Energy Levels of Light Nuclei
$A = 14$

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Abstract: An evaluation of $A = 13$–15 was published in *Nuclear Physics A*152 (1970), 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.

(References closed December 31, 1969)

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^{14}B

^{14}B has been identified in the 5.3 GeV proton bombardment of uranium (1966PO09) and in the 3 GeV proton bombardment of gold (1968TH04). ^{14}B is particle stable (1966PO09). See also (1966GA25, 1969AR13).

^{14}C

(Fig. 5)

GENERAL:

See (1954JA1A, 1956EL1B, 1957VI1A, 1958BA1A, 1959OT1A, 1959SK1A, 1960TA1C, 1960WA12, 1961BA1F, 1961FR1C, 1962TA1E, 1963BL1B, 1963NA04, 1963SO04, 1963VL1A, 1964LI1B, 1964LO1B, 1965BA1X, 1965KO1D, 1965WA1J, 1965ZA1B, 1966BA42, 1966BO1R, 1966GU08, 1966MI1G, 1966ZA03, 1967GR1D, 1967HA10, 1967IN1B, 1967KO1N, 1967KO1F, 1968EI1C, 1968FA1B, 1968FR03, 1968NE1C, 1968RO1C, 1969AR13, 1969AT1A, 1969FR1E, 1969SH1A, 1969SO08, 1969SO1E).

1. ^{14}C(β^-)^{14}N $\quad Q_{\rm m} = 0.156$

Recent values are 5745 ± 50 y (1961MA1L, 1961MA32, 1964HU09), 5780 ± 65 y (1961WA16), 5680 ± 40 y (1962OL04), 5660 ± 30 y (1968BE47), leading to a weighted mean of 5692 ± 21 y. See also (1962GO33). Using $Q_{\rm m}$, $\log ft = 9.03$ (1966BA1A), 9.02 (1969KA1B). The spectrum does not deviate from the allowed shape down to 3 keV (1954MO84). The β-decay rate of ^{14}C and the radiative width of ^{14}N*(2.31) cannot simultaneously be explained by a conventional central force plus spin-orbit interaction together with configuration mixing: the nuclear force must include a tensor part (1968RO1C). For other discussions of the long lifetime of ^{14}C, see (1959AJ76) and (1959JA1B, 1962AL1F, 1962VA1F, 1962WE1B, 1964KU1F, 1966ZA03, 1967BL24, 1968FR03, 1969DE16, 1969EL1B, 1969FR1E).

2. (a) ^{7}Li(^{7}Li, 2n)^{12}C	$Q_{\rm m} = 13.672$	$E_{\rm b} = 26.795$
(b) ^{7}Li(^{7}Li, n)^{13}C	$Q_{\rm m} = 18.619$	
(c) ^{7}Li(^{7}Li, p)^{13}B	$Q_{\rm m} = 5.964$	
(d) ^{7}Li(^{7}Li, d)^{12}B	$Q_{\rm m} = 3.309$	
(e) ^{7}Li(^{7}Li, t)^{11}B	$Q_{\rm m} = 6.197$	
(f) ^{7}Li(^{7}Li, α)^{10}Be	$Q_{\rm m} = 14.783$	
(g) ^{7}Li(^{7}Li, ^{8}Be)^{6}He	$Q_{\rm m} = 7.272$	
(h) ^{7}Li(^{7}Li, ^{7}Li)^{7}Li		

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
g.s.	0^+; 1	$\tau_{1/2} = 5692 \pm 21$ y	β^-	1, 3, 4, 6, 7, 8, 9, 10, 11, 14, 15, 17, 18, 19, 20, 21, 22, 23, 27, 28, 29, 30, 31
6.0932 ± 1.3	1^-	$\tau_m < 0.3$ psec	γ	3, 4, 7, 9, 11, 14, 18, 20
6.5892 ± 1.4	0^+	> 0.6 psec	γ	4, 7, 9, 14, 18
6.7281 ± 1.4	3^-	97 ± 15 psec	γ	4, 7, 9, 14, 17, 18, 20
6.9012 ± 1.5	0^-	< 0.3 psec	γ	4, 9, 14, 17
7.0117 ± 5.2	2^+	< 0.12 psec	γ	4, 7, 9, 18
7.3414 ± 3.4	2^-	< 0.22 psec	γ	4, 7, 9, 14, 18
8.318 ± 5	$(1, 2)^+$	$\Gamma = 12$	n	9, 12, 14, 18
9.801 ± 8	(1)	19	n	12, 14, 18
10.433 ± 10	(2)	16	n	12, 14, 18
10.453 ± 10	≥ 1	9	n	12, 14, 18
10.74 ± 20		< 15		7, 9
(11.35 ± 50)				7
(11.66 ± 50)				7
11.9 ± 300		950 ± 300		12, 14
12.601 ± 20		110 ± 20		14
12.854 ± 20				14
12.958 ± 20				14

These reactions have been studied with $E(^7\text{Li})$ to 6.5 MeV: see (1957NO14, 1957NO17, 1962BE24, 1963CA09, 1963HU02, 1964DZ1A, 1966PI02, 1969CA1A). For $E(^7\text{Li}) = 2.3$ to 5.8 MeV, the cross section for emission of α_0, α_1, α_{2+3+4} (to the first five states of ^{10}Be) increases monotonically with energy (1964DZ1A, 1969CA1A). The measured cross sections for reactions (c), (d), (e) and (f) indicate that the reactions probably occur by a mixture of compound nucleus and direct reaction mechanisms. The Coulomb field appears to have a marked effect on the cross sections (1969CA1A: see also (1963HU02)).

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

See (1967SE08) and ^{15}N.

Table 14.2: ^{14}C levels from ^{12}C(t, p)^{14}C

E_x [a] (MeV ± keV)	(1964MI05) [b] L	(1960JA17) [c] L
0	0	0
6.090 ± 10	(2)	1
6.582 ± 10	1	1
6.725 ± 10	(2)	3
6.893 ± 10	[e]	[e]
7.009 ± 10	(2)	0
7.335 ± 10	[e]	[e]
8.32	2 [f]	
10.74 ± 20 [d]		

[a] The excitation energies of the first six excited states have been determined by (1960JA17); the seventh comes from the ^{13}C(n, n)^{13}C work of (1961CO05); the eighth has been determined by (1964MI05).
[b] $E_t = 11$ MeV; except ground state $E_t = 8$ to 13 MeV.
[c] $E_t = 5.5$ MeV.
[d] $\Gamma < 15$ keV. No states are observed between this level and the broad state at 11.9 MeV (1964MI05).
[e] Weak group.
[f] (1964MI05) suggest $J^\pi = 2^+$; see, however, (1961CO05).

4. ^{9}Be(^{7}Li, d)^{14}C $\qquad Q_m = 10.102$

At $E(^7\text{Li}) = 3.2$ MeV, the ground state deuteron group and the deuteron groups corresponding to the known levels with $E_x < 9$ MeV have been observed (1964CA05)[†] . At $E(^7\text{Li}) = 5.1$ MeV, the γ-decay of the six bound excited states has been studied by (1966CA07): see Table 14.3. Measurements at $E(^7\text{Li}) = 5.7$ MeV give $\tau_m < 0.32$ and < 0.12 psec, respectively, for ^{14}C*(6.09, 7.01). $E_\gamma = 6.0945 \pm 0.0032$, 6.7281 ± 0.0014 and 7.0117 ± 0.0052 MeV for the ground state transitions for these two levels and ^{14}C*(6.73) (1969TH01).

5. (a) ^{11}B(t, n)^{13}C $\qquad Q_m = 12.422 \qquad E_b = 20.598$

[†] Angular distributions of the deuterons to ^{14}C*(0, 6.09, $6.59 + 6.73$, $6.90 + 7.01$, 7.34, 8.32) have been measured at $E(^7\text{Li}) = 5.6$, 5.8, 6.0 and 6.2 MeV (1969SN02).

Table 14.3: Branching ratios of γ-rays in ^{14}C

E_i (MeV)	J_i^π	E_f (MeV)	Branch (%)			
			A	B	C	D
6.09	1^-	0			100	
6.59	0^+	0	1.0 ± 0.4 [c]			
		6.09	99.0 ± 0.4			
6.73	3^-	0	93 ± 2	97.3 ± 1	91 ± 5	
		6.09	7 ± 2	2.7 ± 1	9 ± 3	
6.90	0^-	6.09	100 [a]			
7.01	2^+	0		98.6 ± 0.7	100^{+0}_{-5}	
		6.09		1.4 ± 0.7	< 5	
7.34	2^-	0	18 ± 4	14 ± 4	13 ± 3	13 ± 5
		6.09	47 ± 4	52 ± 5 [b]	60 ± 5	29 ± 13
		6.73	35 ± 7	34 ± 4 [b]	27 ± 5	58 ± 7

A: (1966AL10): ^{13}C(d, p)^{14}C.
B: (1968BE30): ^{12}C(t, p)^{14}C.
C: (1966CA07): ^{9}Be(^{7}Li, d)^{14}C.
D: (1965LA09): ^{13}C(d, p)^{14}C [see also (1966AL10)].
[a] (1958WA02).
[b] δ(M2/E1) $= -0.04 \pm 0.09$ and $+0.07 \pm 0.30$, respectively (1968BE30).
[c] Internal pairs.

(b) ^{11}B(t, α)^{10}Be $\qquad Q_m = 8.586$

Resonant structure has been observed in the yield of neutrons at $E_t = 1.200$, 1.340, 1.567, 1.650, 1.700, 1.800, 1.940, 2.055, 2.245 and 2.315 MeV corresponding to $E_x = 21.540$, 21.650, 21.828, 21.893, 21.933, 22.011, 22.121, 22.211, 22.360 and 22.415 MeV (1965VA13; natural B target). For reaction (b) see (1967SI1F).

6. ^{11}B(α, p)^{14}C $\qquad Q_m = 0.784$

The angular distributions of ground state protons have been measured for $E_\alpha = 2.5$ to 5.0 MeV (1963MA28). See also (1959AJ76) and ^{15}N.

7. ^{11}B(^{7}Li, α)^{14}C $\qquad Q_{\rm m} = 18.131$

At $E(^{7}\text{Li}) = 5$ MeV, α-particle groups are observed to the known states of ^{14}C with $E_{\rm x} < 10$ MeV except ^{14}C*(6.90), and to the (unresolved) 10.4 MeV states. There is some indication also of ^{14}C states at (10.71), 11.35, 11.66, (14.15), (14.73) and (15.07) MeV ($\pm \approx 50$ keV), in addition to the 12 MeV states. The wide state at $E_{\rm x} = 11.9$ MeV is not observed. Angular distributions have been obtained for the α-particles to the ground state of ^{14}C and to the states at $E_{\rm x} = 6.09$ and 8.32 MeV (1966MC05). See also (1963MI02, 1963MO1B).

8. ^{11}B(^{19}F, ^{16}O)^{14}C $\qquad Q_{\rm m} = 8.899$

See (1963HO1E).

9. ^{12}C(t, p)^{14}C $\qquad Q_{\rm m} = 4.641$

Observed proton groups are displayed in Table 14.2. Angular distributions have been observed at $E_{\rm t} = 5.5$ MeV (1960JA17) and $E_{\rm t} = 8$ to 13 MeV (1964MI05). Aside from the ground state and groups corresponding to ^{14}C*(6.59, 8.32), the stripping patterns are inconclusive (1964MI05). Particle-γ correlations have been studied by (1968BE30): see Table 14.3. The lifetime of ^{14}C*(6.73) is 97 ± 15 psec (1968AL12). The $(6.73 \to 0)$ E3 transition is enhanced by 3.3 ± 0.8 W.u. (1968AL12).

See also (1960MU07, 1962GU01, 1962KU09, 1967KE1J, 1969ET01), (1964AB1B, 1965GL07, 1965SH1E, 1966GL1C, 1966SH1F, 1967TI1B, 1969SO08; theor.), (1959AJ76) and ^{15}N.

10. ^{12}C(^{18}O, ^{16}O)^{14}C $\qquad Q_{\rm m} = 0.934$

See (1968HU1H, 1968SC1H, 1969BR1D, 1969SU1E).

11. ^{13}C(n, γ)^{14}C $\qquad Q_{\rm m} = 8.176$

$Q_0 = 8.177 \pm 0.002$ (1967TH05).

The thermal capture cross section is 0.9 ± 0.2 mb (1964ST25), 1.0 ± 0.2 mb (1963MO1C). Two γ-rays are observed with $E_\gamma = 8.174 \pm 0.002$ and 6.093 ± 0.002 MeV [$E_{\rm x} = 6.094 \pm 0.002$ MeV], with intensities of 87 ± 5 and 13 ± 1%. Intensities of transitions via other ^{14}C states are < 2% (1967TH05). See also (1968FO1A).

Table 14.4: Resonances in $^{13}C(n, n)^{13}C$ (1961CO05)

E_{res} (MeV ± keV)	E_x (MeV ± keV)	Γ_{lab} (keV)	σ [a] (b)	J^π
0.153 ± 5	8.318 ± 5	13	7	1^+
1.751 ± 8	9.801 ± 8	20	$[\approx 1.3]$	1
2.432 ± 10	10.433 ± 10	17	$[\approx 1.3]$	2
2.454 ± 10	10.453 ± 10	10	$[\approx 0.7]$	≥ 1
3.8 [b]	11.7			

[a] Corrected peak cross section, above background.

[b] Broad resonance structure.

12. $^{13}C(n, n)^{13}C$ $E_b = 8.176$

The coherent scattering length (thermal, bound) is 6.0 fm (1961WI1A, 1969BA1P). The total cross section has been measured for $E_n = 0.11$ to 9 MeV and 16 to 23 MeV. The observed resonances are listed in Table 14.4. For the 153 keV resonance, the shape excludes $l = 0$; θ^2 for $l = 2$ would be 2.3, thus $l = 1$. The peak cross section is too large for $J = 0$, but lower than expected for $J = 1$: it is concluded that $J^\pi = 1^+$. The peak cross section for the $E_n = 1.75$ MeV level is in excellent agreement with $J = 1$. Formation by $l = 0$ is excluded by the shape, but $l = 1$, 2 remain as possibilities. Peak cross sections for the states at $E_n = 2.43$ and 2.45 MeV indicate $J = 2$ and $J \geq 1$, respectively (1961CO05). See also (1969HO1Y).

13. $^{13}C(n, \alpha)^{10}Be$ $Q_m = -3.836$ $E_b = 8.176$

See (1947HU03, 1954SA68, 1964GA1A).

14. $^{13}C(d, p)^{14}C$ $Q_m = 5.952$

The weighted mean of reported Q-values is 5.948 ± 0.003 MeV: see (1965RY01).

Proton groups reported by (1954SP01, 1955MC75, 1961JA23) are displayed in Table 14.5. See also (1961TE02). Angular distributions have been analyzed by PWBA and DWBA and have led to J^π assignments and to determinations of θ^2: see Table 14.5 (1955MC75, 1958WA02, 1963LI09, 1966GL01, 1967SC29). See also (1963DE19, 1965LA09) and ^{15}N.

Observed γ-radiation assigned to ^{14}C is exhibited in Table 14.6 (1955BE62, 1955MA36, 1958RA13, 1958WA02, 1965LA09, 1966AL10) and in Table 14.3. The internally formed positron distribution shows that the decay of the 6.09 MeV level is E1 and hence that it has $J^\pi = 1^-$; it is presumably

Table 14.5: Proton groups from ^{13}C(d, p)^{14}C

(1954SP01)	(1955MC75)			(1958WA02, 1959WA04)		(1966GL01)		(1960MA32)
E_x (MeV $\pm$ keV)	E_x (MeV $\pm$ keV)	l_n [c]	J^π	J^π	θ_n^2 [g]	θ_n^2 [g,h]	θ_n^2 [g,i]	θ_n^2 [g,k]
0	0	1	$0^+, 1^+, 2^+$	0^+	0.10	0.067	0.031	0.063
6.091 ± 10 [a]	6.09	0	$0^-, 1^-$	1^-	0.40 [j]	0.20	0.13	0.20
	6.589 ± 20	1, 2, 3 [f]	$(1^-, 2, 3^-)$		$\lesssim$ 0.01	0.008		0.006
6.723 ± 10 [b]	6.72	2	$1^-, 2^-, 3^-$	$3^-(2^-)$	0.11	0.065	0.052	0.07
6.894 ± 10 [b]	6.89	0, 1 [f]	0, 1, 2^+	0^-	0.39	0.24		
						0.0012 [l]		
	7.346 ± 20	2	$1^-, 2^-, 3^-$	$2^-, 3^-$	0.11	0.072	0.061	0.06
	8.321 ± 20					0.009		0.0015
	9.800 ± 20							
	10.433 ± 20							
	10.505 ± 20							
	11.9 ± 300 [d]							
	12.601 ± 20 [e]							
	12.854 ± 20							
	12.958 ± 20							

[a] 6.112 ± 0.012 MeV (1961JA23).
[b] The spacing of these two levels is 171 ± 3 keV (1954SP01).
[c] See also (1959AJ76).
[d] $\Gamma_{lab} = 1.10 \pm 0.30$ MeV.
[e] $\Gamma_{lab} = 0.130 \pm 0.020$ MeV.
[f] See footnotes 18 and 31 in (1958WA02).
[g] From PWBA analysis, assuming $J^\pi = 0^+, 1^-, 3^-, 0^-, 2^-$.
[h] $E_d = 12$ MeV.
[i] $E_d = 8$ MeV.
[j] $E_d = 4.7$ and 6 MeV, $\theta^2 = 0.95 \pm 0.24$, DWBA analysis (1963LI09).
[k] $E_d = 14.8$ MeV.
[l] For ^{14}C*(7.01).

Table 14.6: Gamma rays from ^{13}C(d, p)^{14}C

Transition	E_γ (MeV ± keV)				
	(1955MA36)	(1955BE62)	(1958RA13)	(1958WA02)	(1966AL10)
$6.09 \rightarrow$ g.s.	6.090 ± 25 [b]	6.11 ± 30 [b]	6.090 ± 20 [b]	6.09	
$6.73 \rightarrow$ g.s.	6.730 ± 40 [c]	6.720 ± 30 [c]	6.738 ± 25 [c]	6.72	
$7.34 \rightarrow$ g.s. [a]		(7.30 ± 50)	7.323 ± 25 [b]	7.35	
$6.59 \rightarrow 6.09$					0.4958 ± 0.4
$6.90 \rightarrow 6.09$	0.811 ± 3 [d]			0.813 ± 8 [d]	0.8087 ± 1.0
$7.34 \rightarrow 6.73$				0.621 ± 7	
$7.34 \rightarrow 6.09$					1.248 ± 3 [e]

[a] $\Gamma_{7.34}/\Gamma_{6.72} \leq 0.22 \pm 0.07$, $\Gamma_{1.25}/\Gamma_{6.72} = 0.5 \pm 0.2$ (1965LA09).
[b] Corrected for Doppler shift: see (1958WA02).
[c] No Doppler shift: $\tau > 0.3$ psec (1958WA02).
[d] A Doppler shift of 0.5–1.0% applies (1958WA02).
[e] See also (1965LA09).

the analog of the 8.06 MeV level in ^{14}N (1952TH24, 1958CH1A, 1958GO81, 1959CH28, 1959WA04, 1966WA1C). The p-γ correlation is isotropic, consistent with $l = 0$ formation (1963LI09, 1965LA09). The 6.59 MeV state is observed in internal pairs but not in external pair formation. The transition to the ground state is E0, therefore $J^\pi = 0^+$; $\tau_\mathrm{m} > 0.6$ psec (1963AL21, 1964WA05, 1966AL10). The mean lifetime of the 6.73 MeV state is greater than 2 psec (1966AL10) [see also reaction 9] and study of the internal pairs suggests that the ground state transition is E3 (1964WA05, 1966WA1C). The stripping pattern is rather clearly $l = 2$; (p-γ) angular correlations are consistent with $J^\pi = 3^-$: $J = 1$ and 2 are ruled out (1965LA09): see also (1966AL10).

The 0.81 MeV cascade transition from the 6.90 MeV state shows a Doppler shift ($\tau_\mathrm{m} < 0.3$ psec) 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 decay of the 6.90 MeV level (1958WA02). The plane polarization of the 0.81 MeV cascade has been measured in coincidence with the 6.09 MeV ground state transition: the parity of the 6.90 MeV state is negative (1966RI02).

