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Energy Levels of Light Nuclei
$A = 13$

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Abstract: An evaluation of $A = 13$–15 was published in *Nuclear Physics A*523 (1991), p. 1. This version of $A = 13$ differs from the published version in that we have corrected some errors discovered after the article went to press. The introduction and introductory tables have been omitted from this manuscript. Reference key numbers have been changed to the NNDC/TUNL format.

(References closed July 1, 1990)

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Table of Contents for $A = 13$

Below is a list of links for items found within the PDF document. The introductory Table 2 *is available on this website via the link.*

^{13}Li

(Not illustrated)

^{13}Li has not been observed: see (1986AJ01). The calculated value of its mass excess is 60.34 MeV [see (1981AJ01)]: ^{13}Li would then be unstable with respect to ^{11}Li + 2n by 3.34 MeV. (1985PO10) calculate [in a $(0+1)\hbar\omega$ model space] that the first four states of ^{13}Li at 0, 1.42, 2.09 and 2.77 MeV have, respectively, $J^\pi = \frac{3}{2}^-, \frac{7}{2}^-, \frac{1}{2}^-, \frac{5}{2}^-$. See also (1987PE1C, 1989OG1B) and (1988POZS, 1988ZV1A; theor.).

^{13}Be

(Not illustrated)

^{13}Be is reported to have been populated in the ^{14}C(^{7}Li, ^{8}B) reaction at $E(^7\text{Li}) = 82$ MeV. Its atomic mass excess is reported to be 35.0 ± 0.5 MeV and $\Gamma = 0.9 \pm 0.5$ MeV (1983AL20, 1985AL1G). It is then unstable with respect to breakup into ^{12}Be + n by 1.9 ± 0.5 MeV. However, the reported state may not be the ground state of ^{13}Be (1989OG1B). See also (1989DE52). ^{13}Be has not been observed in the interaction of 44 MeV/A ^{40}Ar ions on Ta, as would be expected since it is unstable (1986GI10). A calculation in a $(0+1)\hbar\omega$ model suggests that the first four states of ^{13}Be calculated to be at 0, 0.05, 1.28 and 1.55 MeV have $J^\pi = \frac{1}{2}^-, \frac{5}{2}^+, \frac{5}{2}^-$ and $\frac{1}{2}^+$ (1985PO10). See also (1985GA1C, 1986DO01, 1986GA33; hypernuclei), (1987PE1C), (1986AN07) and (1987SA15, 1989PO1K; theor.).

^{13}B

(Figs. 1 and 4)

GENERAL (See also 1986AJ01).

Model calculations: (1988WO04, 1989PO1K, 1989WO1E)

Complex reactions involving ^{13}B: (1985BO1A, 1986AV1B, 1986BI1A, 1986UT01, 1987AN1A, 1987BA38, 1987SA25, 1987VI02, 1988CA06, 1988RU01, 1988SA19, 1989KI13, 1989SA10, 1989YO02, 1990HA46)

Muon and neutrino capture and reactions: (1985KO39).

Pion capture and reactions (See also reactions 5 and 6): (1985SA06, 1988HA12, 1989JE02).

Hypernuclei: (1986FE1A, 1986ME1F, 1986WU1D, 1988MA1G, 1989BA92).

Antinucleon interactions: (1988MA48).

Other topics: (1985AN28, 1986AN07)

Table 13.1: Energy levels of ^{13}B

E_x (MeV $\pm$ keV)	J^π; T	τ or Γ_{cm} (keV)	Decay	Reactions
g.s.	$\frac{3}{2}^-$; $\frac{3}{2}$	$\tau_{1/2} = 17.36 \pm 0.16$ ms	β^-	1, 2, 3, 4, 5, 6, 7, 8, 9, 11
3.4828 ± 4.5	[a]		(γ)	3
3.5346 ± 3.1	[a]	$\tau_m > 0.3$ ps	γ	2, 3, 5, 6
3.6810 ± 4.5	[a]		(γ)	3, 6
3.7126 ± 4.5	[a]	$\tau_m < 0.38$ ps	γ	2, 3
4.131 ± 6	[a]	$\tau_m = 0.062 \pm 0.050$ ps	γ	2, 3
4.829 ± 6			(γ)	2, 3
5.024 ± 6	[a]			2, 3
5.106 ± 10		$\Gamma = 60 \pm 10$ keV		3
5.388 ± 6		10 ± 10		2, 3
(5.557 ± 7)				2
6.167 ± 6				2, 3
6.425 ± 7		36 ± 5		2, 3, 5, 6
6.934 ± 9		55 ± 15		2, 3
(7.516 ± 8)				2, 6
(7.859 ± 20)				2, 6
8.133 ± 7		100 ± 15		2, 3
8.683 ± 7		89 ± 20		2, 3
9.44 ± 30		81 ± 25		3
(9.5)		broad		9
10.22 ± 20		210 ± 20		3, 6
10.89 ± 20				3
(11.80)				3

[a] See Table 13.3.

Table 13.2: Beta decay of ^{13}B [a]

Decay to ^{13}C* (MeV)	J^π	Branch (%)	log ft [b]
0	$\frac{1}{2}^-$	92.1 ± 0.8	4.034 ± 0.006
3.09	$\frac{1}{2}^+$	≤ 0.7	≥ 5.6
3.68	$\frac{3}{2}^-$	7.6 ± 0.8	4.45 ± 0.05
3.85	$\frac{5}{2}^+$	≤ 0.7	≥ 5.5
7.55	$\frac{5}{2}^-$	0.094 ± 0.020	5.33 ± 0.10
8.86	$\frac{1}{2}^-$	0.16 ± 0.03	4.59 ± 0.09
9.90	$\frac{3}{2}^-$	0.022 ± 0.007	4.95 ± 0.14

[a] For references see Table 13.2 in (1981AJ01).

[b] M.J. Martin, private communication. I am very grateful to Dr. Martin for sending me his calculations.

Ground-state properties of ^{13}B: (1985AN28, 1988VA03, 1988WO04, 1989SA10, 1989WO1E, 1990LO10)

$Q = 47.8 \pm 4.6$ mb (1978LEZA). See also (1989RA17).
$\mu = +3.17778(51)$ nm (1978LEZA).

Interaction cross sections at 790 MeV/A for ^{13}B ions with Be, C, and Al are reported by (1988TA10). The interaction radius and the r.m.s. radius for the nucleon distribution in ^{13}B have also been derived (1988TA10).

1. ^{13}B(β^-)^{13}C $\qquad\qquad$ $Q_{\rm m} = 13.437$

The half-life of ^{13}B is 17.36 ± 0.16 ms: see (1981AJ01). See also (1988SA04). The branching ratios to various ^{13}C states are shown in Table 13.2: they indicate $J^\pi = \frac{1}{2}^-$ or $\frac{3}{2}^-$ for $^{13}B_{g.s.}$. See also (1989PO1K, 1989SA1P, 1989WO1E; theor.).

2. ^{7}Li(^{7}Li, p)^{13}B $\qquad\qquad$ $Q_{\rm m} = 5.962$

Observed proton and γ-ray groups are shown in Table 13.3. See also ^{14}C.

