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ENERGY LEVELS OF LIGHT NUCLEI: A = 13*

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ABSTRACT

Preliminary draft of a compilation of information on energy levels and reactions involving ^{13}Be, ^{13}B, ^{13}C, ^{13}N, and ^{13}O.

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Dear Colleague:

The next sub-set of "Energy Levels of Light Nuclei" will comprise A = 13, 14, 15, and will hopefully be completed by the early Fall. In the meantime here is A = 13† in a preliminary version to which we hope that you will contribute advice, criticism and new information. Please send these to me at the address below.

Many thanks, and a Happy Spring!

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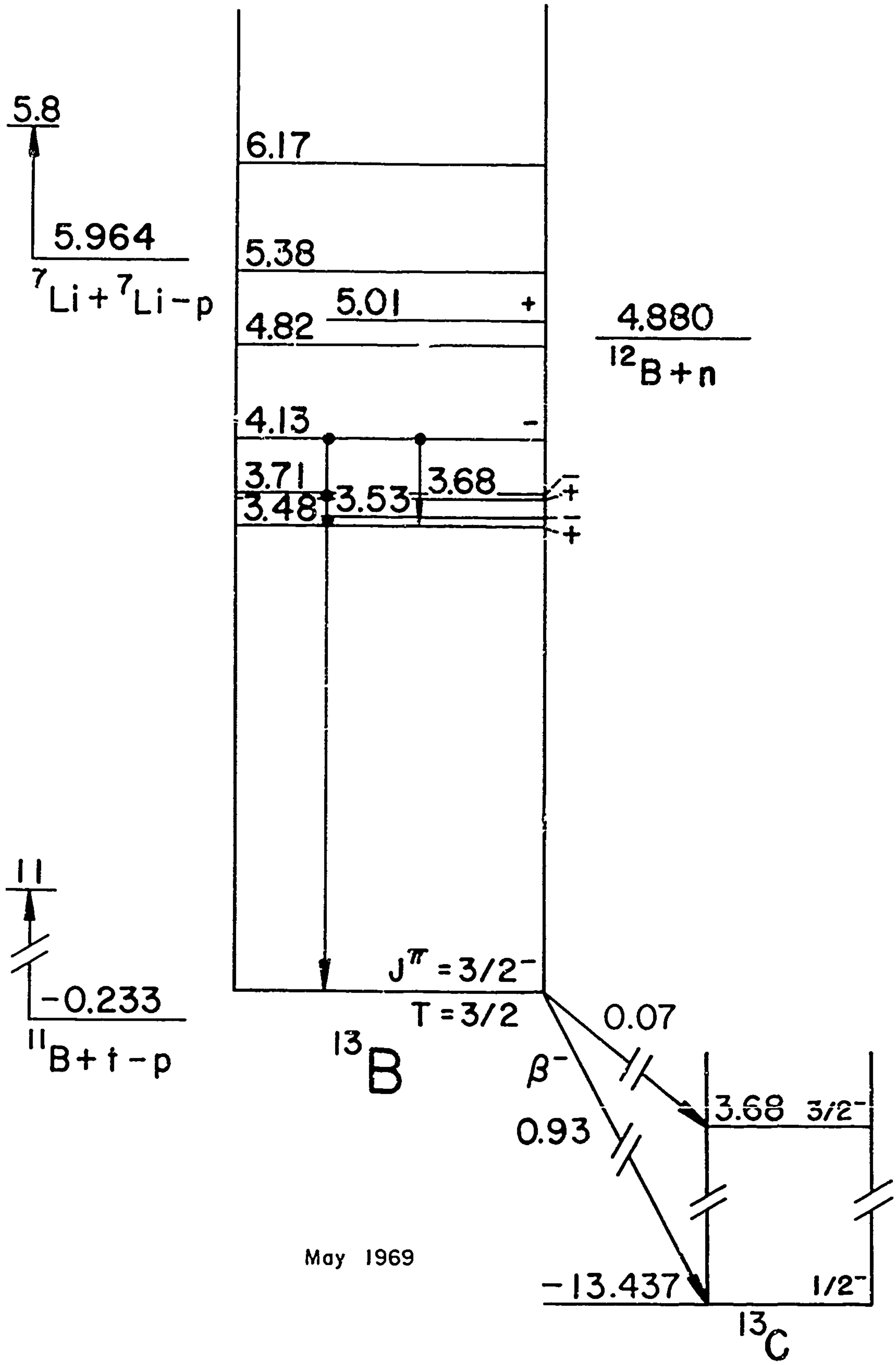
† As of ≈ December 1968.

^{13}Be

The light nuclei observed, by particle-identification techniques, to be emitted in the 5.5-GeV proton bombardment of uranium do not include ^{13}Be. It is therefore particle unstable (Po 68b). (Ga 66c) predict that ^{13}Be is unbound with respect to $^{12}Be + n$ by 2.70 MeV.



5.8
6.17
5.964
5.38
$^7Li + ^7Li - p$
5.01
4.82
4.880
$^{12}B + n$
4.13
3.71
3.68
3.53
3.48
11
$J^{\pi} = 3/2^-$
-0.233
$T = 3/2$
0.07
$^{11}B + t - p$
^{13}B
β^-
3.68 $3/2^-$
0.93
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−13.437
$1/2^-$
^{13}C

^{13}B

General: See (Ta 601, Mo 66).

1. $^{13}B(\beta^-)^{13}C$ $\qquad Q_m = 13.437$

The half-life of ^{13}B is 18.6 ± 0.5 msec. (A determination relative to ^{12}B gives 17.6 ± 0.4 msec.) The characteristics of the β^- decay are shown in Table 13.2. The allowed decay to ^{13}C ($1/2^-$, $3/2^-$) indicates $J^\pi = 1/2^-$ or $3/2^-$; the expected decay to ^{13}C ($5/2^-$) is not observed (Ma 62d). See also (Po 65b) and (Aj 59).

2. $^{7}Li(^{7}Li,p)^{13}B$ $\qquad Q_m = 5.964$

Proton groups have been observed to five states of ^{13}B: see Table 13.2 (Mo 59e, Ca 63d). Angular distribution measurements have been reported by (Wy 67a) in the range $E(^{7}Li)$ = 2.1 to 5.8 MeV. See also (Be 62m), (Aj 59) and ^{14}C.

3. $^{11}B(t,p)^{13}B$ $\qquad Q_m = -0.233$

$$Q_o = -0.233 \pm 0.004 \text{ MeV (Mu 60a)}$$

At E_t = 11 MeV, proton groups are observed to ten states of ^{13}B: see Table 13.2. Angular distributions have been analyzed for seven of the ^{13}B levels (Mi 64e). The ground state is formed by L = 0 transfer, leading to an unambiguous assignment of $J^\pi = 3/2^-$. See also (Ja 60b, Ma 62d). See also (Ba 67hh).

Table 13.1. Energy Levels of ^{13}B

E_x (MeV ± keV)	$J^\pi;T$	$\tau_{1/2}$ (msec)	Decay	Reactions
0	$3/2^-;3/2$	18.6 ± 0.5	β^-	1,2,3
3.483 ± 5	$(1/2 \rightarrow 5/2)^+$		γ	2,3
3.533 ± 5	$(1/2,5/2,7/2)^-$		γ	2,3
3.681 ± 5	$(1/2 \rightarrow 5/2)^+$		γ	2,3
3.712 ± 5	$(1/2,5/2,7/2)^-$		γ	2,3
4.13 ± 10	$(1/2,5/2,7/2)^-$		γ	2,3
4.82 ± 10				3
5.01 ± 10	$(1/2 \rightarrow 5/2)^+$			2,3
5.38 ± 10		Γ = 15 ± 5 keV		2,3
6.17 ± 20				3

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Table 13.2. Beta decay of ^{13}B (Ma 62d)

Decay to $^{13}C^*$ (MeV)	Branch (%)	log ft	E_{β^-} (max)
0	93 ± 1.5	4.01	13.4 ± 0.2
3.09	≤ 0.7	≥ 5.7	
3.68 [a]	7 ± 1.5	4.53	
3.85	≤ 0.7	≥ 5.5	
7.47 [b]	≤ 1.5	≥ 4.2	

[a] The observed E_γ = 3.67 ± 0.02 MeV.

[b] Decay to neutron unstable states of ^{13}C is ≤ 1.5% (Ma 62d); < 0.3% (Po 65b).

Table 13.3. Proton groups from $^{7}Li(^{7}Li,p)^{13}B$ and $^{11}B(t,p)^{13}B$

$^{7}Li(^{7}Li,p)^{13}B$ (Mo 59e, Ca 63d) E_x (MeV ± keV)	$^{11}B(t,p)^{13}B$ (Mi 64e) E_x (MeV ± keV)	L	J^{π}
0	0	0[d]	$3/2^-$
	3.483 ± 5	1	$1/2^+,3/2^+,5/2^+$
3.50 ± 50[a]			
	3.533 ± 5	2	$1/2^-,5/2^-,7/2^-$
	3.681 ± 5	1	$1/2^+,3/2^+,5/2^+$
3.70 ± 50[b]			
	3.712 ± 5	2	$1/2^-,5/2^-,7/2^-$
4.16 ± 50[c]	4.13 ± 10	2	$1/2^-,5/2^-,7/2^-$
	4.82 ± 10		
5.05 ± 80	5.01 ± 10	1	$1/2^+,3/2^+,5/2^+$
5.5 ± 100	5.38 ± 10[e]		
	6.17 ± 20		

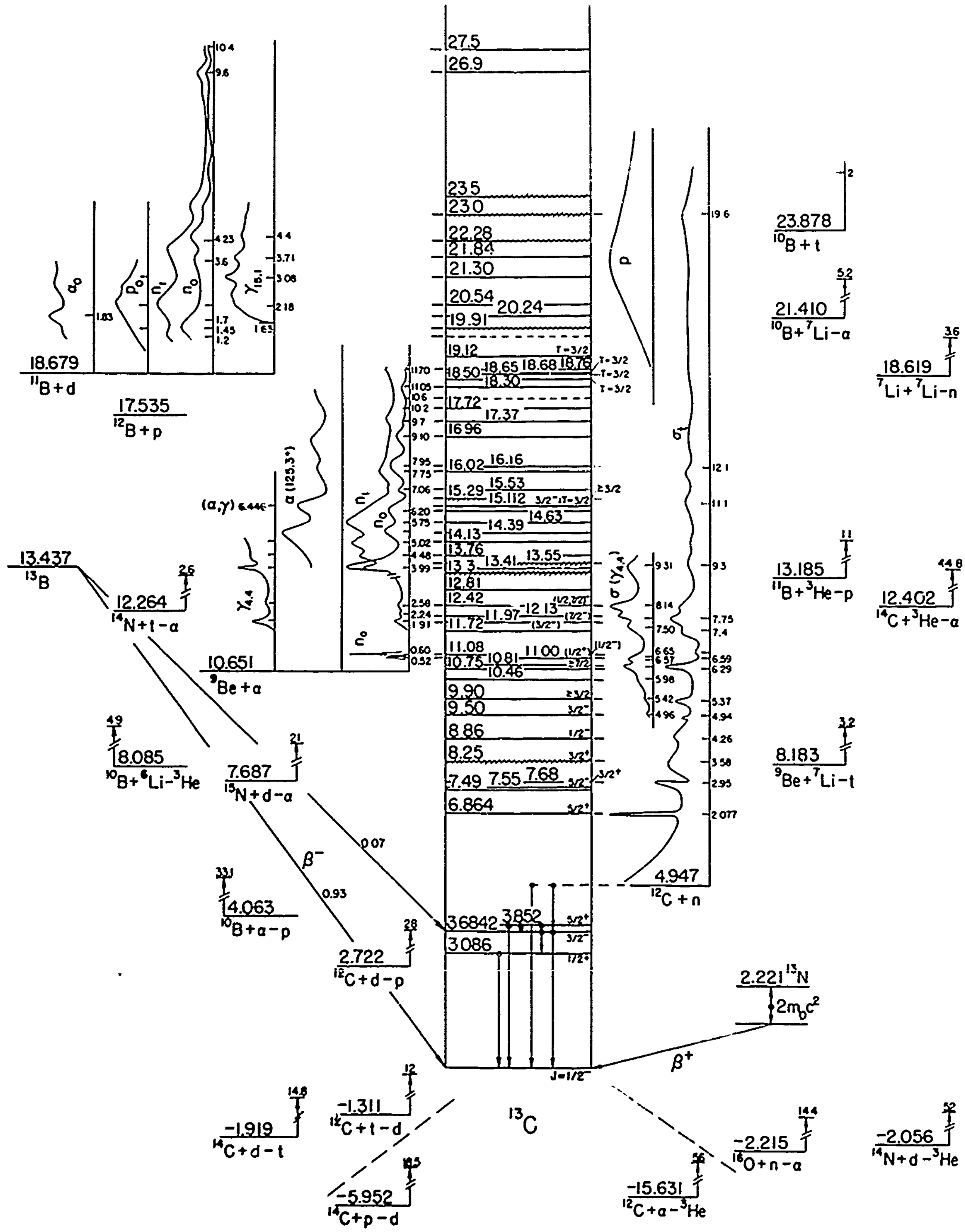
a The decay is by γ-emission to ^{13}B (0).

b The decay is primarily by γ-emission to the ground state: the upper limit to the cascade via ^{13}B (3.5) is 10%.

c The decay is 75 ± 10% to the ground state, 25 ± 10% to ^{13}B (3.5) and < 10% to ^{13}B (3.7).

d See also (Mu 60a).

e Γ = 15 ± 5 keV.



