compare ^{14}N*(10.43) in ^{13}C(p, γ).

The yield of γ-rays in reaction (b) has been measured for $E_{\rm p} = 3.6$ to 5.0 MeV: the 3.1 MeV γ-yield shows broad resonances at $E_{\rm p} = 3.80$, 4.1, and 4.14 MeV, while the 3.7 MeV γ-yield shows one strong resonance at $E_{\rm p} = 4.52$ MeV (^{14}N*(11.1, 11.36, 11.39, 11.7)) (1957BA29, 1957CO1G).

17. ^{13}C(p, n)^{13}N $\qquad Q_{\rm m} = -3.005 \qquad E_{\rm b} = 7.546$

Observed resonances are exhibited in Table 14.9 (1950AD1A, 1951BL1A, 1953BA1C, 1957BA29). Absolute cross sections have been determined from threshold to 5 MeV by (1958MA1F, 1959GI47). The behavior at threshold appears to reflect the effect of a bound level, possibly that at $E_{\rm p} = 3.11$ MeV. See also (1958BL55).

18. ^{13}C(d, n)^{14}N $\qquad Q_{\rm m} = 5.319$

$Q_0 = 5.325 \pm 0.040$ (1955BI1B).

$Q_0 = 5.41 \pm 0.06$ (1955GR1D).

Table 14.9: Resonances in ^{13}C(p, n)^{13}N

E_p [a] (MeV)	Γ [a] (keV)	E_p [b] (MeV)	Γ [b] (keV)	E_x (MeV)
3.78	100	3.77	110	11.06
3.99	15	3.98	25	11.25 [c]
(4.1)	150			(11.35)
4.14	30	4.14	50	11.39
4.49	150	4.51	140	11.73
4.8	100	4.74		11.95
		4.85		12.05
		5.03		12.20
6.20				13.30

[a] (1950AD1A, 1951BL1A, 1953BA1C, 1957BA29).
[b] (1959GI47).
[c] Corresponds to ^{14}N* $= 11.23$ in Table 14.7.

Observed neutron groups are exhibited in Table 14.10 (1952BR1C, 1953BE1D, 1955BI1B, 1955GR1D). At $E_d = 0.86$ MeV the third excited state shows a strong, $l = 0$ stripping pattern (1955GR1D: see also (1955BI1B)). In the range $E_d = 0.4$ to 4.2 MeV, a single strong neutron threshold occurs at $E_d = 0.422 \pm 0.005$ MeV (^{14}N*(5.685 ± 0.007)). The outgoing neutrons are likely to be p-wave, and the incident deuterons s-wave (because of their low energy): the results are consistent with $J = 1^+$ (1955MA76); see, however, (1959WA04). Observed γ-rays attributed to transitions in ^{14}N are shown in Table 14.11 (1952TH24, 1955BE62, 1955MA36, 1958RA13). A study of the angular correlation of internal pairs indicates that the transition ^{14}N*(5.69) $\rightarrow$ g.s. is M1 or E2; of the two transitions ($4.91 \rightarrow$ g.s.) and ($5.10 \rightarrow$ g.s.), one is E1 and the other is E2 or M1 (1958CH1A). See also (1958GO81). See also (1955AU1A, 1956EL1B; theor.).

19. ^{13}C(^{3}He, d)^{14}N $\qquad Q_m = 2.052$

Not observed.

20. ^{13}C(α, t)^{14}N $\qquad Q_m = -12.267$

Not observed.

Table 14.10: Neutron groups from ^{13}C(d, n)^{14}N

^{14}N* (MeV ± keV)			l_p	J^π
(1953BE1D) [a]	(1955BI1B) [b]	(1955GR1D) [c]		
0	0	0	1 [d]	0^+, 1^+, 2^+
2.23 ± 100	2.30 ± 50	2.34 ± 70	1 [e]	0^+, 1^+, 2^+
3.85 ± 80	3.95 ± 30	4.02 ± 70	1 [e]	0^+, 1^+, 2^+
4.80 ± 70	4.95 ± 20 [f]	5.02 ± 70	0 [e]	0^-, 1^-
4.97 ± 70		5.20 ± 70		
(5.5 ± 100)				
5.76 ± 50				
(6.1 ± 100)				
6.23 ± 50				
6.43 ± 40				
7.00 ± 40				
(7.50 ± 40)				
7.72 ± 40				
8.08 ± 60				

[a] $E_d = 3.89$ MeV.
[b] $E_d = 0.92$ MeV.
[c] $E_d = 0.86$ MeV.
[d] (1952BR1C).
[e] (1953BE1D).
[f] May be due to more than one level.