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

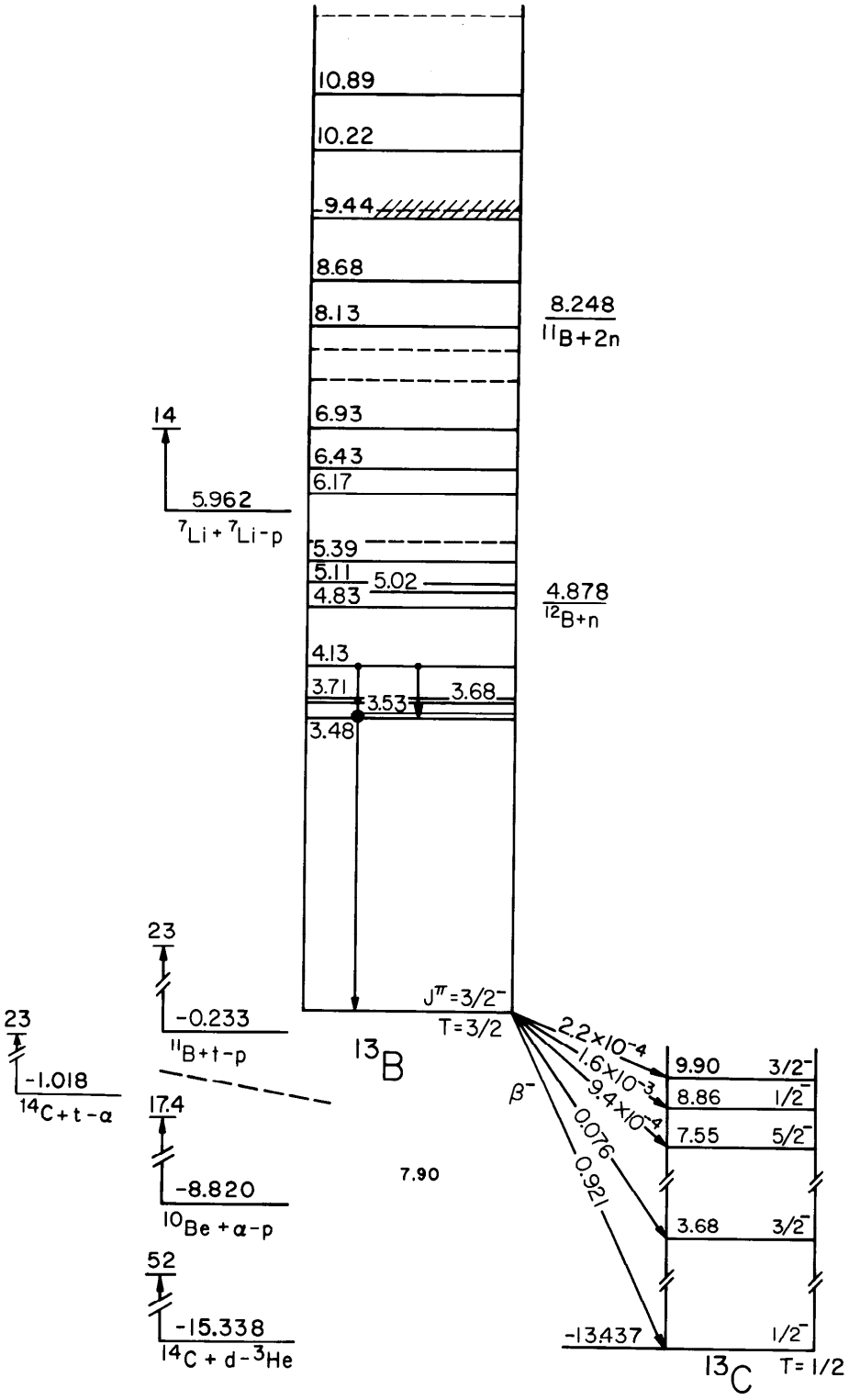


Fig. 1: Energy levels of ^{13}B. For notation see Fig. 2.

Table 13.3: Proton groups from ^{7}Li(^{7}Li, p)^{13}B and ^{11}B(t, p)^{13}B [a]

^{7}Li(^{7}Li, p)^{13}B	^{11}B(t, p)^{13}B				
	$E_t = 11$ MeV			$E_t = 23$ MeV	
E_x (MeV ± keV)	E_x (MeV ± keV)	L	J^π	E_x (MeV ± keV)	Γ_{cm} (keV)
0	0	0	$\frac{3}{2}^-$	0	
	3.483 ± 5	1	$(\frac{1}{2}, \frac{3}{2}, \frac{5}{2})^+$ [g]	3.482 ± 10	
3.5363 ± 4.2 [b]	3.533 ± 5	2	$(\frac{1}{2}, \frac{5}{2}, \frac{7}{2})^-$ [g]	3.531 ± 10	
	3.681 ± 5	1	$(\frac{1}{2}, \frac{3}{2}, \frac{5}{2})^+$ [g]	3.681 ± 10	
[c]	3.712 ± 5	2	$(\frac{1}{2}, \frac{5}{2}, \frac{7}{2})^-$ [g]	3.715 ± 10	
4.1334 ± 7.8 [d]	4.13 ± 10	2	$(\frac{1}{2}, \frac{5}{2}, \frac{7}{2})^-$ [g]	4.128 ± 10	
4.833 ± 10 [e]	4.82 ± 10			4.834 ± 10	
5.033 ± 8	5.01 ± 10	1	$(\frac{1}{2}, \frac{3}{2}, \frac{5}{2})^+$ [g]	5.023 ± 10	
				5.106 ± 10	60 ± 10
5.391 ± 8	5.38 ± 10 [f]			5.393 ± 10	10 ± 10
5.557 ± 8				[h]	
6.169 ± 8	6.17 ± 20			6.164 ± 10	
6.419 ± 8				6.434 ± 10	36 ± 5
6.939 ± 15				6.932 ± 10 [i]	55 ± 15
7.516 ± 8				[h]	
7.859 ± 20				[h]	
8.129 ± 10				8.138 ± 10	100 ± 15
8.682 ± 9				8.684 ± 10	89 ± 20
				9.44 ± 30	81 ± 25
				10.22 ± 20	210 ± 20
				10.89 ± 20	
				(11.80)	

[a] For references see (1981AJ01).

[b] E_γ; $\tau_m > 0.3$ ps.

[c] The decay is primarily by γ_0: the upper limit to the cascade via ^{13}B*(3.5) is 10%; $\tau_m < 0.38$ ps.

[d] The γ-decay is $(75 \pm 10)\%$, $(25 \pm 10)\%$ and $< 10\%$, respectively to ^{13}B*(0, 3.5, 3.7); $\tau_m = 62 \pm 50$ fs.

[e] All values in this column from this entry down are based on $E_x = 4131$ keV for ^{13}B*(4.13).

[f] $\Gamma = 15 \pm 5$ keV.

[g] See, however, (1978AJ02), page 1289.

[h] Not observed.

[i] $L \geq 4$.

Observed proton groups are displayed in Table 13.3.

4. ^{12}C(^{13}C, ^{12}N)^{13}B $\qquad Q_{\rm m} = -30.776$

See (1986VO02, 1988VO06) and ^{12}N in (1990AJ01).

5. ^{13}C(γ, π^+)^{13}B $\qquad Q_{\rm m} = -153.006$

At $E_{\rm e} = 195$ MeV the ^{13}B $E_{\rm x}$ region to 12 MeV has been studied by (1983MI06): they find that the photopion reaction predominantly excites M2 states at low q and M4 states at high q. Fits to the data are obtained by assuming the excitation of ^{13}B$_{\rm g.s.}$ and ^{13}B*(3.5, 6.4, 9.0) [the latter are clearly due to unresolved groupings of levels]. Comparisons are made with the ^{13}C(e, e′) work in the analog region in ^{13}C (1983MI06). [For $T = \frac{3}{2}$ states see Table 13.6.] For other work on this reaction see (1986AJ01). See also reaction 40 in ^{13}C, the "General" section and (1986SI07; theor.).

6. ^{13}C(π^-, γ)^{13}B $\qquad Q_{\rm m} = 126.131$

Gamma rays have been observed which are associated with the ^{13}B ground state; an unresolved doublet at $E_{\rm x} \approx 3.5$–3.7 MeV; sharp states at $E_{\rm x} \approx 6.5$ and 7.6 MeV; a broad level (or unresolved levels) at ≈ 10.2 MeV (1983MA16; see for radiative capture branching ratios). The analogs of the peaks at $E_{\rm x} = 6.5$, 7.6 and 10.2 MeV, calculated to be at ^{13}C*(21.6, 22.7, 25.3), are attributed to a $\Delta L = 1$, $\Delta S = 1$, $\Delta T = 1$ spin-isospin giant dipole resonance of ^{13}C (1983MA16). See also the "General" section.

7. ^{13}C(n, p)^{13}B $\qquad Q_{\rm m} = -12.655$

The 0° ground-state differential cross section has been measured at $E_{\rm n} = 198$ MeV (1988JA01). At $E_{\rm n} = 65$ MeV, ^{13}B*(0, 3.5) and the region from 6–10 MeV have been studied (1986WAZU; prelim.). See also (1986FO1E, 1987BR32, 1989SOZY, 1989SOZW) and (1986ALZJ).

8. ^{13}C(d, 2p)^{13}B $\qquad Q_{\rm m} = -14.880$

At $E_{\rm d} = 70$ MeV the angular distribution to ^{13}B$_{\rm g.s.}$ has been reported. Structures at $E_{\rm x} = 3.8$, 5.2, 6.6 MeV are also observed. For VAP measurements see ^{15}N (1986MO27).