27.5
26.9
23.5
23.0
22.28
21.84
21.30
20.54
20.24
19.91
19.12
18.50
18.65
18.68
18.76
18.30
17.72
17.37
16.96
16.02
16.16
15.29
15.53
15.112
14.63
14.39
14.13
13.76
13.3
13.41
13.55
12.81
12.42
11.97
12.13
11.72
11.08
10.81
11.00
10.75
10.46
9.90
9.50
8.86
8.25
7.49
7.55
7.68
6.864
3.6842
3.852
3.086
J=1/2⁻
18.679
¹¹B+d
17.535
¹²B+p
13.437
¹³B
12.264
¹⁴N+t-α
10.651
⁹Be+α
8.085
¹⁰B+⁶Li-³He
7.687
¹⁵N+d-α
4.063
¹⁰B+α-p
2.722
¹²C+d-p
-1.311
¹²C+t-d
-1.919
¹⁴C+d-t
-5.952
¹⁴C+p-d
23.878
¹⁰B+t
21.410
¹⁰B+⁷Li-α
18.619
⁷Li+⁷Li-n
13.185
¹¹B+³He-p
12.402
¹⁴C+³He-α
8.183
⁹Be+⁷Li-t
4.947
¹²C+n
2.221 ¹³N
2m₀c²
-2.215
¹⁶O+n-α
-2.056
¹⁴N+d-³He
-15.631
¹²C+α-³He
β⁻
β⁺
0.07
0.93
¹³C

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^{13}C

General

Model calculations: (Br 59m, Ph 60a, Ta 60l, Ze 60, Ba 61l, Ba 61n, Ku 61a, Ku 61e, Ne 61c, Ea 62, Bo 63j, Ma 63s, Pe 63a, Se 63n, Tr 63, Am 64, Na 64a, St 64, Co 65i, Ma 65o, Me 65b, Ne 65, We 65d, El 66b, Gu 66d, Ha 66f, Ma 66s, No 66, Ri 66f, Wi 66e, Ba 67jj, Co 67m, Fa 67a, Hu 67c, Ku 67j, Po 67g, Ri 67j, Wa 67i, Fi 68, Ho 68)

Other: (Ba 62p, Li 64i, Bo 65e, He 66d, Ol 66b, Ri 68i, Wi 68b)

Ground state

μ = +0.702381 n.m. (Li 64h; see also (La 58d, Co 67r, Be 64l, Be 63t))

Table 13.4. Energy Levels of ^{13}C

E_x in ^{13}C (MeV ± keV)	$J^{\pi};T$	Γ(keV) or τ_m	Decay	Reactions
0	$1/2^-$	stable	-	2,3,4,9,10,12,13,14,15,16,21,22,23,24,25, 31,32,33,34,35,36,41,42,43,44,45,46,47, 48,49,50,51,52,53,54,55,56,57,59,60,61, 62,63,64,65
3.086±3	$1/2^+$	1.5±0.2 fsec	γ	9,12,13,14,22,24,31,32,37,42,45,49,50,54, 55,59,60,62
3.68415±0.11	$3/2^-$	1.4±0.2 fsec	γ	9,12,13,14,22,24,25,31,32,34,36,37,39,45, 49,50,51,52,54,55,59,60,62
3.854±2	$5/2^+$	$(9.0^{+2.5}_{-1.5})$ psec	γ	9,12,13,14,22,24,31,32,45,49,50,54,55, 59,60,62
6.864±3	$5/2^+$	6 kev	n	9,14,22,24,26,31,54,55,59,60
7.492±10		< 5		9,14,22,24,31,45,50,54,55,60
7.549±9	$5/2^-$	< 5		9,14,22,24,31,45,50,54,55,59,60
7.677±12	$3/2^+$	72±10	n	9,14,22,24,26,31,37,45,55,60
8.25±80	$3/2^+$	1000±200	n	26,31
8.858±14	$1/2^-$	155±20	n	22,24,26,37,54,55,59,60
9.504±7	$3/2^-$	< 10	n	14,22,24,26,27,31,54,55,59,60
9.896±10	≥ 3/2	≤ 30	n	14,22,24,26,27,31,55,60
10.46		200	n	14,27
10.748±14	≥ 7/2	$\lesssim$ 50	n	22,26,27,31,55
10.809±20		< 30	n	22,26,27,37,55
11.000±20	$(1/2^+)$	$\lesssim$ 50	n,α	5,22,26 27,37,55
11.078±20	$(1/2^-)$	< 4	n,α	5,14,22,26,27,55,59
11.721±30	$(3/2^-)$	125±20	n,α	26,27,37,55
11.97	$(7/2^-)$	≈ 150	n,α	5,14,27,54,55

Table 13.4 (continued)

12.131±30		125±30	n,α	5,14,22,26,27,55
12.42±50	$(1/2,7/2)^-$	≈ 200	n,α	5,26,27,30,59
12.81±100				22
13.3		5±1 MeV	"	38
13.41		60 keV	n,α	5,14
13.55		≈ 500	n,α	5,26,27
13.76		≈ 350	n,α	5
14.13		≈ 200	n,α	5
14.39±100		260	n,α	5
14.63		210	n,α	5
14.95±50		380	n,α	5
15.112±5	$3/2^-$;T=3/2	≤ 5	γ,α	4,5,22,41,51,59
15.29	≥ 3/2	450	n,α	5,26
15.53±50		220	n,α	5
16.02		210	n,α	5,14
16.16±50		230	n,α	5,14,26
16.96±50		330	n,α	5
17.37±100		190	n,α	5
17.72±50		170	n,α	5
(17.99)		40	n,α	5
18.30±50		300	n,α	5
18.504±25	T=3/2			22
18.648±15	T=3/2	≈ 35		22
18.679±20	T=3/2			22
18.76±30		70	n,α	5
19.123±10	T=3/2	≈ 35		22
(19.7)			n,d	17

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Table 13.4 (concluded)

19.90	≈ 600	n,p,d	17,18
20.24	≈ 200	n,d,α	17,20
20.54±10	116±10	n,p,d	17,18
21.30±15	159±15	n,p,d	17,18
21.84±20	114±20	n,d	17
22.28	broad	n,p,d	17,29
23.0±200	~ 1 MeV	n,d	17,26
23.5	~ 3 MeV	γ,p	38
26.9		n,d	17
27.5		n,d	17

1. (a) $^{6}Li(^{7}Li,n)^{12}C$ $Q_m = 20.924$ $E_b = 25.871$
(b) $^{6}Li(^{7}Li,p)^{12}B$ $Q_m = 8.337$
(c) $^{6}Li(^{7}Li,2n)^{11}C$ $Q_m = 2.204$
(d) $^{6}Li(^{7}Li,d)^{11}B$ $Q_m = 7.192$
(e) $^{6}Li(^{7}Li,t)^{10}B$ $Q_m = 1.994$
(f) $^{6}Li(^{7}Li,\alpha)^{9}Be$ $Q_m = 15.220$

Differential and total cross sections have been measured for $E(^{7}Li) = 3.8$ to 6.0 MeV for the proton groups to $^{12}B^{*}$ (0, 0.95, 1.67, 2.6 + 2.7, 3.4), the deuteron groups to $^{11}B^{*}$ (0, 2.14, 4.44, 5.02, 6.74 + 6.79, 7.30), the triton groups to $^{10}B^{*}$ (0, 0.72, 1.74) and the α group to ^{9}Be (0). The dominant reaction appears to be the transfer of an α-particle. The total cross sections generally increase smoothly with energy without showing any structure (Ki 67a). See also ^{9}Be and ^{10}B in (La 66) and ^{11}B and ^{12}B in (Aj 68). The ^{11}C yield has been measured for $E(^{6}Li) = 1.2$ to 3.6 MeV by (No 61). See also (No 57a, Ga 63g, Ka 63h, Ga 64c, Be 65a).

2. $^{7}Li(^{7}Li,n)^{13}C$ $Q_m = 18.619$

See (No 57a, Be 62m).

3. $^{7}Li(^{11}B,\alpha n)^{13}C$ $Q_m = 9.954$

See (Ho 63c).

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4. $^{9}Be(\alpha,\gamma)^{13}C$ $Q_m = 10.651$

At $E_\alpha = 6.446 \pm 0.004$ MeV, corresponding to the excitation of the first T = 3/2 state in ^{13}C ($E_x = 15.114 \pm 0.005$ MeV, $\Gamma \le 7$ keV), $\Gamma_\alpha\Gamma_\gamma/\Gamma \sim 2$ eV for the ground state transition. Capture radiation has also been observed to one of the three states $^{13}C^*$ (3.1, 3.7, 3.9) (Mi 66).

5. $^{9}Be(\alpha,n)^{12}C$ $Q_m = 5.704$ $E_b = 10.651$

Resonances for neutron groups to the ground and first excited states of ^{12}C, for γ-rays from $^{12}C^*$ (4.4) and resonances in the total neutron cross section are given in Table 13.5 (Aj 59, Se 63b, Gi 65, Gr 65h, Mi 66d, Da 68X. DaGSG, Fo67I.). See also ^{12}C in (Aj 68) and (Sm 59a, Br 59l, Ve 68). The yield of neutrons to $^{12}C^*$ (7.65) has been measured for E_α = 6 to 10.1 MeV (Mi 66d). Angular distributions of ground-state neutrons suggest two broad resonances in the region E_α = 3.9 to 4.6 MeV, probably $J^\pi = 3/2^+$ and $5/2^+$ (Ri 57). At the threshold for formation of the T = 3/2 state at 15.11 MeV, weak interference anomalies are observed in the n_0 and n_1 yields (Mi 66).

Polarization measurements have been carried out for E_α = 1.9 to 4.5 MeV by (Li 65c: n_0 and n_1) and for 4.5 to 5.9 MeV by (Do 66, De 67i: n_0, n_1). See also (Go 62p, Go 63l, Cl 65, Ts 65, Da 66k, De 66g).

6. $^{9}Be(\alpha,p)^{12}B$ $Q_m = -6.884$ $E_b = 10.651$

See ^{12}B.

Table 13.5. Resonances in $^{9}Be(\alpha,n)^{12}C$

E_{α} [a] (MeV)	E_{α} [b] (MeV)	E_{α} [c] (MeV)	$\Gamma_{c.m.}$ (keV)	J^{π}	$^{13}C^{*}$ [d] (MeV)	References
0.52	0.52		≈ 55 [e]	$(1/2^{+})$	11.01	(Ja 56a, Da 68)
0.60	0.60		< 4 [e]		11.06	(Da 68)
1.9	1.905	1.92	130	$(7/2^{-})$	11.97	(Ta 53, Be 54, Ta 55b, Bo 56d, Gi 65, Ja 56a)
2.24		2.25	280		12.20	(Bo 56d, Gi 65)
2.58	2.6	2.58	≈ 200	$(1/2^{-})$	12.44	(Ta 53, Bo 56d, Ja 56a, Gi 65, Gr 65h)
4.00	3.98	4.00	60		13.41	(Bo 56d, Gi 59, Se 63b, Gi 65, Gr 65h)
4.18			570		13.55	(Ri 57, Gr 65h)
4.50	4.47	4.50	≈ 350		13.76	(Bo 56d, Gi 59, Se 63b, Gi 65, Gr 65h)
5.0	5.02	5.0	≈ 200		14.13	(Bo 56d, Se 63b, Gi 65, Gr 65h)
5.40±0.10	5.3		260		14.39±0.10	(Se 63b, Gr 65h, Mi 66d)
	5.75	5.75	210		14.63	(Gi 59, Se 63b, Gi 65, Gr 65h, Mi 66d)
6.20±0.05			380		14.95±0.05	(Gr 65h)
		(6.7)	broad		(15.29)	(Gi 65)
7.10±0.05	7.00		220		15.53±0.05	(Se 63b, Gr 65h, Mi 66d)
	7.75	7.8	210		16.02	(Gi 59, Se 63b, Gi 65, Gr 65h)
7.95±0.05			230		16.16±0.05	(Gr 65h, Mi 66d)
9.10±0.05		9.1	330		16.96±0.05	(Gi 65, Gr 65h, Mi 66d)
9.7 ±0.10	9.70		190		17.37±0.1	(Gr 65h, Mi 66d)
10.2±0.05			170		17.72±0.05	(Gr 65h, Mi 66d)
(10.60)			40		(17.99)	(Gr 65h)
11.05±0.05			300		18.30±0.05	(Gr 65h, Mi 66d)
11.70±0.03	11.60		70		18.76±0.03	(Gr 65h, Mi 66d)

Table 13.5 (concluded)

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[a] Resonances in neutron yield.

[b] Resonances in n_1 group and for 4.4 MeV γ-rays.

[c] Resonances in total cross section.

[d] Not corrected for effects of Coulomb barrier penetration.

[e] $\omega\gamma$ = 3.79 and 0.88 eV, respectively (Da 68).

7. $^{9}Be(\gamma,d)^{11}B$ $Q_m = -8.028$ $E_b = 10.651$

See ^{11}B.

8. (a) $^{9}Be(\alpha,\alpha)^{9}Be$ $E_b = 10.651$

(b) $^{9}Be(\alpha,\alpha'n)^{8}Be$ $Q_m = -1.665$

(c) $^{9}Be(\alpha,n)3\,^{4}He$ $Q_m = -1.570$

A number of excitation functions have been measured for elastically scattered alpha particles (reaction a) for E_α = 4 to 20 MeV: these show considerable resonance structure with the variations being most prominent below 10 MeV but persisting up to 20 MeV. Angular distributions were analyzed by the optical model (Ta 65b). See also ^{9}Be in (La 66) and (Fu 67i). For reactions (b) and (c), see (Aj 52c) and ^{8}Be in (La 66). See also (Ig 63).

9. $^{9}Be(^{7}Li,t)^{13}C$ $Q_m = 8.183$

At $E(^{7}Li)$ = 3.2 MeV, triton groups are observed to the first eight states of ^{13}C (not all resolved). No triton groups are observed to the previously reported states at 5.51 and 6.10 MeV (Ca 64a).

10. $^{9}Be(^{14}N,^{10}B)^{13}C$ $Q_m = -0.963$

See (Gr 65s) and (El 66).

11. (a) $^{10}B(t,p)^{12}B$ $Q_m = 6.343$ $E_b = 23.878$

(b) $^{10}B(t,d)^{11}B$ $Q_m = 5.199$

(c) $^{10}B(t,\alpha)^{9}Be$ $Q_m = 13.227$

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The p_o and p_1 yields from reaction (a), the d_o yield from reaction (b) and the α_o yield from reaction (c) have been determined for E_t = 0.8 to 2.0 MeV. There is no evidence of resonance behavior (Ho 63k).

12. $^{10}B(\alpha,p)^{13}C$ $Q_m = 4.063$

$$Q_o = 4.0634 \pm 0.0024 \text{ (Od 67)}$$

Proton groups have been observed to the first four states of ^{13}C: see (Aj 59) and (Ed 62). Angular distributions of ground state protons have been measured at E_α = 4.9 to 8.1 MeV (Vo 57), 12.1 to 16.0 MeV (Iv 67a), 22 MeV (Ya 63a), 25.9 MeV (Te 63), 27.5 and 33.1 MeV (Ya 61) and at 30.4 MeV (Hu 59). See also (Ni 65a).