21. ^{14}C(β^-)^{14}N $\qquad Q_m = 0.155$

See ^{14}C.

22. ^{14}C(p, n)^{14}N $\qquad Q_m = -0.628$

$Q_0 = -626.4 \pm 0.5$ keV (1956SA06).

Neutron thresholds have been observed at $E_p = 671.5 \pm 0.5$ and 3149.6 ± 1.1 keV, corresponding to the ground state of ^{14}N and to an excited state at 2.3119 ± 0.0012 MeV (1956SA06). See also ^{15}N.

Table 14.11: Gamma rays from ^{13}C(d, n)^{14}N

(1952TH24) [a]	(1955BE62) [b]	(1955MA36) [c]	(1958RA13) [f]	Assignment
E_γ [d] (keV)	E_γ [e] (keV)	E_γ [d] (keV)	E_γ [e] (keV)	^{14}N*
725 ± 4		729 ± 3		$5.83 \rightarrow 5.10$
1638 ± 8				$3.95 \rightarrow 2.31$
2310 ± 12				2.31
3381 ± 13	3410 ± 40			$5.69 \rightarrow 2.31$
	3920 ± 70 [g]	3910 ± 50		3.95
	4940 ± 40	4930 ± 40	4897 ± 25	4.91
5052 ± 25	5100 ± 50	5130 ± 30	5102 ± 25	5.10
5690 ± 50	5720 ± 40	5730 ± 30	5669 ± 25	5.69
			5833 ± 30 [d]	5.83
	6490 ± 60	6450 ± 50	6419 ± 30	6.43
	7050 ± 40		7012 ± 25	7.02
	7300 ± 50 [g]			7.40

[a] $E_d = 1.2$, 1.6 MeV.
[b] $E_d = 2$, 4 MeV.
[c] $E_d = 1.4$ MeV.
[d] Not corrected for Doppler shift.
[e] Includes ≈ 0.5% Doppler correction.
[f] $E_d = 4.5$ MeV.
[g] Assignment not certain.

23. ^{14}C(^{3}He, t)^{14}N $\qquad Q_m = 0.137$

Not observed.

24. (a) ^{14}N(γ, n)^{13}N $\qquad Q_m = -10.551$
(b) ^{14}N(γ, p)^{13}C $\qquad Q_m = -7.546$
(c) ^{14}N(γ, np)^{12}C $\qquad Q_m = -12.491$
(d) ^{14}N(γ, α)^{10}B $\qquad Q_m = -11.615$

The cross section for neutron production, reactions (a) and (c), exhibits a maximum at E_γ = 22.5 MeV, $\Gamma = 3.2$ MeV, $\sigma = 15.3$ mb (1954FE16: see also (1951JO1B, 1957LI1A)). Below this maximum, there are less intense peaks in the cross section of reaction (a) at (≈ 10.8), ≈ 11.5, and ≈ 12.7 MeV. The latter two have widths of ≈ 0.3 and ≈ 1 MeV, respectively (1955CH1B). At E_{γ}(max) $= 23$ MeV, proton + recoil energies (reaction (b)) of 0.51, 1.63, and 2.92 MeV are observed, corresponding to the 8.06, 9.18, and 10.43 MeV levels of ^{14}N. Integrated cross sections of 0.6, 0.8, and 1.2 MeV-mb respectively, are found, in good agreement with those obtained from the inverse reaction ^{13}C(p, γ)^{14}N (1956WR22). In a resonance absorption experiment, using γ-radiation from ^{13}C(p, γ)^{14}N at $E_{\rm p} = 1.76$ MeV, ((1957HA1K) and private communication) find for the 9.17 MeV level of ^{14}N, $\Gamma = 0.07 \pm 0.02$ keV, $\sigma_{\rm res} \approx 6$ b, $(2J+1)\Gamma_{\gamma} \approx 48$ eV. For the 8.06 MeV level, (1956GR17, 1958GR97) finds $\Gamma_{\gamma} = 10.5 \pm 6$ eV (compare ^{13}C(p, γ)^{14}N).