9. ^{13}C(^{7}Li, ^{7}Be)^{13}B $\quad Q_{\rm m} = -14.299$

At $E(^{7}\mathrm{Li}) = 21$ MeV/A, forward angular distributions are reported to $^{13}\mathrm{B}_{\mathrm{g.s.}}$ and to unresolved structures at 3.5, 4.0, 5.1, 6.3, 7.0 and 7.6 MeV, and to a broad ($\Gamma \approx 2.3$ MeV) structure at 9.5 MeV. The latter is suggested to be due to the GDR (1990NA03) [see for possible J^{π} assignments].

10. ^{14}C(γ, p)^{13}B $\quad Q_{\rm m} = -20.832$

See (1987GO09; theor.).

11. ^{14}C(t, α)^{13}B $\quad Q_{\rm m} = -1.017$

See (1986AJ01).

^{13}C

(Figs. 2 and 4)

GENERAL (See also 1986AJ01).

Nuclear models: (1985KW02, 1987KI1C, 1988MI1J, 1988WO04, 1989AM02, 1989PO1K, 1989WO1E, 1990FE01, 1990HO01, 1990VA01).

Special states: (1984KO40, 1985GO1A, 1985RO1J, 1985SH24, 1986AN07, 1986XU02, 1987KI1C, 1988KW02, 1988MI1J, 1988RO1R, 1988ZH1B, 1989AM02, 1989OR02, 1989RO03, 1990HO01).

Electromagnetic transitions and giant resonances: (1984VA06, 1985GO1A, 1986AD1B, 1986ER1A, 1987KI1C, 1989AM02).

Astrophysical questions: (1982BU1A, 1982CA1A, 1982GR1A, 1982WO1A, 1985BR1E, 1985HA1R, 1985HE1F, 1985MI1E, 1985PR1D, 1985RI1B, 1986DO1L, 1986FR1G, 1986GO1Q, 1986LA1C, 1986MA2E, 1986SN1C, 1986SN1D, 1986WI1H, 1987AR1C, 1987AU1A, 1987BE1H, 1987BO1B, 1987BR1P, 1987DO1A, 1987HA1C, 1987HA1U, 1987KR1M, 1987MA1C, 1987MA2G, 1987PI1E, 1987PR1A, 1987SO1F, 1987WA1L, 1987WA1F, 1987ZI1C, 1988AP1A, 1988AR1H, 1988AS1D, 1988CR1A, 1988DE1I, 1988JA1B, 1988JU1C, 1988PI1C, 1988SC1A, 1988TR1H, 1989AB1J, 1989BA2I, 1989BA2K, 1989BO1S, 1989BR1I, 1989BR1M, 1989CH1X, 1989CH1Z, 1989FR1J, 1989GI1E, 1989GU1L, 1989HA1O, 1989HO1F, 1989JI1A, 1989KA1K, 1989LO1C, 1989LO1D, 1989ME1C, 1989NO1A, 1989SM1A, 1989ST1K, 1989WE1G, 1989WH1B, 1989WY1A, 1990CA1O, 1990FU03, 1990HO1I, 1990MO1I, 1990PI1F, 1990TU1A, 1990WE1I).

Applied work: (1986BR1Q, 1986BU1H, 1986DO1M, 1986DR1E, 1986EN1A, 1986FO1D, 1986FR1H, 1986GE1C, 1986HE1F, 1986KI1J, 1986KN1E, 1986KR1F, 1986MA2D, 1986MA2G, 1986NI1C, 1986NO1C, 1986SR1B, 1986ST1K, 1986XU1C, 1987BO1U, 1987DU1A, 1987KI1I, 1987NA1O, 1987ST1C, 1988AR1G, 1988BU1C, 1988DO1D, 1988FA1A, 1988GO1J, 1988MA1A, 1988PU1A, 1988SC1C, 1989CE1D, 1989GR1F, 1989KU1P, 1989MU1A, 1989RA1M, 1990DO1C, 1990FR1F).

Complex reactions involving ^{13}C: (1984BO1H, 1985KI1E, 1985KW03, 1985PO11, 1985PO14, 1985UT01, 1986AV1B, 1986GR1A, 1986HA1B, 1986HO1K, 1986MA19, 1986MA1O, 1986ME06, 1986MO15, 1986PO06, 1986SA30, 1986SO10, 1986UT01, 1986XU02, 1986XU1B, 1987AR19, 1987BA38, 1987BE1I, 1987BU07, 1987GA17, 1987GE1B, 1987LY04, 1987NA01, 1987PE1B, 1987PO23, 1987RI03, 1987SI1C, 1987SN01, 1987ST01, 1987VI02, 1987YA16, 1988BE56, 1988CA06, 1988GA11, 1988HA03, 1988JO1B, 1988KI06, 1988RU01, 1988SA19, 1989AJ1A, 1989BA92, 1989CH1U, 1989GIZV, 1989GRZQ, 1989HO16, 1989KI13, 1989POZT, 1989PR02, 1989SA10, 1989SE03, 1989TE02, 1990CH09).

Muon and neutrino capture and reactions: (1985DE42, 1985KO39, 1985MI21, 1986IS02, 1986MI09, 1986MI1M, 1987SU06, 1990CH13, 1990FU03, 1990LU1D, 1990MI1J).

Pion capture and reactions involving pions and ρ-mesons (See also reactions 27 and 41, and reaction 23 in ^{13}N): (1983MA16, 1984BO1H, 1984CH1K, 1985SA06, 1986BO1N, 1986CE04,

1986DO01, 1986ER1A, 1986KO26, 1986LI1N, 1986LI1P, 1986MI1M, 1986SI07, 1986SI13, 1986SI22, 1986SU18, 1987DU08, 1987GI1C, 1987MI08, 1987PI1B, 1988BU1I, 1988CH24, 1988CH1L, 1988CHZU, 1988GIZU, 1988HA12, 1988KIZW, 1988PE1F, 1988PE1H, 1988PO1H, 1988POZV, 1988US01, 1989CH31, 1989GE10, 1989IT04, 1989JE02, 1989JO07, 1989KI25, 1989MO09, 1989PI11, 1990BE12, 1990CH12, 1990ER03, 1990ER1E, 1990FE01, 1990KO19, 1990TA1K, 1990TI1B).

Table 13.4: Energy levels of ^{13}C [a]

E_x in ^{13}C (MeV $\pm$ keV)	J^π; T	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
g.s.	$\frac{1}{2}^-$; $\frac{1}{2}$		stable	5, 6 ,7, 8, 10, 11, 13, 14, 15, 19, 20, 21, 22, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 67, 68, 69, 70, 71, 72, 73
3.089443 ± 0.020	$\frac{1}{2}^+$	$\tau_m = 1.55 \pm 0.15$ fs [c]	γ	5, 6, 7, 8, 11, 13, 19, 20, 21, 22, 27, 28, 29, 31, 32, 35, 36, 40, 41, 42, 43, 44, 45, 46, 47, 50, 59, 60, 61, 62, 63, 64, 65, 67, 69, 71
3.684507 ± 0.019	$\frac{3}{2}^-$	1.59 ± 0.13 fs [c]	γ	5, 6, 7, 8, 11, 13, 14, 19, 20, 21, 22, 27, 28, 29, 31, 32, 34, 37, 40, 41, 42, 43, 44, 45, 46, 47, 48, 59, 60, 61, 62, 63, 64, 67, 69
3.853807 ± 0.019	$\frac{5}{2}^+$	12.4 ± 0.2 ps [d]	γ	5, 6, 7, 8, 11, 13, 19, 20, 21, 27, 28, 29, 30, 32, 34, 37, 40, 41, 42, 43, 44, 45, 46, 50, 59, 60, 62, 64, 69, 71
6.864 ± 3 [f]	$\frac{5}{2}^+$	$\Gamma = 6$	γ, n	5, 6, 7, 8, 11, 12, 13, 19, 21, 23, 27, 28, 29, 40, 43, 45, 46, 59, 61, 64, 67

Table 13.4: Energy levels of ^{13}C [a] (continued)