A study of gamma rays from this reaction and from $^{12}C(d,p)^{13}C$ shows three lines with $E_\gamma = 0.1695 \pm 0.0004$, 3.844 ± 0.015 and 3.69 ± 0.02 MeV. The lifetime of $^{13}C^*$ (3.85) is $(9.0 {}^{+2.5}_{-1.5})$ psec (Ri 68h). See also (Di 59). The 3.69-MeV line shows approximately the maximum possible Doppler shift ($\tau < 3 \times 10^{-13}$ sec). [See also Table 13.16.] The 170-keV line is due to the cascade transition between the 3.84 and 3.68-MeV states; the internal conversion coefficient is consistent with E1, although M1 cannot be excluded. The probability of this cascade decay of the 3.84-MeV state is 0.24 ± 0.05 (Ma 56f). The cascade decay via the 3.09 MeV state has a strength relative to all other decays of $(9.3 \pm 2.0) \times 10^{-3}$. This branching ratio is of the order expected for an E2 transition of single-particle (proton) strength (Pi 60a). The angular distributions and p-γ correlations for the 3.8-MeV radiation indicate $J^{\pi} = 5/2^{+}$ for the 3.84-MeV state. If the 170-keV line is due to an E1 transition, the J^{π} of the 3.68-MeV state is then $3/2^{-}$ ($J^{\pi} = 1/2^{-}, 3/2^{-}$ follows from $^{12}C(d,p)^{13}C$); the angular distribution of the 3.68-MeV radiation is consistent with M1 (St 54c): $\Gamma_{\gamma} = 0.40$ to 0.75 eV (Ka 60g). The 3.68-MeV state also decays via the 3.09-MeV state with a probability of $(6.5 \pm 1.0) \times 10^{-3}$ (Ka 60g). See also (El 60).

13. $^{10}B(^{6}Li,{}^{3}He)^{13}C$ $Q_m = 8.085$

The first four states of ^{13}C have been observed at $E(^{6}Li) = 4.89$ MeV (Mc 66a). See also (Ca 65e).

14. $^{10}B(^{7}Li,\alpha)^{13}C$ $Q_m = 21.410$

At $E(^{7}Li) = 5.20$ MeV, angular distributions have been measured for the α-particles to $^{13}C^{*}$ (0, 3.1, 3.7 + 3.9, 6.9). Alpha groups have also been observed to $^{13}C^{*}$ (7.5 + 7.7, 9.5, 9.9, 10.5, 11.1, 12, 13.5, 16.1) (Mc 66a). See also (Mi 63b, Mo 63j, Ca 65e).

15. (a) $^{10}B(^{14}N,{}^{11}C)^{13}C$ $Q_m = 1.143$

(b) $^{10}B(^{19}F,4\alpha)^{13}C$ $Q_m = -2.257$

For reaction (a) see (Co 66k); for reaction (b) see (Ho 63o).

16. $^{11}B(d,\gamma)^{13}C$ $Q_m = 18.679$

See (Su 61, Su 63, Su 66).

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17. $^{11}B(d,n)^{12}C$ $Q_m = 13.732$ $E_b = 18.679$

The yield of neutrons has been measured for $E_d = 0.2$ to 11 MeV: observed resonant structure is displayed in Table 13.6 (Al 65h). See also (Aj 59, Ne 59, Cl 65d, Si 65, Hu 66). The yield of 15.1 MeV γ-rays shows 4 resonances for $E_d = 1.5$ to 5.5 MeV: see Table 13.6 (Ka 58a, Ku 64i). See also (Ki 63, Le 67g). Polarization of the neutrons has been studied at $E_d = 1.4$ to 1.9 (Ma 66z: n_o, n_1), 2 (Mi 67a: n_o, n_1, n_2, n_3, n_7), 2.8 (Ch 64f: n_o, n_1), 2.8 to 4.0 (Me 67f: n_o, n_1), 3.0 (Br 66dd: n_o), and 12.3 MeV (Sm 64a: n_o, n_1). See also (Br 59l) and ^{12}C.

18. $^{11}B(d,p)^{12}B$ $Q_m = 1.144$ $E_b = 18.679$

It is reported that the thin-target yield rises smoothly from $E_d = 0.3$ to 3.1 MeV with no evidence of resonances (Hu 49j, Ka 58a, Ro 63j, Sa 65g). However (Br 64k) reports a strong resonance at $E_d = 2.3$ MeV in the p_o, p_1 and p_2 yield. Analysis of yield curves of 0.95 and 1.67 MeV γ-rays (Ch 68b) also suggest a broad resonance at $E_d \sim 2.1$ MeV. See also (Se 63i). The polarization of ^{12}B recoils has been studied for $E_d = 0.9$ to 3.2 MeV: resonances in the recoil polarization are observed at $E_d \approx 1.5$, 2.1 and 3.0 MeV (see Table 13.6) (Pf 67a). See also (Be 67d). See also ^{12}B and (Ti 64a, Bo 67p, Ti 67a).

19. $^{11}B(d,d)^{11}B$ $E_b = 18.679$

See ^{11}B and (Ne 63h).

Table 13.6. Resonant Structure in $^{11}B + d$

Resonant Structure in Yield of								
n_o [a]	n_1 [a]	n_2 [a]	n_3 [a] (MeV ± keV)	$\gamma_{15.1}$ [b]	p	α [d]	Γ_{cm} (keV)	E_x (MeV)
	1.2							19.7
1.45					1.5[f]		≈ 600	19.90
1.6	1.8[e]					1.83	≈ 200	20.24
	2.2[e]			2.180 ± 10	2.2[c,f]		116 ± 10	20.54
				3.080 ± 15	3.0[f]		159 ± 15	21.30
3.6				3.71 ± 20			114 ± 21	21.84
4.23	4.1	4.1		4.4			broad	22.28
	(5.2)							(23.1)
9.6	9.6	9.6	9.6					26.9
10.4		10.4	10.4					27.5

a (Al 65h, Di 67b).

b (Ka 58a, Ku 64i).

c Yield of p_o, p_1 and p_2 (Br 64k).

d Yield of α_o and α_2 (Du 64c); $\Gamma_{cm} \sim 200$ keV.

e (Al 65h) report a resonance at 1.8 MeV while (Di 67b) report one at 2.2 MeV, in addition to a sharper structure at 1.2 MeV.

f Resonances in polarization of ^{12}B recoils (Pf 67a).

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20. $^{11}B(d,\alpha)^{9}Be$ $Q_m = 8.028$ $E_b = 18.679$

The excitation function for α particles to the ground state increases monotonically for $E_d = 0.39$ to 1.05 MeV (Ro 63j, Sa 65g); that for the α particles to $^{9}Be^*$ (2.43) increases monotonically for $E_d = 0.39$ to 0.70 MeV (Sa 65g). At $E_d = 1.83$ MeV, a pronounced resonance is observed in the α_o and α_2 yield: $\Gamma_{cm} \sim 200$ keV (Du 64c). Some gross structure is observed in these two yields for $E_d = 1.2$ to 3.2 MeV (Br 64k). See also (Dr 66e) and ^{9}Be in (La 66).

21. $^{11}B(t,n)^{13}C$ $Q_m = 12.422$

See ^{14}C.

22. $^{11}B(^{3}He,p)^{13}C$ $Q_m = 13.185$

$Q_o = 13.1854 \pm 0.0040$ (Od 67); see also (Ma 64ii)

Levels derived from reported proton groups are listed in Table 13.7. The proton groups thought to correspond to ^{13}C levels at $E_x = 5.51$ and 6.10 MeV (Mo 58f) come instead from the proton decay of $^{13}N^*$ (9.48, 10.37) fed in the reaction $^{11}B(^{3}He,n)^{13}N$ (Ch 66j). See also (Ga 63). At $E(^{3}He) = 8$ to 12 MeV, proton groups are observed to the first five $T = 3/2$ states of ^{13}C: see Table 13.7 (He 65d, He 66b). The angular distribution of the protons to the first $T = 3/2$ state at $E_x = 15.106$ MeV are consistent with $J^{\pi} = 3/2^-$ (the known character of ^{13}B (g.s.)) (He 65d). Preliminary results for the "isospin forbidden" neutron decay of ^{13}C (15.10) to ^{12}C (0, 4.4) are $\Gamma_{n_0}/\Gamma = 0.041 \pm 0.015$ and $\Gamma_{n_1}/\Gamma = 0.23 \pm 0.03$ (Ad 67d): Compare $^{11}B(^{3}He,n)^{13}N$. ~~this is a violation of mirror symmetry~~. Other angular distributions have been measured at $E(^{3}He) = 4.5$ MeV (Ho 57b; p_0, p_1, $(p_2 + p_3)$), and 8.6, 9.6 and 10.3 MeV (Ma 63g; p_0). See also (Al 59b, Cl 63a).

23. $^{11}B(\alpha,d)^{13}C$ $\qquad Q_m = -5.168$

Differential cross sections of deuterons corresponding to ^{13}C (0) have been measured at $E_\alpha = 23$ and 25 MeV (Al 68a). See also (Ze 68).

24. $^{11}B(^{6}Li,\alpha)^{13}C$ $\qquad Q_m = 17.207$

Angular distributions have been measured at $E(^{6}Li) = 4.72$ MeV to the ^{13}C ground state and to $^{13}C^*$ (3.1, 3.8 (unres.), 6.9, 7.5 (unres.)). The ^{13}C states at 8.85, 9.51 and 9.90 MeV have also been observed (Mc 66a). See also (Mo 63j, Ca 65e).

25. $^{12}C(n,\gamma)^{13}C$ $\qquad Q_m = 4.947$

$Q_0 = 4.94603 \pm 0.00015$ (Sp 68)

$Q_0 = 4.94647 \pm 0.00017$ (Pr 67d)

$Q_0 = 4.947 \pm 0.001$ (Ja 65k)

The thermal capture cross section is 3.4 ± 0.3 mb (St 64i). Reported γ-transitions are listed in Table 13.8. See also (Ma 63c). Fo 67I

Table 13.7. Levels of ^{13}C from $^{11}B(^{3}He,p)^{13}C$

E_x (MeV ± keV)	Γ_{cm} (keV)	References
0		(Mo 58f, Bi 55, Ga 63)
3.09		(Mo 58f, Bi 55, Ga 63)
3.68	< 5	(Mo 58f, Bi 55, Ga 63)
3.86	< 5	(Mo 58f, Ga 63)
6.871 ± 12	< 10	(Yo 59a, Ga 63)
7.500 ± 12	< 5	(Yo 59a, Ga 63)
7.554 ± 12	< 5	(Yo 59a, Ga 63)
7.694 ± 14	75 ± 15	(Yo 59a, Ga 63)
8.869 ± 36	175 ± 50	(Yo 59a)
9.509 ± 12	< 10	(Yo 59a)
9.896 ± 12	< 10	(Yo 59a)
10.9 ± 150		(Ga 57)
11.1 ± 150		(Ga 57)
12.08 ± 100		(Ga 57)
12.81 ± 100		(Ga 57)
15.106 ± 10[a]	≤ 5	(He 65d)
18.504 ± 25[a]		(He 66b)
18.648 ± 15[a]	~ 30-40	(He 66b)
18.679 ± 20[a]		(He 66b)
19.123 ± 10[a]	~ 30-40	(He 66b)

[a] It is suggested that these states have T = 3/2 (He 65d, He 66b).

Table 13.8. Neutron capture gamma rays in ^{13}C

E_γ (MeV ± keV)	Transition	Intensities [a] A	B	C	D
4.9458 ± 0.6	capt. → g.s.	68 ± 1			
4.94546 ± 0.17 [b]	"				
4.948 ± 8 [c]	"		70		
4.950 ± 15	"			75	
4.946	"				69
3.68428 ± 0.14	3.68 → g.s.	32 ± 1			
3.68394 ± 0.17 [b]	"				
3.68 ± 50	"		30		
3.68 ± 20	"			25	
3.680	"				31
1.26176 ± 0.07	capt. → 3.68	32 ± 1			
1.26192 ± 0.06 [b]					
1.260 ± 15				25	
1.27					30

[a] Gamma rays per 100 captures.

[b] (Pr 67d).

A: (Sp 68)

B: (Ba 53d); intensities of 3.1 and 3.9 MeV γ-rays < 10 and < 6, respectively.

C: (Gr 58a).

D: (Ja 61n).

[c] E_γ = 4.946 ± 1 (Ja 65k).

26. $^{12}C(n,n)^{12}C$ $E_b = 4.947$

The total cross section data up to 164 MeV is summarized in (St 64i). Angular distributions are summarized in (Go 63h). See also (Ga 66j, La 67q). The coherent scattering length (thermal, bound) is 6.6 Fm (Wi 61h). See also (Da 66k).

In the region E_n = 0 to 20 MeV a number of resonances have been reported: see Table 13.9 (Ts 60, La 61, Fo 61b, Li 66, Ha 64p, Ha 65l, Da 68j), and (Aj 59) for a listing of the earlier references. Table 13.10 lists recent cross section measurements: see also ^{12}C in (Aj 68), (St 64i) and (Ha 59e, De 66g).

Polarization measurements have been carried out with E_n up to 24 MeV: see Table 13.11 for recent references and (Aj 59) for earlier ones. See (Ha 63m, Da 66k, Ro 66w) for a general discussion of $^{12}C + n$ polarization.

See also (Ma 59g, Pr 59a, Pe 60, Sa 60l, Ku 63l, An 65c, De 65r, Fr 65b, Ch 67l, Ma 67e) and (Ke 59a, Wi 59c, Ho 60b, Mi 60g, To 60e, Bl 62c, Ca 62h, Ka 62f, Ed 63b, Ka 63f, Lu 63e, Mc 63b, Cr 64d, Sl 65, Co 66g, Ja 66f, Le 66o, Se 66d, Pi 67a, Re 67b, Ro 67, Sc 67h, Ta 67c, Ch 68e, Ko 68e, Ti 68).