Protons leading to the 7.34 MeV state exhibit a clear $l = 2$ pattern: therefore $J^\pi = 1^-$, 2^- or 3^-. The level decays via cascades through the 6.09 (1^-) and 6.73 (3^-) states: see Table 14.3 (1958RA13, 1958WA02, 1965LA09, 1966AL10). The strength of the cascade ($7.34 - 6.09$) compared to the ground state transition argues against $J^\pi = 1^-$ and 3^- for the 7.34 MeV state (1958WA02, 1966AL10); the angular correlation data is consistent with $J^\pi = 2^-$ and excludes $J = 3$ (1965LA09). Comparison of reduced widths and calculations of level shifts suggests the following associations of ^{14}C and ^{14}N levels: $6.09 - 8.06$, $6.59 - 8.62$, $6.73 - 8.91$, $6.90 - 8.80$,

$(7.01-9.17)$, $7.34-9.51$ and $(8.32-10.43)$ (1960WA12). See also (1959KU1C).

15. ^{13}C(t, d)^{14}C $\qquad Q_m = 1.919$

At $E_t = 5.5$ MeV, the ground state deuterons have been observed (1961BA10).

16. ^{13}C(α, ^{3}He)^{14}C $\qquad Q_m = -12.402$

Not reported.

17. ^{13}C(^{11}B, ^{10}B)^{14}C $\qquad Q_m = -3.280$

See (1967PO13, 1969BR1D).

18. (a) ^{14}C(p, p′)^{14}C*
(b) ^{14}C(d, d′)^{14}C*

At $E_d = 14.9$ MeV, inelastic deuteron groups have been seen to the states at 6.09, 6.58, 6.72, 7.01 ± 0.02, 7.34, 8.32, 9.80 and 10.5 MeV (1959AR1A). An angular distribution of elastically scattered deuterons has been obtained at $E_d = 3.4$ MeV by (1967NE06). See also (1960WA12). For reaction (a), see (1969CU1D).

19. ^{14}C(^{3}He, ^{3}He)^{14}C

See (1968BA1E, 1968CE1C, 1969DA1P).

20. ^{14}N(n, p)^{14}C $\qquad Q_m = 0.626$

The weighted mean of five Q-value determinations is 626 ± 1 keV (1957VA11). (1965IS1A) report 621 ± 6 keV. (1969NY1A) report γ-rays with $E_\gamma = 6.082 \pm 0.010$ (Doppler corrected) and 6.732 ± 0.005 MeV. τ_m of ^{14}C*(6.09) ≤ 0.3 psec (1969NY1A). See also (1959GA14, 1959HA13, 1963MO04, 1964MO1D, 1967AN08, 1969DI1B), (1959AJ76) and ^{15}N.

21. ^{14}N(t, ^{3}He)^{14}C $Q_{\rm m} = -0.137$

See (1968ST1U).

22. ^{15}N(γ, p)^{14}C $Q_{\rm m} = -10.208$

See (1964KO10) and ^{15}N.

23. ^{15}N(n, d)^{14}C $Q_{\rm m} = -7.984$

The angular distributions of ground state neutrons have been determined at $E_{\rm n} = 14.1$ and 14.8 MeV (1967FE06). See also (1956FR1A).

24. ^{15}N(d, ^{3}He)^{14}C $Q_{\rm m} = -4.715$

Not reported.

25. ^{15}N(t, α)^{14}C $Q_{\rm m} = 9.606$

Not reported.

26. ^{16}O(n, ^{3}He)^{14}C $Q_{\rm m} = -14.616$

Not reported.

27. ^{16}O(p, 3p)^{14}C $Q_{\rm m} = -22.334$

See (1961TA10).

28. ^{17}O(n, α)^{14}C $Q_{\rm m} = 1.819$

See ^{18}O and (1965BE1N).

29. ^{18}O(d, ^{6}Li)^{14}C $Q_{\rm m} = -4.755$

See (1963DR1B, 1964BL1C, DE65C, 1966DA1C, 1966DE09).

30. ^{18}O(^{12}C, ^{16}O)^{14}C $Q_{\rm m} = 0.934$

See (1968GO1Q) and reaction 10.

31. ^{19}F(d, ^{7}Be)^{14}C $Q_{\rm m} = -7.139$

See (1967DE03).

32. ^{22}Ne(α, ^{12}C)^{14}C $Q_{\rm m} = -8.620$

Not observed: see (1962LA15).

^{14}N

(Figs. 6 and 8)

GENERAL:

Model calculations: (1957HU1C, 1959BA1F, 1959BR1E, 1959OT1A, 1959SK1A, 1960PA08, 1960TA1C, 1960WA12, 1961BA1F, 1961BA1E, 1961FR1C, 1961TR1B, 1962IN1C, 1962TA1E, 1962WE1C, 1963KU1B, 1963NA04, 1963SE19, 1963TR02, 1963WA15, 1964AM1D, 1964BR1L, 1964FE02, 1964LO1B, 1964MA1G, 1964NE1E, 1964ST1B, 1964UL1A, 1965CO25, 1965GL09, 1966BO1R, 1966HA18, 1966HA31, 1966HE1E, 1966MAZY, 1966MI1G, 1966WI1E, 1967CO32, 1967EV1C, 1967KU1E, 1967LI06, 1967PA05, 1967SO1A, 1968CO13, 1968DE13, 1968EI1C, 1968GO01, 1968HO1H, 1968KU1E, 1968NO1C, 1968RA10, 1968SO1B, 1968ZH05, 1969UL03, 1969VA1C).

General calculations and reviews: (1960PA08, 1962MA1P, 1963BL1B, 1963VL1A, 1964LI1B, 1964MC1C, 1964TH03, 1964YO1B, 1965BE1B, 1965GI1B, 1965KO1D, 1965MA1N, 1966DA1E, 1966MAZY, 1966WI1E, 1966ZA03, 1967BI06, 1968FR03, 1968GA03, 1968HI1H, 1968LA1J, 1968RI1H, 1968RO1C, 1969AT1A, 1969FR1E, 1969WA1F).

Electromagnetic transitions: (1959FA1C, 1959WA16, 1959WA04, 1960WA12, 1962MO1A, 1962UN1A, 1963KU03, 1964HE1F, 1965BI10, 1966HA31, 1966WA1E, 1967KU1E, 1967PO1J, 1967WA1C, 1968RO1C, 1969VA1C).

Meson interactions: (1967BA2H, 1967BA78, 1967BU1D, 1967FO1A, 1967KO1D, 1967MI1B, 1968BA2G, 1968BA1M, 1968BA48, 1968CH1F, 1968GO1T, 1968KO1C, 1968NO1A, 1968RI1H, 1968TA1C, 1968WI1B, 1968ZU1A, 1969CH1C, 1969MO1E, 1969SA1L, 1969WU1A).

Spallation: (1965ZH1A, 1967AU1B).

Ground state: $J = 1$; $\mu = +0.40361$ nm (1964LI14).

$$Q = 16 \pm 7 \text{ mb (1960LI10).}$$

See also (1959KA07, 1960PA08, 1961BR13, 1962BA1K, 1962HE1A, 1966MA1P, 1967SH05, 1967SH14, 1968PE16, 1968RO1C, 1969AL04, 1969FU11, 1969VA1C, 1969WU1A).

1. (a) ^{9}Be(^{6}Li, n)^{14}N $\qquad Q_{\rm m} = 14.504$
   (b) ^{9}Be(^{7}Li, 2n)^{14}N $\qquad Q_{\rm m} = 7.251$

Gamma rays due to the $3.95 \rightarrow 2.31$, $4.91 \rightarrow 0$, $6.21 \rightarrow 2.31$ and $6.44 \rightarrow 0$ transitions have been observed in these reactions and in reactions 6 and 19: $E_\gamma = 1631.3 \pm 1.3$, 4913.8 ± 3.0, 3883.0 ± 1.9 and 6443.7 ± 1.8 keV, respectively. $\tau_{\rm m} = 0.62 \pm 0.08$ psec for ^{14}N*(6.44) [see also Table 14.12] (1969TH01). For reaction (b), see also (1957NO17).

Table 14.7: Energy levels of ^{14}N [a]

E_x in ^{14}N (MeV $\pm$ keV)	$J^\pi; T$	τ_m (psec) or Γ (keV)	Decay	Reactions
0	1^+; 0	stable	γ	1, 6, 7, 8, 9, 10, 11, 16, 17, 18, 19, 20, 21, 22, 23, 24, 30, 31, 32, 33, 34, 35, 36, 37, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 54, 56, 57, 58, 59, 60, 61, 62, 63
2.31281 ± 0.06	0^+; 1	$\tau_m = 0.085 \pm 0.010$	γ	1, 6, 9, 10, 16, 17, 19, 24, 30, 31, 32, 36, 37, 39, 40, 41, 42, 43, 45, 46, 51, 52, 54, 57, 58
3.9447 ± 1.2	1^+; 0	0.0045 ± 0.0004	γ	1, 6, 7, 9, 10, 16, 17, 18, 19, 20, 22, 24, 30, 31, 32, 36, 37, 40, 41, 42, 43, 45, 46, 51, 52, 54, 57, 58
4.9134 ± 2.4	$(0, 1)^-$; 0	< 0.050	γ	1, 6, 7, 9, 17, 18, 19, 22, 24, 30, 31, 32, 37, 40, 41, 42, 43, 45, 46, 52, 54, 58
5.10587 ± 0.18	2^-; 0	12.4 ± 1.4	γ	6, 7, 16, 17, 18, 19, 22, 24, 30, 31, 32, 37, 40, 41, 42, 43, 45, 46, 52, 54, 58
5.691 ± 3	1^-; 0	< 0.036	γ	6, 7, 17, 18, 19, 24, 30, 31, 32, 33, 37, 41, 42, 43, 45, 46, 52, 54, 58
5.833 ± 2	3^-; 0	18 ± 2	γ	6, 7, 16, 17, 18, 19, 20, 24, 30, 31, 32, 33, 37, 40, 41, 42, 43, 45, 46, 52, 54, 58
6.1976 ± 2.0	1^+; 0		γ	1, 6, 7, 17, 18, 19, 24, 30, 31, 37, 42, 43, 45, 46, 52, 54, 58
6.4436 ± 1.6	3^+; 0	0.62 ± 0.06	γ	1, 6, 7, 17, 18, 20, 24, 30, 31, 37, 41, 42, 43, 46, 52, 54, 58
7.028 ± 4	2^+; 0	$\tau_m = 5.4 \pm 0.5$ fsec	γ	6, 7, 17, 18, 19, 24, 30, 31, 37, 39, 40, 41, 42, 43, 45, 46, 52, 54, 57, 58
7.966 ± 1	$2^{(-)}$; 0	$\Gamma < 0.37$	γ, p	6, 7, 17, 18, 19, 24, 30, 31, 40, 42, 46, 52, 54, 58

Table 14.7: Energy levels of ^{14}N [a] (continued)

E_x in ^{14}N (MeV ± keV)	$J^\pi; T$	τ_m (psec) or Γ (keV)	Decay	Reactions
8.061 ± 2	$1^-; 1$	30 ± 1	γ, p	17, 24, 25, 30, 31, 38, 39, 42, 52, 54
8.489 ± 3	(4^-); 0	≤ 0.2	γ, p	6, 7, 17, 18, 19, 24, 31, 54, 58
8.617 ± 3	$0^+; 1$	7 ± 1	γ, p	17, 24, 25, 31, 52, 54, 58
8.80 ± 50	$0^-; 1$	≈ 500	γ, p	24, 25, 31, 33, 54
8.907 ± 3	$3^-; 1$	16 ± 2	γ, p	24, 25, 30, 31, 33, 40, 52, 54
8.963 ± 3	5^+; 0	< 1	γ, p	17, 18, 19, 20, 24, 31, 52
8.979 ± 4	2^+; (0)	9 ± 2	γ, p	6, 7, 24, 25, 30, 31, 52
9.129 ± 2	2^-; 0	< 1	γ, p	6, 7, 24, 31
9.172 ± 1.5	$2^+; 1$	0.074 ± 0.008	γ, p	17, 19, 24, 31, 38, 39, 40, 42, 52, 54, 57
9.388 ± 4	2^-; 0	13 ± 3	p	6, 7, 17, 18, 19, 25, 52, 54, 58
9.508 ± 3	$2^-; 1$	41 ± 2	γ, p	24, 25, 52, 54, 58
9.702 ± 4	1^+	15 ± 3	p	6, 7, 17, 18, 19, 25, 52, 54, 58
10.063 ± 15	$T = 0$			17
10.10 ± 15	$(1, 2)^+$	5	γ, p	6, 7, 17, 18, 19, 24, 25, 52, 58
10.228 ± 10	$1^{(-)}$; 0	80 ± 15	γ, p	24, 25, 52, 58
10.434 ± 8	$2^+; 1$	33 ± 3	γ, p	6, 7, 17, 24, 25, 37, 38, 40, 52, 54, 58
10.56 ± 10	1^-	140	p, d	12, 17, 25
10.809 ± 12	4^+; 0			17, 18, 19, 20, 52, 58
11.04 ± 32	1^+; 0	95	γ, n, p, d	12, 17, 18, 19, 24, 25, 26, 40, 52, 58
11.051 ± 14		< 30	γ, p	6, 7, 24, 52
11.246 ± 12	$3^-; 1$	11	n, p, d	12, 17, 19, 25, 26, 42, 43, 45, 52, 58
11.30	2^-; 0	180	γ, n, p, d	12, 17, 19, 24, 25, 26, 52, 58
11.374 ± 12	1^+; 0	32	n, p, d	12, 13, 17, 19, 25, 26, 52, 58

Table 14.7: Energy levels of ^{14}N [a] (continued)

E_x in ^{14}N (MeV $\pm$ keV)	$J^\pi; T$	τ_m (psec) or Γ (keV)	Decay	Reactions
11.516 ± 13	3^+	5	p, d	12, 13, 17, 19, 52, 58
11.66 ± 40	$(1^+, 2^-)$	≈ 95	n, p, d	12, 17, 52
11.75	1^+	100	γ, n, p, d	12, 17, 24, 25, 26, 52
11.81	(2^+)	≈ 100	n, p	25, 26, 52
11.95 ± 30	2^+			17, 19, 52
12.23	3^-		n, p, d	12, 26, 52
12.29 ± 15			p, α	3, 52
12.414 ± 6	4^-	37 ± 3	n, p, d, α	3, 4, 12, 13, 17, 19
12.47 ± 10		≈ 20	p, α	3, 24, 37
12.504 ± 7		31 ± 5	n, p, d, α	3, 12, 17, 24, 37, 52
12.608 ± 6	3^+	47 ± 3	p, d, α	3, 12, 13, 17, 19, 52
12.689 ± 4	3^-	17 ± 3	n, p, d, α	2, 3, 4, 12, 13, 17, 19, 26
12.793 ± 6	4^+	18 ± 3	n, p, d, α	2, 3, 4, 12, 13, 17, 18, 20, 52
12.825 ± 7	4^-	7 ± 2	n, p, d, α	3, 4, 12, 13, 52
12.853 ± 15		71 ± 7	n, p, d	12, 17, 26
12.942 ± 7	4	24 ± 4	p, d, α	3, 4, 12, 13, 17, 18
13.03		190	γ, p	24
13.05 ± 20	$T = 0$	< 70		18
13.164 ± 8	$(0, 1)^-$	16 ± 6	n, p, d, α	2, 3, 4, 5, 12, 13, 17, 18, 52
13.23 ± 10		97 ± 7	n, p, α	2, 3, 26, 52
13.3		≈ 1000	γ, p	24
13.66 ± 10	$(2, 3)^+$	≈ 110	p, d, α	3, 5, 12, 13
13.71 ± 10		≈ 100	n, p	2, 3
13.75 ± 10	$1^+; 1$	210 ± 30	n, p, d	3, 12, 13, 26, 37, 52, 54
14.04			p, d	12, 13
14.17		290	n, p, d, α	3, 12, 13, 26
14.40		≈ 140	p, d, α	3, 12, 13
14.70			d	13, 18
14.84		140	n, p, d, α	2, 3, 12, 13, 15, 17, 26
15.0		≈ 1000	γ, p	24

Table 14.7: Energy levels of ^{14}N [a] (continued)

E_x in ^{14}N (MeV $\pm$ keV)	$J^\pi; T$	τ_m (psec) or Γ (keV)	Decay	Reactions
15.10	6^-	40	n, p, d, α	2, 3, 13, 17, 18, 20, 26
15.26			p, d	12, 13
15.47		≈ 70	n, p, d, α	2, 3, 12, 15, 18
15.7		320	n, p, d, α	12, 13, 17, 26
16.3		140	n, p, d, α	15, 18, 26
17.2 ± 200		≈ 400	γ, n, p, d, α	13, 15, 17, 18, 24, 26
17.7				18
≈ 18	3^-	≈ 2000	d, α	15
18.1		550	n, p	24, 26
19.6	(5^+)		p, d	12, 13, 24
20.5	(5^+)	≈ 1000	γ, n, p, d	12, 13, 24
21.15 ± 150	(4^-)	≈ 1400	d, α	13, 15
≈ 22.5		≈ 3000	γ, n, p	24, 38
22.70 ± 100		≈ 900	d, α	15
23.0		≈ 450	γ, p	24
23.7		≈ 450	γ, p	24
≈ 23.9		≈ 1000	n, ^{3}He, α	8
≈ 24		several MeV	γ	39
≈ 30			γ	39

[a] See also Tables 14.9 and 14.13.

Table 14.8: Resonances in $^{10}B + \alpha$

E_α (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Outgoing particle [a] (x)	Γ_x (keV)	θ^2_x	$^{14}N^*$ (MeV)	J^π [b]	Refs.
0.95		p_0			12.29		1953MA42
1.13 ± 5	30 ± 5	p_0, p_1, p_2, p_3, d			12.42	4^-	{ 1953MA42, 1953SH64, 1954ST20, 1969GA01
1.20 ± 5	≈ 20	$p_0, (p_2), p_3$			12.47		1953MA42, 1969GA01
1.23 ± 5	35 ± 5	p_0, p_3			12.49		1953SH64, 1969GA01
1.40 ± 5	46 ± 4	$p_1, p_2, (p_3)$			12.61	3^+	1953SH64, 1969GA01
1.508 ± 4	17 ± 3	α	1.7	6.0	12.690	3^-	1953SH64, 1953TA06, 1954ST20, 1957BR18, 1969GA01
		p_0	0.62	0.012			
		p_1	0.17	0.29			
		p_2	0.70	0.31			
		p_3	5.6	0.47			
		d	0.93	0.26			
		n	4.3	0.19			
1.64 ± 5	16 ± 3	α	1.0	8.2	12.79	4^+	1953SH64, 1953TA06, 1954ST20, 1969GA01
		p_0	0.18	0.012			
		p_1	0.085	2.7			
		p_2	0.44	3.0			
		p_3	9.6	4.9			
		d	2.0	3.9			
		n	0.59	0.16			
1.68 ± 5	5 ± 2	p_1, p_2, p_3, d			12.81	4^-	1953SH64, 1953TA06, 1954ST20, 1969GA01
1.83 ± 5	22 ± 4	p_0, p_1, p_2, p_3, d			12.92	4^+	1953SH64, 1953TA06, 1954ST20, 1969GA01
2.16 ± 5	14 ± 4	p_0, p_1, p_2, p_3, d, α_1, n			13.16		1953TA06, 1955SH46, 1969GA01
2.26 ± 5	97 ± 7	p_0, p_1, p_2, p_3, n			13.23		1953TA06, 1955SH46, 1969GA01
2.86 ± 5	≈ 110	p_1, p_2, α_1			13.66		1969GA01
2.94 ± 5	≈ 100	p_0, p_1, p_3, n, α_1			13.71		1953TA06, 1956BO61, 1959GI47, 1969GA01
2.99 ± 5		p_2			13.75		1969GA01
3.6	290	p			14.2		1956BO61, 1959GI47

Table 14.8: Resonances in ^{10}B + α (continued)

E_α (MeV $\pm$ keV)	$\Gamma_{\mathrm{c.m.}}$ (keV)	Outgoing particle [a] (x)	Γ_x (keV)	θ_x^2	^{14}N* (MeV)	J^π [b]	Refs.
3.94	$\approx$ 140	p			14.43		1956BO61
4.53	140	n, p			14.85		1956BO61, 1959GI47
4.85	$\approx$ 35	n, p			15.08		1956BO61, 1959GI47
5.36	$\approx$ 70	n, p			15.44		1956BO61

[a] p_0, p_1, p_2, p_3 correspond to the ground state and the 3.1, 3.7, 3.9 MeV states of ^{13}C, and the corresponding γ-rays.