E_x in ^{13}C (MeV $\pm$ keV)	$J^\pi; T$	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
7.492 ± 10	$(\frac{7}{2}^+)$	< 5		5, 8, 12, 14, 19, 21, 28, 40, 45, 46, 63, 64
7.547 ± 3	$\frac{5}{2}^-$	1.2 ± 0.3	γ, n	5, 8, 11, 12, 14, 19, 21, 23, 28, 37, 40, 41, 42, 43, 44, 45, 46, 47, 48, 59, 63, 64, 67
7.686 ± 6	$\frac{3}{2}^+$	70 ± 5	γ, n	11, 12, 19, 21, 28, 29, 38, 43, 45, 46, 59, 64
8.2 ± 100	$\frac{3}{2}^+$	1100 ± 300	γ, n	8, 23, 28, 29, 30, 43, 59
8.860 ± 20	$\frac{1}{2}^-$	150 ± 30	γ, n	19, 23, 28, 37, 40, 41, 43, 45, 46, 59, 60, 63, 64, 67
9.4998 ± 0.1 [b]	$\frac{9}{2}^+$	≤ 5	γ, n	5, 8, 12, 19, 23, 27, 28, 29, 30, 40, 43, 45, 46, 59, 63, 64, 67
9.897 ± 5	$\frac{3}{2}^-$	26 ± 3	γ, n	5, 11, 12, 19, 23, 28, 37, 38, 40, 43, 45, 59, 64
10.46		200	n	23
10.753 ± 4	$\frac{7}{2}^-$	55 ± 2	γ, n	5, 12, 19, 23, 28, 29, 40, 43, 45, 64
10.818 ± 5	$(\frac{5}{2}^-)$	24 ± 3	γ, n	5, 12, 19, 23, 28, 40, 43, 45, 64
10.996 ± 6	$\frac{1}{2}^+$	37 ± 4	γ, n, α	2, 19, 23, 28, 38, 43, 59, 64
11.080 ± 5	$\frac{1}{2}^-$	< 4	γ, n, α	2, 19, 23, 28, 40, 43, 45, 46, 59, 64, 67
11.748 ± 10	$\frac{3}{2}^-$	110 ± 15	n	19, 23, 28, 43, 59, 64
11.848 ± 4	$\frac{7}{2}^+$	68 ± 4	γ, n	5, 23, 28, 40, 41, 43, 45, 46, 60, 67
11.95 ± 40	$\frac{5}{2}^+$	500 ± 80	n, α	2, 23, 28, 40, 43
12.106 ± 5	$\frac{3}{2}^+$	540 ± 70	(γ), n, (α)	2, 23, 28, 38, 43
12.13 ± 50	$\frac{5}{2}^-$	80 ± 30	n, (α)	2, 5, 23, 64
12.14 ± 70	$\frac{1}{2}^+$	430 ± 70	n, (α)	2, 23, 43

Table 13.4: Energy levels of ^{13}C [a] (continued)

E_x in ^{13}C (MeV ± keV)	J^π; T	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
12.187 ± 10	$\frac{3}{2}^-$	150 ± 40	γ, n, (α)	2, 23, 40
12.438 ± 12	$\frac{7}{2}^-$	140 ± 30	γ, n, α	2, 23, 40, 43, 67
13.0 ± 1000		broad	γ, n	38
(13.28)	($\frac{3}{2}^-$)	340	α	4, 43, 59
13.41	($\frac{9}{2}^-$)	35 ± 3	n, α	2, 4, 5, 43
13.57	$\frac{7}{2}^-$	620 ± 50	n, α	2, 4, 23, 43
13.76	($\frac{5}{2}$, $\frac{3}{2}$)$^+$	≈ 300	n, α	2, 4, 43
14.13	$\frac{3}{2}^-$	≈ 150	n, α	2, 4, 5, 23, 43
14.390 ± 15	($\frac{1}{2}$, $\frac{5}{2}$)$^-$	280 ± 70	γ, n, α	2, 40, 43
14.582 ± 10	($\frac{7}{2}^+$, $\frac{9}{2}^+$)	230 ± 40	γ, n, α	2, 40, 43
14.983 ± 10	($\frac{7}{2}^-$)	380 ± 60	γ, n, α	2, 23, 40, 43
15.1082 ± 1.2 [e]	$\frac{3}{2}^-$; $\frac{3}{2}$	5.49 ± 0.25	γ, n, α	2, 4, 19, 23, 40, 43, 45, 59, 67
15.27	$\frac{9}{2}^+$		n	23
15.526 ± 11	($\frac{3}{2}^-$)	150 ± 30	γ, n, α	2, 23, 4, 43
16.080 ± 7	($\frac{7}{2}^+$)	150 ± 15	γ, n, α	2, 23, 40, 41, 43, 45
16.15 ± 50	($\frac{5}{2}^-$)	230	n, α	2, 43
(16.183 ± 28)		(40 ± 20)	γ	40
16.95 ± 50		330	n, α	2, 43
17.36 ± 100		190	n, α	2, 43
17.533 ± 3	($T = \frac{3}{2}$)	17 ± 6	n	23
17.699 ± 5	($\frac{3}{2}$, $\frac{5}{2}$)	170	n, α	2, 43
(17.92 ± 50)				41
18.082 ± 3	($T = \frac{3}{2}$)	12 ± 7	n	23
18.30 ± 50		300	n, α	2, 43
(18.497 ± 10)		(91 ± 23)	γ	40
18.699 ± 5	($\frac{3}{2}^+$, $\frac{5}{2}^+$)	100 ± 15	γ, n, (p), α	2, 39, 40, 43
19.51	($\frac{5}{2}^-$)	≥ 500	n, d	16, 23, 43
19.9		≈ 600	n, p, d	16, 43
20.021 ± 13		230 ± 30	γ	40, 43

Table 13.4: Energy levels of ^{13}C [a] (continued)

E_x in ^{13}C (MeV $\pm$ keV)	$J^\pi; T$	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
20.057 ± 4		11 ± 8	n	23
(20.11)	$(\frac{1}{2}^-)$	1090	n	23
(20.11)	$(\frac{5}{2}^+)$	440	n	23
20.20 ± 70	$(\frac{7}{2}^+)$	560 ± 90	γ, n, d, α	15, 16, 18, 22, 23
(20.30)	$(\frac{7}{2}^-)$	1560	n	23
(20.34)	$(\frac{9}{2}^+)$	320	n	23
20.429 ± 8		115 ± 25	γ, n, p, d	16, 40, 43
20.52 ± 70		510 ± 70	γ, n, p	16, 23
20.6 ± 800		5600 ± 400	γ, n, d	15, 22, 38
(20.93 ± 100)		(240 ± 100)		43
21.28 ± 15		159 ± 15	n, p, d	16, 17, 43
21.466 ± 8	$(\frac{7}{2}^+, \frac{9}{2}^+)$	270 ± 20	γ	40, 43
21.703 ± 4	$(T = \frac{3}{2})$	18 ± 9	n	23, 27
21.81 ± 20	$(\geq \frac{5}{2})$	114 ± 21	n, d	16, 43
22.2 ± 100	$(\leq \frac{5}{2})$	1100 ± 500	n, d	16, 43
23	$(\leq \frac{5}{2})$	≈ 1000	n	23, 43
24		≈ 4000	γ, n, p	38
(26)		broad	γ, p	39
26.8			n, d	16
27.5		≈ 1000	n, p, d, t	16
30			γ, n	38

[a] See also Table 13.5.

[b] See footnote [b] in Table 13.10.

[c] From Table 13.5 in (1981AJ01).

[d] Weighted mean of values displayed in Table 13.5 in (1981AJ01) and in (1981RU04).

[e] See Table 13.6.

[f] See also footnote [c] in Table 13.11.

Kaon capture and reactions: (1984BO1H, 1985GA1C, 1986DO01, 1986FE1A, 1986GA33, 1986MA1C, 1986MA1W, 1987FA1A, 1987PI1B, 1987PO1H, 1988FA1B, 1988PE1F, 1988PE1H, 1988PO1H, 1988ZH1H, 1989CH52, 1989DO1K, 1989PI11, 1990FE01).