27. (a) $^{12}C(n,n')^{12}C^*$ $E_b = 4.947$

(b) $^{12}C(n,n')3^4He$ $Q_m = -7.274$

From threshold to E_n = 9.8 MeV, ten resonances are observed in the

Table 13.9. Resonances in $^{12}C(n,n)^{12}C$

E_{res} (MeV ± keV)	Γ_{cm} (keV)	$^{13}C^*$ (MeV)	ℓ_n	J^π	θ^2	References [a]
		3.09			0.20±0.02	Se 631
2.077 ± 3	6	6.864	2	$5/2^+$		Pi 63, La 61, Da 68j
2.95		7.67	2	$3/2^+$		
3.58 ± 80	1000 ± 200	8.25	2	$3/2^+$	0.35	Fo 61b, Li 66, Ts 60
4.26 ± 30	180 ± 50	8.88	1	$1/2^-$	0.03	Fo 61b, Li 66, Ts 60
4.94 ± 10	≤ 10	9.50				Fo 61b, Ts 60
5.37	30	9.90		≥3/2		Fo 61b[c]
6.29	65	10.75		≥7/2		Fo 61b[c]
6.5[b]		10.9				Fo 61b
6.59[b]		11.03				Fo 61b[c]
6.7[b]		11.1				Fo 61b
(7.4)	(250)	(11.8)		(≥5/2)		Fo 61b
7.75	(200)	12.10		(≥7/2)		Fo 61b[c]
(8.1)	(150)	(12.4)				Fo 61b
9.3	370	13.5				Fo 61b
11.1	450	15.2		(≥3/2)		Fo 61b
12.1	230	16.1				Fo 61b
19.6 ± 0.2	~ 1000	23.0				Ha 64p, Ha 651

[a] See (Aj 59) for earlier references; see also (St 641).

[b] These three structures may be part of the same resonance (Fo 61b).

[c] I am indebted to J. C. Davis and H. H. Barschall for sending me these revised values based on a change in the calibration of the analyzing magnet used by (Fo 61b).

Table 13.10. $^{12}C + n$ Total Cross Section Measurements[a]

E_n (MeV)	References	E_n (MeV)	References
0.003 → 10 eV	(Wa 60a)	3.3 → 5.0	(Ts 60)
1.44 eV	(Ra 65)	3.4 → 16	(Fo 61b)
0.003 → 0.66	(Se 63l)	5.6	(Br 60b)
0.01 → 0.50	(Mo 66f)	7.0 → 14.3	(Ma 64gg)
0.15 → 0.2	(Bi 59)	15 → 120	(Bo 61a)
0.18 → 0.70	(Wi 61a)	17 → 21	(Ha 64p, Ha 65l)
0.2 → 140	(La 66n)	17.8,20.6,25.3,28.3,29.1	(Pe 60f)
0.50 → 1.35	(Hu 60)	88 → 151	(Me 66i)
2.61 → 2.83	(So 65)		
3.10 → 15	(Gl 63a)		

[a] See (Aj 59) and (St 64i) for earlier references.

Table 13.11. $^{12}C(n,n)^{12}C$ Polarization Studies[a]

E_n (MeV)	Neutron groups	References
0.4 → 2.4	n_o	(El 62)
0.5 → 2.0	n_o	(La 67q)
0.8, 1.2	n_o	(Be 63e)
1.0 → 2.2	n_o	(As 64b, As 66b, As 67b)
2 → 4	n_o	(Bu 59d)
2.4, 2.7	n_o	(Sa 64b)
2.8	n_o	(Iy 62)
2.8 → 4.7	n_o	(We 65)
3.2	n_o	(St 59)
3.5	n_o	(Ot 62)
4	n_o	(Go 64h)
4.4 → 8.5	n_o	(Ke 65c)
14.7	n_o, n_1	(Br 65a, Zo 67)
15.85	n_o, n_1	(Ma 67s, Ma 68r, Me 68g)
24	n_o	(Wo 62a)

[a] See (Aj 59) for earlier references. See also (Du 60).

yield of 4.4 MeV γ-rays: see Table 13.12 (Ha 59n). Cross sections have also been measured for various of the inelastic transitions for E_n = 5.5 to 14.1 MeV by (Pe 64h, Wi 65c, Ha 59e, Be 60g, Cl 64b, Bo 63e, St 64g, Si 59b). See (Aj 59) for a listing of the earlier references. See also (Ga 59d) and ^{12}C.

For reaction (b), see ^{12}C and (Aj 59).

28. $^{12}C(n,2n)^{11}C$ $\quad Q_m = -18.720 \quad E_b = 4.947$

See (Br 61d, Br 52e, As 58).

29. (a) $^{12}C(n,p)^{12}B$ $\quad Q_m = -12.588 \quad E_b = 4.947$

(b) $^{12}C(n,np)^{11}B$ $\quad Q_m = -15.957$

The cross section for reaction (a) has been measured from threshold to E_n = 22 MeV (Kr 59a, Ri 68d). It exhibits a strong resonance with a peak cross section of 19 mb at $E_x \approx 22$ MeV in ^{13}C and another weaker resonance corresponding to $E_x \approx 20.5$ MeV (Ri 68d). See also (Al 59a, Le 63i, Je 66a).

For reaction (b) see (Au 62b).

30. $^{12}C(n,\alpha)^{9}Be$ $\quad Q_m = -5.704 \quad E_b = 4.947$

The cross section for the transition to ^{9}Be (0) shows a broad structure at $E_n \approx 8$ MeV (Da 63b). See also (Ch 63d, Al 63e, Hu 66e, Ko 67p) and ^{9}Be in (La 66).

Table 13.12. Resonances in $^{12}C(n,n'\gamma_{4.4})^{12}C$ (Ha 59n)

E_n (MeV)	Γ_{cm} (keV)	E_x in ^{13}C (MeV)
4.96	< 80	9.52
5.42	< 80	9.95
5.98	200	10.46
6.35	120	10.79
6.57	< 80	11.01
6.65	< 80	11.08
7.50	260	11.87
7.81	180	12.15
8.14	220	12.46
9.31	500	13.54

31. (a) $^{12}C(d,p)^{13}C$ $Q_m = 2.722$
(b) $^{12}C(d,np)^{12}C$ $Q_m = -2.225$

$Q_o = 2.725 \pm 0.005$ (Lo 61d)

$Q_o = 2.7223 \pm 0.00061$ (Od 67)

Measurements on the proton groups are summarized in Table 13.13. In addition to a number of relatively sharp states, the proton spectrum exhibits a conspicuous broad structure attributed to a ^{13}C level at $E_x = 8.4$ MeV, $\Gamma = 1.1 \pm 0.3$ MeV. [It seems probable that this level is to be identified with the $D_{3/2}$ level of similar width observed in $^{12}C(n,n)^{12}C$ at $E_x = 8.25$ MeV: see Table 13.9.]

Angular distributions have been studied at many energies, and analyzed by PWBA and DWBA. A listing of the early work is given in (Aj 59). Recent experiments are listed in Table 13.14. See also (Ga 65i). A DWBA stripping description of the direct reaction interaction part of the reaction almost certainly will require the use of spin dependent potentials. There is pronounced compound nucleus formation even up to $E_d = 11$ MeV (Ev 63a, Sc 671).

Observed gamma rays are listed in Table 13.15. The cascade decay of the 3.85 MeV state (via $^{13}C^*$ (3.68)) occurs in 37 ± 4% of the decays; the direct transition occurs in 62 ± 4% of the events (Go 66a). The mixing ratio for the transition 3.68 → 0 $\chi(E2/M1) = -(0.096^{+0.030}_{-0.021})$,

Table 13.13. Levels of ^{13}C from $^{12}C(d,p)^{13}C$

$^{13}C^*$ (MeV ± keV)						
(St 51, Va 51a)	(Sp 54e)	(Do 56c, Ja 61m)	(Mc 55c)	ℓ_n	J^π	θ_n^2(%)[f]
0	0		0	1[d]	$1/2^-, 3/2^-$	2.6[g]
3.086 ± 6	3.090 ± 10	3.093 ± 6	3.09[a]	0[d]	$1/2^+$	14[h]
3.686 ± 11	3.684 ± 10	[3.681 ± 3]	3.68[a]	1[d]	$1/2^-, 3/2^-$	0.7
	3.855 ± 7	[3.851 ± 3]	3.84[a]	2[d]	$3/2^+, 5/2^+$	4.7
			6.87[a]	(0,2)[e]	$(\le 5/2^+)$	
			7.470 ± 20			
			7.533 ± 20			
			7.641 ± 20[b]			
			8.4 ± 300[c]			
			9.500 ± 20			
			9.897 ± 20			
			10.759 ± 20			

a Energies given for identification only.

b $\Gamma = 70 \pm 15$ keV.

c $\Gamma = 1.1 \pm 0.3$ MeV.

d See (Aj 59) for early references.

e (Mc 55c).

f PWBA and DWBA analyses: $E_d = 8$ and 12 MeV (Gl 66c).

g 3.7 ± 0.3 (Ha 61e), 3.5 (Sc 64e); see also (Ka 66b).

h 15.7 (Sc 64e).

Table 13.14. $^{12}C(d,p)^{13}C$ Angular Distribution Studies[a]

E_d (MeV)	Distributions of proton groups	References
0.7 → 1.7	p_0	(Wi 65k)
0.9 → 1.75	p_0, p_1	(Po 67e, Kl 66)
1.2 → 4.5	p_0	(Ga 66b)
1.7, 2.7, 3.1, 4.0	p_0, p_1, p_2, p_3	(Fi 65)
2.1 → 2.9	p_1, p_2, p_3	(Ka 66b)
2.1 → 3.1	p_0	(Se 59)
2.8 → 3.7	p_2, p_3	(Ge 63)
4	p_1	(Se 60b)
4.7 → 13.3	p_0	(Za 60)
6.6	p_0, p_1	(Zh 62)
7 → 11	p_0, p_1	(Ev 63a)
8, 12	p_0, p_1, p_2, p_3	(Gl 66c)
9.2 → 13.9	p_0, p_1	(Ga 66af)
10.2, 12.4, 14.8	p_0, p_1	(Ha 61e, Ha 59b)
11, 13	p_0, p_1, p_2, p_3	(Sc 66g)
11.8	p_0, p_1	(Sc 64e)
12	p_0, p_2	(Sc 67l)
12.1, 13.3	p_1, p_2, p_3	(Za 60)
13.3	p_0	(Ma 66ss)
14.9 → 19.6	p_0, p_1, p_2, p_3	(Mo 60b)
14.5	p_0, p_2, p_5	(Ka 68c)
25.9	p_0, p_1	(Va 63i)
27.7	p_0, p_2	(Sl 62a)

[a] See (Aj 59) for earlier references. See also ^{14}N.

Table 13.15. Gamma Radiation from $^{12}C(d,p)^{13}C$

E_γ [a] (MeV ± keV)	E_γ [b] (MeV ± keV)	References
3.86 ± 20	(3.84 ± 30)	(Be 55a)
3.844 ± 15		(Ma 56f)
3.863 ± 15		(Go 61q)
0.1695 ± 0.4 [e]		(Ma 56f; see also Ch 60a)
(3.76 ± 20) [c]	3.74 ± 30	(Be 55a)
(3.69 ± 20) [c]	3.675 ± 15 [d]	(Ma 56f)
(3.687 ± 15) [c]		(Go 61q)
(3.097 ± 5) [c]	3.082 ± 7	(Th 52)
(3.110 ± 12) [c]		(Go 61q)

[a] Uncorrected for Doppler shift.

[b] Corrected for Doppler shift.

[c] Doppler shift correction is not required for the 3.86-MeV radiation, but is required for the 3.09 and 3.68-MeV radiation (Ma 56f, Th 52).

[d] Value obtained by subtraction: 3.844-0.170 (Ma 56f).

[e] From the proton groups ΔE = 170 ± 3 keV (Sp 54e) and 170 ± 1.5 keV (Do 56c).

while for the transition 3.85 → 0, χ(E3/M2) = +(0.12 ± 0.03). Angular correlation measurements at E_d = 2.8 to 3.7 MeV show $\Gamma(E2)/\Gamma_\gamma \lesssim$ 5% for $^{13}C^*$ (3.68) and $\Gamma(E3)/\Gamma_\gamma \lesssim$ 2% for $^{13}C^*$ (3.85) (Fl 62). See also (Ka 66b, Pr 66e, Ti 67a). The lifetime of $^{13}C^*$ (3.09) is < 10 fsec (Ri 68h), < 15 fsec (Al 68) [see also (Me 67b)]; τ_m for $^{13}C^*$ (3.68) < 26 fsec (Ri 68h); τ_m for $^{13}C^*$ (3.85) = 7.5 $^{+3}_{-2}$ psec (Si 62b): see also Table 13.16

A study with polarized deuterons at E_d = 7 and 10 MeV is reported by (Yu 68a: p_0, p_1). For other polarization measurements see ^{14}N, (Aj 59) and (Go 61m). For reaction (b), see (Pi 63a, Bo 68e).

See also (Ar 58a, Lo 59, Al 60h, Ba 60t, Go 61k, Pu 61, St 61d, Al 62a, Gr 62d, Ne 63d, Ne 63e, Se 63j, Va 63k, Ri 64, He 65c, Zi 65, Be 66k, Go 66f, Go 66g, Wa 67i, Fo 68) and (Am 59, Bo 59d, Ho 59e, Be 60h, Bu 60e, Lu 60, Ne 60, Gi 61, Ro 61a, Jo 62c, Gl 63d, Sm 63a, Ta 63, Va 64e, Za 64d, Ba 65aa, St 65a, Ho 66i, Pe 66d, Le 67k, Mo 67e, Be 68h, Ed 68a).

32. $^{12}C(t,d)^{13}C$ $\qquad Q_m$ = -1.311

At E_t = 12 MeV, DWBA fits have been made of the angular distributions of the deuterons to ^{13}C (0, 3.09, 3.68, 3.85) (Gl 66c). See also (Ba 61c, Mu 60a).

33. $^{12}C(^3He,2p)^{13}C$ $\qquad Q_m$ = -2.771

See (Do 65b, Fo 67c, He 67e).

34. $^{12}C(\alpha,{}^3He)^{13}C$ $Q_m = -15.631$

At $E_\alpha = 56$ MeV, angular distributions of the ^3He particles to ^{13}C (0, 3.7) have been analyzed by DWBA (Sy 67).

35. (a) $^{12}C(^{11}B,{}^{10}B)^{13}C$ $Q_m = -6.509$

(b) $^{12}C(^{14}N,{}^{13}N)^{13}C$ $Q_m = -5.606$

(c) $^{12}C(^{19}F,{}^{18}F)^{13}C$ $Q_m = -5.483$

For reaction (a) see (Sa 631, Po 67a). For reaction (b), see (Ga 65g, Bi 67). For reaction (c), see (Ga 68b).