At E_{γ}(max) $= 70$ MeV, reaction (d) appears to proceed via a level at 8.2 MeV in ^{10}B (which then decays by proton emission) (1956LI05). See also (1950HO80, 1954BI04, 1955RA1E, 1955SA1F, 1955TI1A, 1956GO1G, 1956JO1C, BE57A, 1958CO1F, 1958JO1C, 1958RH1A) and (1955AJ61).

25. ^{14}N(n, n$'$)^{14}N*

Elastic scattering of 14 MeV neutrons has been studied by (1952CO41, 1954SM97, 1956BU95). At $E_{\rm n} = 3.95$ MeV, a 2.30 ± 0.05 MeV γ-ray is observed (1956DA23). See also ^{15}N.

26. ^{14}N(n, d)^{13}C $\quad Q_{\rm m} = -5.319$

At $E_{\rm n} = 14$ MeV, deuteron groups are observed leading to ^{13}C*(0, 3.7). The reduced width of ^{14}N(0) for separation into p + ^{13}C(0) is $\theta^2_{\rm p_0} = 0.025$; for separation into p + ^{13}C*(3.7), $\theta^2_{\rm p_2} = 0.06$. The ratio is consistent with ^{14}N(0) = ^{3}S$_1$ but not with pure ^{3}D$_1$. On the other hand, the value of $\theta^2_{\rm p_0}$, when suitably corrected, is consistent with a large amount of D character for ^{14}N(0). Upper limits for decomposition into ^{13}C*(3.09) or ^{13}C*(3.86) are $\theta^2_{\rm p_1} < 0.003$ and $\theta^2_{\rm p_3} < 0.03$ (1957CA07): see also ^{14}N(p, d)^{13}N.

27. ^{14}N(p, d)^{13}N $\quad Q_{\rm m} = -8.324$

Angular distributions measurements for ground-state deuterons at $E_{\rm p} = 18$ MeV indicate $l_{\rm n} = 1$. The peak cross section (18°, c.m.) is 5.0 ± 0.6 mb/sr, yielding a reduced width $\theta^2 = 0.021$ for ^{14}N(0). With appropriate correction, the reduced width is in qualitative agreement with that calculated form the independent-particle model and the result suggests that the ^{14}N ground state is largely D. Upper limits of 0.1 to 0.4 mb/sr are quoted for the transition to the first excited state of ^{13}N and are taken to indicate admixtures of p^{8}s^2 or p^{8}sd in ^{14}N of a few per cent or less (1954ST1D, 1956ST1D). See also ^{14}N(n, d)^{13}C.

28. (a) ^{14}N(p, p′)^{14}N*
(b) ^{14}N(d, d′)^{14}N*

Elastic proton scattering has been studied at $E_p = 9.5$ MeV (1954FR38, 1957GI14), $E_p = 9.8$ MeV (1957HI56), 19.4 MeV (1956VA1B, 1957VA1B) and 20 MeV (1955CH1A). Analysis in terms of the optical model is not entirely satisfactory (1956BU95, 1957HI56). Elastic deuteron scattering has been studied at $E_d = 8$ MeV by (1952GI01).

Observed inelastic proton and deuteron groups are shown in Table 14.12 (1952AR29, 1953BO70, 1956BU16). At $E_p = 9.5$ MeV, the p_1 group (to the 2.3 MeV first excited state) is surprisingly weak: $< \frac{1}{6}$ of p_2 (1954FR38). At $E_p = 6.98$ MeV, $\theta = 90°$, the ratio of the intensities of the p_1 and p_2 groups to the p_0 (elastic group) is 5 and 10 %, respectively. For deuterons, the ratio for the d_2 group is 10%, while an upper limit of about 0.5% is set for the d_1 group corresponding to the $T = 1$, 2.31 MeV state, as expected from the T selection rule (1953BO70). Angular distributions of the p_0 and p_2 groups have been studied at $E_p = 9.5$ MeV (1954FR38). See also (1956BA1G; theor.). At $E_p = 96$ and 185 MeV, inelastic groups with $Q = -9.2$, -17, and -21.5 MeV are reported (1958TY46: see also (1956ST30)). See also (1958MA1B, 1958TY49). Inelastic scattering of deuterons is also reported at $E_d = 9$ MeV by (1956GR37): the d_2, d_3 and d_4 groups are observed.