Table 13.5: Summary of results: total radiation widths of low-lying levels of ^{13}C-^{13}N [a]

$J_i^\pi \to J_f^\pi$	^{13}C* (MeV)	Γ_γ (eV)	^{13}N* (MeV)	Γ_γ (eV)
$\frac{1}{2}^+ \to \frac{1}{2}^-$	3.09 [b]	0.43 ± 0.04	2.37	0.50 ± 0.04 [g]
$\frac{3}{2}^- \to \frac{1}{2}^-$	3.68 [c]	0.41 ± 0.04	3.51 [f]	0.70
$\frac{5}{2}^+ \to \frac{1}{2}^-$	3.85 [d]	$(5.32 \pm 0.09) \times 10^{-5}$ [e]	3.55	$< 2 \times 10^{-3}$

[a] See also Tables 13.12 and 13.17. For references see Table 13.6 in (1981AJ01).

[b] $E_x = 3089.443 \pm 0.020$ keV, $E_\gamma = 3089.049 \pm 0.020$ keV* (1980WA24: here, and in footnote [d], measured values are starred (*); the others are derived.)

[c] Branching ratio for cascade via ^{13}C*(3.09) is $(0.75 \pm 0.04)\%$ (1980WA24), $(0.74 \pm 0.05)\%$ (1982MU14). $E_x = 3684.482 \pm 0.023$ keV, $E_\gamma = 3683.921 \pm 0.023$ keV. δ(E2/M1) $= -0.094 \pm 0.009$. E_γ for the transition to ^{13}C*(3.09) is 595.013 ± 0.011 keV (1980WA24).

[d] Branching ratios for cascades via ^{13}C*(3.68, 3.09) are $(36.3 \pm 0.6)\%$ and $(1.20 \pm 0.04)\%$, respectively (1980WA24). $E_x = 3853.783 \pm 0.022$ keV, $E_\gamma = 3853.170 \pm 0.022$ keV; E_γ for the transition to ^{13}C*(3.09, 3.68) are 764.316 ± 0.010 keV* and 169.300 ± 0.004 keV* (1980WA24) [169.356 ± 0.020 keV* (1984SC09)].

[e] The ground-state branching ratio is $(62.5 \pm 0.6)\%$ (1980WA24) and δ(E3/M2) $= +0.12 \pm 0.03$ (1966PO11).

[f] Branching ratio for cascade via ^{13}N*(2.37) is $(8 \pm 1)\%$ (1974RO29). See also footnote [g] in Table 13.17.

[g] See the discussion in (1985BA75).

Hypernuclei: (1984BO1H, 1984ZH1B, 1985BA1F, 1985BA2D, 1985GA1C, 1985KO1W, 1985KO2B, 1985YA1C, 1986AN1R, 1986BA1H, 1986DA1G, 1986DA1B, 1986DO01, 1986ER1A, 1986FE1A, 1986GA33, 1986KO1A, 1986LA1R, 1986MA1C, 1986MA1W, 1986ME1F, 1986WU1C, 1986WU1D, 1986YA1F, 1987CO1E, 1987FA1A, 1987MA08, 1987MI38, 1987PI1C, 1987PO1H, 1988CH48, 1988FA1B, 1988GA1A, 1988GA1I, 1988IT02, 1988MA1G, 1988MA58, 1988MO1L, 1988PE1H, 1988PO1H, 1988TA29, 1988WA1B, 1988ZH1H, 1989BA92, 1989BA93, 1989CH52, 1989DO1K, 1989DO1N, 1989FE07, 1989IT04, 1989KI25, 1989KO1H, 1989KO37, 1989KO48, 1989LA1H, 1989LA1I, 1989MA30, 1989MI30, 1989PI11, 1990FE01, 1990IT1A, 1990OS1A).

Other topics: (1985AN28, 1985SH24, 1986AN07, 1988KW02, 1989FU05, 1989OR02, 1990MU10).

Ground state of ^{13}C: (1985AN28, 1985GO1A, 1986GL1A, 1986SI22, 1987AB03, 1987FU06, 1987GI1C, 1987KI1C, 1987SA15, 1988AR1I, 1988KE1B, 1988VA03, 1988WA08, 1988WO04, 1989AM02, 1989AN12, 1989FU05, 1989GOZQ, 1989WO1E, 1990VA01).

$\mu = +0.702411(1)$ nm (1978LEZA)

$\langle r^2 \rangle^{1/2} = 2.4628(39)$ fm (1985DE42) [charge radius, from muonic ^{13}C]
[The neutron r.m.s. radius is 2.35 (3) fm (1979JO08).]

Natural abundance: $(1.10 \pm 0.03)\%$ (1984DE53)

^{13}C*(3.85): $g = -0.558 \pm 0.015$ (1981RU04). From the γ-ray due to the transition ^{13}C*(3.85 $\rightarrow$ 3.68), $\Delta E_{\rm x} = 169.356 \pm 0.020$ keV: see (1986AJ01). See also (1989RA17).

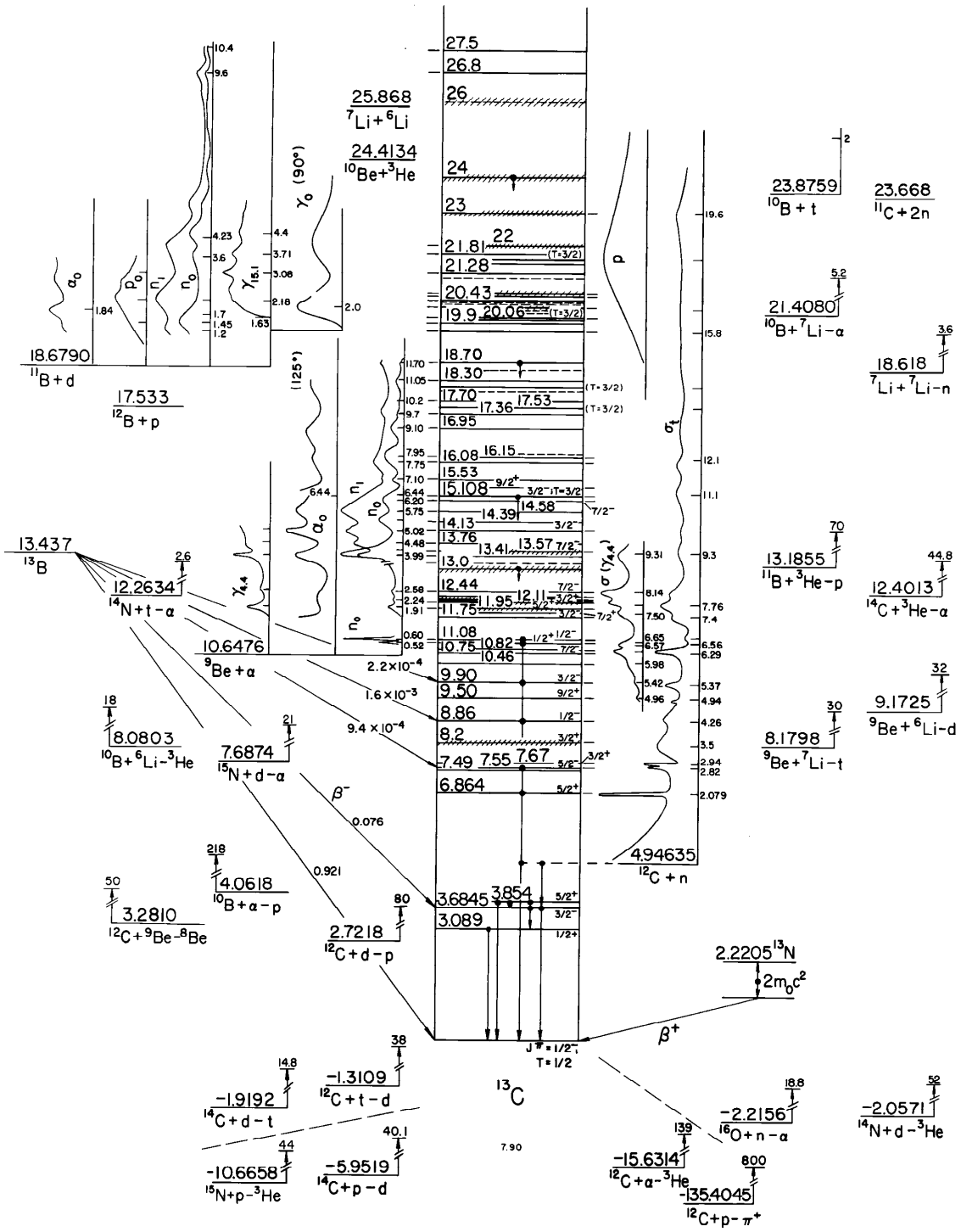
1. (a) ^{6}Li(^{7}Li, γ)^{13}C	$Q_{\rm m} = 25.868$	
(b) ^{6}Li(^{7}Li, n)^{12}C	$Q_{\rm m} = 20.921$	$E_{\rm b} = 25.868$
(c) ^{6}Li(^{7}Li, p)^{12}B	$Q_{\rm m} = 8.334$	
(d) ^{6}Li(^{7}Li, d)^{11}B	$Q_{\rm m} = 7.189$	
(e) ^{6}Li(^{7}Li, t)^{10}B	$Q_{\rm m} = 1.992$	
(f) ^{6}Li(^{7}Li, α)^{9}Be	$Q_{\rm m} = 15.220$	