36. $^{13}B(\beta^-)^{13}C$ $Q_m = 13.437$

^{13}B β^- decays to the ground and 3.68-MeV states of ^{13}C: see ^{13}B and Table 13.2 (Ma 62d).

37. $^{13}C(\gamma,\gamma)^{13}C$

By means of nuclear resonant scattering of bremsstrahlung, τ_m of $^{12}C^*$ (3.09) = 1.5 ± 0.2 fsec (Ro 68a): τ_m of $^{12}C^*$ (3.68) = 1.4 ± 0.2 fsec (Sw 68b).

38. $^{13}C(\gamma,n)^{12}C$ $Q_m = -4.947$

The cross section appears to exhibit structure at ≈ 7.8, 8.9, 10.9 and 11.6 MeV (Be 65i) and at 13.3 ± 1 (Γ = 5 ± 1 MeV) and at ≈ 22 MeV (Γ ≈ 7 MeV) (Co 57b). For analyses of the work done on this reaction, see (Ha 63e, Me 65b). See also (Ed 60, Gr 64j) and (Fu 59, Fr 60b, Ba 611, Fr 64c, Sh 64m).

39. $^{13}C(\gamma,p)^{12}B$ $Q_m = -17.535$

(De 64i) report structure at E_γ = 18.5, 20.0, 23.5, 26.0 and 29.0 MeV. The main part of the cross section is in the 23.5 MeV peak which has $\Gamma \approx 3$ MeV. A broad maximum near 25.5 MeV has been reported by (Co 57b, Co 56f). See also (Me 65b) and (Ne 62f, Ko 64c).

40. $^{13}C(\gamma,\alpha)^{9}Be$ $Q_m = -10.651$

See (Mi 53c, Gr 64d).

41. $^{13}C(e,e)^{13}C$

From a study at E_e = 250 MeV, the ratio of the rms radius of the charge distribution for ^{13}C to that of ^{12}C is found to be 0.96 $\pm$ 0.01 (Cr 67b). See also (Ra 68a). The M1 radiation width to the ground state of $^{13}C^*$ (15.11) excited by 40 to 65 MeV electrons is 25 $\pm$ 7 eV (Pe 67g) in good agreement with the prediction of (Co 65i). See also (Ka 67e).

42. $^{13}C(p,p')^{13}C^*$

Angular distributions of the 3.09-MeV γ-rays are isotropic for E_p up to 5 MeV consistent with the assignment J = 1/2 (Ba 60f). The elastic differential cross section has been studied for E_p = 1.37 to 2.38 MeV (Ge 66), and at E_p = 32.9 MeV (Ma 68h). See also (Ro 61a). The Doppler shift method leads to lifetime limits of $\tau < 10$ fsec and $\tau < 26$ fsec for $^{13}C^*$ (3.09, 3.68) (Ri 68h): see Table 13.16.

43. $^{13}C(d,d)^{13}C$

Angular distributions of elastically scattered deuterons have been measured at E_d = 4.7, 5.0 and 5.3 MeV (Co 68h) and 15 MeV (Di 65a). See also ^{15}N.

44. $^{13}C(^3He, ^3He)^{13}C$

Angular distributions of elastically scattered ^3He's have been studied at $E(^3He)$ = 12, 15 and 18 MeV (Ke 66b). See also (Ar 68e, Ce 68).

45. $^{13}C(\alpha,\alpha)^{13}C$

Angular distributions of scattered α-particles have been studied at E_α = 33.4 MeV (Ar 68e: $^{13}C^*$ (0, 3.68, 7.5) and 40.5 MeV (Ha 66i: $^{13}C^*$ (0, 3.09, 3.68 + 3.85, 7.5)). See also (Fu 59a, Fa 68).

46. (a) $^{13}C(^6Li,^6Li)^{13}C$
(b) $^{13}C(^7Li,^7Li)^{13}C$

Angular distributions of elastically scattered ^6Li and ^7Li ions have been measured at E(Li) = 20 MeV (Be 68k).

47. (a) $^{13}C(^{12}C,^{12}C)^{13}C$
(b) $^{13}C(^{16}O,^{16}O)^{13}C$

Angular distributions of elastically scattered ^{12}C and ^{16}O ions have been studied for E = 10 to 30 MeV (Go 68i).

Table 13.16. Summary[a] of results on the total radiation widths of the low-lying levels of ^{13}C - ^{13}N

$^{13}C^*$ (MeV)	Γ_γ (eV)	Method[b]	References	$^{13}N^*$ (MeV)	Γ_γ [c] (eV)	References
3.09	0.44 ± 0.05	(γ,γ)	(Ro 68a)	2.37	0.45 ± 0.05	(Ri 68h)
	> 0.066	DS	(Ri 68h)		0.67	see (Aj 59)
3.68	> 0.025	DS	(Ri 68h)	3.51	0.53	(Yo 63a)
	0.47 ± 0.07	(γ,γ)	(Sw 68b)		0.69	see (Aj 59)
3.86	$(7.3 \pm 1.6) \times 10^{-5}$	DS	(Ri 68h)	3.56	$<200 \times 10^{-5}$	(Yo 63a)
	$(8.8 \pm 3.0) \times 10^{-5}$	DS	(Si 62b)			
	$(4.4 \pm 0.6) \times 10^{-5}$	DS	(Al 68)			

a (Ri 68h)

b DS = Doppler Shift.

c Obtained from $^{12}C(p,\gamma)^{13}N$.

48. $^{13}N(\beta^+)^{13}C$ $Q_m = 2.221$

See ^{13}N.

49. $^{14}C(p,d)^{13}C$ $Q_m = -5.952$

At E_p = 12 MeV, the angular distribution of the deuterons to ^{13}C (0) is PWBA-fitted with ℓ=1: θ^2= 0.038 (Gl 66c). At E_p = 18.5 MeV, angular distributions have also been obtained for $^{13}C^*$ (3.09, 3.68, 3.86) (Le 63, Le 61g).

50. $^{14}C(d,t)^{13}C$ $Q_m = -1.919$

At E_d = 12 MeV, angular distributions of the tritons to ^{13}C (0, 3.09, 3.68, 3.85) have been PWBA fitted: θ^2 = 14.5, 0.43 and 5.76 for the three most energetic triton groups. The group to ^{13}C (3.85) does not show a stripping pattern (Gl 66c). See also (Mo 58e, Ku 59d).

51. $^{14}C(^3He,\alpha)^{13}C$ $Q_m = 12.402$

Angular distributions of the alpha particles to ^{13}C (0) have been determined at $E(^3He)$ = 2, 6, 8, 10 (Du 64d) and 44.8 MeV (Ba 66q). See also (Ba 67vv). At the highest energy, the differential cross sections to $^{13}C^*$ (3.68) and to the T = 3/2 state at 15.11 MeV have also been measured (Ba 66q). See also (Go 66e).

52. $^{14}N(n,d)^{13}C$ $Q_m = -5.325$

Angular distributions of ground state deuterons have been determined at E_n = 14.1 to 14.7 MeV (Za 63, An 67, Fe 67d, Mi 68d). Excitation of $^{13}C^*$ (3.68) is also reported (Za 63, Fe 67d, Ca 57e).* See also (Ha 59c, Mo 63, Mo 64j).

53. $^{14}N(p,2p)^{13}C$ $\qquad Q_m = -7.550$

At E_p = 460 MeV, the summed proton spectrum shows three peaks with binding energies 7.5 $\pm$ 0.5, 15.3 $\pm$ 0.5 and 19.8 $\pm$ 0.6 MeV ($^{13}C^*$ = 0, 7.8 and 12.3 MeV) corresponding to the ejection of $p_{1/2}$ protons in the case of the ground state and $p_{3/2}$ protons in the case of the two excited states. There is also some indication of other structure (Ty 66). At E_p = 19 MeV, the reaction proceeds at least in part by a two-step process involving an excited state of ^{14}N at $\sim$ 11.2 MeV (De 65l, De 65m). See also (Cl 61c, Cl 63c, Ma 62s) and (Ba 62j, Ba 62o, El 63a, Ba 65s).

54. $^{14}N(d,^3He)^{13}C$ $\qquad Q_m = -2.056$

At E_d = 52 MeV, angular distributions have been measured for the ^3He particles to $^{13}C^*$ (0, 3.09, 3.68, 6.87, 7.5, 8.85, 9.51, 11.9 $\pm$ 0.15) and analyzed by DWBA: $J^\pi = 5/2^-, 1/2^-, 3/2^-$ and $3/2^-$, respectively, are assigned to $^{13}C^*$ (7.5, 8.85, 9.51, 11.9) (Hi 68c). As expected, angular distributions of ^3He's and of tritons (from $^{14}N(d,t)^{13}N$) to analogue states are identically the same: this has been shown for the ground state ^3He and triton groups (De 66h: E_d = 28.5 MeV) and for the groups to $^{13}C^*$ (8.9 + 9.5) and $^{13}N^*$ (9.2) (Hi 68c: E_d = 52 MeV). See also (Ba 68p).

* Gamma rays with energies of 3.686 $\pm$ 0.003 and 3.853 $\pm$ 0.003 MeV are reported by (Be 69b).

55. $^{14}N(t,\alpha)^{13}C$ $Q_m = 12.264$

Observed particle groups at $E_t = 2.6$ MeV are displayed in Table 13.17 (Si 62b). See also (Sc 64b) and ^{16}O.

56. $^{14}N(\alpha,p\alpha)^{13}C$ $Q_m = -7.546$

This sequential reaction has been studied at $E_\alpha = 22.9$ MeV (Be 67kk).

57. $^{14}N(^{14}N,^{15}O)^{13}C$ $Q_m = -0.257$

See (Ga 66a).

58. $^{15}N(n,t)^{13}C$ $Q_m = -9.903$

Not reported.

59. $^{15}N(p,^3He)^{13}C$ $Q_m = -10.667$

At $E_p = 43.7$ MeV, ^3He groups have been observed to eleven states of ^{13}C: see Table 13.17 (Fl 68, Ce 66): see Table 13.13. Angular distributions of the ^3He particles to these states are generally found to be in agreement with DWBA predictions, using intermediate coupling wave functions to obtain the two-nucleon structure factors (Fl 68). Detailed comparisons are made with the results of the mirror reaction $^{15}N(p,t)^{13}N$: the (p,t) transitions are generally stronger than expected relative to the mirror $(p,^3He)$ transitions. This may arise from interference effect terms due to a spin-orbit interaction in the optical potential, or to interference terms between direct-reaction and core-excitation (Fl 68a, Fl 68).

Table 13.17. Energy levels of ^{13}C from $^{14}N(t,\alpha)^{13}C$ (Si 62a) and from $^{15}N(p,^{3}He)^{13}C$ (Fl 68).

E_x in ^{13}C [a] (MeV ± keV)	Γ_{cm}	E_x in ^{13}C [b] (MeV ± keV)	J^{π}
0		0	$1/2^-$
3.09[c]		3.08 ± 20	$1/2^+$
3.68[c]		3.68[c]	$3/2^-$
3.85[c]			
6.87[c]		6.87[c]	$5/2^+$
7.5[c]		7.55 ± 20	$5/2^-$
7.68[c]			
8.860 ± 20	145 ± 20	8.86 ± 60	$1/2^-$
9.509[d]		9.52 ± 30	$(3/2^-)$
9.897[d]			
10.736 ± 20	< 30		
10.809 ± 20	< 30		
11.000 ± 20	< 30		
11.078 ± 20	< 30	11.09 ± 50	$(1/2^-)$
11.721 ± 30	125 ± 20	11.80 ± 30	$(3/2^-)$
12.131 ± 30	125 ± 30		
		12.40 ± 50	$7/2^-$
		15.103 ± 45[e]	$3/2^-$

[a] From $^{14}N(t,\alpha)^{13}C$ (Si 62a).
[b] From $^{15}N(p,^{3}He)^{13}C$ (Fl 68).
[c] Observed but E_x not decermined.
[d] E_x values of other levels given in terms of E_x of these two levels.
[e] (Ce 66).

Table 13.18. ^{13}C states from $^{15}N(d,\alpha)^{13}C$

(Ma 51) (MeV ± keV)	(Ja 61m) (MeV ± keV)	(Wa 57) (MeV ± keV)[a]
0	0	0
3.083 ± 5	3.100 ± 20	3.09
3.677 ± 5	3.695 ± 10	3.68
		3.85
		6.87
		7.47, 7.53, 7.64[b]
		8.80 ± 40
		9.5
		9.9

[a] Level energies for identification purposes only except for $^{13}C^* =$ 8.80 MeV.

[b] Not resolved.

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60. $^{15}N(d,\alpha)^{13}C$ $Q_m = 7.687$

$Q_o = 7.675 \pm 0.009$ (Lo 61f)

Observed alpha particle groups are displayed in Table 13.18 (Ma 51, Ja 61m, Wa 57). Angular distributions of α-particles have been measured at E_d = 1.0 to 1.2 MeV (St 66q: α_o), 20.9 MeV (Pr 68a: α_o, α_1) and 21 MeV (Fi 59: α_o). See also (Ma 65k, Lo 61b).

61. $^{15}N(\alpha,{}^6Li)^{13}C$ $Q_m = -14.688$

At E_α = 42 MeV, the angular distribution of the ^6Li particles to ^{13}C (0) has been measured (Mi 68e).

62. $^{16}O(n,\alpha)^{13}C$ $Q_m = -2.215$

At E_n = 14.1 to 14.9 MeV angular distributions of alpha particles have been measured: see (Ci 61, Mc 66f, Le 68j: α_o), (Hs 67a: α_o, α_1, $\alpha_2 + \alpha_3$), (Ma 68j: α_o, $\alpha_1 + \alpha_2 + \alpha_2$).* See also (Aj 59, Ro 62b, Da 63b, Mo 63, Se 63d, Ma 64m, Mo 64j, Ch 65b, Ci 66a, Fa 66, Si 67e).

63. $^{17}O(d,{}^6Li)^{13}C$ $Q_m = -4.885$

See (De 66a).

64. $^{18}O(d,{}^7Li)^{13}C$ $Q_m = -5.678$

See (Cr 63a, De 67).

65. $^{20}Ne(n,2\alpha)^{13}C$ $Q_m = -6.944$

See (Pe 66f).