For $E_p = 3.9$ to 4.9 MeV, the 2.3 MeV γ-radiation is isotropic, confirming the $J = 0$ assignment to the first excited state (1956BA34). The Doppler shift is very nearly the maximum possible, indicating a half-life less than 3.5×10^{-13} sec (1955SH84), $< 2 \times 10^{-13}$ sec (1955TH1A). See also ^{15}O.

29. ^{14}N(α, α')^{14}N*

At $E_\alpha = 21.5$ MeV, inelastic alpha groups are reported to ^{14}N states at 3.95 ± 0.04, 5.12 ± 0.07, 5.79 ± 0.07, 6.47 ± 0.09, 7.02 ± 0.06, 7.94 ± 0.07, 8.45 ± 0.07 and 10.05 ± 0.07 MeV. Except for the 7.94 MeV level, which has recently been observed in ^{13}C(p, γ)^{14}N, the last three have not been reported in other reactions. The absence of the $Q = -2.3$ and $Q = -8.06$ MeV groups is consistent with their $T = 1$ assignment (1956MI17: see also (1956WA29)). At $E_\alpha = 31.5$ MeV, the upper limit for the α_1 group, corresponding to ^{14}N*(2.3), $T = 1$, is 6% of the α_2 group (1956WA29).

30. ^{14}O(β^+)^{14}N $\qquad Q_m = 5.147$

The decay proceeds almost entirely to the $J^\pi = 0^+$; $T = 1$ state of ^{14}N at 2.3 MeV: see ^{14}O.

31. ^{15}N(p, d)^{14}N $\qquad Q_m = -8.615$

Table 14.12: ^{14}N levels from ^{14}N(p, p′)^{14}N* and ^{14}N(d, d′)^{14}N*

^{14}N* (MeV ± keV)			
(p, p′) [a]	(p, p′) [b]	(p, p′) [c]	(d, d′) [c]
2.32 ± 20	[f]	2.313 ± 5	[d]
3.96 ± 20	[f]	3.945 ± 5	3.95
	[f]	4.910 ± 10	[e]
5.09 ± 20	[f]	5.104 ± 10	[e]
	5.69 ± 30		
	5.83 ± 30		
	(5.95)		
	6.23 ± 20		
	6.46 ± 20		
	(6.60 ± 40)		
	7.03 ± 20		
	7.40 ± 20		
	7.60 ± 20		

[a] (1952AR29: $E_{\rm p} = 8$ MeV).
[b] (1956BU16: $E_{\rm p} = 9.5$ MeV).
[c] (1953BO70: $E = 7$ and 7.6 MeV).
[d] Intensity $< 0.5\%$ of d_0 group at $E_{\rm d} = 7.0$ MeV, $\theta = 90°$.
[e] No attempt to observe.
[f] Also observed.

At $E_{\rm p} = 18.6$ MeV, the transitions to the ground and first excited states of ^{14}N have been observed. The angular distributions of both groups are fitted by $l_{\rm n} = 1$ pickup curves. The peak cross section for the ground state is about 7 times greater than that for the 2.31 MeV state (1957BE49, 1957SH1B). See also (1956FR1A; theor.).

32. ^{15}N(d, t)^{14}N $\qquad Q_{\rm m} = -4.583$

Not reported.

33. ^{15}N(^{3}He, α)^{14}N $\qquad Q_{\rm m} = 9.736$

Not reported.

34. ^{16}O(n, t)^{14}N $Q_{\rm m} = -14.470$

Not reported.

35. ^{16}O(p, ^{3}He)^{14}N $Q_{\rm m} = -15.235$

Not reported.

36. ^{16}O(d, α)^{14}N $Q_{\rm m} = 3.116$
$Q_0 = 3.108$ (1955BR1B: see also (1954VA1B)).

Alpha-particle groups leading to ^{14}N levels at 0, 3.95, 5.01, and 5.70 MeV are reported by (1951AS1A); 0, 3.98 ± 0.04, 5.06 ± 0.05 MeV by (1951BU1A); 0, 3.9, and $\gtrsim$ 5 MeV by (1953FR23); 0, 3.949 MeV by (1955BR1B). The group leading to ^{14}N*(2.3), $T = 1$, is ordinarily not observed; however, careful studies in the range $E_{\rm d} = 5.5$ to 7.5 MeV (1956BR36) and $E_{\rm d} = 6.8$ to 8.9 MeV (1958DA16) show a weak α_1-group whose intensity shows marked resonance effects. The observed intensity is consistent with the expected isobaric spin impurity of the ^{16}O, ^{18}F*, and ^{14}N* states involved (1956BR36): see ^{18}F. Angular distributions of α-groups have been measured at $E_{\rm d} = 7.0$ MeV (1956BR36; α_0, α_1, α_2), 6.8 and 8.9 MeV (1958DA16; α_0, α_2) and at 19 MeV (1953FR23; α_0). See also (1957EL1D; theor.) and (1953SP1A, 1956GR37).