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

2. ^{10}B(α, n)^{13}N $Q_{\mathrm{m}} = 1.060$ $E_{\mathrm{b}} = 11.613$

Resonances are reported at $E_\alpha = 1.507 \pm 0.004$ MeV (1961BA22) and at 1.64, 2.16, 2.26, 2.95, 4.53, 4.85 and 5.36 MeV: see Table 14.8 (1953SH64, 1955SH46, 1956BO61, 1959GI47). See also (1969ED1C).

3. ^{10}B(α, p)^{13}C $Q_{\mathrm{m}} = 4.063$ $E_{\mathrm{b}} = 11.613$

Observed resonances in the yield of 3.09, 3.68, 3.85 and 0.17 [$3.85 \rightarrow 3.68$] MeV γ-rays and of various proton groups are displayed in Table 14.8 (1953SH64, 1954ST20, 1969GA01). Excitation functions have also been measured for $E_\alpha = 4.5$ to 10 MeV (1969ED1C), 12.4 to 16 MeV (1967IV1B; p_0) and 9.5 to 26 MeV (1966SP08). See also (1959AJ76).

4. ^{10}B(α, d)^{12}C $Q_{\mathrm{m}} = 1.341$ $E_{\mathrm{b}} = 11.613$

Observed resonances below $E_\alpha = 2$ MeV are exhibited in Table 14.8 (1953SH64). Excitation curves have also been determined for $E_\alpha = 3.2$ to 3.8 MeV (1960ON01), $E_\alpha = 12$ to 24 MeV (d_0) and 18 to 25 MeV (d_1) (1967AL16). Clear resonance structure is not observed at these higher energies. See also (ED69D).

5. ^{10}B(α, α)^{10}B $E_{\mathrm{b}} = 11.613$

The yield of 0.72 MeV γ-rays has been measured for $E_\alpha = 2.1$ to 3.5 MeV: observed resonances are shown in Table 14.8 (1969GA01).

6. ^{10}B(^{6}Li, d)^{14}N $Q_{\mathrm{m}} = 10.141$

At $E(^{6}\mathrm{Li}) = 5$ MeV, deuteron groups are observed to the ground state of ^{14}N and to excited states at 3.95, 4.91, 5.10, 5.69, 5.83, 6.23, 6.44, 7.03, 7.97, 8.47, 9.00, 9.13, 9.41, 9.71, 10.09, 10.43 and 11.06 MeV.

The $T = 1$ state at 10.43 MeV is populated weakly ((1966MC05) and private communication). See also (1963MO1B, 1969CO1D). Branching ratios for the γ-decay of ^{14}N states have been measured: see Table 14.9 (1966CA07). See also reaction 1 (1969TH01). See also (1964CA18, 1965CA05, 1967CA1D), (1966BR1G) and (1965RO1M, 1966RO1E, 1968TA1N).

Table 14.9: Radiative decays in ^{14}N

E_i (MeV)	$J^\pi_i; T$	E_f (MeV)	$J^\pi_f; T$	Branch (%)	Γ_γ (eV) [a]	Refs.
2.31	$0^+; 1$	0	$1^+; 0$	100	$(8.1 \pm 1.4) \times 10^{-3}$	1966CA07, 1968RO1C et al.
3.95	$1^+; 0$	0	$1^+; 0$	6 ± 3		1966CA07
				3.8 ± 0.5		1965RI02
				3.7 ± 0.3	(M1) $(5.8 \pm 1.2) \times 10^{-4}$	1967OL02, 1968RO1C
					(E2) $(4.81 \pm 0.33) \times 10^{-3}$	
				3.7 ± 0.6		1956GO42, 1957BR18
				3.6 ± 0.6		1966GO15
				4.9 ± 0.6		1969YO1B
				5.3 ± 1		1956LE28
				3.9 ± 0.2		mean
		2.31	$0^+; 1$	94 ± 3		1966CA07
				96.3 ± 0.3	0.140 ± 0.013	1967OL02, 1968RO1C
				95.1 ± 0.6		1969YO1B
				96.4 ± 0.6		1966GO15
				96.1 ± 0.3		mean
4.91	$(0, 1)^-; 0$	0	$1^+; 0$	100		1966CA07, 1969YO1B
		2.31	$0^+; 1$	0.4 ± 0.7		1965NE06; see also (1966GO15)
		3.95	$1^+; 0$	1.3 ± 1.0		1965NE06
				≤ 0.5		1966GO15
				≤ 1		1969YO1B
5.11	$2^-; 0$	0	$1^+; 0$	70 ± 5		1966CA07
				75 ± 3		1964WA09
				71 ± 5		1965WA06
				81.2 ± 1.0		1969YO1B
				79 ± 4	$(4.0 \pm 0.5) \times 10^{-5}$	1966GO15, 1968AL12
				79.9 ± 1.0		mean
		2.31	$0^+; 1$	30 ± 4		1966CA07

Table 14.9: Radiative decays in ^{14}N (continued)

E_i (MeV)	$J^\pi_i; T$	E_f (MeV)	$J^\pi_f; T$	Branch (%)	Γ_γ (eV) [a]	Refs.
				25 ± 3		1964WA09
				18.0 ± 1.0		1969YO1B
				29 ± 5		1965WA06
				21 ± 4		1966GO15
				19.7 ± 1.2		mean
		3.95	$1^+; 0$	(0.7 ± 0.4)		1966GO15
				0.8 ± 0.2		1969YO1B
5.69	$1^-; 0$	0	$1^+; 0$	37 ± 2		1963AL21
				40 ± 4		1966CA07
				40 ± 3		1964WA09
				38.4 ± 1.7		1969YO1B
				36 ± 4		1966GO15
				38.1 ± 1.1		mean
		2.31	$0^+; 1$	60 ± 5		1966CA07
				60 ± 3		1964WA09
				64 ± 4		1966GO15
				61.6 ± 1.7		1969YO1B
				63 ± 2		1963AL21
				61.9 ± 1.1		mean
		3.95	$1^+; 0$	< 2		1966GO15
				< 1		1969YO1B
		4.91	$(0, 1)^-; 0$	< 2		1966GO15
				< 1		1969YO1B
5.83	$3^-; 0$	0	$1^+; 0$	25 ± 4		1966CA07
				25 ± 5		1965WA06
				19.4 ± 1.5		1969YO1B
				29 ± 4		1966GO15

Table 14.9: Radiative decays in ^{14}N (continued)

E_i (MeV)	$J^{\pi}_{i}; T$	E_f (MeV)	$J^{\pi}_{f}; T$	Branch (%)	Γ_{γ} (eV) [a]	Refs.
					$(M2) = (3.4 \pm 1.4)\ \mu eV$ $(E3) = (5 \pm 2)\ \mu eV$	GA69J
				21.3 ± 1.3		mean
		2.31	$0^+; 1$	< 3		1966GO15
				< 1		1969YO1B
		3.95	$1^+; 0$	< 1		1966GO15, 1969YO1B
		4.91	$(0, 1)^-; 0$	< 1		1966GO15, 1969YO1B
		5.11	$2^-; 0$	75 ± 5		1966CA07
				75 ± 5		1965WA06
				80.6 ± 1.5		1969YO1B
				71 ± 4	2.7×10^{-5}	1966GO15, 1968AL12
				78.8 ± 1.3		mean
		0	$1^+; 0$	25 ± 4		1966CA07
6.20	$1^+; 0$			24 ± 3		1964WA09
				24.1 ± 1.1		1969YO1B
				21 ± 3		1966GO15
				23.8 ± 1.0		mean
		2.31	$0^+; 1$	72 ± 5		1966CA07
				76 ± 3		1964WA09
				74.6 ± 1.2		1969YO1B
				79 ± 3		1966GO15
				75.2 ± 1.0		mean
		3.95	$1^+; 0$	< 1		1966GO15, 1969YO1B
		4.91	$(0, 1)^-; 0$	1.3 ± 0.2		1969YO1B
		5.11	$2^-; 0$	< 1		1966GO15, 1969YO1B
		0	$1^+; 0$	73 ± 5		1959RO54, 1966CA07
6.44	$3^+; 0$			65 ± 3		1964WA09

Table 14.9: Radiative decays in ^{14}N (continued)

E_i (MeV)	$J^{\pi}_i; T$	E_f (MeV)	$J^{\pi}_f; T$	Branch (%)	Γ_{γ} (eV) [a]	Refs.
				75.3 ± 1.6		1969YO1B
				74 ± 4		1966GO15
				73.1 ± 1.5		mean
		3.95	$1^+; 0$	20 ± 4		1966CA07
				18.2 ± 1.1		1969YO1B
				21 ± 2		1964WA09
				19 ± 4		1966GO15
				18.9 ± 0.9		mean
		5.11	$2^-; 0$	7 ± 3		1966CA07
				14 ± 3		1964WA09
				6.5 ± 0.6		1969YO1B
				7 ± 2		1966GO15
				6.8 ± 0.6		mean
		5.83	$3^-; 0$	< 3		1964WA09
				< 2		1966GO15
				< 1		1969YO1B
7.03	$2^+; 0$	0	$1^+; 0$	100		1960RO13, 1966CA07, 1966GO15, 1969YO1B
				91 ± 4		1965WA06
				98.6 ± 0.3	(M1)$(9.1 \pm 1.3) \times 10^{-2}$	1967OL02, 1968RO1C [c]
					(E2)$(3.3 \pm 0.9) \times 10^{-2}$	
		2.31	$0^+; 1$	< 5		1965WA06
				< 3		1966GO15
				< 1		1969YO1B
				0.5 ± 0.1	(E2)$(6.2 \pm 1.4) \times 10^{-4}$	1967OL02, 1968RO1C
		3.95	$1^+; 0$	2 ± 1		1967BL22
				9 ± 5		1965WA06
				0.9 ± 0.25	$< (11 \pm 3) \times 10^{-4}$	1967OL02, 1968RO1C

Table 14.9: Radiative decays in ^{14}N (continued)

E_i (MeV)	$J^\pi_i; T$	E_f (MeV)	$J^\pi_f; T$	Branch (%)	Γ_γ (eV) [a]	Refs.
				< 1		1969YO1B
				< 2		1966GO15
		other states		≤ 0.4		1967OL02
				< 1		1969YO1B
				< 4		1966GO15
7.97	$2^-; 0$	0	$1^+; 0$	55 ± 3	$\omega\Gamma_p\Gamma_\gamma/\Gamma = 0.012$	1960HE14
		3.95	$1^+; 0$	45 ± 3	$= 0.010$	1960HE14
		other states		≤ 3		1960HE14
8.06	$1^-; 1$	0	$1^+; 0$	82	$\Gamma_\gamma = 10.5 \pm 6$	1956GR17, 1958GR97
		2.31	$0^+; 1$	≈ 2		1956LE28, 1957BR25, 1957WI27
		3.95	$1^+; 0$	11	1.2 ± 0.3	1960WA12
		5.69	$1^-; 0$	5	≈ 0.7	1956LE28, 1957WI27, 1959WA04
8.49	$4^-; 0$	5.11	$2^-; 0$	100	$(5.6 \pm 2.0) \times 10^{-3}$	1965DE19, 1966CA07, 1967GA12
8.62	$0^+; 1$	0	$1^+; 0$	23	1.20	1959WA16
		3.95	$1^+; 0$	24	1.26	1959WA16
		5.69	$1^-; 0$	13	0.69	1956LE28, 1957WI27, 1959WA16
		6.20	$1^+; 0$	40		1957WI27
8.80	$0^-; 1$	0	$1^+; 0$		43 ± 9	1960WA12
		3.95	$1^+; 0$		0.9 ± 0.3	1960WA12
8.91	$3^-; 1$	0	$1^+; 0$		$(6.6 \pm 2.2) \times 10^{-3}$	1968CL05
		5.11	$2^-; 0$	5.5 ± 2.5	$\omega\Gamma_\gamma = 0.040$	1959WA04
		5.83	$3^-; 0$	90 ± 3	$= 0.65$	1959WA04
		6.44	$3^+; 0$	3 ± 1	$= 0.022$	1959WA04
		7.03	$2^+; 0$	1.4 ± 0.8	$= 0.010$	1959WA04
8.96	$5^+; 0$	0	$1^+; 0$	< 1	$\Gamma_p/\Gamma_\gamma = 4.1 \pm 0.5$	1967BL22, 1967GA12
		6.44	$3^+; 0$	100	$\Gamma_\gamma = (1.36 \pm 0.21) \times 10^{-3}$	1965DE19, 1966CA07, 1967GA12
9.13	$2^-; 0$	0	$1^+; 0$	> 80	$\omega\Gamma_\gamma \approx 0.03$	1965DE19

Table 14.9: Radiative decays in ^{14}N (continued)

E_i (MeV)	$J^\pi_i; T$	E_f (MeV)	$J^\pi_f; T$	Branch (%)	Γ_γ (eV) [a]	Refs.
9.17	$2^+; 1$	0	$1^+; 0$	79 ± 4	7.7 ± 0.9	1959HA11, 1960RO13, 1963PR03, 1967GA12, 1968CL05
		2.31	$0^+; 1$	1.1 ± 0.4	0.11 ± 0.4	1963PR03, 1968CL05
		5.11	$2^-; 0$	< 1		1960RO13
		5.69	$1^-; 0$	< 6	0.3 ± 0.25	1960RO13, 1968CL05
		5.83	$3^-; 0$	3 ± 2	0.33	1960RO13
		6.44	$3^+; 0$	8 ± 2	0.78 ± 0.35	1960RO13, 1968CL05
				6.3 ± 0.5	0.85 ± 0.15	1963PR03
		7.03	$2^+; 0$	3 ± 1	0.3 ± 0.15	1960RO13, 1968CL05
				3.5 ± 0.5	0.34 ± 0.05	1963PR03
9.51	$2^-; 1$	3.95	$1^+; 0$	6 ± 1	0.37	1959WA04
		5.11	$2^-; 0$	78 ± 3	4.8	1959WA04
		5.83	$3^-; 0$	16 ± 2	1.0	1959WA04
10.23	$1^{(-)}; 0$	2.31	$0^+; 1$		4 ± 1.3	1963RO17
10.43	$2^+; 1$	0	$1^+; 0$	82 ± 6	12.1 ± 1.5	1964RO03, 1968CL05
		2.31	$0^+; 1$	< 1		1964RO03
		3.95	$1^+; 0$	< 2		1964RO03
		5.11	$2^-; 0$	2 ± 1	0.3 ± 0.2	1964RO03, 1968CL05
		5.69	$1^-; 0$	< 3		1964RO03
		5.83	$3^-; 0$	< 1		1964RO03
		6.44	$3^+; 0$	8 ± 1	1.2 ± 0.4	1964RO03, 1968CL05
		7.03	$2^+; 0$	6 ± 1	0.88 ± 0.31	1964RO03, 1968CL05

[a] See also Table 14.13.

[b] See also (1969HA49).

7. ^{10}B(^{7}Li, t)^{14}N $\qquad Q_m = 9.146$

Triton groups corresponding to a number of ^{14}N states have been observed at $E(^7\text{Li}) = 5$ MeV: see (1966MC05) and reaction 6. The angular distribution of the ground state tritons has been measured at $E(^7\text{Li}) = 4.5$ MeV by (1963MO1B). See also (1965CA05, 1967CA1D) and (1966RO1E).

8. (a) ^{11}B(^{3}He, γ)^{14}N $\qquad Q_m = 20.735 \qquad E_b = 20.735$
(b) ^{11}B(^{3}He, n)^{13}N $\qquad Q_m = 10.182$
(c) ^{11}B(^{3}He, p)^{13}C $\qquad Q_m = 13.185$
(d) ^{11}B(^{3}He, d)^{12}C $\qquad Q_m = 10.463$
(e) ^{11}B(^{3}He, t)^{11}C $\qquad Q_m = -1.999$
(f) ^{11}B(^{3}He, ^{3}He)^{11}B
(g) ^{11}B(^{3}He, α)^{10}B $\qquad Q_m = 9.122$
(h) ^{11}B(^{3}He, ^{6}Li)^{8}Be $\qquad Q_m = 4.566$

The capture γ-rays (reaction (a)) havre been studied for $E(^3\text{He}) = 1$ to 3 MeV. The differential cross section (at $90°$) for the γ_0 transition increases rapidly with energy from ≈ 0.002 μb/sr at 1 MeV to ≈ 0.5 μb/sr at 3.0 MeV. At the latter energy $I_\gamma/I_{\gamma_0} \approx 0.22 \pm 0.08$. There is some evidence also for transitions to higher excited states of ^{14}N (1965PU1B).

The excitation function at $0°$ in the range $E(^3\text{He}) = 1.5$ to 5.6 MeV for neutrons corresponding to ^{13}N(0) (reaction (b)) shows a broad peak at $E(^3\text{He}) = 4.15$ MeV which may indicate the existence of a ^{14}N state at $E_x \approx 24.0$ MeV, $\Gamma \approx 1$ MeV (1966DI04). The excitation function for reaction (b) has also been measured for $E(^3\text{He}) = 6$ to 18 MeV (1967HA20). See also (1964DI1C, 1965BR42).

Yield curves for protons (reaction (c)) have been measured for $E(^3\text{He}) = 3.0$ to 5.5 MeV (p_0, p_1, $p_1 + p_2 + p_3$): they are rather featureless (1959HO01). This is also true for the ground state deuterons of reaction (d) in the same energy interval (1959HO01). Yield curves for reaction (e) have been measured for $E(^3\text{He}) = 6$ to 18 MeV (1967HA20) and 10 to 30 MeV (1965BR42). See also ^{13}C, and ^{11}C and ^{12}C in (1968AJ02). For reaction (f), see (1968PA1Y).

The excitation functions of α-particle groups (α_0, α_1, α_2, α_3) (reaction (g)) have been measured for $E(^3\text{He}) = 2.2$ to 5.5 MeV. No significant resonance behavior is seen except for the α_2 group which, in the $15°$ excitation function, exhibits a resonance at $E(^3\text{He}) = 4$ MeV, $\Gamma \approx 1$ MeV (1965FO06). See also ^{10}B in (1966LA04). The excitation function for the reaction ^{11}B(^{3}He, ^{6}Li$_{\text{g.s.}}$)^{8}Be$_{\text{g.s.}}$ has been measured for $E(^3\text{He}) = 1.4$ to 5.8 MeV: no pronounced compound nucleus effects are observed (1967YO02, 1967YO1C).