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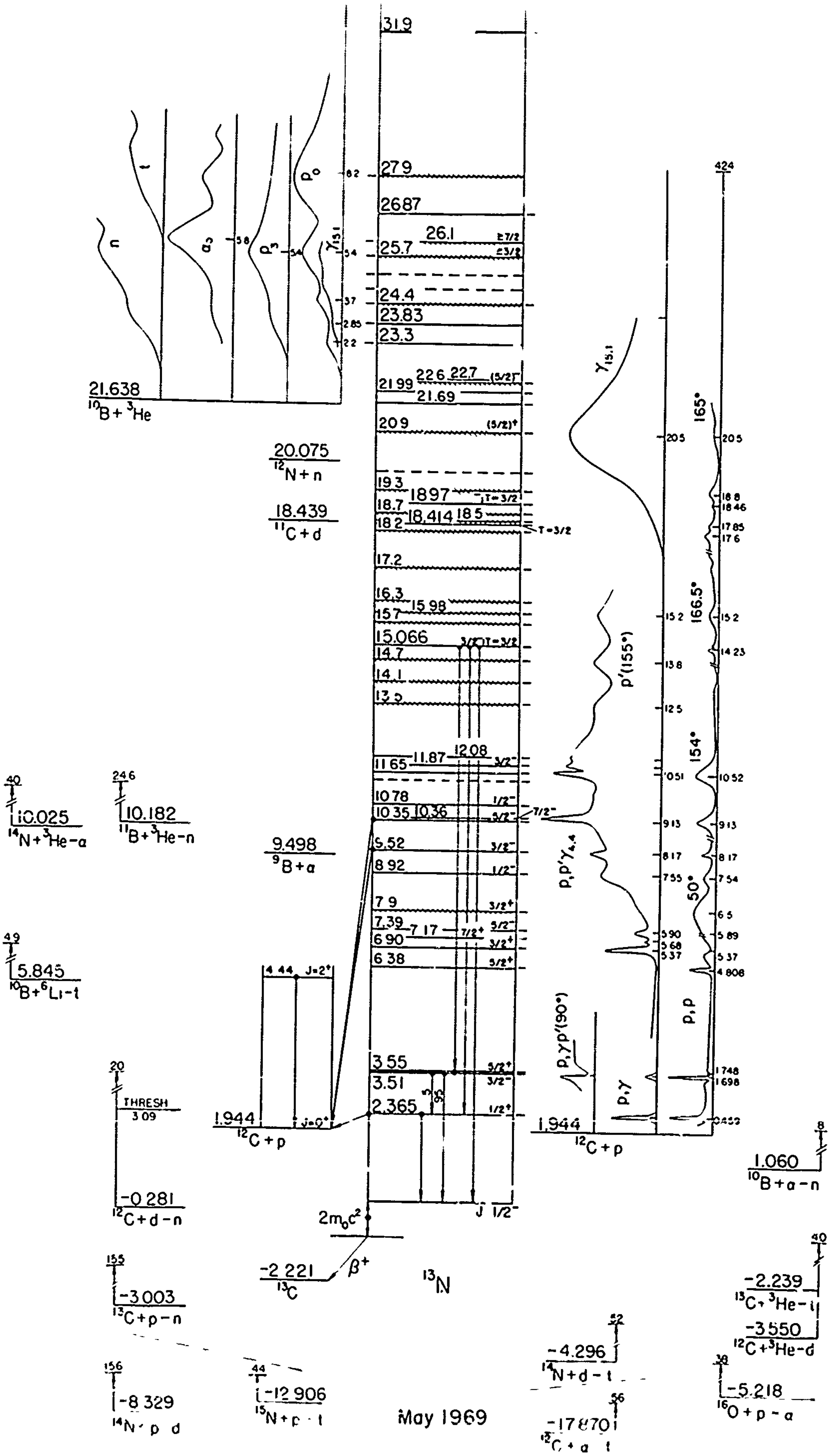
* Two γ-rays with energies of 3.685 ± 0.003 and 3.855 ± 0.003 MeV are reported by (Be 69b).



31.9
27.9
26.87
26.1
25.7
24.4
23.83
23.3
22.6 22.7
21.99
21.69
20.9
19.3
18.97
18.7
18.414 18.5
18.2
T=3/2
17.2
16.3
15.98
15.7
15.066
14.7
14.1
13.5
12.08
11.87
11.65
10.78
10.35 10.36
9.52
8.92
7.9
7.39
7.17
6.90
6.38
3.55
3.51
2.365
4.44 J=2+
J=0+
21.638
$^{10}B+^{3}He$
20.075
$^{12}N+n$
18.439
$^{11}C+d$
9.498
$^{9}B+\alpha$
10.025
$^{14}N+^{3}He-\alpha$
10.182
$^{11}B+^{3}He-n$
5.845
$^{10}B+^{6}Li-t$
THRESH
3.09
-0.281
$^{12}C+d-n$
1.944
$^{12}C+p$
$2m_0c^2$
-2.221
^{13}C
β^+
^{13}N
-3.003
$^{13}C+p-n$
-8.329
$^{14}N+p-d$
-12.906
$^{15}N+p-t$
1.060
$^{10}B+\alpha-n$
-2.239
$^{13}C+^{3}He-t$
-3.550
$^{12}C+^{3}He-d$
-4.296
$^{14}N+d-t$
-5.218
$^{16}O+p-\alpha$
-17.870
$^{12}C+\alpha-t$
$\gamma_{15.1}$
p'(155°)
p,p'$\gamma_{4.4}$
p,γp'(90°)
p,γ
p,p
165°
166.5°
154°
50°
May 1969

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^{13}N

General

Model calculations: (Am 64, Ba 59n, Ba 63h, Bo 63j, Bo 64o, Bo 65i, Br 67d, El 66b, Fa 67a, Fi 68, Go 68, Ha 66f, Ho 68, Hu 57d, Hu 67c, In 62, Ku 61a, Ku 61e, Ku 67j, La 55b, Ma 65o, Me 65b, Ne 61c, Ne 67b, No 66, Ph 60a, Po 67g, Se 63n, St 64, Ta 60l, Ta 62f, Tr 63, Wa 67i, We 65d).

Other: (Au 67a, Ep 67b, Ba 68y, Ba 68ll, Vo 68).

Ground State: $\mu = (-)\ 0.32212 \pm 0.00035$ n.m. (Be 64l; see also (Po 61a, Li 64h).)

1. $^{13}N(\beta^+)^{13}C$ $\qquad Q_m = 2.221$

Measured values of the half life are displayed in Table 13.20. The positon spectrum shows no deviation from the allowed shape; it is concluded that the Fierz coefficient in the Fermi interaction is < 11% (Da 58e, Da 57b, Da 68i). Log ft = 3.664 based on Q_m and $\tau_{1/2}$ = 9.961 min. The positon polarization has been studied by (Ha 57g, Bo 57h). The results indicate that the positons are completely polarized and hence that Fermi transitions as well as G-T transitions exhibit the maximum effect of parity non-conservation. See also (Aj 59) and (Ga 65h, Mi 66j, Am 67a).

Table 13.19. Energy Levels of ^{13}N

E_x in ^{13}N (MeV ± keV)	J^{π};T	Γ(keV) or $\tau_{1/2}$	Decay	Reactions
0	$1/2^-$	$\tau_{1/2}$ = 9.961 ± 0.005 min.	β^+	1,3,9,10,11,12,19,20,21,22,23,24,25,26, 27,28,29,30,31,32,33,34,35,36,37
2.3660±1.0	$1/2^+$	35±1 keV	γ,p	10,12,15,19,20,27,29,30,31
3.509±2	$3/2^-$	63±5	γ,p	10,12,15,19,20,21,22,23,26,27,29,30,31, 33,36
3.547±6	$5/2^+$	74	p	10,15,19,20,21,22,23,27,29,36
6.382±10	$5/2^+$	11	p	10,15,27,31,33,36
6.898±10	$3/2^+$	115±5	p	15,31
7.166±8	$7/2^+$	9±0.5	p	15,27,31
7.387±6	$5/2^-$	75±5	p	15,27,28,29,30,31,33,36
7.9	$3/2^+$	≈ 1500	p	15
8.92±30	$1/2^-$	230	p	15,27,29,30,33
9.52±20	$3/2^-$	30	p	11,15,27,30
10.35±20	$5/2^-$	30	p	11,15
10.36	$7/2^-$	76	p	15
10.78±40	$1/2^-$			27,33
(11.44)			p	15
11.65		80	p	15
11.87±30	$3/2^-$	130	p	15,27,29,30,33
12.08		140	p	15
13.5		≈ 500	p	15
14.1		≈ 500	p,(γ)	12,15
14.7		≈ 500	p	15
15.066±5	$3/2^-$;T=3/2	1.13±0.3	γ,p,α	11,12,15,18,27,33
15.7		≈ 500	p	15

Table 13.19 (concluded)

15.98±50		≈ 500	p	15,27
16.3		≈ 500	p	15
17.2		≈ 500	p	15
18.2		≈ 500	p	15
18.414±6	T=3/2	≈ 50	p	11,15
18.5		≈ 500	p	15
18.7		≈ 500	p	15
18.974	-;T=3/2	≤ 15	p	11,15
19.3		≈ 500	p	15
(19.8)		≈ 500	(γ,p)	12,15
20.9	$(5/2)^+$	≈ 1500	p	15
21.69			p	15
21.99			p	15
22.6	$(5/2)^-$	≈ 1000	p	15
22.7			γ	12
23.3		400	p,^{3}He	5
23.83		350±50	p,^{3}He	5
24.4		≈ 500	p,^{3}He	5,15
(24.8)		100	p,^{3}He	5
(25.2)	$(3/2)^-$	120	p,^{3}He	5,15
25.7	≥ 3/2	≈ 1000	p,^{3}He	5
26.1	≥ 7/2	≈ 1000	d,^{3}He,α	6,8
26.87			p	15
27.9		broad	p,^{3}He	5
31.9			p,γ	12

Table 13.20. The half life of ^{13}N [a]

$\tau_{1/2}$ (min.)	Reference
9.96 ± 0.03	(Ar 58)
9.96 ± 0.03	(Da 58e)
9.96 ± 0.005	(Ja 60j)
9.93 ± 0.05	(Ki 60)
9.96 ± 0.02	(Eb 65)
10.05 ± 0.05	(Bo 65a)
9.961 ± 0.005	Weighted average

[a] See also (Aj 55, Aj 59, Ra 61).

2. $^{7}Li(^{6}Li,2n)^{11}C$ $Q_m = 2.204$ $E_b = 23.651$

See (No 60b).

3. $^{9}Be(^{6}Li,2n)^{13}N$ $Q_m = 3.951$

See (No 57a).

4. $^{10}B(^{3}He,n)^{12}N$ $Q_m = 1.563$ $E_b = 21.638$

The cross section has been measured for $E(^{3}He)$ = 1 to 6.3 MeV. There is some evidence of broad structures (Pe 63c). See also (Za 66) and ^{12}N.

5. $^{10}B(^{3}He,p)^{12}C$ $Q_m = 19.695$ $E_b = 21.638$

Observed resonances in the yields of proton groups and γ-rays for $E(^{3}He)$ = 1.2 to 12 MeV are displayed in Table 13.21 (Sc 56f, Ku 64i, Pa 66g). For polarization measurements see (Si 65a, Si 67a) and (Mi 66l). See also ^{12}C.

6. $^{10}B(^{3}He,d)^{11}C$ $Q_m = 3.199$ $E_b = 21.638$

Excitation functions for the ground state group have been measured for $E(^{3}He)$ = 3.5 to 10 MeV: a resonance is reported at $E(^{3}He) \approx 5.8$ MeV (Pa 65g). See also (Br 65i, Ha 67r). See also ^{11}C.

7. $^{10}B(^{3}He,t)^{10}C$ $Q_m = -3.624$ $E_b = 21.638$

The excitation function for ^{10}C production has been measured from threshold to $E(^{3}He)$ = 10.5 MeV. σ_{max} (at 10.5 MeV) = 435 ± 87 μb. No detailed structure is observed (Os 64). See also (Ma 66h).

Table 13.21. Structure in $^{10}B + ^{3}He$

(Sc 56f)		(Ku 64i)		(Pa 66g)	(. 65c)	Res in	E_x in $^{13}N^*$
E_{res} (MeV)	Γ (keV)	E_{res}	Γ	E_{res}	E_{res}		
2.0[a,b]	500			2.2		p_o, (p_1)	23.3
		2.85 ± 50	450 ± 50			$\gamma_{15.1}$	23.83
3.7[a]	700			3.5[a] 3.7		p_1, p_o	24.5
4.1	120					p_o	24.8
4.6[a]	150					p_o, (p_1)	25.2
		5.2 ± 100[c]	240 ± 80	5.4[d]		p_o, $\gamma_{15.1}$ p_2, p_3	25.7
					5.8[f]	α_o, d_o	26.1
				8.2[e]		p_o	27.9

a See, however, (Ku 64i).

b See also (Si 67a).

c See, however, (Ba 66p).

d $J \geq 3/2$, $\Gamma \approx 1$ MeV (Pa 66g).

e $J \geq 7/2$ (Pa 66g).

f $\Gamma \sim 1$ MeV. This resonance is also seen in the d_o excitation curve (Pa 65g).

8. $^{10}B(^{3}He,\alpha)^{9}B$ $Q_m = 12.140$ $E_b = 21.638$

The excitation function for α-particles to ^{9}B (0), measured for $E(^{3}He)$ = 2 to 10 MeV, indicates a strong resonance at $E(^{3}He)$ = 5.8 MeV ($^{13}N^*$ = 26.1), $\Gamma \simeq 1$ MeV. This resonance does not appear in the excitation function for alphas to $^{9}B^*$ (2.3) measured over the same energy range. Minor structure is observed in both excitation functions approximately every 2 MeV (Pa 65c). See also ^{9}B and (Ta 68j).

9. $^{10}B(\alpha,n)^{13}N$ $Q_m = 1.060$

See (Aj 59) and (He 59c, Ka 60g, Ro 61h, Ed 62, Ni 65a, Za 66).

10. $^{10}B(^{6}Li,t)^{13}N$ $Q_m = 5.845$

At $E(^{6}Li)$ = 4.9 MeV, triton groups are observed to ^{13}N (0, 2.4, 3.6 (unresolved), 6.38) (Mc 66a). See also (Ca 65e, Mo 63j).

11. $^{11}B(^{3}He,n)^{13}N$ $Q_m = 10.182$

Ground state angular distributions have been measured for $E(^{3}He)$ = 2.0 to 5.3 MeV (Di 66b). Work at $E(^{3}He)$ = 1.2 to 2.0 MeV has shown that previously reported states at E_x = 5.51 and 6.10 MeV in the $^{11}B(^{3}He,p)^{13}C$ reaction are instead due to the proton decay to ^{12}C (0) of ^{13}N states at $E_x = 9.52 \pm 0.02$ and 10.35 ± 0.02 MeV (Ch 66j).