37. ^{17}O(p, α)^{14}N $Q_{\rm m} = 1.197$

See ^{18}F.

^{14}O

(Not illustrated)

GENERAL:

Mass of ^{14}O: The mass excess of ^{14}O is 12.149 ± 0.007 MeV, based on the threshold energy of the ^{12}C(^{3}He, n)^{14}O reaction (1957BR18) and on the Wapstra masses (1955WA1A) for ^{12}C, ^{3}He and n. The binding energies of a proton, alpha particle, ^{3}He-particle and deuteron in ^{14}O are, respectively, 4.621, 10.25, 17.563 and 22.58 MeV. In terms of the Mattauch masses (1956MA1U), the mass excess obtained by (1957BR18) is 12.146 ± 0.0065 MeV.

1. ^{14}O(β^{+})^{14}N $\qquad Q_{\rm m} = 5.147$

The decay proceeds primarily (99.4 ± 0.1 %) (1955SH84) to the $J = 0^{+}$; $T = 1$ first excited state of ^{14}N: $E_{\beta^{+}}$(max) $= 1.835 \pm 0.008$ (1954GE38); 1.830 ± 0.030 MeV (1954PE1B); $E_{\gamma} = 2.30 \pm 0.03$ MeV (1953SH38). Using Q for ^{12}C(^{3}He, n)^{14}O $= 1.1585$, ^{14}N* $= 2.313 \pm 0.005$, and mass excess of (1956MA1U), (1957BR18) calculate $E_{\beta^{+}}$(max) $= 1.8097 \pm 0.0078$. The positron spectrum has an allowed shape (1954GE38). The half-life is 72.1 ± 0.4 sec (1954GE38), $ft = 3088 \pm 56$ sec (1957BR18); see also (1958GE33). The direct ground state transition occurs in (0.60 ± 0.10)% of the cases: $ft = (2.0 \pm 0.3) \times 10^{7}$ sec. The corresponding matrix element is about 50 times larger than that for ^{14}C(β^{-})^{14}N. Explicit wave functions for ^{14}O, ^{14}N, and ^{14}C are derived (1955SH84: see also (1954JA1A, 1956EL1B, 1957VI1A). A slight deviation from linearity in the Kurie plot is predicted by (1957VI1A, 1958GO1F). The polarization of the positrons has been studied by (1958GE36). See also (1957SH1B, 1958BE1G, 1958GE1C, 1958MA1K, 1958SU1C; theor.).

2. ^{10}B(^{6}Li, 2n)^{14}O $\qquad Q_{\rm m} = 1.988$

See (1957NO17).

3. ^{12}C(^{3}He, n)^{14}O $\qquad Q_{\rm m} = -1.159$

$E_{\rm thresh.} = 1.4496 \pm 0.0028$ MeV;

$Q_{0} = -1.1585 \pm 0.003$ MeV (1957BR18).

This reaction has been studied from threshold to $E(^{3}\mathrm{He}) = 2.7$ MeV (1957BR18: see ^{15}O). (1956BU22) report a tentative threshold value of $E(^{3}\mathrm{He}) = 1.435$ MeV; $Q = -1.148 \pm 0.004$ (1958WA1C).

Table 14.13: Energy levels of ^{14}O

E_x (MeV)	J^π	$\tau_{1/2}$ or Γ	Decay	Reactions
0	0^+	72.1 ± 0.4 sec	β^+	1, 2, 3, 4
≈ 6.2		broad or unresolved		4
≈ 7.5		broad or unresolved		4
≈ 9.3		broad or unresolved		4

4. ^{14}N(p, n)^{14}O $\qquad Q_m = -5.930$

At $E_p = 17.3$ MeV, neutron groups are observed to the ground state and to broad or unresolved states of ^{14}O at ≈ 6.2, 7.5 and 9.3 MeV (1954AJ11). See also (1958BO63).

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(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.

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