9. ^{11}B(α, n)^{14}N $\qquad Q_m = 0.157$

Table 14.10: Resonances in ^{12}C + d

E_d (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Particles out	^{14}N* [a] (MeV)	$J^\pi; T$	Refs. [b]
0.335		p	10.559		1956KO26, 1956VA17
0.92	95	n, p_0, p_1	11.06	$1^+; 0$	1957SA01, 1960KA06, 1969BO32
1.13		p_0, p_1	11.24	; 1	1957SA01, 1963JE02, 1969BO32
1.19	190	n, p_0, p_1, d	11.29	$2^-; 0$	1957SA01, 1960KA06, 1963JE02, 1966LA1Q, 1969BO32
1.23		p_0	11.33	(3^+)	1969BO32
1.30	30	n, p_0, p_1, d	11.38	$1^+; 0$	1957SA01, 1960KA06, 1963JE02, 1965FI05, 1966LA1Q, 1969BO32, 1969JA06
1.39		p_0	11.46	(2^-)	1969BO32
1.446	5	p_0, p_1, d	11.51	3^+	1957SA01, 1960KA06, 1963JE02, 1965FI05, 1966LA1Q, 1969BO32
1.55		p_0	11.60	(2^-)	1969BO32
1.62		n, p	11.65	(2^-)	1969BO32, 1969JA06
1.68		p_0, p_1	11.71	$(1^+, 2^-)$	1963JE02, 1965FI05, 1966KL05, 1968BE2A
1.78	85	n, p_0, p_1	11.80	1^+	1960KA06, 1963JE02, 1965FI05, 1969BO32, 1969JA06
1.95		p_0	11.94	(1^-)	1969BO32
2.30		n, p_1, p_2, p_3	12.24		1965FI05, 1969JA06
2.498 ± 6	40 ± 3	n, p_0, p_1, p_2, p_3, d	12.411	4^-	1956MC88, 1958MC63, 1960CH12, 1963JE02, 1965FI05, 1969JA06
2.622 ± 8	19 ± 9	n, p_1, p_2, p_3	12.517		1956MC88, 1958MC63, 1960CH12, 1965FI05, 1969JA06
2.726 ± 10	47 ± 3	(n), p_1, p_2, p_3, d	12.606	3^+	1956MC88, 1958MC63, 1960CH12, 1963JE02, 1965FI05, 1969JA06
2.817 ± 7	27 ± 6	n, p_1, p_2, p_3, d	12.684		1956MC88, 1960CH12, 1963JE02, 1965FI05, 1966GU04, 1969JA06
2.946 ± 6	22 ± 6	p_2, p_3, d	12.794		1956MC88, 1960CH12, 1963JE02
2.982 ± 6	11 ± 3	n, p_3, d	12.825		1956MC88, 1960CH12, 1969JA06
3.015 ± 15	71 ± 7	n, p_0	12.853		1966GU04, 1966SA05
3.119 ± 6	29 ± 9	p_1, p_2, p_3, d	12.942	$(3^-, 4^-)$	1956MC88, 1960CH12, 1963OH02, 1965FI05
3.39 ± 12	47 ± 15	n, p_2, p_3, d	13.17	$(0^-, 1^-)$	1955MA76, 1956MC88, 1963JE02, 1963OH02, 1966SA05,

Table 14.10: Resonances in ^{12}C + d (continued)

E_d (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Particles out	^{14}N* [a] (MeV)	$J^\pi; T$	Refs. [b]
					1969JA06
3.97 ± 30	< 200	p_0, p_2, p_3, (d)	13.67	$(2^+, 3^+)$	1963JE02, 1965FI05, 1966BR2B, 1967FU03
4.02^{+20}_{-10}	≈ 235	n, (p), d	13.71	(1^+)	1963OH02, 1966BR2B, 1966HO11, 1966SA05, 1967FU03, 1969JA06
4.40		p_0, p_1, p_2, p_3, d	14.04		1963JE02, 1966BR2B
4.55		n, p_2, d	14.17		1966BR2B, 1966HO11
4.80		p_0, p_2, d	14.38		1963OH02, 1966BR2B
5.17		d	14.70		1966BR2B
5.34	≈ 100	p_0, p_1, p_2, p_3, d, α	14.84		1956BO08, 1963OH02, 1966BR2B, 1966PA1J, 1969CO02
5.65		d	15.11		1956BO08, 1963OH02, 1966BR2B
5.83		p_1, p_3, d	15.26		1966BR2B
6.07		p_1, p_2, α	15.47		1966BR2B, 1966PA1J, 1969CO02
6.3		p_0, p_3, d, α	15.7		1966BR2B
7.2		α	16.4		1966PA1J, 1969CO02
8.1		p_0, p_2, d, α	17.2		1963OH02, 1966PA1J, 1969CO02
10.9		p_0, d	19.6	(5^+)	1963OH02, 1968KL06
11.8		n, p_0, d	20.4	(5^+)	1965BA06, 1968KL06
12.70 ± 150	≈ 1400	d, α_2	21.15	(4^-)	1968JA09, 1968KL06
14.52 ± 100	≈ 900	α_2	22.70		1968JA09

[a] (1963JE02) report 39 excited states of ^{14}N with $11.2 < E_x < 14.2$ MeV.

[b] See also (1959AJ76) and (1959EL44, 1961CI08, 1961GR06, 1961JA08, 1961ST10, 1966KA05, 1966KL05, 1966LA1P, 1966LA1Q, 1968BE2A, 1969PA1K).

Table 14.11: Recent $^{12}C + d$ yield curves [a]

E_d (MeV)	Yield of	Refs.
0.7 – 1.4	n_0	(1961JA08)
1.2 – 4.5	σ_t	(1969JA06)
1.4 – 3.1	n_0	(1959EL44)
2.7 – 3.2	n_0	(1966GU04)
2.8 – 4.2	n_0	(1966SA05)
3.8 – 4.2	n_1	(1966SA05)
3.8 – 4.2	n_0	(1967FU03)
3.8 – 5.0	n_0, n_1	(1966HO11)
9.2 – 13.8	σ_t	(1965BA06)
0.7 – 2.0	p_0, p_1	(1960KA06)
0.8 – 1.1	p_0	(1961GR06)
0.8 – 1.2	p_0	(1962WE12)
0.9 – 1.8	p_0	(1966KL05)
0.9 – 2.0	p_0	(1969BO32)
0.9 – 5.0	p_0, p_1, p_2, p_3	(1963FR1D, 1963JE02)
1 – 2	p_0, p_1	(1966LA1P)
1.1 – 1.2	p_0	(1961ST10)
1.2 – 4.3	p_1, p_2, p_3	(1960GO19, 1965FI05)
1.2 – 4.4	p	(1965BA1W)
1.5 – 4.0	p_0, p_1, p_2, p_3	(1967LE1K)
1.7 – 3.1	p_3	(1960CH12)
2 – 3.3	p_1, p_2, p_3	(1966KA05)
2.6 – 4.0	p_0, p_1, p_2, p_3	(1966GE03)
2.7 – 3.2	p_0	(1966GU04)
4 – 7	p_0, p_1, p_2, p_3	(1966BR2B)
5 – 10	p_0, p_1, p_2, p_3, p_4	(1969CO02)
8.5 – 10	p_5, p_6, p_7	(1969CO02)
5.5 – 12	p_0, p_1	(1963EV04)
9 – 14	p_0	(1968KL06)

Table 14.11: Recent ^{12}C + d yield curves [a] (continued)

E_d (MeV) (MeV)	Yield of	Refs.
9.9	σ_t	(1962WI15, 1963WI1D)
$0.9-2.0$	d_0	(1969BO32)
$0.9-5$	d_0	(1963FR1D, 1963JE02)
$1-2$	d_0	(1966LA1P)
$1.5-2.0$	d_0	(1960KA06)
$2.0-3.3$	d_0	(1966KA05)
$2-6$	d_0	(1967PL1B)
$2.6-4.0$	d_0	(1966GE03)
$3-12$	d_0	(1963OH02)
$4-7$	d_0	(1966BR2B)
$4.5-5.7$	d_0	(1968CO04)
$5-10$	d_0	(1969CO02)
$8.5-10$	d_1	(1969CO02)
$9-14$	d_0	(1968KL06)
26.5	σ_t	(1965MA57)
$5-9$	α	(1966PA1J)
$5-10$	α_0, α_1	(1969CO02)
$7-10$	α_3	(1969CO02)
$9-10$	α_4	(1969CO02)
$9-12.5$	$\alpha_0, \alpha_1, \alpha_2, \alpha_3$	(1966ME09)
$9.2-13.8$	$\alpha_0, \alpha_1, \alpha_3, \alpha_4$	(1965BA06, 1966BA32)
$11-14$	α_2	(1969SM03)
$13-21$	α_2	(1968JA09)
$15-20$	$\alpha_0, \alpha_1, \alpha_2, \alpha_3, \alpha_4$	(1963YA1B)
$21-29$	$\alpha_0, \alpha_1, \alpha_3, \alpha_4, \alpha_5$	(1969YA1C)

[a] See also (1959AJ76).

Angular distributions have been measured for $E_\alpha = 2.4$ to 3.7 MeV (1966MA04; n_0), 3.4 to 3.7 MeV (1966MA04; n_1), 2.1 to 5.4 MeV (1962CA05; n_0) and 13.5 and 13.9 MeV (1962KJ03; n_0, n_2). See also (1959HE1B) and (1959AJ76).

10. ^{11}B(^{6}Li, t)^{14}N $\qquad Q_{\rm m} = 4.942$

At $E(^6{\rm Li}) = 4.5$ MeV, the angular distributions of the triton groups to ^{14}N*(0, 2.31, 3.95) have been measured (1963MO1B). See also (1965CA05).

11. ^{12}C(d, γ)^{14}N $\qquad Q_{\rm m} = 10.272$

The capture cross section is reported to be $\approx 0.6 \pm 0.2$ μb at $E_{\rm d} = 1$ MeV (1961KN03): at $E_{\rm d} = 1.5$ MeV it is < 1 μb (1955AL16).

12. (a) ^{12}C(d, n)^{13}N $\qquad Q_{\rm m} = -0.281 \qquad E_{\rm b} = 10.272$

(b) ^{12}C(d, p)^{13}C $\qquad Q_{\rm m} = 2.722$

Resonances in the yields of neutrons and protons are displayed in Table 14.10. Recent measurements of the yields of neutrons and protons are listed in Table 14.11. See also (1965WI11, 1968CO04, 1969RO1R) and (1959AJ76).

Angular distributions of neutrons and protons have been reported at many of the energies listed in Table 14.11. Except at very low energies, direct interaction is the predominant mechanism although resonances are observed for the first few MeV (see Table 14.10) and fluctuations persist to 12 MeV (1963EV04). See also (1955WI43), (1959AJ76), ^{13}C and ^{13}N. At $E_{\rm d} = 2.50$ MeV (^{14}N* $= 12.41$) the (d, p$_3\gamma$) angular correlation is undistorted. This is an example of a resonant direct reaction due to a single-particle state (1966KA05).

Polarization measurements are summarized in Table 14.12. See also (1968BA2R, 1968BA47; theor.) (reaction (a)), and (1959AL08, 1962GR10, 1963BE1M, 1966SK1A, 1967GR1L; exp.), (1967CI1A, 1967KH1A, 1968BA2R, 1968BA47, 1969PE1N, 1969PE1L; theor.) (reaction (b)). See also the reviews by (1961GO1K, 1963HA1G, 1966DA1B, 1966MI1E).

For reaction (a) see also (1959BR75, 1966WY01, 1967SC43, 1967WY02; exp.) and (1961MA1E, 1964CA1F, 1967HO1K, 1968NO1C; theor.). For reaction (b) see also (1963GE03, 1967AU05, 1967MO1P, 1967TI1A, 1968NO1C, 1969PE09). For a discussion of sequential decay, see (1963PI04) and ^{13}C and ^{13}N.

13. ^{12}C(d, d)^{12}C $\qquad E_{\rm b} = 10.272$

Reported resonances are displayed in Table 14.10. Recent measurements of yields of scattered deuterons are listed in Table 14.11. See also (1961CI08, 1962GR10, 1963GE03, 1965BA1W, 1967AU05, 1968BA2P, 1968GO1N), and (1965SA1H, 1966BA60, 1967HO1K, 1969IW1D). See also ^{12}C in (1968AJ02) and (1959AJ76).

Polarization measurements are summarized in Table 14.12. See also (1963ZA1B, 1965CA05, 1967RU1A; theor.).

Table 14.12: ^{12}C + d polarization studies

E_d (MeV)	Groups	Refs.
1.5 – 1.8	n_0	(1968KA1K)
1.7 – 2.8	n_0	(1966ME16)
2.8	n_0	(1965GA1G)
2.8, 3.0	n_0	(1963HA1G)
2.8 – 4.0	n_0	(1966SA05)
3.8 – 4.2	n_0	(1968DO09)
4 – 7.5	n	(1965KE10)
4.2 – 5.0	n_0	(1966MO14)
5.2 – 6.2	n_0, n_1	(1968DO09)
6 – 6.5	n_0, n_1	(1963BA38, 1963BA66, 1966BA33)
11.8	n_0	(1961LE1E)
12.9	n_3	(1959BU1E, 1960BU15)
51.5	n_0	(1969BR1E)
0.8 – 1.1	p_0	(1961GR06)
0.9, 1.0	p_0	(1968GL1B)
1.1	p_0	(1959CI38, 1959JU1A, 1964AS03)
2.4	p_0	(1963MI1G)
2.8, 3.0, 3.2	p_1	(1966HE1G)
2.9, 3.1, 3.3	p_0	(1969SO07)
4.0	p_0	(1966ST1N)
5.5 – 9.5	p_0	(1963EV04)
7 – 11	p_1	(1963EV04)
7, 10	p_0, p_1	(1968YU01)
8.9	p_0	(1959HI1E)
10	p_0	(1959AL09, 1962AL03)
10.8	p_0, p_1	(1961JO14)
11.9	p_0, p_1	(1968BA19)
13.6	p_0	(1966JI1A)
13.8	p_0	(1966MA25)
15	p_1	(1962IS04, 1964RE04)
21	p_0	(1963BO1J)

Table 14.12: ^{12}C + d polarization studies (continued)

$E_{\rm d}$ (MeV)	Groups	Refs.
$2.8 - 4.4$	d_0	(1969PA1K)
$3.5 - 7.1$	d_0	(1968CO10)
6	d_0	(1960AL09)
$6 - 10.5$	d_0	(1967CL07)
6.5	d_0	(1963NE1H)
12	d_0	(1968BA17)
13.6	d_0	(1968ZA02)
13.8	d_0	(1966MA2H)
22	d_0	(1965AR1F, 1965GR1Q)
51	d_0	(1968SE1E)

14. ^{12}C(d, t)^{11}C $\quad Q_{\rm m} = -12.462 \quad E_{\rm b} = 10.272$

The cross section rises from ≈ 0.1 mb at $E_{\rm d} = 16$ MeV to ≈ 10 mb at 20 MeV (1955WI43). See also ^{11}C in (1968AJ02).

15. ^{12}C(d, α)^{10}B $\quad Q_{\rm m} = -1.341 \quad E_{\rm b} = 10.272$

Excitation functions have been measured for $E_{\rm d} = 5$ to 29 MeV: see Table 14.11.

Resonant structure has been reported by (1966PA1J) and (1968JA09): see Table 14.10. Angular distributions have been measured at many of the above energies and analyzed by DWBA: see (1968KL06, 1969YA1C) and ^{10}B in (1966LA04). See also (1963PE07, 1967HO1K).

The yield of the α_2 group (to ^{10}B*(1.74) [$J^\pi = 0^+; T = 1$] is typically < 1% of the intensity of the groups to the neighboring $T = 0$ states in the range $E_{\rm d} = 9$ to 12.5 MeV. This is partly due to isospin conservation and partly to the J^π selection rule involved in this transition. When the latter effect is calculated and the corresponding factor removed, the intensities of the $T = 1$ α_2-groups range from ≈ 10% of the intensities of the $T = 0$ α-groups at $E_{\rm d} = 9$ MeV to $\approx 1 - 2$% at $E_{\rm d} = 11$ MeV. Above $E_{\rm d} = 11.5$ MeV, the yield of the α_2 group increases slightly indicating perhaps a direct-interaction mechanism involving isospin mixing at the surface of the nucleus (1966ME09). [See, however, below). The mixing might also occur through Coulomb excitation during the d-capture or the α-emission (1966ME09). Some fluctuations in the cross sections, with widths of a few hundred keV, are observed at forward and backward angles. Ericson fluctuations may be involved (1966ME09). The data of (1966ME09) have been interpreted as indicating an intermediate structure resonance corresponding to $E_x \approx 18$ MeV, $\Gamma \approx 2$ MeV [$J^\pi = 3^-$], whose doorway state is a single-particle cluster resonance in either, or both, the entrance or exit channels (1968NO1C). However, (1969SM03) find that the broad structure reported by (1966ME09) at $E_d \approx 13$ MeV can be resolved into at least three separate peaks, in contradiction to the predictions of (1968NO1C). Both the angular distributions and the excitation functions can be interpreted in terms of a few resonant states of ^{14}N [$l = 4$ and 5 account for most of the cross section at $E_d \approx 12.5$ MeV], without introducing any large direct reaction amplitudes (1969SM03). See also (1969NO1C).

16. ^{12}C(t, n)^{14}N $\quad Q_m = 4.015$

Angular distributions of the n_0, n_1 and n_2 groups have been measured at $E_t = 1.7$ MeV (1966MA2G). At $E(^{12}\text{C}) = 12$ to 20 MeV, the lifetimes of ^{14}N*(5.11, 5.83) have been determined using recoil distance method: $\tau_m(5.11) = 12.4 \pm 1.4$ psec, $\tau_m(5.83) = 18 \pm 2$ psec: see Tables 14.9 and 14.13. The $5.11 \rightarrow 0$ transition is enhanced by 2.2 ± 0.7 W.u. The allowed M2 $5.11 \rightarrow 2.31$ transition has $|M|^2 = 0.83 \pm 0.14$ W.u. while the isospin forbidden part of the $5.11 \rightarrow 0$ transition has $|M|^2 = (3.3 \pm 1.3) \times 10^{-3}$ W.u. (1968AL12). See also (1966AL11).

17. ^{12}C(^{3}He, p)^{14}N $\quad Q_m = 4.779$

$Q_0 = 4.7763 \pm 0.0015$ (1967OD01);
$Q_0 = 4.806 \pm 9$ (1964MA57);
$Q_0 = 4.787 \pm 10$ (1962SH21);
$Q_0 = 4.764 \pm 7$ (1959YO25);
$Q_{2.31} = 2.4684 \pm 0.0010$ (1962BA26).

Many proton groups have been observed: see Table 14.14. At $E(^3\text{He}) = 20$ MeV angular distributions of the protons corresponding to states with $0 < E_x < 12.6$ MeV have been measured by (1968MA29) and analyzed using the distorted-wave calculations of (1965GL09) and spin-independent interaction potential. L-values have been assigned and are displayed in Table 14.14. It is pointed out that in this reaction unnatural parity states of $T = 1$ are not allowed: the proton groups corresponding to the 0^- 8.80-MeV state and the 2^- 9.51-MeV state, both of which are $T = 1$, are not observed (1967MA1G, 1968MA29). Angular distributions have also been obtained at many other energies: see (1965GR1R: $1 - 1.8$ MeV; p_0, p_1, p_2), (1963LU01, 1963LU1F, 1964LU1B: $2.3 - 3$ MeV; p_2), (1964KU05: $2.5 - 4.9$ MeV; $p_0 \rightarrow p_9$), (1969HA49: $3.0 - 9.2$ MeV; p_0, p_1: $3.0 - 11$ MeV; $p_2 \rightarrow p_4$: $5.1 - 11$ MeV; $p_5 \rightarrow p_9$), (1967CL1C: 3.5 MeV; $p_0 \rightarrow p_8$), (1966BL01: 5.1 MeV; $p_2 \rightarrow p_6$), (1968LA19: $5.3 - 5.5$ MeV; p_1, p_2, p_3, p_5), (1965FU16: $6.6 - 10.7$ MeV), (1960PR12: 13.9 MeV; p_0, p_1, p_2), (1969HO23: 15 MeV: $0 < E_x < 12.8$ MeV), (HO66,

Table 14.13: Lifetimes of some ^{14}N states [a]

E_x (MeV)	τ_m (psec)	Reaction	Refs.
2.31	0.083 ± 0.019	^{12}C(^{3}He, p)	(1966LI07)
	0.083 ± 0.03	^{12}C(^{3}He, p)	(1965LO07)
	0.097 ± 0.03	^{14}N(γ, γ)	(1964BO22)
	0.077 ± 0.018	^{14}N(γ, γ)	(1961SW01)
	0.033 ± 0.003	^{14}O(β^+)	(1966SI05)
	0.083 ± 0.011		mean [b]
3.95	≤ 0.087	^{12}C(^{3}He, p)	(1966LI07)
	0.0045 ± 0.0004	^{14}N(e, e)	(1964BI09, 1967OL02)
	≤ 0.025	^{12}C(^{3}He, p)	(1965LO07)
	≤ 0.02	^{14}N(n, n)	(1969NY1A)
4.91	< 0.050	^{12}C(^{3}He, p)	(1967LI04)
	< 0.050	^{13}C(d, n)	(1963AL21)
	< 0.06	^{12}C(^{3}He, p)	(1970GA09)
5.11	12.4 ± 1.4	^{12}C(t, n)	(1968AL12)
	$4.5 < \tau < 20$	^{12}C(^{3}He, p)	(1967LI04)
	> 0.6	^{12}C(^{3}He, p)	(1965LO07)
	> 0.3	^{13}C(p, γ)	(1959WA04)
5.69	≤ 0.036	^{12}C(^{3}He, p)	(1967LI04)
	≤ 0.05	^{12}C(^{3}He, p)	(1970GA09)
5.83	18 ± 2	^{12}C(t, n)	(1968AL12)
	> 4.5	^{12}C(^{3}He, p)	(1967LI04)
	> 23	^{12}C(^{3}He, p)	(1964BE12)
6.20	< 0.04	^{12}C(^{3}He, p)	(1970GA09)
6.44 [c]	0.63 ± 0.08	reactions 1, 6, 19	(1969TH01)
	0.59 ± 0.12	^{12}C(^{3}He, p)	(1964BE12)
	0.65 ± 0.05	^{12}C(^{3}He, p)	(1969GA16)
	0.63 ± 0.04	^{12}C(^{3}He, p)	(1970GA09)
	0.63 ± 0.03		mean
7.03 [c]	5.4 ± 0.5 fsec	^{14}N(γ, γ)	(1966SW01)
	< 0.05 psec	^{12}C(^{3}He, p)	(1970GA09)

[a] See also Table 14.9.
[b] Not included the value of (1966SI05).
[c] See also (1969NY1A).