In a study with $E(^{3}He)$ = 7.0 to 13.5 MeV, neutron groups have been observed to T = 3/2 states at $E_x = 15.068 \pm 0.008$ MeV ($\Gamma < 15$ keV), 18.44 ± 0.04 MeV and 18.98 ± 0.02 MeV (Γ = 40 ± 20 keV). J^{π} (determined by DWBA) for $^{13}N^*$ (15.07) is $3/2^-$. The ratio of the number of γ-rays from $^{13}N^*$ (15.07) to the number of protons from this level to ^{12}C (0), $\Gamma_{\gamma_o}/\Gamma_{p_o}$, has been determined to be 12 ± 2%: Γ is then calculated to be 1.13 ± 0.3 keV (Co 69). The isospin forbidden decay from the first T = 3/2 levels in ^{13}C and ^{13}N by neutron and proton emission, respectively, to $^{12}C^*$ (0, 4.44) is quite different: $\theta^2_{0.0}/\theta^2_{4.4}$ = 1.3 for ^{13}N and 0.2 for ^{13}C suggesting some admixture of charge-dependent forces (Ad 67d). This is illustrated also by the difference in the total widths of $^{13}N^*$ (15.07) and $^{13}C^*$ (15.112):Γ = 1.13 ± 0.3 keV and 4.7 ± 1.6 keV, respectively, (Co 69). See also (Br 64h, Ti 67).

12. (a) $^{12}C(p,\gamma)^{13}N$ Q_m = 1.944
(b) $^{12}C(p,\gamma p')^{12}C$

Resonances for capture radiation are displayed in Table 13.22. [See also Table 13.16 for a summary on the total radiation widths of the low lying levels of ^{13}C - ^{13}N.] No resonance is observed at E_p = 1.73 MeV, corresponding to $^{13}N^*$ (3.56) (Se 51e, Yo 63a).

No capture radiation is observed for E_x = 5 to 10.4 MeV: the upper limits to the (p,γ_o) cross sections are 2 mb/sr at the known (p,p) resonances (Pa 62). At E_p = 14.2 MeV, capture radiation from the first T = 3/2 state at E_x = 15.07 MeV is observed. $\Gamma_p\Gamma_\gamma/\Gamma$ =

5.5 $\pm$ 0.8 eV for the ground state transition which, combined with Γ_p/Γ = 0.20 $\pm$ 0.025 from (Ad 67d), yields Γ_γ = 27 $\pm$ 5 eV. The amplitude ratio of E2/M1 = -0.095 $\pm$ 0.07. For the transitions to $^{13}N^*$ (2.37) and $^{13}N^*$ (3.51 + 3.56), Γ_γ < 4.5 and 23 $\pm$ 5 eV, respectively. The angular distributions of the γ-rays determine $J^\pi = 3/2^-$ for $^{13}N^*$ (15.07) (Di 68a). No clear structure is observed in the ground state capture cross section for E_p = 14 to 19.5 MeV (Wa 62k). Resonances reported by (Fi 63b) in the yields of γ_0 and γ_2 are displayed in Table 13.22. See also (Ta 64d).

The capture cross section at low energy is of interest in connection with stellar energy generation: see (Aj 59) and (Ca 59, Ca 65, Ba 66ff). Fo 67I

In the range E_p = 1.2 to 2.5 MeV, reaction (b) is observed, involving a γ-transition to the 2.37-MeV state. P-wave resonant capture at E_p = 1.70 MeV, with Γ_γ = 0.04 eV, interferes with direct p-wave capture (Wo 54). See also (Su 59, De 59a, Co 63d, Al 64r, Fa 65, Ma 65y, Ed 66a).

13. $^{12}C(p,n)^{12}N$ $\qquad Q_m$ = -18.131 $\qquad E_b$ = 1.944

The cross section for this reaction has been measured from threshold to E_p = 50 MeV: resonant structure is observed corresponding to E_x = 21, 24 and, possibly, $\sim$ 27 MeV (Ri 68e). See also (Va 63h, Sp 66c) and ^{12}N.

Table 13.22. Resonances in $^{12}C(p,\gamma_o)^{13}N$

E_p (MeV ± keV)	Γ_{lab} (keV)	$\omega\Gamma_\gamma$ (eV)	$^{13}N^*$ (MeV)	Res. in Yield of	References
0.4568 ± 0.5	39.5 ± 1.0	0.67	2.365	γ_o	(Hu 53, Se 51e, Fo 49b)
	36.5 ± 2.0				(Bl 68a)
	36.7 ± 1.0	0.45 ± 0.05			(Ri 68h)
1.698 ± 5	72 ± 9	1.39	3.510	γ_o	(Va 49, Se 51e)
	67 ± 4	1.06[a]			(Yo 63a, Bl 68a)
13[b]			14	γ_o	(Fi 63b)
14.2	(see text) T = 3/2 state		15.0	γ_o, γ_1, $\gamma_2 + \gamma_3$	(Di 68a)
20[b]			20	γ_o	(Fi 63b)
24.5			22.6	γ_2	(Fi 63b)
32.5[b]			31.9	γ_o	(Fi 63b)

[a] $\omega\Gamma_\gamma$ for $^{13}N^*$ (3.56) < 0.006 eV (Yo 63a).

[b] T = 1/2 dipole states (Fi 63b, Ta 64d).

14. $^{12}C(p,pn)^{11}C$ $Q_m = -18.720$ $E_b = 1.944$

Cross sections have been measured to $E_p = 385$ MeV: see (Au 62b, Cu 63, Ka 6l Me 66b, An 68b) and (Aj 59). See also (Va 63h).

15. (a) $^{12}C(p,p)^{12}C$ $E_b = 1.944$

(b) $^{12}C(p,p')^{12}C^*$

(c) $^{12}C(p,2p)^{11}B$ $Q_m = -15.957$

Yield curves for elastic protons, protons inelastically scattered to $^{12}C^*$ (4.4), and for γ-rays from $^{12}C^*$ (12.7) and (15.1) have been studied at many energies up to $E_p = 48.5$ MeV: see Table 13.23 for a display of the characteristics of the observed structure.

Total cross section measurements have been made at $E_p = 16.4$ (Po 65e), 16.2 to 28 (Ma 65r), 20 and 42 (Gi 64a), 24.5 to 46.1 (Mc 67j), 29 (Ma 64c), 34 (Go 59f), 45 (Ca 67e), 61 (Me 60b), 142 (Ta 61a), 180 MeV (Jo 61j) and 1 GeV (Ig 67a). Non-elastic cross sections have been measured at $E_p = 9.9$ and 10.2 MeV (Ig 62, Wi 63b) and at 77, 95, 113 and 133 MeV (Go 62). The (p,2p) cross section has been determined at $E_p = 120$ to 150 MeV (Au 62b) and that of the $^{12}C(p,p')3^4He$ at 90 MeV (Ga 61h). See also (Wa 62k, Be 67cc, Wa 67k).

A summary showing the energies at which polarization measurements have been made is presented as Table 13.24. Reviews of the experimental evidence are given by (Ph 59b, Ro 62f, Da 66k, Ro 66t, Ro 66w). See

Table 13.23. ^{13}N levels from $^{12}C(p,p)^{12}C$ and $^{12}C(p,p')^{12}C^*$

E_{res} (MeV ± keV)	$^{13}N^*$ (MeV)	Γ_{cm} (keV)	ℓ_p	J^π	θ_p^2	References
0.461 ± 3	2.370	31	0	$1/2^+$	0.54	(Ja 53b, Mi 54)
1.686 ± 6	3.502	63	1	$3/2^-$	0.031	(Ja 53b, Ar 66a)
1.734 ± 6	3.547	74	2	$5/2^+$	0.21	(Ja 53b, Ar 66a)
4.808 ± 10	6.382	11	2	$5/2^+$	0.0031	(Re 56c, Me 64b, Ba 67i)
5.370 ± 10	6.898	115 ± 5	2	$3/2^+$	0.13	A
5.65 ± 10	7.16	9 ± 0.5	4	$7/2^+$	0.016	(Ba 63g, Ba 63h, Ni 63b, Yo 60)
5.891	7.379	75 ± 5	3	$5/2^-$	0.069	B
6.5	7.9	≈ 1500	2	$3/2^+$	0.14	C
7.54	8.90	230	1	$1/2^-$	0.02	D
8.17	9.48	30	1	$3/2^-$	0.001	D and (Sw 66)
9.13[a]	10.36	30	3	$5/2^-$		E
9.13[a]	10.36	76	3	$7/2^-$		E
(10.31)	(11.44)					(Bo 60c, Mc 61b)
10.52	11.65	80				(Ad 61a, Na 61, Bo 60c, Mc 61b)
10.74	11.85	130				(Ad 61a)
10.99	12.08	140				(Ad 61a, Bo 60, Br 59b, Mc 61b)
12.5	13.5	≈ 500				(Na 61)
13.2	14.1	≈ 500				(Na 61)
13.8	14.7	≈ 500				(Na 61, Da 64a)
14.231 ± 6	15.065 ± 6	1.9 ± 0.6	1	$3/2^-$;T=3/2		F
14.9	15.7	≈ 500				(Da 64a)
15.2	16.0	≈ 500				(Na 61, Da 64a, Ku 67f)

Table 13.23 (continued)

15.6	16.3	≈ 500		(Da 64a)
16.5	17.[illegible]	≈ 500		(Da 64a)
17.6	18.2	≈ 500		(Da 64a, Ku 67f)
17.854 ± 6	18.414	≈ 50	T=3/2	(Ku 67f, Le 68)
17.9	18.5	≈ 500		(Da 64a)
18.2	18.7	≈ 500		(Da 64a)
18.461	18.974	≲ 15	(-),T=3/2	(Ku 67f, Le 68)
18.8	19.3	≈ 500		(Da 64a)
(19.4)	(19.8)	≈ 500		(Da 64a)
20.5	20.9	≈ 1500	$(5/2)^+$	(Me 63c, Ma 65r, Lo 661, Sc 67g)
21.41	21.69			(Di 63b, Wa 64e, Cr 66)
21.73	21.99			(Di 63b, Wa 64e, Cr 66)
22.4	22.6	≈ 1000	$(5/2)^-$	(Me 63c, Lo 661, Sc 67g)
24.2	24.3	≲ 500		(Me 63c, Lo [illegible])
25.5	25.5		$(3/2)^-$	(Sc 67g)
27.02	26.87			(Di 63b, Wa 64e, Cr 66)

[a] The resonant energies probably do not differ by more than 2 keV (Be 68t).

A (Re 56c, Ad 61a, Sh 62c, Ba 63g, Ba 63h, Ni 63b, Me 64b, Ba 66bb, Ba 67i, Du 67b, Be 68t; see also Bo 60c, Be 65h).

B (Br 56d, Ad 61a, Sh 62c, Ba 63g, Ba 63h, Ni 63b, Me 64b, Ba 66bb, Sh 66j, Be 68t; see also Bo 60c).

C (Sc 56d, Bo 60c, Na 61, Sh 62c, Me 64b, Ba 66bb).

D (Ad 61a, Sh 62c, Ba 66bb; see also Bo 60c, Mc 61b).

E (Ad 61a, Sh 62c, Ba 66bb, Sw 66, Sw 67a, Be 68t; see also Bo 60c, Mc 61b, Na 61).

F (Br 66f, Br 66r, Ku 67f, Le 67b, Te 67, Te 68).

also (Aj 59).

The polarization and asymmetry in the elastic scattering of 32.9-MeV protons are equal to ± 2.5%: therefore no violation of time-reversal invariance is observed in that part of the nuclear force which flips the spin of proton (Gr 68h).

The following is a list of recent theoretical papers bearing on these reactions: (De 55a, Ba 59l, Ke 59a, Pu 59, Ri 59, Wi 59c, Ni 60-, Sa 60g, Sa 60i, Sa 61b, Ma 62t, No 62, No 62b, No 62c, Ro 62a, Vo 62c, Ba 63h, Ho 63l, Lo 63a, Lu 63d, Ro 63e, Sc 63d, Cr 64d, Gr 64k, Iy 64, Ta 64a, Ve 64, Ba 65d, Be 65w, Cl 65c, Fa 65, Ha 65k, Pe 65c, Sa 65i, Ba 66f, Ba 67i, Sa 67e, Ta 67c, Wo 67c, Ba 68mm, Ch 68e, Ta 68g, Ti 68).

See also (Bu 59e, De 60a, Jo 61k, Pa 62, Az 63a, Fi 64c, Cl 65a, Gr 65d, Va 65, Ha 66r, Ma 66ff, Re 66b, Ar 67e, Vo 67c).

16. $^{12}C(p,d)^{11}C$ $Q_m = -16.495$ $E_b = 1.944$

The yield has been measured for E_p = 18 to 19.8 MeV: no structure is observed (Wa 62k). Polarization measurements are reported by (Co 60b, Ch 67j). See also ^{11}C in (Aj 68).

17. $^{12}C(p,t)^{10}C$ $Q_m = -23.319$ $E_b = 1.944$

See (Co 67i, Mc 67i) and ^{10}C in (La 66).