The yield curves for $\rm d_0$ ($E(^{6}\text{Li}) = 4$ to 14 MeV), $\rm t_0$ ($E(^{7}\text{Li}) = 5$ to 14 MeV) and α_0 ($E(^{6}\text{Li}) = 4$ to 14 MeV) show broad, uncorrelated structures. Energy-averaged differential cross sections are also reported for a number of ^{12}B, ^{11}B and ^{10}B states. Total cross sections have been measured for $E(^{7}\text{Li}) = 3.8$ to 6.0 MeV for $\rm p_0 \rightarrow p_2$, $\rm p_{3+4}$, $\rm p_5$; $\rm d_0 \rightarrow d_3$, $\rm d_{4+5}$, $\rm d_6$; $\rm t_0 \rightarrow t_2$; and α_0: the total cross sections generally increase smoothly with energy without showing any structure: see (1981AJ01). For reaction (b) see (1987SC11).

2. (a) ^{9}Be(α, n)^{12}C	$Q_{\rm m} = 5.7012$	$E_{\rm b} = 10.6476$
(b) ^{9}Be(α, 2n)^{11}C	$Q_{\rm m} = -13.021$	

Resonances for $\rm n_0$ and $\rm n_1$, for γ-rays from ^{12}C*(4.4, 12.7, 15.1) and resonances in the total neutron cross section are given in Table 13.7. In addition the yield of neutrons to ^{12}C*(7.65, 9.64) has been measured in the range $E_\alpha = 2.9$–6.4 MeV. The $\rm n_0$ and $\rm n_1$ excitation functions exhibit weak resonance anomalies at $E_\alpha = 6.44$ MeV corresponding to the $J^\pi = \frac{3}{2}^-$, $T = \frac{3}{2}$ state at $E_{\rm x} = 15.11$ MeV: see Tables 13.6 and 13.7 (1978HI06). For thick target yields see (1982WE16). See also (1989HE04). For polarization measurements (E_α to 100 MeV) see (1981AJ01). Reaction (b) has been studied at a number of energies for $E_\alpha = 17$ to 44 MeV: see (1981AJ01, 1986AJ01). See also ^{12}C in (1990AJ01), (1987EL1B, 1989CR07; applied) and (1985CA41; astrophysics).

Fig. 2: Energy levels of ^{13}C. In these diagrams, energy values are plotted vertically in MeV, based on the ground state as zero. Uncertain levels or transitions are indicated by dashed lines; levels which are known to be particularly broad are cross-hatched. Values of total angular momentum J, parity, and isobaric spin T which appear to be reasonably well established are indicated on the levels; less certain assignments are enclosed in parentheses. For reactions in which ^{13}C is the compound nucleus, some typical thin-target excitation functions are shown schematically, with the yield plotted horizontally and the bombarding energy vertically. Bombarding energies are indicated in laboratory coordinates and plotted to scale in cm coordinates. Excited states of the residual nuclei involved in these reactions have generally not been shown; where transitions to such excited states are known to occur, a brace is sometimes used to suggest reference to another diagram. For reactions in which the present nucleus occurs as a residual product, excitation functions have not been shown; a vertical arrow with a number indicating some bombarding energy, usually the highest, at which the reaction has been studied, is used instead. Further information on the levels illustrated, including a listing of the reactions in which each has been observed, is contained in the master table, entitled "Energy levels of ^{13}C".


27.5
26.8
26
25.868
7Li+6Li
24.4134
10Be+3He
24
23
22
21.81
21.28
20.43
19.9
20.06
18.70
18.30
17.70
17.36
17.53
16.95
16.08
16.15
15.53
15.108
14.58
14.39
14.13
13.76
13.41
13.57
13.0
12.44
12.11
11.95
11.75
11.08
10.75
10.82
10.46
9.90
9.50
8.86
8.2
7.49
7.55
7.67
6.864
3.6845
3.854
3.089
4.94635
12C+n
23.8759
10B+t
23.668
11C+2n
21.4080
10B+7Li-α
18.618
7Li+7Li-n
13.1855
11B+3He-p
12.4013
14C+3He-α
9.1725
9Be+6Li-d
8.1798
9Be+7Li-t
18.6790
11B+d
17.533
12B+p
13.437
13B
12.2634
14N+t-α
10.6476
9Be+α
8.0803
10B+6Li-3He
7.6874
15N+d-α
4.0618
10B+α-p
3.2810
12C+9Be-8Be
2.7218
12C+d-p
2.2205 13N
2m0c2
β+
β−
0.076
0.921
2.2×10−4
1.6×10−3
9.4×10−4
J π = 1/2−
T = 1/2
13C
7.90
-1.9192
14C+d-t
-1.3109
12C+t-d
-10.6658
15N+p-3He
-5.9519
14C+p-d
-2.2156
16O+n-α
-15.6314
12C+α-3He
-135.4045
12C+p-π+
-2.0571
14N+d-3He
γ0 (90°)
(125°)
γ15.1
γ4.4
σ (γ4.4)
σt
p
a0
p0
n1
n0

3. (a) ^{9}Be(α, d)^{11}B $Q_{\rm m} = -8.0314$ $E_{\rm b} = 10.6476$

(b) ^{9}Be(α, t)^{10}B $Q_{\rm m} = -13.2283$

Excitation curves have been measured for $E_\alpha = 15$ to 27.5 MeV for reaction (a) [involving $\rm d_0$, $\rm d_1$ and at the higher energies $\rm d_2$, $\rm d_3$, $\rm d_{4+5}$, $\rm d_6$] and at 26.0 to 27.5 MeV for reaction (b) [$\rm t_0$, $\rm t_1$, $\rm t_3$]: no structures are observed: see (1981AJ01). See also ^{11}B in (1990AJ01) and ^{10}B in (1988AJ01).

4. ^{9}Be(α, α)^{9}Be $E_{\rm b} = 10.6476$

A number of excitation functions have been measured for elastically scattered α-particles for $E_\alpha = 1.4$ to 20 MeV: these show considerable resonance structure with the variations being most prominent below 10 MeV but persisting up to 20 MeV. The parameters resulting from a best-fit of the excitation functions are displayed in Table 13.8: see the footnotes to that table for a summary of the most important caveats. A weak resonance is observed in the α_0 yield at $E_\alpha = 6.44$ MeV corresponding to the excitation of the first $T = \frac{3}{2}$ state at $E_{\rm x} = 15.11$ MeV: see Table 13.6 for the parameters of that state. For a measurement of the total reaction cross section at $E_\alpha = 100$ MeV see (1986DU15). See also (1987BU27) and (1986SA30; theor.).

5. ^{9}Be(^{6}Li, d)^{13}C $Q_{\rm m} = 9.1725$

Angular distributions have been studied at $E(^{6}\text{Li}) = 32$ MeV to ^{13}C*(0, 3.09, 3.68 + 3.85, 6.86, 7.5, 9.5, 9.9, 10.75, 13.42). The spectra are dominated by the deuteron group to a state (or states) at $E_{\rm x} = 10.75 \pm 0.018$ MeV, with $\Gamma = 130$ keV [suggesting that both ^{13}C*(10.75, 10.82) are populated]. Two states, consistent with ^{13}C*(11.35, 12.13) are also populated, as is a broad group at 14.13 MeV (1989AS01; see for spectroscopic factors).

6. ^{9}Be(^{7}Li, t)^{13}C $Q_{\rm m} = 8.1798$

Angular distributions for $\rm t_0$, $\rm t_1$, $\rm t_{2+3}$, $\rm t_4$ are reported at $E(^{7}\text{Li}) = 5.6$ to 6.2 MeV: see (1976AJ04).