1967FO1E: 15 MeV), (1968MA46: 25.3 MeV: $0 < E_x < 9.5$ MeV) and (1959AJ76) for a listing of the earlier work. See also ^{15}O. The parity of ^{14}N*(6.44) is even from angular distribution measurements of protons and γ-rays at the $E(^3\text{He}) = 2.99$ MeV resonance (1964KU05).

The γ decay of many states has been studied: Table 14.9 displays observed branching ratios and radiative widths (1964WA09, 1965NE06, 1965RI02, 1965WA06, 1966GO15, 1967CH19, 1967GA12, 1967OL02, GA69J, 1969HA49). A very accurate value of the excitation energy of ^{14}N*(5.11) is derived from E_γ: $E_x = 5.10587 \pm 0.00018$ MeV (1967CH19). p-γ angular correlations have been measured at many energies. The results demand $J = 0$ or 1 for ^{14}N*(4.91) and $J = 2$ for ^{14}N*(5.11). The ground state transition for the latter contains E1, M2 and E3 components (1959WA04, 1965BL04, 1965NE06, 1966GO15), $J = 2$ for ^{14}N*(7.03) and the angular correlation of the 2.51 MeV γ-ray ($8.96 \rightarrow 6.44$) indicates $J \leq 5$ for ^{14}N*(8.96) (1967BL22). $J^\pi = 5^+$ (1967GA12). See also (1963LU01, 1963LU1F, 1964LU1B) and Table 14.9. Polarization measurements lead to $J^\pi = 0^-$, 1^- for ^{14}N*(4.91) and odd parity for ^{14}N*(5.11, 5.83) (1963BE33, 1968BL09). The parity of ^{14}N*(6.21) is even (1964WA09). An analysis of elastic ^{3}He, the angular distribution of the protons to ^{14}N*(6.44) and of the subsequent ground state γ-rays at $E(^3\text{He}) = 2.99$ MeV (^{15}O*(14.46)) leads to even parity for ^{14}N*(6.44) (1964KU05). The angular correlation of internal pairs is consistent with E2 radiation (1964WA09) for the $6.44 \rightarrow 0$ transition.

Measurements of mean lifetimes are displayed in Table 14.13 (1964BE12, 1965LO07, 1966LI07, 1967LI04, 1969GA16, 1970GA09). See also (1963BE33).

See also (1959AL96, 1959FA1A, 1959HI69, 1960HA31, 1961CE02, 1967BE2G, 1967FO1E, 1967OG1A, 1969BA1Z, 1969GO11, 1969HA2D) and (1959EL43, 1960EL1C, 1960NE1A, 1962EL1C, 1967HA1T, 1969BO1G, 1969LI1D; theor.).

18. ^{12}C(α, d)^{14}N $\qquad Q_m = -13.575$

Angular distributions of deuterons corresponding to various states of ^{14}N (see Table 14.15) have been measured at $E_\alpha = 42$ to 53 MeV (1959BO40, 1960HA32, 1962CE01, 1962HA40, 1965PE03, 1967ZA01). See (1962CE01, 1963GL1C, 1965GL09) for discussions of the analysis. The known $T = 1$ states are not excited in this reaction: see Table 14.15 and (1960HA32, 1965PE03, 1967ZA01, 1968NO1C). [It should be noted that in addition to isospin conservation, angular momentum and parity considerations would also inhibit the excitation of the $J^\pi = 0^+$; $T = 1$ 2.31-MeV state; see, e.g., (1960HA32).] No evidence is seen at $E_\alpha = 42$ MeV for deuterons in the $J^\pi = 0^+$; $T = 1$ singlet state leading to the excitation of the 2.31-MeV state: $\overline{d}_1/d_0 = 5 \times 10^{-3}$ (1967CR1G, 1969BR1N). The deuteron spectrum is dominated by very strong groups corresponding to the $(d_{5/2})^2$, $J^\pi = 5^+$, state at 8.96 MeV, and to a state at 15.1 MeV (1962HA40, 1966RI04).

Comparison of the angular distribution of ground state deuterons ($E_\alpha = 41.7$ MeV) with that of the ground state alphas from the ^{14}N(d, α)^{12}C reaction ($E_d = 20$ MeV) leads to an upper limit of 3% for the time reversal non-conserving fraction of the Hamiltonian (1959BO40, 1959HE1C).

See also (1964NA1E, 1965PE17, 1966BR1G, 1967OG1A) and (1961EL1A, 1968ZE1B; theor.).

Table 14.14: Excited states of ^{14}N from $^{12}C(^{3}He, p)^{14}N$

E_x (MeV ± keV)					
(1960HI07)	(1968GR1G)	(1959YO25)	(1961ER01) [a]	(1969HO23)	L [b]
0	0	0		0	2
2.314 ± 10		2.313 ± 17		2.319 ± 15	0
3.946 ± 10	3.948 ± 5	3.946 ± 17		3.952 ± 15	0
4.909 ± 10	4.913 ± 5	4.888 ± 18		4.927 ± 15	1
5.102 ± 10	5.107 ± 5	5.078 ± 18		5.117 ± 15	1
5.686 ± 10	5.693 ± 5		5.692 ± 8	5.713 ± 15	1
5.830 ± 10	5.834 ± 5	5.812 ± 18	5.835 ± 8	5.885 ± 15	3
	6.202 ± 5 [f]	6.21 ± 20 [b]	6.204 ± 8	6.224 ± 15	0
	6.450 ± 5	6.46 ± 18 [b]	6.441 ± 8	6.468 ± 15	2
E_x (MeV ± keV)			E_x (MeV ± keV)		
(1968MA29)	(1969HO23)	L	(1968MA29)	(1969HO23)	
7.01 ± 42	7.036 ± 15	2	11.27 ± 50	11.249 ± 15	
7.95 ± 26	7.974 ± 15	3	11.39 ± 40	11.357 ± 15	
8.05 ± 35	8.072 ± 15	1	11.51 ± 30	11.517 ± 15	
8.47 ± 30 [c]	8.493 ± 15	3	11.66 ± 40		
8.61 ± 34	8.625 ± 15	0	11.79 ± 110		
	8.912 ± 15		11.95 ± 30		
8.96 ± 19	8.97 ± 15	3, 4, 2		12.29 ± 15	
9.15 ± 18	9.126 ± 15		12.40 ± 30	12.425 ± 15	
	9.176 ± 15		12.50 ± 20	12.506 ± 15	
9.39 ± 26 [d]	9.389 ± 15		12.63 ± 25	12.608 ± 15	
9.70 ± 22	9.703 ± 15			12.69 ± 15	
10.08 ± 18	10.063 ± 15		12.74 ± 30	12.80 ± 15	
	10.101 ± 15		12.90 ± 25		
10.43 ± 20	10.441 ± 15		13.15 ± 40		
10.56 ± 28			14.91 ± 60		
10.81 ± 23 [e]	10.812 ± 15		15.8 ± 200		
11.06 ± 50	11.053 ± 15		17.4 ± 200		

[a] Based on Q_m.
[b] From (1968MA29).
[c] 4^-; 0 (1968MA29).
[d] 2^-; 0 (1968MA29).
[e] 4^+; 0 (1968MA29).
[f] Private communication.

19. $^{12}C(^{6}Li, \alpha)^{14}N$ $\qquad Q_m = 8.800$

At $E(^{6}Li) = 20$ MeV, α-groups corresponding to most of the $T = 0$ states with $E_x < 12.7$ MeV are reported. See Table 14.15. The spectrum is dominated by the α-group corresponding to the 5^+ state at 9.0 MeV (1968ME10). See also (1962HO06, 1967DZ01). The α_1 group to the $J^\pi = 0^+$; $T = 1$ state at 2.31 MeV has been observed. Its intensity ($<$ 3% of α_0) decreases sharply from $E(^{6}Li) = 4$ to 5.5 MeV, while the intensities of the α_0 and α_2 groups (to $T = 0$ states) increase rapidly. It is suggested that broad levels at the higher excitation energies corrrespond to such short lifetimes that the Coulomb forces do not have enough time to change the relative amountss of various isospin components in the compound nucleus wave function (1965CA06). See also (1962HO06, 1967DZ01).

Angular distributions of α-particles have been reported for $E(^{6}Li) = 2.0$ and 2.4 MeV (1966BE07; α_0, α_2), 3.0 MeV (1963BA08; α_0), 3.2 to 4.0 MeV (1962HO06; α_0, α_1, α_2), 4.0 to 5.5 MeV (1965CA06; α_1), 4.5 to 5.5 MeV (1966HE05; α_0, α_2) and 20 MeV (1968ME10: see Table 14.15).

Doppler-shift attenuation measurements have led to the determination of τ_m for the 6.44 MeV state: (0.63 ± 0.08) psec (1969TH01): see Table 14.13 and reaction 1. See also Table 14.9.

See also (1960SH01, 1960SH05, 1961MA1K, 1961MA33, 1962LI08, 1963OL1B, 1964CA18, 1967CH34, 1967OG1A, 1968DA20) and (1962IN1C, 1963TA1B, 1966RO1E, 1966RO1F, 1968HO1J, 1968RO1D; theor.).

20. (a) $^{12}C(^{9}Be, ^{7}Li)^{14}N$ $\qquad Q_m = -6.421$
(b) $^{12}C(^{11}B, ^{9}Be)^{14}N$ $\qquad Q_m = -5.547$

At $E(^{11}B) = 115$ MeV, the ^{9}Be spectrum is dominated by groups corresponding to the ^{14}N 5^+ state at $E_x = 8.96$ MeV, the 4^+ state at $E_x = 12.79$ MeV and to the 6^- state at $E_x = 15.10$ MeV, the levels also strongly populated in the $^{12}C(\alpha, d)^{14}N$ reaction (see reaction 18) (1966PO1E, 1967PO1E) and private communication). Groups to ^{14}N*(0, 3.95, 5.83, 6.44, 10.81) are also reported (J.E. Poth, private communication). See also (1967VO1A). The angular distributions of the two strong groups are smoothly varying, exponential functions of angle, and have been fitted, in terms of a surface-diffuseness parameter, using a diffraction model (1965SA07). See also (1965DA1E, 1965GR1F) and (1964FL1D, 1964NA1E, 1967OG1A, 1968RO1D, 1969RO1G, 1969BR1D). For reaction (a), see (1969RO1G).

21. $^{12}C(^{12}C, ^{10}B)^{14}N$ $\qquad Q_m = -14.916$

See (1962CH01).

Table 14.15: Energy levels of ^{14}N from ^{12}C(α, d)^{14}N and ^{12}C(^{6}Li, α)^{14}N

E_x [a] (MeV)	σ [a] (mb)	$\sigma/\sigma_{g.s.}$ [b]	Angular distribution [c]
0	5.8	1.00	d, α
2.31 [d]	[d]		α
3.94	4.8	0.31	d, α
4.91	4	0.16	α
5.10	5	1.32	d, α
5.69	4	0.11	α
5.83	6	0.97	d, α
6.21	7.0	0.24	α
6.44	13.0	1.15	d
7.03	4.0	0.18	d, α
7.97	5.0	0.16	d, α
8.47	8.3	0.53	d, α
9.00 ± 0.05 [e]	28.0	3.67	d, α
9.17	medium	(0.30)	
9.41	8.1	0.30	d, α
9.71	6.9	0.18	α
10.09	13.8	0.5	α
10.76 ± 0.02 [f]	medium	0.62	
11.06	weak	very weak [h]	
11.23	medium		
11.29	medium		
11.39	medium	very weak, broad	
11.51	weak		
11.97	weak		
12.21	weak	weak	
12.41	medium		
12.61	strong		
12.69	strong	strong, broad ($E_x = 12.76$)	
13.05 ± 0.02 [g]		very weak	
14.7 [h]		weak, broad	

Table 14.15: Energy levels of ^{14}N from ^{12}C(α, d)^{14}N and ^{12}C(^{6}Li, α)^{14}N (continued)

E_x [a] (MeV)	σ [a] (mb)	$\sigma/\sigma_{g.s.}$ [b]	Angular distribution [c]
15.1 ± 0.1 [e]		strong, sharp	
15.5		weak	
16.0		weak	
16.3		medium	
17.1		medium	
17.7		medium	

[a] From ^{12}C(^{6}Li, α). $E(^{6}\text{Li}) = 20$ MeV (1968ME10).
[b] Cross section (relative to ground state) integrated for $0° - 90°$ (c.m.), from ^{12}C(α, d)^{14}N, $E_\alpha = 42$ MeV (1967ZA01). The $T = 1$ states at $E_x = 2.31, 8.06, 8.63, 9.51, 10.41$ MeV were not observed: $\sigma/\sigma_{g.s.} < 0.0027, 0.027, 0.018, 0.30, 0.03$, respectively. For absolute cross sections at $E_\alpha = 53$ MeV, see (1965PE03).
[c] d and α refer to angular distributions of the corresponding group from the ^{12}C(α, d)^{14}N and the ^{12}C(^{6}Li, α)^{14}N reactions: see text for E_α, $E(^{6}\text{Li})$ and references.
[d] See text.
[e] (1966RI04).
[f] $E_x = 10.85 \pm 0.02$ MeV (1967ZA01).
[g] From ^{12}C(α, d)^{14}N (1967ZA01): $\Gamma < 70$ keV.
[h] Comments here and below are from (1965PE03).

22. ^{12}C(^{14}N, ^{12}C)^{14}N

At $E(^{14}\text{N}) = 28$ MeV, excitation of ^{14}N*(0, 3.95, 4.91, 5.11) and some higher states is reported. The total cross section for excitation of the $T = 1$ state at $E_x = 2.31$ MeV is < 60 μb (1961HA04). See also (1968HU1H, 1969BR1D, 1969HE06).

23. ^{12}C(^{18}F, ^{16}O)^{14}N $\qquad Q_m = 2.745$

See (1968RO1D).

24. ^{13}C(p, γ)^{14}N $\qquad Q_m = 7.550$

Table 14.16: Levels of ^{14}N from ^{13}C(p, γ)^{14}N and ^{13}C(p, p)^{13}C [a]

E_p (MeV $\pm$ keV)	Γ_{lab} (keV)	l_p	$\omega\Gamma_\gamma$ (eV)	$J^\pi; T$	^{14}N*	Refs.
0.4485 ± 0.5	< 0.4	2	0.022	2^-	7.966	1960HE14
0.551 ± 1	32.5 ± 1	0	9.2	$1^-; 1$	8.061	A, 1960HE14, 1961KA04
1.012 ± 2	≤ 0.21	4	$\cong 0.01$	$(4^-); 0$	8.489	1965DE19
1.150 ± 2	7.5 ± 1	1	1.3	$0^+; 1$	8.617	A, 1961KA04, 1966LA03
1.34 ± 50	≈ 500	0	12.8	$0^-; 1$	8.80	A, 1961KA04, 1966LA03
1.462 ± 3	17 ± 2	2	0.72	$3^-; 1$	8.907	A, 1959WA04, 1961KA04, 1966LA03, 1969WA1H
1.523 ± 2	< 1		$\cong 0.003$	$5^+; 0$	8.963	1965DE19
1.540 ± 3	9 ± 2	1, (3)	0.13	2^+	8.979	A, 1961KA04, 1966LA03
1.701 ± 1	< 1	2	$\cong 0.03$	$2^-; 0$	9.129	1965DE19
1.7476 ± 0.9 [b]	0.075 ± 0.050		14.8	$2^+; 1$	9.172	B, 1959BO14, 1959RO54, 1959WA04, 1960RO13, 1960RO23, 1963PR03
1.980 ± 3	14 ± 3	2		$3^-, 2^-$	9.388	C, 1966LA03
2.110 ± 3	44 ± 2	2	6.2	$2^-; 1$	9.508	D, 1966LA03
2.319 ± 4	16 ± 3	1		1^+	9.702	C, 1966LA03
2.743 [c]	5.5	1	[d]	$1^+, (2^+)$	10.096	1960RO23, 1961KA04
2.885 ± 10 [c]	85 ± 15	0, 2		$1(^-); 0$	10.228	C, 1961KA04, 1963RO17
3.105 ± 7 [c]	36 ± 3	1	17	$2^+; 1$	10.432	1957WI30, 1960RO23, 1961KA04, 1964RO03
(3.12 ± 30)	80 ± 10				(10.45)	C
3.20 [c]	150	0, 2		1^-	10.52	1961KA04
3.77	< 33		[f]		11.05	1967RI1D
3.79	100			1^+	11.07	1960BA35, 1961KA04, 1967RI1D
3.98 [c]	12	2		3^-	11.24	1961KA04

Table 14.16: Levels of ^{14}N from ^{13}C(p, γ)^{14}N and ^{13}C(p, p)^{13}C [a] (continued)

E_p (MeV $\pm$ keV)	Γ_{lab} (keV)	l_p	$\omega\Gamma_\gamma$ (eV)	$J^\pi; T$	^{14}N*	Refs.
4.04 [c]	190	2	[f]	2^-	11.30	1960BA35, 1961KA04, 1967RI1D
4.14 [c]	30	1		1^+	11.39	1960BA35, 1961KA04
4.52	130		[f]	1^+	11.75	1960BA35, 1961BA09, 1967RI1D
4.60	≈ 100				11.82	1961BA09
5.31	55		[f]		12.48	1967RI1D
5.90	200		[f]		13.03	1967RI1D
6.20	≈ 1100		[f]		13.30	1967RI1D
8.0	[e]		[f]		15.0	1968BL1E, 1968RI1R
10.4	[e]		[f,g]		17.2	1968BL1E, 1968RI1R
12.6	[e]		[f]		19.2	1968BL1E, 1968RI1R
14.0	[e]		[f]		20.5	1968BL1E, 1968RI1R
16.1	≈ 500		[f]		22.5	1968BL1E, 1968RI1R
16.6	≈ 500		[f]		23.0	1968BL1E, 1968RI1R
17.4	≈ 500		[g]		23.7	1968BL1E, 1968RI1R

A: (1952SE01, 1953WO41, 1954MI05).

B: (1952SE01, 1953WO41, 1956MA87).

C: (1957ZI09, 1958ZI17).

D: (1952SE01, 1953WO41, 1957ZI09, 1958ZI17, 1959WA04).

[a] See also Table 14.9.

[b] See also (1963BO07, 1966MA60).

[c] Reduced width for proton emission is of the order of 1% of the Wigner limit (1961KA04).

[d] $(2J + 1)\ \Gamma_\gamma = 0.5 \pm 0.2$ eV, $\Gamma = 12 \pm 3$ keV (1960RO23).

[e] $\Gamma \approx 0.8$ to 1.5 MeV for these resonances (1968RI1R).

[f] Resonance in γ_0.

[g] Resonance in γ_1.