18. $^{12}C(p,\alpha)^{9}B$ $Q_m = -7.554$ $E_b = 1.944$

Resonance behavior at $E_p \sim 14.2$ MeV corresponding to the first

Table 13.24. Summary[a] of $^{12}C(p,p)^{12}$ Polarization Measurements

E_p (MeV)	^{12}C States	References
1.2 → 2.4	g.s.	(Bo 65c)
1.5 → 3.0	g.s.	(Tr 67)
1.5 → 5.0	g.s.	(Ph 59b)
1.7 → 1.9	g.s.	(Ba 66zz)
2.3 → 4.3	g.s.	(Ev 60c)
2.4 → 3.4	g.s.	(Be 65c)
2.9	g.s.	(Hs 66)
3.0	g.s.	(Ne 62g)
3.8 → 4.8	g.s.	(Go 62d, Dr 64, Dr 64b, Dr 64c)
4.4 → 10	g.s.	(Te 68d, Be 68t)
4.5	g.s.	(Bo 64i)
4.6 → 5.5	g.s.	(Go 61p)
4.65 → 5.0	g.s.	(To 60)
4.6 → 7.2	g.s.	(Te 65)
4.7 → 11.3	g.s.	(Mo 65e)
5.0 → 10.5	g.s.	(Ev 61b)
5.1 → 6.8	g.s.	(Wa 59d)
5.4 → 19.7	g.s.	(Ro 62f)
6.0	g.s.	(Bo 65l)
6.0 → 6.8	g.s.	(Be 64d, Be 64q)
6.2	g.s.	(Cl 65b)
6.3	g.s.	(Ma 62u)

Table 13.24 (continued)

6.5	g.s.	(Be 62j)
6.7	g.s.	(Be 64g)
6.8	g.s.	(Pa 60a)
8.6	g.s.	(Ro 61f)
9.2	g.s.	(Ho 61b)
9.4	g.s.	(St 60b)
10.8, 12.7	g.s.	(Sa 63h)
11.7	g.s.	(Ro 61b)
12.8 → 13.4	g.s.	(St 66g)
14.5	g.s., 4.4	(St 62d, Ro 65m, Ro 62l)
16.5	g.s., 4.4	(Da 66j)
16.6, 19.3	g.s., 4.4	(Bo 62a)
17.7	g.s., 4.4	(Br 59g)
17.8	g.s., 4.4	(Ba 65i)
19.3	9.6	(Bo 62a)
19.7	9.6	(Ro 62f)
20 → 28		(Lo 66l)
20.2 → 28.3	g.s., 4.4	(Cr 66)
21	g.s.	(Be 66t)
29, 49	g.s., 4.4	(Cr 63a, Cr 66c)
32.9	g.s.	(Gr 68h)
38	g.s., 4.4	(Hw 63)
40	g.s., 4.4	(Bl 66d, Fr 67d)
43.5	g.s.	(Ca 66e)
50	g.s.	(Fa 67)

Table 13.24 (continued)

57	g.s.	(Ya 62b)
75, 152	g.s.	(Ro 66i)
80		(Ma 66qq)
139	g.s.	(He 63a)
140		(Ja 66c, Ja 66d, Ja 66f)
141		(Po 65d)
143		(St 64j)
145	g.s., 4.4, 9.6, 14, 18.5	(Em 66a)
150	g.s., 4.4, 7.7, 9.6	(Sa 62a, Ta 65c)
155	g.s., 4.4	(Al 57b)
173	g.s., 4.4, 9.6, 15.1	(Ty 57, Hi 57b)
424	g.s.	(He 57c)
725	g.s.	(Mc 65)
2,000; 3,600		(Ba 67ee)

[a] See also (Az 63, Az 65, Le 66c).

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T = 3/2 state at 15.07 MeV has been reported for the α_o and α_1 groups (Le 67b, Le 68, Te 68). See also (Ba 64v, Ba 66bb, Va 63h, Re 66b) and ^9B in (La 66).

19. (a) $^{12}C(d,n)^{13}N$ $Q_m = -0.281$
(b) $^{12}C(d,pn)^{12}C$ $Q_m = -2.224$

Neutron groups have been observed corresponding to excited states of ^{13}N at 2.38 ± 0.05 and 3.53 ± 0.05 MeV (Mi 53). The angular distributions of n_o, n_1 and $n_2 + n_3$ at E_d = 9 MeV are consistent with ℓ_p = 1, 0 and 2. The dimensionless reduced widths of the ground and 3.5-MeV states are, respectively, 0.056 and 0.19 (Ca 57a; see also Mi 53). (Mc 58d) finds 0.09 ± 0.035 for the reduced width for ^{13}N (0). Angular distributions have also been measured at E_d = 1.5 to 3.0 MeV (El 59c; see also Ho 63i: n_o), 3.78 to 4.20 MeV (Fu 66; n_o) and at 13 MeV (Ko 63c). See also ^{14}N.

In the range E_d = 2.8 to 3.7 MeV, a single neutron threshold is observed at E_d = 3.09 ± 0.02 MeV, corresponding to $^{13}N^*$ = 2.36 (5) ± 0.02 MeV (Ma 55j).

At E_d = 4.7 to 5.5 MeV, broad proton groups are reported from the sequential decay $^{12}C + d \rightarrow {}^{14}N^* \rightarrow {}^{13}N^* + n \rightarrow {}^{12}C + n + p$ via $^{13}N^*$ (3.51, 3.56) (Pi 63a). The proximity scattering associated with this process is characterized by a mean lifetime for the intermediate state of 0.7×10^{-20} sec (La 66m, La 65b). See also (Bo 68e).

See also (Aj 59), (Ma 60e, Ke 61b, Le 61h, Yn 61, Ya 61a, Ca 64b, Ga 65b, Jo 65e, Si 65e, Ho 66i, Og 67) and (Ho 61i, Sm 63a, Tr 63a, Sh 64m, Ma 65q, St 66l).

20. $^{12}C(^{3}He,d)^{13}N$ $Q_m = -3.550$

Angular distributions of deuterons to ^{13}N (0) have been measured at $E(^{3}He)$ = 6.0, 8.8, 9.4 and 10.1 MeV (Hi 60b), at 13.9 MeV (Pr 60), at 21.6 and 24.7 MeV (We 60) and at 29 MeV (Ga 62g). At the three highest energies, the angular distributions of the deuterons to ^{13}N (2.4) and (3.5-unresolved) have also been determined. See also (Fr 52e, Yn 61, Ec 66a, Ha 66n, Fo 67b, Ha 67s, Ho 67j).

21. $^{12}C(\alpha,t)^{13}N$ $Q_m = -17.870$

Angular distributions have been measured at E_{α} = 43 MeV (De 67d: t_o) and 56 MeV (Sy 67: t_o, t_{2+3}). See also (Yn 61, Tr 63a, Sh 64m).

22. $^{12}C(^{10}B,^{9}Be)^{13}N$ $Q_m = -4.644$

At $E(^{10}B)$ = 105 MeV, the ground state of ^{13}N and $^{13}N^*$ (3.5-unresolved) are observed (Sa 65d). See also (Gr 63h, Gr 65s).

23. $^{12}C(^{11}B, ^{10}Be)^{13}N$ $Q_m = -9.285$

At $E(^{11}B)$ = 116 MeV, the ground state of ^{13}N and $^{13}N^*$ (3.5-unresolved) are observed (Sa 65d, Po 67a). See also (Da 65f, Gr 65s).

24. $^{12}C(^{12}C,^{9}B)^{13}N$ $Q_m = -17.764$

See (Ch 62).

25. $^{12}C(^{14}N,^{13}C)^{13}N$ $Q_m = -5.606$

See (Bi 67).

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

$E_{thresh.} = 3.2353 \pm 0.0015$ (Be 61f)

$E_{thresh.} = 3.2371 \pm 0.0016$ (Be 61f: see Bo 64b)

$E_{thresh.} = 3.2354 \pm 0.0024$ (Bo 66k)

$E_{thresh.} = 3.2357 \pm 0.0007$ (recommended by Ma 66n)

Angular distributions of ground state neutrons have been measured at E_p = 3.1 to 5.3 MeV (Al 61e), 3.39 to 12.86 MeV (Da 61), 5.0 to 13.3 MeV (Wo 61) and 18.5 MeV (An 64a). See also (Pa 62, St 64d, Va 65) and (Bl 59b, El 63, Ca 64b, Sa 64i, Pa 66e).

Two thresholds are observed at E_p = 3.235 and 6.965 MeV ($\pm$ 10 keV), corresponding to ^{13}N (0) and $^{13}N^*$ (3.464) (Ri 66c). The neutron group corresponding to $^{13}N^*$ (2.3) is verv weak compared to the groups to ^{13}N (0) and $^{13}N^*$ (3.5) at the energies studied (Da 61). See also (Aj 59), (Un 66, At 68, Li 68h, Wo 68), and ^{14}N.

27. $^{13}C(^3He,t)^{13}N$ $Q_m = -2.239$

At $E(^3He)$ = 39.6 MeV, angular distributions have been obtained for the tritons corresponding to the ground state of ^{13}N and to the excited states at 2.37, 3.53 $\pm$ 0.03 (unresolved), 6.38, 7.17, 7.39, 8.92 $\pm$ 0.04, 11.85 $\pm$ 0.04 and 15.07 MeV. States at E_x = 9.5, 10.78 $\pm$ 0.04 and 15.98 $\pm$ 0.05 MeV were also populated, the first of these weakly (Ba 68kk). See also (Ec 66a, Ce 68).

28. $^{14}N(\gamma,n)^{13}N$ $Q_m = -10.553$

See (Fu 63a) and ^{14}N.

29. (a) $^{14}N(p,d)^{13}N$ $Q_m = -8.329$

(b) $^{14}N(p,pn)^{13}N$ $Q_m = -10.553$

Angular distributions have been determined at E_p = 18.5 MeV (Be 61d: d_o, d_1, d_{2+3}), 30.3 MeV (Ko 67j: d_o, d_2, and the deuterons to $^{13}N^*$ (7.38, 8.93, 11.80)), 45 MeV (Ma 66v: d_o, d_1, d_{2+3}, and the deuterons to $^{13}N^*$ (7.4 ± 0.1, 11.8 ± 0.2)) and 155.6 MeV (Ba 66gg: d_o, d_{2+3}, and the deuterons to $^{13}N^*$ (7.4, 9.0, 11.9)). See also (El 64, Og 67). For reaction (b) see (Ba 62o). See also ^{14}N.

30. $^{14}N(d,t)^{13}N$ $Q_m = -4.296$

Angular distributions of the tritons to $^{13}N^*$ (0, 3.51, 7.38, 8.93 + 9.48, 11.8) have been obtained at E_d = 52 MeV and analyzed by DWBA. The spectroscopic factors for the ^{13}N states [and the mirror states reached in the $^{14}N(d,^3He)^{13}C$ reaction] are in good agreement with theory and are additional evidence for the J^π assignments of $1/2^-$, $3/2^-$, $5/2^-$, $1/2^-$, $3/2^-$ and $3/2^-$ to these states (Hi 68c). Comparisons of (d,t) and (d,^{3}He) angular distributions are also reported by (De 66h, Ga 68h).

31. (a) $^{14}N(^3He,\alpha)^{13}N$ $Q_m = 10.025$

(b) $^{14}N(^3He,p\alpha)^{12}C$ $Q_m = 8.081$

$Q_o = 1.803 \pm 0.010$ (Yo 59a)

Alpha particle groups have been observed to the ground state of ^{13}N and to excited states at 2.358 ± 0.010, 3.471 ± 0.015 (Ta 60f), 6.38, 6.91, 7.166 ± 0.008 and 7.388 ± 0.008 MeV (Cl 62d). See also (Ga 63). Angular distributions have been studied at $E(^3He)$ = 4.5, 5.5 and 7.0 MeV (Kn 67: α_o, α_1, α_{2+3}), 13.9 MeV (Lu 68: α_o, α_1, α_{2+3}, α_4, α_{6+7}), 17.4 to 36.6 MeV (Ar 65b: α_o, α_1, α_{2+3}, α_{5+6} and the alphas to $^{13}N^*$ (11.4)), 29 MeV (Se 62e: α_o) and at 40-45 MeV (Ba 67vv). For reaction (b) see (De 67c). See also (El 64, Bo 65i, Bo 66e, Be 67p, Og 67, Ze 68).

32. $^{14}N(^{14}N,^{15}N)^{13}N$ $Q_m = 0.282$

See (Ka 68a, Na 68a).

33. $^{15}N(p,t)^{13}N$ $Q_m = -12.906$

At E_p = 43.7 MeV, angular distributions have been obtained for the tritons corresponding to the ground state of ^{13}N and the excited states at 3.51 ($3/2^-$), 6.38 ± 0.03 ($5/2^+$), 7.38 ($5/2^-$), 8.93 ± 0.05 ($1/2^-$), 10.78 ± 0.06 ($1/2^-$), 11.88 ± 0.04 ($3/2^-$) and 15.07 ($3/2^-$; T = 3/2) MeV states [J^π values in parentheses, as determined by DWBA analyses using intermediate-coupling wave functions to obtain the two-nucleon structure factors] (Fl 68). Detailed comparisons have been made with the $(p,^3He)$ reaction to the mirror states in ^{13}C (Fl 68, Fl 68a). See also (Ce 66, Ce 66f).

34. $^{16}O(\gamma,t)^{13}N$ $Q_m = -25.032$

See (Bu 65f, Bu 68).

35. (a) $^{16}O(p,\alpha)^{13}N$ $Q_m = -5.218$

(b) $^{16}O(p,p\alpha)^{12}C$ $Q_m = -7.161$

$Q_o = -5.206 \pm 0.010$ (Wh 60)

Angular distributions of the ground state alpha particles have been measured at E_p = 7.9 to 10.2 MeV (Da 64), 13.5 to 18.1 MeV (Ma 61g) and 38 MeV (Ga 68). See also (Va 62e, Ce 64), (Ch 57c, Wi 61e, Ho 64g) and ^{17}F. For reaction (b), see (Ch 67f).

36. $^{16}O(^3He,^6Li)^{13}N$ $Q_m = -9.239$

At E(^{3}He) = 65.3 MeV, ^{6}Li groups are observed to $^{13}N^*$ (0, 3.6-unresolved, 6.4 and 7.4) (Ce 66).

37. $^{18}O(d,^7Li)^{13}N$ $Q_m = -7.899$

See (Da 66).

^{13}O

(Not Illustrated)

^{13}O has been produced in the reaction $^{16}O(^{3}He,^{6}He)^{13}O$ at $E(^{3}He)$ = 65 MeV; the mass excess of ^{13}O is 23.11 ± 0.07 MeV (Ce 66). ^{13}O is then bound with respect to ^{12}N + p by 1.54 MeV. A computation using the three other members of the T = 3/2 quartet predicts M-A (^{13}O) = 23.10 ± 0.05 (Ce 66).

^{13}O has also been reported in the $^{14}N(p,2n)^{13}O$ reaction initiated by 50 MeV protons: $\tau_{1/2}$ = 8.7 ± 0.4 msec. ^{13}O is a delayed proton emitter decaying via $^{13}N^{*}$ (8.90, 9.48) to (^{12}C + p). The relative intensities are 100:24; on this scale the intensity of possible transitions to ^{13}N (7.42; $5/2^{-}$) is < 15, log ft > 5.5 (Mc 65g).

See also (Go 60p, Ba 61f, Ba 63t, Vl 63, Go 64j, Ja 65c, Go 66j, Ke 66c).

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