7. ^{9}Be(^{9}Be, nα)^{13}C $Q_{\rm m} = 9.0741$

Cross sections for gamma rays from the decay of ^{13}C*(3.09, 3.68, 3.84) are reported by (1988LA25) for $E(^{9}\text{Be}) = 2.8$ to 6 MeV.

Table 13.6: Parameters of the first $T = \frac{3}{2}$ states in ^{13}C and ^{13}N [a]

	^{13}C*(15.11)	^{13}N*(15.06)
E_x (MeV)	15.1082 ± 0.0012	15.06457 ± 0.0004
J^π	$\frac{3}{2}^-$	$\frac{3}{2}^-$
$\Gamma_{c.m.}$ (keV)	5.49 ± 0.25	0.932 ± 0.028
Γ_{γ_0} (eV)	22.4 ± 1.5 (M1), 0.6 ± 0.1 (E2)	24.2 ± 1.5 (M1) [e], 0.32 ± 0.12 (E2) [f]
Γ_{γ_1} (eV)	4.12 ± 0.74	$\leq 2.82 \pm 0.30$ [g]
$\Gamma_{\gamma_{2+3}}$ (eV)	18.2 ± 2.4	19.6 ± 1.4 [h]
Γ_{γ_0}/Γ (%)	0.396 ± 0.030 [b]	
$\Gamma_{p_0}\Gamma_{\gamma_0}/\Gamma$ (eV)		5.79 ± 0.20
$\Gamma_{\gamma_0}/\Gamma_{p_0}$ (%)		12.1 ± 1.1
Γ_{n_0} or Γ_{p_0} (keV) [c]	0.38 ± 0.10	0.228 ± 0.016 [i]
Γ_{n_1} or Γ_{p_1} (keV) [c]	1.43 ± 0.18	0.140 ± 0.014 [i]
Γ_{n_2} or Γ_{p_2} (keV) [c]	0.14 ± 0.10	0.049 ± 0.015 [i]
Γ_{p_3} (keV) [c]		0.089 ± 0.014 [i]
Γ_{p_5} (keV) [c]		0.15 ± 0.04 [i] [j]
Γ_{α_0} (keV) [d]	0.104 ± 0.028	0.046 ± 0.026 [i]
Γ_{α_1} (keV) [d]		0.036 ± 0.036 [i]
Γ_{α_2} (keV) [d]		0.067 ± 0.042 [i]

[a] For references see Table 13.7 in (1981AJ01).

[b] The decay width to ^{13}C*(7.55) is < 0.9 eV.

[c] Widths for ^{13}C*(15.11)$\rightarrow{}^{12}$C$_{g.s.} + n_0$ or ^{13}N*(15.06)$\rightarrow{}^{*12}$C$_{g.s.} + p_0$ (n_1, p_1, n_2, p_2; and p_3 and p_5 refer to the decays to ^{12}C*(4.4, 7.7, 9.6, 10.8), respectively).

[d] Widths for ^{13}C*(15.11)$\rightarrow{}^{9}$Be$_{g.s.} + \alpha_0$ or ^{13}N*(15.06)$\rightarrow{}^{9}$B$_{g.s.} + \alpha_0$ [α_1 and α_2 refer to the decays to ^{9}B*((1.6), 2.4)].

[e] $\delta = -0.15 \pm 0.07$. Here $\delta = B(^{13}\text{C})/B(^{13}\text{N})$-1.

[f] $\delta = 1.0 \pm 0.6$.

[g] $\delta \geq 0.83 \pm 0.29$.

[h] $\delta = -0.04 \pm 0.14$.

[i] Based on measured branching ratios and on $\Gamma_{c.m.} = 0.932 \pm 0.028$ keV. See also footnote [d] in Table 13.18.

[j] The decay width to ^{12}C*(12.71) is < 0.13 keV. It is expected to be ≈ 0.03 keV. The sum of the branching ratios for all measured decays of ^{13}N*(15.06) is $(92 \pm 8)\%$. It is apparent from the character of the decay modes of this state that 2s1d shell isospin admixtures are important.

Table 13.7: Resonances in ^{9}Be(α, n)^{12}C [a]

E_α [b] (MeV)	E_α [c] (MeV)	E_α [d] (MeV)	$\Gamma_{\rm c.m.}$ (keV)	J^π	^{13}C* [e] (MeV)
0.52	0.52		≈ 55 [f]	$(\frac{1}{2}^+)$	11.01
0.60	0.60		< 4 [f]		11.06
1.9	1.905	1.92	130	$(\frac{7}{2}^-)$	11.97
2.24		2.25	280		12.20
2.58	2.6	2.58	≈ 200	$(\frac{1}{2}^-)$	12.43
4.00	3.98	4.00	35 ± 3		13.41
4.18			570	$(\frac{3}{2}^+)$	13.54
4.50	4.47	4.50	≈ 350	$(\frac{5}{2}^+)$	13.75
5.0	5.02	5.0	≈ 200		14.12
5.40 ± 0.10	5.3		260	$(\frac{1}{2}^-, \frac{5}{2}^-)$	14.39 ± 0.1
	5.75	5.75	210		14.63
6.20 ± 0.05			380	$(\frac{3}{2}^+)$	14.94 ± 0.05
	6.44 [g]			$(\frac{3}{2}^-; T = \frac{3}{2})$	15.1086
7.10 ± 0.05	7.00		220		15.56 ± 0.05
	7.75	7.8	210		16.01
7.95 ± 0.05			230		16.15 ± 0.05
9.10 ± 0.05		9.1	330		16.95 ± 0.05
9.7 ± 0.10	9.70		190		17.36 ± 0.1
10.2 ± 0.05			170		17.71 ± 0.05
11.05 ± 0.05			300		18.30 ± 0.05
11.70 ± 0.03	11.60		70		18.75 ± 0.03

[a] For references see (1981AJ01).

[b] Resonances in total neutron yield.

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

[d] Resonances in total cross section.

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

[f] $\omega\gamma = 3.79$ and 0.88 eV, respectively.

[g] Anomalies in n_0 and n_1 yields at $E_\alpha = 6443.5 \pm 2.0$ keV: see Table 13.6 for parameters of 15.11 MeV state.

Table 13.8: Resonances in ^{9}Be(α, α_0) [a]

E_α (MeV)	$\Gamma_{\rm c.m.}$ (keV)	l_α	J^π	^{13}C* (MeV)
3.80	343	0, 2	$\frac{3}{2}^-$ [b]	13.28
4.00	58	(4, 6)	$(\frac{9}{2}^-)$	13.42
4.20	685	1, 3	$\frac{5}{2}^+$ [c]	13.56
4.50	247	1, 3	$\frac{3}{2}^+$ [c]	13.76
5.00	75	2, 4	$\frac{5}{2}^-$ [d]	14.11
5.075	73	3, 5	$\frac{7}{2}^+$ [d]	14.161
(5.50)	400	(1, 3)	$(\frac{5}{2})^+$	(14.46)
6.44	[e]		$\frac{3}{2}^-; T = \frac{3}{2}$	15.11

[a] (1973GO15): from analysis in the single-level approximation. This assumes the J^π ordering suggested by (1965LI09). See also (1981AJ01).

[b] Favored by the analysis but the assignment is not certain and more than one state may be involved.

[c] The ordering of these two J^π values is not clear.

[d] An equally good fit to the data is obtained with a $\frac{7}{2}^-$ state at 5.0 MeV and a ($\frac{3}{2}$, $\frac{5}{2}$, $\frac{7}{2}$)$^+$ state at 5.08 MeV.

[e] Weak anomaly at $E_\alpha = 6443.5 \pm 2.0$ keV: see Table 13.6 for parameters of 15.11 MeV state, and reaction 2.

8. ^{9}Be(^{12}C, ^{8}Be)^{13}C $\quad Q_{\rm m} = 3.2810$

Angular distributions have been measured for $E(^{12}\text{C}) = 10.5$ to 15 MeV and at $E(^{9}\text{Be}) = 20$ MeV: (see (1981AJ01, 1986AJ01).