Observed resonances are displayed in Table 14.16. The decay schemes of various levels of ^{14}N, as derived from the γ-spectra in this and other reactions are exhibited in Table 14.9 (1953WO41, 1959WA04, 1960HE14, 1960RO13, 1960RO23, 1963PR03, 1963RO17, 1964RO03, 1965DE19, 1967RI1D, 1968BL1E, 1968RI1R).

The low-energy capture cross-section yields an extrapolated σ-factor at $E_{\rm p} = 25$ keV (cm), $S_0 = 6.0 \pm 0.8$ keV · b (1960HE14). See also (1963BR14, 1964FO1A, 1966BA2P, 1967FO1B). The capture cross section rises from $(7.7 \pm 1.8) \times 10^{-10}$ b at $E_{\rm p} = 100$ keV to $(9.8 \pm 1.2) \times 10^{-9}$ b at $E_{\rm p} = 140$ keV (1961HE02).

Direct radiative capture of protons into the lowest three odd-parity states ^{14}N*(4.91, 5.11, 5.69, 5.83) has been studied by (1964TR04). See also (1963RO17).

The angular distribution of the γ-rays at the $E_{\rm p} = 0.45$ MeV resonance (^{14}N* $= 7.97$ MeV) is consistent with $J^\pi = 2^-$ (1960HE14). The width of the $E_{\rm p} = 0.55$ MeV resonance and the isotropy of the γ-rays (1949DE1A, 1953WO41) indicate s-wave formation of ^{14}N*(8.06): $J^\pi = 1^-$ from ^{13}C(p, p)^{13}C. The decay properties of this state (see Table 14.9) show that the ground state transition is an uninhibited E1 transition, and thus that ^{14}N*(8.06) has $T = 1$ (1953CL39) but with a strong $T = 0$ admixture [as shown by a 2% ($8.06 \rightarrow 2.31$) transition] (1956LE28, 1957BR25, 1957WI27). The strong transition $8.06 \rightarrow 5.69$ admits either E1, $\Delta T = 1$ or M1, $\Delta T = 1$. Since the transition $5.69 \rightarrow 2.31$ is observed, ^{14}N*(5.69) cannot have $J^\pi = 0^+$, and 2^+ is excluded by the strength of the $8.62 \rightarrow 5.69$ transition. It appears then that ^{14}N*(5.69) has $J = 1$: see (1956LE28, 1957WI27, 1959WA04).

Anomalies in the capture cross section ("midget resonances") are observed at $E_{\rm p} = 1.01$, 1.52 and 1.70 MeV: see Table 14.16. The predominant γ-decay at the first resonance, ^{14}N*(8.49), is to the 5.10 MeV state. The angular distribution of the γ-rays and $\omega\Gamma_\gamma$ are consistent with $J^\pi = 4^-$; $T = 0$ for ^{14}N*(8.49). The γ-decay of the second state, ^{14}N*(8.96), is predominantly to the 6.44 MeV state: it's $J^\pi = 5^+$. The third state decays primarily to the ground state: the angular distribution of the γ-rays is consistent with $J^\pi = 2^-$; $T = 0$ for ^{14}N*(9.13) (1965DE19).

The narrow $E_{\rm p} = 1.16$ MeV resonance, ^{14}N*(8.62) [$J = 0^+$ from ^{13}C(p, p)^{13}C] shows strong transitions to ^{14}N*(0, 3.95, 5.69): hence $T = 1$ (1959WA16). The strong transition $8.62 \rightarrow 3.95$ requires dipole radiation and hence $J = 1$ for the latter (1959WA04) while the strength of the transition $8.62 \rightarrow 6.21$ and the angular correlation in the cascade $8.62 \rightarrow 6.21 \rightarrow$ g.s. is consistent with $J^\pi = 1^+$; $T = 0$ for ^{14}N*(6.21): see (1956GO1L, 1956GO39, 1957GA1B, 1957GO30, 1957WI27, 1959GA05).

The $E_{\rm p} = 1.25$ MeV resonance, ^{14}N*(8.80) [$J^\pi = 0^-$ from ^{13}C(p, p)^{13}C] has a large γ-width consistent with E1 radiation and $T = 1$ (1953WI1A). At $E_{\rm p} = 1.47$ MeV, the plane polarization of 0.73 MeV γ-rays (from $5.83 \rightarrow 5.11$) suggests odd parity for both these states (1962RO21).

Angular correlation and angular distributions of γ-rays at the $E_{\rm p} = 1.75$ MeV resonance, ^{14}N*(9.17), indicates $J = 2^+$ for that state, $J = 3$ for ^{14}N*(6.44) and $J = 2$ for ^{14}N*(7.03) (1959RO54, 1959WA04, 1960RO13, 1960RO23, 1963PR03). The angular distribution of the 2.73 MeV γ-rays ($9.17 \rightarrow 6.44$) suggests odd parity for ^{14}N*(6.44) (1961SE03, 1963PR03).

Marked variations are observed in the $(\cos\theta)$ term at $E_{\rm p} = 2.75$ and 2.90 MeV [^{14}N*(10.09) and (10.23)] (1960RO23). The angular distribution of the γ-rays from the $10.23 \rightarrow 2.31$ transition ($E_{\rm p} = 2.88$ MeV resonance) is consistent with $J^\pi = 1^+$, assuming a single state at 10.23

MeV: M^2(M1) leads to a $T = 0$ assignment (1963RO17). At the $E_p = 3.11$ MeV resonance [^{14}N*(10.43)], the angular distribution of ground state γ-rays is consistent with $J = 2$ (1959WA16, 1960RO23): the similar decay characteristics of ^{14}N*(10.43) and of the $J^\pi = 2^+$; $T = 1$ state at $E_x = 9.17$ MeV suggest that the 10.43 MeV state is in fact also a $J^\pi = 2^+$; $T = 1$ level (1964RO03).

The yield of γ_0 for $E_p > 3.5$ MeV shows a steady rise marked at first by pronounced resonances and then by broad structures most of which are related to levels seen in the inverse reaction (^{14}N(γ, p)^{13}C). The γ_1 yield (to ^{14}N*(2.31)) is on the average only about a third the γ_0 yield with roughly constant cross section for $E_p = 7$ to 18 MeV. Only weak structure is observed (1967RI1D, 1968BL1E, 1968RI1R): see Table 14.16.

See also (1959WA02, 1962WA1C), (1965FA1E, 1965MA1H; theor.) and (1959AJ76).

25. (a) ^{13}C(p, p)^{13}C $\qquad$ $E_b = 7.550$

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

The elastic scattering has been studied for $E_p = 0.14$ to 0.75 MeV (1960HE14), 0.45 to 1.60 MeV (1954MI05), 1.0 to 2.6 MeV (1966LA03), 1.5 to 3.4 MeV (1957ZI09, 1958ZI17), 2.6 to 5.0 MeV (1961KA04), 5 to 8.1 MeV (1965BA1W), and 7 to 11 MeV (1966SH1H): parameters of resonances observed in this reaction and in the ^{13}C(p, γ)^{14}N reaction are displayed in Table 14.16. Angular distributions of elastically scattered protons have been measured at many of these energies.

The yield of γ-rays in reaction (b) has been measured for $E_p = 3.6$ to 5.0 MeV: the 3.1 MeV γ-yield shows broad resonances at $E_p = 3.80$, 4.1, 4.14 and 4.60 MeV while the 3.7 MeV γ-yield shows one resonance at $E_p = 4.52$ MeV (^{14}N* $= 11.07$, 11.30, 11.39, 11.82 and 11.75 MeV, respectively) (1960BA35, 1961BA09): see Table 14.16. The angular distribution of inelastic protons to ^{13}C*(3.68) at the $E_p = 4.52$ MeV resoance leads to the assignment $J^\pi = 1^+$ for ^{14}N*(11.75) (1961BA09). The excitation functions for proton groups to ^{13}C*(3.09, 3.68, 3.85) have been measured for $E_p = 5$ to 11 MeV (1965BA1W, 1966SH1H). See also (1962BE04).

Polarization measurements for elastically scattered protons are reported at $E_d = 7$ MeV by (1969GU02) and at $E_p = 14.5$ MeV by (1962RO20, 1965RO22, 1966RO1B, 1966RO1R). At $E_p = 32.9$ MeV, the polarization and asymmetry in the elastic scattering have been compared. They are equal to within 1%, and there is therefore no evidence for violation of time reversal invariance for strong interactions, at least for that part of the force which flips the spin of the proton (1968GR1K, 1969MA2D).

See also (1962WA1C, 1963GE03, 1964FO02, 1967AR1D), (1967HO1L, 1969WA11), (1964PF1A, 1966AM1B; theor.) and (1959AJ76).

26. ^{13}C(p, n)^{13}N $\qquad$ $Q_m = -3.003$ $\qquad$ $E_b = 7.550$

The yield of neutrons has been measured from threshold to $E_p = 13.7$ MeV: see (1959AJ76) and (1959BR06, 1960BA35, 1961DA09, 1961WO03, 1966DI03). Observed resonances are displayed in Table 14.17. Angular distributions have been measured at many energies: over much of the energy range (below $E_p = 10$ MeV) there is pronounced backward peaking with a secondary maximum near $50°$ and no forward peak (1961DA09). The polarization of neutrons corresponding to ^{13}N(0) has been studied for $E_p = 6.9$ to 12.3 MeV (1964WA1G, 1965WA02). See also (1962BE04, 1964CA1F, 1965VA23, 1969BA1N) and ^{13}N.

27. ^{13}C(p, d)^{12}C $\quad Q_m = -2.722 \quad E_b = 7.550$

The yield of ground state deuterons has been determined for $E_p = 5$ to 11 MeV (1965BA1W, 1966SH1H). See also (1962BE04). A polarization measurement at $E_p = 7$ MeV is reported by (1969GU02). See also (1968TA1V) and ^{12}C in (1968AJ02).

28. ^{13}C(p, t)^{11}C $\quad Q_m = -15.185 \quad E_b = 7.550$

See (1968TA1V).

29. ^{13}C(p, α)^{10}B $\quad Q_m = -4.063 \quad E_b = 7.550$

Alpha-particle yields have been measured for $E_p = 7$ to 12 MeV (1963PE07, 1964FO02, 1966SH1H).

30. ^{13}C(d, n)^{14}N $\quad Q_m = 5.325$

Observed neutron groups are exhibited in Table 14.18. Recent angular distribution measurements are reported by (1969CH04: 0.5 to 0.8 MeV; n_3), (1961JA09: 1.2 MeV; $n_0 \rightarrow n_6$), (1961ZD01, 1964WI03: 1.3 to 2.5 MeV; n_0, n_1, n_2), (1963BE05: 3.9 MeV; n_0, n_1, n_2, $n_3 + n_4$), (1966FU10, 1966SI02, 1967FU04: 5.5 and 6 MeV; many groups), (1968CO24: 7 to 12 MeV; n_0, n_1, n_2), and (1969VE1D: 11.8 MeV; n_0, n_1, n_2). See also (1960VA11, 1962SH19, 1963DE19). Comparison of relative spectroscopic factors here and in the ^{13}C(^{3}He, d)^{14}N reaction [see Table 14.19] shows smaller values for the $T = 1$ state [^{14}N*(2.31)] in this reaction than in the (^{3}He, d) reaction (1966SI02, 1967FU04). Simple DWBA calculations would suggest that the factors would be the same in both proton pickup reactions. However, the dependence of the cross section magnitude on the T of the final state [the $t{\cdot}T$ term] appears to be energy dependent: see Table 14.19 (1968CO24). See also (1967LE1F).

Table 14.17: Resonances in $^{13}C(p, n)^{13}N$ (1961DA09) [a]

E_p (MeV)	Γ (keV)	$^{14}N^*$ (MeV)
3.76 ± 0.05	100	11.04
3.98 ± 0.02	30	11.24
4.05		11.31
4.15 ± 0.02	40	11.40
4.5 ± 0.1	100	11.7
4.7 ± 0.1	150	11.9
5.03 [b]		12.22
(5.44 ± 0.03)	(60)	(12.60)
5.53 ± 0.03	50	12.68
5.72 ± 0.03	60	12.86
6.20 ± 0.04	70	13.30
6.67 ± 0.13	250	13.74
7.0 ± 0.1	150	14.1
7.3		14.3
7.85 ± 0.08	150	14.84
7.93 ± 0.03	50	14.91
8.03 ± 0.03	50	15.00
8.7 ± 0.2	350	15.6
9.3 ± 0.1	150	16.2
10.2 ± 0.2	400	17.0
11.4 ± 0.3	600	18.1

[a] See also (1960BA35) and Table 14.9 in (1959AJ76).
[b] (1959GI47).

Table 14.18: ^{14}N levels from ^{13}C(d, n)^{14}N and ^{13}C(^{3}He, d)^{14}N

E_x (MeV)	$J^\pi; T$	l_p [a]	l [c]
0	$1^+; 0$	1	1
2.31	$0^+; 1$	1	1
3.95	$1^+; 0$	1	1
4.91	$(0^-); 0$	0	0
5.11	$2^-; 0$	2	2
5.69	$1^-; 0$	0	0
5.83	$3^-; 0$	2	2
6.21	$1^+; 0$	unspec.	1
6.44	$3^+; 0$	iso.	1
7.03	$2^+; 0$	1	1
7.97	$2^-; 0$	[b]	[d]
8.06	$1^-; 1$	0	
8.91	$3^-; 1$	(1, 2)	[d]
8.98	$2^+; (0)$	(1, 2)	

[a] ^{13}C(d, n)^{14}N: $E_d = 5.5$ and 6 MeV (1966FU10). See also Table 14.10 in (1959AJ76) and (1961JA09, 1963BE05, 1967FU04, 1968CO24).
[b] Group was masked by contaminant.
[c] ^{13}C(^{3}He, d)^{14}N: $E(^3\text{He}) = 15$ MeV (1966HO15).
[d] See (1969HO23).

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* $= 5.691 \pm 0.006$) (1955MA76). See also (1965MA1K).

Observed γ-rays attributed to transitions in ^{14}N are shown in Table 14.20 (1952TH24, 1955BE62, 1955MA36, 1958RA13, 1966AL10). The decay of ^{14}N*(5.69) is via ^{14}N*(2.31) [63 ± 2%] and directly to ^{14}N(0) [37 ± 2%]. τ_m [^{14}N*(4.91)] < 0.5 psec (1963AL21) [see also Tables 14.9 and 14.13]. The angular correlation of internal pairs conclusively establish the parities of ^{14}N*(4.91, 5.10, 5.69) as odd (1964WA05).

See also (1959CH28, 1959GO78, 1966EV1B), (1959NE1B, 1960AB02, 1964BA1G, 1966BA2R, 1966ST1L, 1967BA2J; theor.) and (1959AJ76). See also ^{15}N.

31. ^{13}C(^{3}He, d)^{14}N $\qquad Q_m = 2.056$

$Q_0 = 2.070 \pm 0.015$ (1962SH21);
$Q_0 = 2.048 \pm 0.014$ (1963SP1B);
$Q_0 = 2.050 \pm 0.015$;
$Q_1 = -0.265 \pm 0.015$ [$E_x = 2.315 \pm 0.022$] (1959YO25).

Table 14.19: Spectroscopic factors for ^{14}N states [a]

E_x (MeV)	$J^\pi; T$	^{13}C(d, n)^{14}N E_d (MeV)				^{13}C(^{3}He, d)^{14}N $E(^3$He) (MeV)			Theory [f]
		3.9 [b]	5.5 [c]	6.0 [d]	7.0 to 12.0 [a]	13 [c]	15 [e]	17 [c]	
0	$1^+; 0$	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1
2.31	$0^+; 1$	0.97	1.1	1.15	0.920 ± 0.052	1.93	1.53	1.6	1.24
3.95	$1^+; 0$	0.72	0.8	0.57	0.551 ± 0.032	0.52	0.39	0.5	0.29

[a] Normalized to 1.0 for the ground state (1968CO24).
[b] (1963BE05).
[c] (1966SI02).
[d] (1966FU10).
[e] (1966HO15).
[f] (1967CO32).

Angular distributions have been obtained at $E(^3$He$) = 13$ and 17 MeV (1966SI02: ^{14}N*(0, 2.31, 3.95)), 15 MeV (1966HO15, 1969HO23: ^{14}N*($0 \rightarrow 9.17$)), 17.8 MeV (1966EC1B: ^{14}N*(0, 2.31, 3.95)) and 22 MeV (1969MA1R: ^{14}N*(0, 2.31)). Relative spectroscopic factors for the first three states have been compared with those obtained in the ^{13}C(d, n)^{14}N reaction (1966HO15, 1966SI02): see reaction 30 and Table 14.19. See also (1967LE1F). Spectroscopic factors for the higher states have also been obtained by (1966HO15), from a DWBA analysis. l-values for the observed groups are in agreement with those obtained by (1966FU10) in the (d, n) reaction: see Table 14.18. See also (1965HE01, 1967BA1D).

32. ^{13}C(α, t)^{14}N $\qquad Q_m = -12.264$

Angular distributions have been obtained at $E_\alpha = 46$ MeV of the tritons corresponding to the first seven states of ^{14}N: the data are consistent with the assumption of a direct interaction in which a proton is transferred from the incident α-particle (1969FO1C).

Table 14.20: Gamma rays from ^{13}C(d, n)^{14}N

(1952TH24) [a] E_γ [e] (keV)	(1955BE62) [b] E_γ [f] (keV)	(1955MA36) [c] E_γ [e] (keV)	(1958RA13) [d] E_γ [f] (keV)	Assignment ^{14}N*
725 ± 4		729 ± 3	728.3 ± 1.0 [g]	$5.83 \rightarrow 5.11$
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	5.11
5690 ± 50	5720 ± 40	5730 ± 30	5669 ± 25	5.69
			5833 ± 30 [e]	5.83
	6490 ± 60	6450 ± 50	6419 ± 30	6.44
	7050 ± 40		7012 ± 25	7.03

[a] $E_d = 1.2$, 1.6 MeV.
[b] $E_d = 2$, 4 MeV.
[c] $E_d = 1.4$ MeV.
[d] $E_d = 4.5$ MeV.
[e] Not corrected for Doppler shift.
[f] Includes $\approx 0.5\%$ Doppler correction.
[g] (1966AL10).

33. ^{13}C(^{11}B, ^{10}Be)^{14}N $\qquad Q_m = -3.678$

At $E(^{11}B) = 113.5$ MeV, ^{10}Be groups are observed corresponding to ^{14}N*$(5.69 + 5.83)$, $(8.80 + 8.91)$ and possibly to ^{14}N*(12.2). The two lower transitions correspond to the addition of $s_{1/2}$ and $d_{5/2}$ protons to the ^{13}C target core. States which were not excited would have required the excitation of the target core in addition to the transfer of a nucleon (1967PO13). See also (1969BR1D).

34. ^{13}C(^{14}N, ^{13}C)^{14}N

See (1968HU1H).

35. ^{14}C(β^-)^{14}N $\qquad Q_m = 0.156$

See ^{14}C.

36. ^{14}C(p, n)^{14}N $Q_m = -0.626$

Neutron thresholds have been observed at $E_p = 671.5 \pm 0.5$ and 3149.6 ± 1.1 keV (1956SA06) and at $E_p = 4910 \pm 8$ keV (1960BA34) corresponding to the ground state of ^{14}N and to excited states at 2.3119 ± 0.0012 and 3.952 ± 0.008 MeV. Angular distributions of the neutrons corresponding to ^{14}N*(0, 2.31, 3.95) have been obtained for $E_p = 6$ to 14 MeV. At the highest energies these have been analyzed by using finite range DWBA, taking into account various isospin and spin factors. The ground state transition is not inhibited, whereas the ^{14}C β-decay is. This requires spin-flip mechanisms such as a tensor interaction or particle exchange (1967WO05). See also (1969MA1G). Angular distributions are also reported at $E_p = 20$ and 30 MeV (1969SA1M; n_0, n_1, n_2). See also ^{15}N.

37. ^{14}C(^{3}He, t)^{14}N $Q_m = 0.138$

At $E(^3\text{He}) = 44.8$ MeV, triton groups are observed corresponding to all the known levels of ^{14}N with $E_x < 7.1$ MeV. Triton groups were also seen to unresolved states with $E_x = 8.0 - 9.5$ MeV, to ^{14}N*(10.43) and to excited states with $E_x = 12.49 \pm 0.04$, 12.83 ± 0.05 and 13.70 ± 0.04 MeV. Angular distributions were obtained for nine of the triton groups and analyzed using a local two-body interaction with an arbitrary spin-isospin exchange mixture. Dominant $L = 0$ transitions are found to ^{14}N*(2.31, 3.95, 13.7), $L = 1$ to ^{14}N*(5.11), $L = 2$ to ^{14}N*(0, 7.03, 10.43) and $L = 3$ to ^{14}N*(5.83) (1967BA13, 1968BA1E, 1969BA06). See also (1969MA1G) and reaction 45.

38. (a) ^{14}N(γ, n)^{13}N $Q_m = -10.553$
(b) ^{14}N(γ, p)^{13}C $Q_m = -7.550$
(c) ^{14}N(γ, d)^{12}C $Q_m = -10.272$
(d) ^{14}N(γ, pn)^{12}C $Q_m = -12.497$
(e) ^{14}N(γ, α)^{10}B $Q_m = -11.613$
(f) ^{14}N(γ, nα)^{9}B $Q_m = -20.051$
(g) ^{14}N(γ, pα)^{9}Be $Q_m = -18.201$

The total absorption over the range $E_\gamma = 9$ to 31 MeV is dominated by a single peak at 22.5 MeV [estimated $\sigma \approx 29$ mb, $\Gamma \approx 2 - 3$ MeV] and appreciable strength extending beyond 30 MeV. The cross section cannot be accounted solely by the (γ, n) and (γ, p_0) processes: particle unstable excited states of ^{13}C, ^{13}N are believed involved (1969BE92). Over the interval $E_\gamma = 20.0$ to 20.5

MeV, the average cross section is 10.5 ± 4 mb (1959CA1C, 1960CA09). See also (1968CO13). The cross section for neutron production, reactions (a) and (d), exhibits maximum at $E_{\gamma} = 22.5$ MeV, $\Gamma = 3.2$ MeV, $\sigma = 15.3$ mb (1954FE16) [$\Gamma = 3.8$ MeV, $\sigma = 14.5$ mb (1960FA06)]. The cross section for reaction (a) shows a maxima at $E_{\gamma} = 11.7$, 13.2, 15.2, 19.5 and 22.8 MeV (1960KI02). [The peak cross sections for the two highest energy maxima are ≈ 1.8 and 2.8 mb, respectively; the widths are $\approx 2 - 3$ MeV, estimated from the published curve.] Breaks in the (γ, n) activation curve are reported at $E_{\gamma} = 11.07$ MeV (1960GE06) and 11.49, 11.61, 12.39, 12.92, 13.28, 13.87, 14.62, 15.25, 16.35, 18.05 and 19.10 MeV (1959MU08, 1960MU02: ± 50 keV). See also (1959FU1A, 1960BA15, 1960KO05, 1960SA09, 1962GO1E, 1962KO23, 1963CO1D, 1963FU06, 1970LO1A).

Studies of reaction (b) indicate the involvement of ^{14}N*(8.06, 9.17, 10.43) (1956WR22, 1960WA17) as well as of ^{14}N states with $E_{\rm x} = 11.8$, 13.0 and 15.2 MeV (1960WA17). See also (1959FU1A, 1960BA15, 1960KO05, 1962GO1E, 1962KO23, 1963FI1B, 1964ED01, 1964KO1D). For reaction (c), see (1964ED01). For reaction (d) see also (1959RE1A, 1960BA15, 1962GO1E, 1962KO23, 1963KO1B, 1964KO1D).

For reactions (e), (f) and (g) see (1956LI05, 1958MA1A, 1960BA15, 1960KO05, 1962GO1E, 1962MO16, 1964ED01, 1964TO1B). See also (1959AJ76).

39. ^{14}N(γ, γ)^{14}N

Resonant absorption measurements give $\Gamma = 72 \pm 10$ eV (1965LU05), 77 ± 12 eV (1959HA11) for ^{14}N*(9.17): $\omega\Gamma_{\gamma} = 14.5 \pm 2$ eV consistent with dipole radiation (1959HA11). (1966SW01) finds $E_{\rm x} = 7.029 \pm 0.006$ MeV for ^{14}N*(7.03). The angular distribution of the scattered radiation is consistent with $J = 2$. Assuming that ^{14}N*(7.03) decays entirely to the ground state [actually 98%: see Table 14.13], $\tau_{\rm m} = 5.4 \pm 0.5$ fsec (1966SW01). The mean lifetime for ^{14}N*(2.31) is 77 ± 18 fsec (1961SW01), 97 ± 30 fsec (1964BO22). For ^{14}N*(8.06), (1956GR17, 1958GR97) finds $\Gamma_{\gamma} = 10.5 \pm 6$ eV. See Tables 14.9, 14.13 and 14.21.

An elastic scattering study shows a broad (several MeV wide) maximum centered around $E_{\gamma} = 24$ MeV and indicates a secondary maximum around 30 MeV (1967LO1B).

40. ^{14}N(e, e)^{14}N

The r.m.s. radius of ^{14}N at $E_{\rm e} = 400$ MeV is 2.58 ± 0.05 fm (1968DA1Q). See also (1964BI04). See also (1959ME24). Measurements of magnetic form factors at $E_{\rm e} = 100$ to 180 MeV favor jj-coupling for ^{14}N(0) (1966RA29).

Inelastic scattering ($\theta = 180°$) gives evidence for the excitation of ^{14}N*(8.91, 9.17, 10.43): the ground state Γ_{γ} are given in Table 14.21 (1962ED02, 1963BA19, 1966KO08, 1968CL05). In addition (1968CL05) report the excitation of a state with $E_{\rm x} = 11.01 \pm 0.07$ MeV and (1966KO08) report structure at $E_{\rm x} = 11.7$ and 12.7 MeV. Partial Γ_{γ} [for cascade transitions of ^{14}N*(9.17,

Table 14.21: Gamma widths [a] of unbound levels from ^{13}C(p, γ)^{14}N, ^{14}N(γ, γ)^{14}N and ^{14}N(e, e)^{14}N

E_x (MeV)	$J^\pi; T$	Γ_γ to g.s. (eV)	Multipol.	Reaction	Refs.
8.06	$1^-; 1$	10.5 ± 6	E1	(γ, γ)	(1956GR17, 1958GR97)
8.91	$3^-; 1$	$(6.6 \pm 2.2) \times 10^{-3}$	M2	(e, e)	(1968CL05)
		$(16 \pm 4) \times 10^{-3}$		(e, e)	(1966KO08)
9.17	$2^+; 1$	7.7 ± 0.9	M1	(e, e)	(1968CL05)
		8.7 ± 1.5		(γ, γ)	(1959HA11)
		9 ± 3		(e, e)	(1962ED02)
		13 ± 3		(e, e)	(1966KO08)
		4.6 ± 1.4		(e, e)	(1963BA19)
10.43	$2^+; 1$	12.1 ± 1.5	M1	(e, e)	(1968CL05)
		16.4 ± 3.0		(e, e)	(1966KO08)
		17 ± 5		(p, γ)	(1957WI30)
		20 ± 6		(e, e)	(1962ED02)
		4.9 ± 1.5		(e, e)	(1963BA19)

[a] See also Table 14.9.

10.43)] have been obtained by (1968CL05) and are shown in Table 14.9. See also (1963GO04). Inelastic scattering is also reported to ^{14}N*(2.3, 3.95, 5.1, 5.85, 7.05, 8.0) (1964BI09). See also (1964BI04). See (1962BA1D) for a general discussion. See also (1958CA1B, 1960PA08, 1963GU1A, 1967KA1A, 1969VI02).

41. ^{14}N(n, n′)^{14}N*

Angular distributions of elastically and inelastically scattered neutrons are displayed in Table 14.23. See also (1959AJ76) and ^{15}N.

Observed gamma rays are displayed in Table 14.23 (1969DI1B, 1969NY1A). See also (1959HA13, 1968CO1W). Lifetime measurements are reported in Table 14.22 (1969NY1A).

See also ^{15}N, (1961AS1B, 1963MO04, 1963OP1A, 1964EN1B, 1964MO1D, 1964PE20, 1965VA1K, 1966MO1C) and (1965JO07, 1965TA07, 1968CA1A, 1969WA11).

42. (a) ^{14}N(p, p′)^{14}N*

(b) ^{14}N(p, 2p)^{13}C $\qquad Q_m = -7.550$

(c) ^{14}N(p, pd)^{12}C $\qquad Q_m = -10.272$

Table 14.22: Gamma rays from ^{14}N(n, n′)^{14}N*

E_γ [a] (MeV ± keV)	E_γ [d] (MeV)	Transition
0.727 ± 3 [b]	0.728	$5.83 \rightarrow 5.11$
1.634 ± 5 [b]	1.622	$3.95 \rightarrow 2.31$
2.312 ± 3 [b]	2.313	$2.31 \rightarrow$ g.s.
	2.49	$6.44 \rightarrow 3.95$
2.792 ± 3	2.792	$5.11 \rightarrow 2.31$
	3.372	$5.69 \rightarrow 2.31$
	3.895	$6.20 \rightarrow 2.31$
4.919 ± 10 [c]	4.91	$4.91 \rightarrow$ g.s.
5.106 ± 3	5.105	$5.11 \rightarrow$ g.s.
	5.685	$5.69 \rightarrow$ g.s.
5.835 ± 5 [b]	5.833	$5.83 \rightarrow$ g.s.
6.426 ± 10 [c]	6.44	$6.44 \rightarrow$ g.s.
7.021 ± 10 [c]	7.03	$7.03 \rightarrow$ g.s.

[a] (1969NY1A): $E_n = 15$ MeV.

[b] $E_x(3.95)$ is then 3.947 ± 0.005 MeV and $E_x(5.83)$ is 5.833 ± 0.003 MeV.

[c] These γ-ray energies have been corrected for Doppler shift.

[d] (1969DI1B): $E_n = 8.6$ MeV: gamma-ray peaks located in terms of the 2.313 and 5.105 MeV γ-rays. No attempt was made to obtain accurate γ-ray energies.

Angular distributions of elastically and inelastically scattered protons have been measured and analyzed at a number of energies: see Table 14.23. See also ^{15}O and (1968OD1B). Observed inelastic proton groups are shown in Table 14.24. The proton groups corresponding to ^{14}N*(7.40, 7.60) reported by (1956BU16) are spurious: see (1964DO03, 1964EA04). See also (1963BR14, 1966ME1L). (1965DE21) reports the excitation of ^{14}N states with $E_x = 11.2 \pm 0.2$ and 12.8 ± 0.4 MeV, and the measurement of the angular distribution of the protons from the decay of ^{14}N*(11.2). See also (1957HO34, 1961CL09, 1969CU1D) and (1962KA1E, 1962WA1D, 1965TA07, 1969MA1G, 1969WA11). See also (1959AJ76) and (1960WA12).

Reaction (b) at $E_p = 19$ MeV proceeds at least in part through an intermediate state in ^{14}N at $E_x \approx 11.2$ MeV (1965DE21). See also (1961CL09, 1965RI1A, 1966TY01) and (1965BE1E, 1965DE1P, 1967JA1E, 1967KO1P, 1969KO1J; theor.) and ^{13}C. For reaction (c) see (1961CL09) and (1964BA1P, 1966JA1A; theor.).

43. ^{14}N(d, d′)^{14}N*

Angular distributions of elastically and inelastically scattered deuterons have been obtained at

Table 14.23: ^{14}N(n, n), (p, p), (d, d), (^{3}He, ^{3}He) and (α, α) angular distribution studies

(a) *Angular distribution of neutrons*

$E_{\rm n}$ (MeV)	Angular distribution to ^{14}N*	Refs.
$1.6 - 3.2$	g.s.	(1966FO1D, 1966FO1E)
$5.0 - 6.5$	g.s.	(1960SM02)
$6.8 - 14.0$	g.s.	(1967BA03)
14	g.s.	(1961ST22, 1963BA46)
14	2.31	(1961BO28)
14.1	g.s.	(1966BE1P)
14.8	g.s.	(1967LU1B)

(b) *Angular distribution of protons*

$E_{\rm p}$ (MeV)	Angular distribution to ^{14}N*	Refs.
$6 - 9$	2.31	(1968SH11)
$6 - 11.4$	g.s., 3.95	(1968BO36, 1968SH11)
7.7, 8.5, 10.5, 14.1	g.s., 2.31	(1960OD01)
9.5	g.s., 3.95	(1954FR38, 1957GI14)
9.8	g.s.	(1957HI56)
$9.9 - 11.4$	5.11, 5.83	(1968BO36)
10.2	$3.95 \rightarrow 7.03$	(1964DO03)
10.5, 14.1	3.95	(1960OD01)
12.2	g.s.	(1968RI1Q)
19.4	g.s.	(1956VA1B, 1957VA1B)
20	g.s.	(1955CH1A)
21	g.s.	(1969BA23)
24.8	2.31	(1967AU1E)
31	g.s.	(1964KI06)
142	g.s.	(1961TA06)
155	g.s., 2.31, 3.95, $4.91 + 5.11$, $5.69 + 5.83$	(1968GE04)

(c) *Angular distribution of deuterons*

$E_{\rm d}$ (MeV)	Angular distribution to ^{14}N*	Refs.

Table 14.23: ^{14}N(n, n), (p, p), (d, d), (^{3}He, ^{3}He) and (α, α) angular distribution studies (continued)

0.7 – 2.1	g.s.	(1963SE05)
1.2 – 3.1	g.s.	(1969GO14)
1.3 – 3.2	g.s.	(1969BE08)
5.5 – 10.2	2.31, 3.95	(1968DU1E)
8	g.s.	(1952GI01)
11	g.s.	(1960TA08)
11.8	g.s.	(1967FI07)
13.6	g.s.	(1963NE1C, 1964NE1D)
14.2	g.s., 3.95, 4.91, 5.11	(1966NG01)
21	g.s.	(1959FI30)
27	g.s.	(1962ER03)
28	g.s.	(1968GA13)
28.5	g.s.	(1966VI1A)
52	g.s., 3.95, 4.91 + 5.11, 5.69 + 5.83, 7.03	(1968HI09, 1968HI14)

(d) *Angular distribution of ^{3}He particles*

$E(^3$He) (MeV)	Angular distribution to ^{14}N*	Refs.
17.4, 25.4, 36.6	g.s.	(1965AR1E)
25.7	g.s.	(1964SE05)
29	g.s., 3.95, 4.91 + 5.11	(1962SE13)
44.6	g.s., 2.31, 3.95, 4.91, 5.11, 5.69, 5.83, 7.03, 11.24, 12.77	(1968BA1E, 1969BA06)

(e) *Angular distribution of α particles*

E_α (MeV)	Angular distribution to ^{14}N*	Refs.
11.4 – 12.7	2.31	(1966CH1E)
19.2	g.s., 3.95, 4.91 + 5.11	(1961PL01)
20.1 – 23.3	g.s.	(1967BO1M)
25.7 – 32.9	g.s., 3.95	(1963NO1B)
37.9	g.s.	(1960AG01)
40	g.s.	(1959YA01)
40.5	g.s., 3.95, 4.91, 5.11, 5.69, 5.83, 6.21, 6.44, 7.03	(1966HA19)
56	g.s.	(1969GA11)
65	g.s.	(1964HA16)

Table 14.23: ^{14}N(n, n), (p, p), (d, d), (^{3}He, ^{3}He) and (α, α) angular distribution studies (continued)

104	g.s.	(1968HA1D, 1969HA14)

a number of energies: see Table 14.23. See also ^{16}O in (1971AJ02). Inelastic deuteron groups are displayed in Table 14.24. The deuteron group to the 0^+; $T = 1$ state at $E_x = 2.31$ MeV is isospin forbidden: its intensity is $1 - 3$ % of the deuteron group to ^{14}N*(3.95) for $E_d = 7.7$ to 10.2 MeV (1968DU1E). See also (1953BO70). The deuteron group to the $T = 1$ state ^{14}N*(8.06) is also not seen: see Table 14.24. See also general discussions in (1960WA12, 1966BR1G, 1968NO1C). See also (1968ME1E, 1969CU08).

44. ^{14}N(t, t)^{14}N

See (1964SC09).

45. ^{14}N(^{3}He, ^{3}He$'$)^{14}N*

Angular distributions of elastically and inelastically scattered ^{3}He particles have been determined by (1962SE13, 1964SE05, 1965AR1E, 1969BA06): see Table 14.23. See also (1967KN1B).

At $E(^3\text{He}) = 44.6$ MeV, twelve ^{3}He groups are reported corresponding to states in ^{14}N: see Table 14.24 (1969BA06). The angular distributions were analyzed using a local two-body interaction with an arbitrary spin-isospin exchange mixture. A comparison of the cross sections of the reactions ^{14}N(^{3}He, t)^{14}O$_{\text{g.s.}}$, ^{14}N(^{3}He, ^{3}He$'$)^{14}N(2.31) and ^{14}C(^{3}He, t)^{14}N(0) [which all correspond to transitions between identical initial and final states] shows that they are roughly equal, as would be expected fron charge independence, once detailed-balance, isospin coupling and phase-space correactions have been applied (1969BA06). See also (1968HO1C, 1968LE1G, 1969RA1B).

46. (a) ^{14}N(α, α')^{14}N*
(b) ^{14}N(α, αp)^{13}C $\qquad Q_m = -7.550$
(c) ^{14}N(α, αd)^{12}C $\qquad Q_m = -10.272$

Angular distributions of elastically and inelastically scattered α-particles have been measured for $E_\alpha = 11$ to 104 MeV: see Table 14.23. The intensity of the isospin-forbidden α_1 group to ^{14}N*(2.31) is low. The highest intensities reported are 0.18 of the α_0 group and 0.4 of the α_2 group for $E_\alpha = 11.4$ to 12.7 MeV (1966CH1E). Generally the intensity of the α_1 group is much smaller than that, typically a few percent of the α_0 or α_2 group: see (1959AJ76, 1966HA19): see also Table 14.23.

Table 14.24: ^{14}N levels from ^{14}N(p, p′), (d, d′), (^{3}He, ^{3}He′) and (α, α')

^{14}N*(MeV ± keV)				L [k]
(p, p′)	(d, d′)	(^{3}He, ^{3}He′)	(α, α')	
2.313 ± 5 [a]	see text	[h]	see text	
3.945 ± 5 [a]	[f]	[h]	[j]	2
4.910 ± 10 [a]	[f]	[h]	[j]	1, 3
5.104 ± 10 [a]	[f]	[h]	[j]	1, 3
5.69 ± 30 [b]	[f]	[h]	[j]	1, 3
5.83 ± 30 [b]	[f]	[h]	[j]	1, 3
6.23 ± 20 [b]	[f]	[h]	[j,l]	
6.46 ± 20 [b]	[f]		[j,l]	
$(6.60 \pm 40$ [b]				
7.03 ± 20 [b]	[f]	[h]	[j]	2
7.97 [c]			[m]	
8.06 [c]		$8.0 \rightarrow 11.0$ [i]		
9.2 [d]				
11.2 ± 200 [e]	[f,g]	11.22 ± 50 [h]		
12.8 ± 400 [e]	[f,g]	12.77 ± 50 [h]		
17 [d]				
21.5 [d]				

[a] (1953BO70). See also (1952AR29, 1964EA04).
[b] (1956BU16). See also text, and (1964EA04).
[c] (1964EA04).
[d] (1958TY46).
[e] (1965DE21).
[f] Observed: see (1953BO70, 1966NG01, 1968DU1E, 1968HI09, 1968HI14).
[g] $E_x = 11.3$ and 13 MeV (1968HI14).
[h] (1969BA06).
[i] Unresolved structure (1969BA06).
[j] (1966HA19).
[k] From (α, α'): (1966HA19).
[l] Relatively low cross section due to two-nucleon transition (1966HA19).
[m] See also (1956MI17).

Reduced transition probabilities are reported by (1966HA19): B(E2)$\downarrow$ $/e^2 = 6.5$ and 3.3 fm^4, respectively for ^{14}N*(3.95, 7.03); B(E3)$\downarrow$ $/e^2 = 40$ and 60 fm^6, for ^{14}N*(5.11, 5.83). See also (1962HA40, 1962JO14, 1963MI1C, 1969BA06), (1968FA1A), (1960WA12), (1968NO1C, 1968RA1C; theor.) and ^{18}F in (1972AJ02).

At $E_\alpha = 22.9$ MeV, reaction (b) to ^{13}C(0) appears to involve twelve states of ^{14}N with $E_\text{x} = 8.4$ to 13.2 MeV, while reaction (c) proceeds via five states with $E_\text{x} = 11.5$ to 12.9 MeV (1969BA17). See also (1967BE30, 1968KU1C).

47. ^{14}N(^{9}Be, ^{9}Be)^{14}N

See (1964KU1D, 1969BR1D).

48. ^{14}N(^{12}C, ^{12}C)^{14}N

See (1961NE04, 1962SM02, 1964KU1D).

49. ^{14}N(^{14}N, ^{14}N)^{14}N

See (1962SM02, 1968JA1N) and (1967BR1M, 1969VO1E).

50. ^{14}N(^{16}O, ^{16}O)^{14}N

See (1961NE04, 1968JA1P).

51. ^{14}O(β^+)^{14}N $\qquad Q_\text{m} = 5.144$

The decay proceeds almost entirely to the $J^\pi = 0^+$; $T = 1$ state of ^{14}N at 2.31 MeV: see ^{14}O. Measurement of the γ-ray energy from the decay of ^{14}N*(2.31) leads to $E_\text{x} = 2.31287 \pm 0.00010$ MeV for this state (1968FR08), 2.31289 ± 0.00010 MeV (1967CH19). The spectrum shape for the transition to ^{14}N(0) differs markedly from the statistical shape. τ_m for ^{14}N*(2.31) extracted from these data is 33 ± 3 fsec (1966SI05): see, however, Table 14.13.

52. ^{15}N(p, d)^{14}N $\qquad Q_\text{m} = -8.610$

Angular distributions have been obtained for the deuterons corresponding to ^{14}N*(0, 2.31, 3.95) (1961BE12: $E_p = 18.6$ MeV) and to ^{14}N*($0 - 8.06$, 8.62, 8.91, $8.96 + 8.98$, $9.17 - 10.43$, 10.81, 11.04, $11.24 + 11.30$, $11.39 - 11.66$, $11.75 + 11.81$, 11.95, $12.23 + 12.29$, 12.50, 12.61, $12.79 + 12.83$, $13.16 + 13.23$, 13.72) (1969SN04: $E_p = 39.8$ MeV). Spectroscopic factors were extracted by DWBA analysis of the $l_n = 1$ pickup angular distributions. $\Gamma = 210 \pm 30$ keV for ^{14}N*(13.75). Weak deuteron groups to ^{14}N states at $E_x = 6.70$, 7.40 and 7.60 MeV are reported [see, however, reaction 54] (1969SN04).

53. ^{15}N(d, t)^{14}N $\qquad Q_m = -4.577$

Not reported.

54. ^{15}N(^{3}He, α)^{14}N $\qquad Q_m = 9.743$

At $E(^3\text{He}) = 2.8$ MeV, α-particle groups are observed to ^{14}N states at $E_x = 3.95$, 4.91, 5.113 ± 0.008, 5.691 ± 0.008, 5.832 ± 0.008, 6.048 ± 0.012 [see, however, (1969HO23)], 6.224 ± 0.012, 6.436 ± 0.012, 7.032 ± 0.010, 7.97 and 8.06 MeV (1962CL12, 1962CL1D). The previously reported states at $E_x = 6.70$, 7.40 and 7.60 MeV are unobserved (1962CL12, 1969HO23). Angular distributions have been obtained at $E(^3\text{He}) = 2.8$ MeV (1962CL12: to ^{14}N*(3.95, 5.69, 5.83)), 15 MeV (1969HO23: to ^{14}N*($0 - 8.91$, $9.17 - 9.70$) and 39.8 MeV (1966BA13: to ^{14}N*(0, 2.31, 3.95, 7.03, 9.17, 10.43) and to a state at $E_x = 13.72 \pm 0.04$ MeV). See also (1965SE01).

55. ^{16}O(n, t)^{14}N $\qquad Q_m = -14.479$

Not reported.

56. ^{16}O(p, pd)^{14}N $\qquad Q_m = -20.736$

See (1964BA1C).

57. ^{16}O(p, ^{3}He)^{14}N $\qquad Q_m = -15.243$

At $E_p = 40$ MeV, angular distributions have been measured for the ^{3}He particles corresponding to ^{14}N*(0, 2.31, 3.95) (1966BR1X, 1966HO1F). The excitation of ^{14}N*(7.03, 9.17) is also reported (1965PE17). At $E_p = 43.7$ MeV, a comparison has been made between the angular distributions of the ^{3}He particles to ^{14}N*(2.31) and the tritons (from the ^{16}O(p, t)^{14}O reaction) to ^{14}O$_{\rm g.s.}$. As would be expected from charge independence, the shape of the distributions and the cross sections are approximately the same to the two analog states: σ(p, t)/σ(p, ^{3}He) $= 1.12/1$ (1964CE02).

58. ^{16}O(d, α)^{14}N $\qquad Q_{\rm m} = 3.111$

$Q_0 = 3.110 \pm 0.006$ (1964MA57).

Angular distribution of α-particles have been measured at many energies: see Table 14.25. See also (1959FI30).

Alpha particle groups have been seen corresponding to most known states of ^{14}N with $E_{\rm x} \leq 11.51$ MeV (in some cases, the identification of the groups is inconclusive), with the exception of previously reported states at $E_{\rm x} = 6.05$, 6.70, 7.40 and 7.60 MeV (1968JO07: $E_{\rm d} = 5$ to 9 MeV). See also (1965IS04). The yield of the isospin-forbidden α_1 group [to ^{14}N*(2.31)] has been studied for $E_{\rm d} = 3$ to 15 MeV. The intensity of the α_1 group, relative to the α_0 and α_2 groups [to the $T = 0$ states of ^{14}N*(0, 3.95)] depends on the deuteron energy and on the angle of observation [the isospin impurity in the compound nucleus is a function of the excitation energy in ^{18}F and of J] (1969JO09). Studies of the α_1 yield have also been conducted for $E_{\rm d} = 5.5$ to 7.5 MeV (1956BR36) and 6.8 to 8.9 MeV (1958DA16). For further discussions, see (1963CE02, 1966BR1G, 1968NO1C, 1969NO1B, 1969NO1C). See also (1960HU10, 1961PE09, 1961YA08, 1963JA03, 1963YA1B) and ^{18}F in (1972AJ02).

Preliminary results on the absolute cross sections of this reaction and its inverse [^{14}N(α, d)^{16}O] are in agreement, to ± 0.56%, with the principle of detailed balance (1967TH1E, 1968TH1J, 1969PL1C).

See also (1961TE02, 1963DO1B, 1963VA1E, 1964RI1C, 1966BE1E, 1966JA05, 1966KL1E, 1968KO24), (1960EL1E, 1961BA1J, 1961JA1H, 1964HO1E, 1966ME1E, 1967JO1H; theor.) and (1959AJ76).

59. ^{16}O(α, ^{6}Li)^{14}N $\qquad Q_{\rm m} = -19.264$

See (1965PE17).

60. ^{16}O(^{10}B, 3α)^{14}N $\qquad Q_{\rm m} = -2.822$

See (1965SH10, 1965SH14).

61. ^{17}O(p, α)^{14}N $\qquad Q_{\rm m} = 1.193$

Table 14.25: ^{16}O(d, α)^{14}N angular distribution studies

E_d (MeV)	Angular distribution to ^{14}N*	Refs.
1.3 – 1.9	g.s.	(1964AM1A)
1.8 – 2.4	g.s.	(1965MA59)
1.9 – 3.6	g.s.	(1968DI06)
3.3 – 11.0	2.31	(1969JO09)
3.8, 3.9	g.s.	(1963JA03)
3.9	2.31	(1963JA03)
4.4, 4.6, 4.7	g.s.	(1967TH1E)
5.5 – 6.7	g.s.	(1965SA18)
5.6 – 6.9	g.s., 3.95	(1968JO07)
5.8 – 6.6	3.95	(1965SA18)
6.3	g.s.	(1969CO12)
6.6	3.95	(1964GR19)
6.8, 6.9	g.s., 3.95	(1958DA16)
7	g.s., 2.31, 3.95	(1956BR36)
9	g.s., 3.95	(1956GR37)
10.5 – 11.4	g.s.	(1960HU10)
11.4, 12.4	g.s., 3.95	(1965DO08)
14.5	g.s., 3.95	(1961YA07)
14.7	g.s.	(1961YA08)
14.9 – 19.6	g.s., 3.95	(1963YA1B)
15	g.s., 3.95	(1961PE09, 1965PE09)
15	g.s. $\rightarrow$ 7.97, 8.49, 8.91, 9.17 $\rightarrow$ 9.51, 10.09	(1969HO23)
19	g.s.	(1953FR23)
24	g.s., 3.95, 4.91 + 5.11, 5.69 + 5.83, 6.21 + 6.44, 7.03	(1965PE17)

See ^{18}F in (1972AJ02).

62. ^{19}F(d, ^{7}Li)^{14}N $Q_{\rm m} = -6.121$

See (1967DE03).

63. ^{20}Ne(d, 2α)^{14}N $Q_{\rm m} = -1.619$

See (1966KU1D).

^{14}O
(Figs. 7 and 8)

GENERAL:

See (1959OT1A, 1960PI1C, 1960TA1C, 1961FR1C, 1963BL1B, 1964LO1B, 1965KO1D, 1966BO1R, 1966KE16, 1966MI1G, 1967AU1B, 1968EI1C, 1968FA1B, 1968NE1C, 1969GA1G, 1969SO08).

1. ^{14}O(β^+)^{14}N $\qquad Q_{\rm m} = 5.144$

The decay proceeds primarily to the $J^\pi = 0^+; T = 1$ first excited state of ^{14}N: see Table 14.27. Weak branches are also observed to the ground state of ^{14}N and to the 3.95 MeV state.

The ground-state decay is considerably faster than the mirror transition ^{14}C $\rightarrow$ ^{14}N supporting the hypothesis that both decays are inhibited by accidental cancellation of matrix elements: see ^{14}C and (1968RO1C).

The decay of ^{14}N*(2.31) is an example of pure Fermi $0 \rightarrow 0$ transition and provides a precise determination of the fundamental coupling constant $G_{\rm V}$ (see surveys by (1964WU01, 1966FR15, 1968MO1F)). $G_{\rm V} = 1.4025 \times 10^{-49}$ erg$\cdot$cm^3 (1962BA26), 1.409×10^{-49} erg$\cdot$cm^3 (1968BR1L: see (1969DA06)), 1.407×10^{-49} erg $\cdot$ cm^3 (1969DA06). See also (1959KI1C, 1960BA36, 1967BL24, 1968BE03). According to the hypothesis of a universal weak interaction, with conserved vector current, $G_{\rm V} = G_\mu$, the coupling constant for muon decay. The mean for seven cases cited by (1966FR15) is $(G_\mu - G_{\rm V}/G_\mu = (2.2 \pm 0.1 \pm 0.5)$%, where the second error reflects the uncertainty of radiative corrections. See also (1962BA26, 1968BR1L, 1969BL1E, 1969DA06).

The transition to ^{14}N*(3.95) appears to be super allowed. See also (1962BR16, 1964GA1B, 1966FR15, 1966CH1J, 1966MAZY, 1969LO1F).

The polarization of the positrons has been studied by (1959GE36, 1961HO04). See also (1959AJ76) and (1958AL1E, 1959JA1B, 1960DU1B, 1961BL1A, 1962AL1F, 1962WE09, 1962WE1H, 1962BL1D, 1963LO04, 1964BA1T, 1965BL1E, 1964NA1C, 1965MI1B, 1966BA1A, 1966MA57, 1967CH24, 1967SA1H, 1968BH1C, 1968DA1J, 1968HA38, 1968LA1J, 1968YA1F).

2. ^{10}B(^{6}Li, 2n)^{14}O $\qquad Q_{\rm m} = 1.990$

See (1957NO17).

3. ^{12}C(^{3}He, n)^{14}O $\qquad Q_{\rm m} = -1.148$

Table 14.26: Energy levels of ^{14}O

E_x (MeV ± keV)	$J^\pi; T$	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
0	$0^+; 1$	$\tau_{1/2} = 70.98 \pm 0.06$ sec	β^+	1, 2, 3, 4, 5, 6, 7
5.17 ± 40	(1^-)	$\Gamma \leq 150$ keV		3, 5
5.905 ± 12	(0^+)	≤ 60		3, 5
6.29 ± 25	(3^-)	≈ 120		3, 4, 5
6.586 ± 12	2^+	≤ 60		3, 5
6.79 ± 30	$\pi = (-)$			5
7.78 ± 30	2^+			3, 4, 5
8.74 ± 60				5
(9.74 ± 30) [a]				3, 4, 5
10.89 ± 50				5
11.24 ± 50				5
(11.97) [a]				5
12.84 ± 50				5
13.01 ± 50				3, 5
14.15 ± 40				5
14.64 ± 60				5
17.40 ± 60				5

[a] Possibly more than one level.

Reported values of the threshold energy are displayed in Table 14.28. Neutron groups have been observed corresponding to ^{14}O states at 5.17 (1967AD1D, 1968TO09), 5.905 ± 0.012, 6.30 ± 0.03 and 6.586 ± 0.012 MeV, with widths ≤ 60, 120 and ≤ 60 keV, respectively (1961TO03). Higher excited states at 7.78 (1967AD1D), 8.0 ± 0.4, 10.1 ± 0.4 and 13.3 ± 0.4 MeV are reported by (1964BR13). Angular distributions are reported at many energies from 1.9 to 25 MeV: see (1957BR18, 1960AJ03, 1960GA13, 1963MA22, 1964DE1C, 1964DI02, 1964KU05, 1967AD1D, 1967MC03, 1967SC27, 1968TO09).

The angular distributions for n_0 and for p_1, to ^{14}N*(2.3), show strng forward peaking in the range $E(^3\text{He}) = 6.5$ to 11 MeV. The distributions are similar in detail, and well fitted by plane wave direct interaction theory with $L = 0$. Excitation functions at $\theta = 10^\circ$ show marked energy dependence, but $(d\sigma_n/d\sigma_p)$ is nearly constant at the expected value of 2.0 (1965FU16). Angular distributions (at $E(^3\text{He}) = 9.2$ and 10.2 MeV) of the ^{3}He groups to ^{14}O*(0, 5.17, 5.91, 6.29),

Table 14.27: Positron decay of ^{14}O

	(1954GE38, 1955SH84)	(1961HE03)	(1961BU04)	(1962BA26)	(1963FR10, 1965FR09)	(1965KAZX, 1966SI05)
E_0 [a] (keV)	4145 ± 20			4124 ± 2	4085 ± 30	
E_1 [a] (keV)	1835 ± 8	$[1810.6 \pm 1.5]$ [b]	1809.7 ± 1.5	1812.6 ± 1.4 [e]	1821 ± 7	
$\tau_{1/2}$ (sec)	72.1 ± 0.4	70.91 ± 0.04	$[71.4 \pm 0.2]$	71.00 ± 0.13	71.3 ± 0.1	
branch$_0$ (%) [a]	0.60 ± 0.10				0.65 ± 0.05	0.61 ± 0.01
branch$_1$ (%) [a]	99.4 ± 0.1	$[99.4 \pm 0.1]$	$[99.4 \pm 0.1]$	$[99.4 \pm 0.1]$	99.35 ± 0.05	
branch$_2$ (%) [a]						0.062 ± 0.007 [d]
ft_0 (sec)	$(2.0 \pm 0.3) \times 10^7$				$(1.7 \pm 0.2) \times 10^7$	$(2.14 \pm 0.03) \times 10^7$ [f]
ft_1 (sec)	3275 ± 75	3061 ± 10	3057 ± 20	3074 ± 10 [c]	3137 ± 70	3076 ± 7 [g]
ft_2 (sec)						1200 ± 150 [d]

[a] End-point enegies and branches, to ^{14}N(g.s.: 1^+; 2.31: 0^+; 3.95: 1^+), respectively.
[b] Square brackets indicate values used for ft-calculations but not determined in present experiment.
[c] Using τ(partial) $= [71.36 \pm 0.009]$ sec; includes form-factor and screening corrections. Radiative corrections of (1959KI1C) increase ft to 3126 sec: see also (1966BA1A, 1966FR15, 1967SU1E).
[d] And private communication: 0.025 β^+ (1969KA1B).
[e] 1809.1 ± 1.5 keV is obtained from measurements of the threshold energy of the ^{14}N(p, n)^{14}O reaction and the energy of ^{14}N*(2.31). This value leads to a 0.8% decrease in the ft value of (1962BA26, 1968FR08).
[f] $(1.9 \pm 0.2) \times 10^7$ (1969KA1B).
[g] (1969KA1B).

Table 14.28: Threshold energy of the ^{12}C(^{3}He, n)^{14}O reaction [a]

$E_{\rm thresh.}$ (keV)	Refs.
1449.6 ± 2.8	(1957BR18)
1436.2 ± 0.9	(1961BU04)
1434.8 ± 1.6	(1961TO06)
1437.5 ± 0.7	(1962BA26)
1436.7 ± 0.5	recommended value: (1966MA60)

[a] See also (1965RY01).

analyzed by DWBA double stripping theory, give $L = 0$; $L = 1$ or (0); $L = 0$ or (1); $L = 3$ or 4, respectively. These fits, taken together with the relatively sharp widths of the three excited states (see Table 14.25), lead to probable J^π for ^{14}O*(5.17, 5.91, 6.29) of 1^-, 0^+, 3^-, respectively (1968TO09). See also (1960NE1A, 1961GI1B, 1963GL1C, 1964HE06, 1965BR1H, 1966HA1Q, 1966SH1F, 1967CH19) and ^{15}O.

4. ^{14}N(p, n)^{14}O $\qquad Q_{\rm m} = -5.927$

$$E_{\rm thresh.} = 6.3544 \pm 0.0016 \text{ (1968FR08)};$$
$$E_{\rm thresh.} = 6.3588 \pm 0.0030 \text{ (1956KU1A; see also (1964KU06))}.$$

The angular distribution of ground state neutrons has been determined at $E_{\rm p} = 14.8$ and 31.5 MeV (1960DA06, 1961AD02). Neutron groups are reported corresponding to broad or unresolved states at $E_{\rm x} \approx 6.2$, 7.5 and 9.3 MeV (1954AJ11). See also (1966SI05, 1968RI1Q, 1969MA1G, 1969PA1J, 1969VE02).

5. ^{14}N(^{3}He, t)^{14}O $\qquad Q_{\rm m} = -5.163$

Triton groups observed at $E(^{3}{\rm He}) = 44.6$ MeV are displayed in Table 14.29. Comparisons of angular distributions of the tritons to the first eight states of ^{14}O with those of triton groups in other reactions involving known l-transfers lead to the J^π assignements quoted in the table (1967BA13, 1969BA06). See also (1968BA1E) and reaction 45 in ^{14}N.

6. ^{16}O(γ, 2n)^{14}O $\qquad Q_{\rm m} = -28.887$

Table 14.29: ^{14}O levels from ^{14}N(^{3}He, t)^{14}O (1967BA13)

E_x (MeV $\pm$ keV)	J^{π} [a]
0	0^+
5.17 ± 40	(1^-)
5.91 ± 40	(0^+)
6.28 ± 30	(3^-)
6.60 ± 30	2^+
6.79 ± 30	(2^-)
7.78 ± 30	2^+
8.74 ± 60	
9.74 ± 30	
10.89 ± 50	
11.24 ± 50	
11.97 [b]	
12.84 ± 50	
13.01 ± 50	
14.15 ± 40	
14.64 ± 60	
17.40 ± 60	

[a] See text.

[b] Unresolved states.

See (1959OC07, 1962BR16, 1964MO26).

7. ^{16}O(p, t)^{14}O $\qquad Q_m = -20.406$

The angular distribution of ground state protons has been determined at $E_p = 43.7$ (1964CE02). See also (1966CE05, 1969SO08).

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(Closed 31 December 1969)

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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