9. (a) ^{10}B(t, p)^{12}B $\quad Q_{\rm m} = 6.342 \quad E_{\rm b} = 23.8759$

(b) ^{10}B(t, d)^{11}B $\quad Q_{\rm m} = 5.1969$

(c) ^{10}B(t, α)^{9}B $\quad Q_{\rm m} = 13.2282$

Yields have been measured for $E_{\rm t} = 0.5$ to 2.0 MeV. There is no evidence of resonance behavior: see (1981AJ01). In the range $E_{\rm t} = 3.0$ to 7.3 MeV a broad structure is reported in the activation cross section (reaction (a)) at $E_{\rm t} \approx 5.5$ MeV, $\Gamma \approx 2.7$ MeV (1985AB10). See also ^{9}Be in (1988AJ01).

10. ^{10}B(^{3}He, π^{+})^{13}C $\qquad Q_{\rm m} = -115.711$

At $E(^{3}\mathrm{He}) = 260$ and 280 MeV, $^{13}\mathrm{C}_{\rm g.s.}$ and an unresolved group at $E_{\rm x} \approx 3.6$ MeV are observed: see (1986AJ01).

11. ^{10}B(α, p)^{13}C $\qquad Q_{\rm m} = 4.0618$

Angular distributions have been measured at many energies up to $E_{\alpha} = 31.2$ MeV: see (1970AJ04, 1986AJ01). For γ-decay measurements see Table 13.6. At $E_{\alpha} = 218$ MeV, ^{13}C* (0, 3.09, 3.7, 6.9, 7.6, 9.9) are populated (1987BI1C; prelim.). For a study of high $E_{\rm x}$ states see (1987BRZV, 1987MIZY, 1988BRZY; prelim.). See also ^{14}N, (1989BR1J) and (1986BA58; axion search).

12. ^{10}B(^{6}Li, ^{3}He)^{13}C $\qquad Q_{\rm m} = 8.0803$

Comparisons of the relative intensities of the ^{3}He groups in this reaction and of the triton groups in the mirror reaction (see reaction 6 in ^{13}N) at $E(^{6}\mathrm{Li}) = 18$ MeV suggest that the following states are analogs: 6.86–6.36, 7.49–7.16, 9.50–9.00, 9.90–9.48, $(10.82 + 10.75)$–$(10.36 + 10.36)$ [the first (set of) $E_{\rm x}$ is in ^{13}C, the second in ^{13}N]: see (1981AJ01).

13. ^{10}B(^{7}Li, α)^{13}C $\qquad Q_{\rm m} = 21.4080$

Angular distributions have been measured at $E(^{7}\mathrm{Li}) = 5.20$ MeV for the α_0, α_1, α_{2+3} and α_4 groups: see (1981AJ01).

14. ^{10}B(^{14}N, ^{11}C)^{13}C $\qquad Q_{\rm m} = 1.139$

At $E(^{10}\mathrm{B}) = 100$ MeV angular distributions are reported for the transitions to ^{13}C*(0, 3.7, 7.5, 11.8): see (1981AJ01).

15. ^{11}B(d, γ)^{13}C $\qquad Q_{\rm m} = 18.6790$

The 90° γ_0 excitation curve measured for $E_{\rm d} = 1.0$ to 12.0 MeV shows resonant structure at $E_{\rm d} = 2.0 \pm 0.1$ and 4.0 ± 0.1 MeV, $\Gamma \approx 0.6$ and ≈ 1 MeV, corresponding to states at $E_{\rm x} = 20.4$ and 22.1 MeV: see Table 13.9 and (1986AJ01). More recently (1985AU10) have studied the 90°

Table 13.9: Resonant structure in ^{11}B + d [a]

Resonant structure in yield of (MeV ± keV)							$\Gamma_{\rm c.m.}$ (keV)	$E_{\rm x}$ (MeV)
γ_0	n_0	n_1	n_2	n_3	$\gamma_{15.1}$	α [b]		
		1.2						19.7 [d]
	1.45						≈ 600	19.90
	1.6	1.8				1.85	≈ 200	20.24
2.0 ± 100 [c]								20.4
		2.2			2.180 ± 10		116 ± 10	20.52
					3.080 ± 15		159 ± 15	21.28
	3.6				3.71 ± 20		114 ± 21	21.81
4.0 ± 100[c]	4.23	4.0	4.1		4.4		≈ 1000	22.1
		(5.2)						(23.1)
	9.6	9.6	9.6	9.6				26.8
	10.4		10.4	10.4				27.5

[a] For references see Table 13.10 in (1981AJ01).

[b] Yield of α_0, α_1, α_2, α_3.

[c] (1981KA16): part of the GDR. More recent work (see reaction 15) suggests two states at $E_{\rm x} = 20.20 \pm 0.07$ and 20.57 ± 0.84 MeV with $\Gamma_{\rm c.m.} = 0.56 \pm 0.09$ and 5.64 ± 0.43 MeV, respectively (1985AU10).

[d] $J^\pi = \frac{5}{2}^-$ is suggested.

γ_0 differential cross sections at $E_{\vec{\rm d}} = 1.65$ to 3.5 MeV, angular distributions at 1.6, 1.8, 2.0 and 4.0 MeV, and analyzing powers at $E_{\vec{\rm d}} = 2.0$ and 4.0 MeV $(90°)$ and 1.6 and 1.8 MeV $(125°)$. The data are interpreted in terms of two doorway states at $E_{\rm x} = 20.57 \pm 0.84$ and 20.20 ± 0.07 MeV with $\Gamma_{\rm c.m.} = 5.64 \pm 0.43$ and 0.56 ± 0.09 MeV, respectively (1985AU10). See also reaction 22 and (1990HO06).

16. (a) ^{11}B(d, n)^{12}C $\quad Q_{\rm m} = 13.7326 \quad E_{\rm b} = 18.6790$

    (b) ^{11}B(d, 2n)^{11}C $\quad Q_{\rm m} = -4.989$

The yields of neutron and 15.1 MeV γ-rays have been measured in the range $E_{\rm d} = 0.2$ to 11 MeV: see Table 13.9. At $E_{\vec{\rm d}} = 79$ MeV, VAP measurements are reported for ^{12}C*(0, 4.4, 9.6, 12.7, 15.1) (1987FO22, 1986FO08). See also (1981AJ01). The thick-target yield in reaction (b) has been measured for $E_{\rm d} = 7.00$ to 16.01 MeV: see (1986AJ01). See also ^{12}C in (1990AJ01).

17. (a) ^{11}B(d, p)^{12}B $Q_{\rm m} = 1.145$ $E_{\rm b} = 18.6790$
(b) ^{11}B(d, d)^{11}B

For reaction (a) see (1981AJ01, 1986AJ01). For $E_{\rm d} = 2.99$ to 6.99 MeV the activation cross section does not show any evidence of structure (1985AB10). For reaction (b) see (1981AJ01). See also ^{12}B in (1990AJ01).

18. ^{11}B(d, α)^{9}Be $Q_{\rm m} = 8.0314$ $E_{\rm b} = 18.6790$

At low energies the excitation functions for α_0 and α_1 increase monotonically: see (1970AJ04). Then at $E_{\rm d} = 1.85$ MeV a pronounced resonance is observed in the α_0, α_1, α_2 and α_3 yields: see Table 13.9. Some gross structure is also observed in these yields for $E_{\rm d} = 1.0$ to 3.2 MeV: see (1981AJ01). See also ^{9}Be in (1988AJ01).

19. ^{11}B(^{3}He, p)^{13}C $Q_{\rm m} = 13.1855$

Levels derived from proton groups are displayed in Table 13.11 of (1981AJ01). [The only level parameters included in the values of Table 13.4 are $E_{\rm x} = 7500 \pm 12$ keV and $\Gamma_{\rm c.m.} < 5$, 70 ± 10 and 150 ± 30 keV for ^{13}C*(7.49, 7.69, 8.86).] The neutron decays of ^{13}C*(6.86, 9.90, 11.75) are to $^{12}C_{\rm g.s.}$ $(99 \pm 9)\%$ and $(100 \pm 20)\%$ for the first two states, and to ^{12}C*(0, 4.4) $(67 \pm 16)\%$ and $(33 \pm 8)\%$ for the third (1973AD02). The decay parameters for the first $T = \frac{3}{2}$ state, ^{13}C*(15.11), are shown in Table 13.6. See also (1986AJ01).

20. ^{11}B(α, d)^{13}C $Q_{\rm m} = -5.1677$

Angular distributions have been measured at $E_\alpha = 15.1$ to 31.2 MeV: see (1981AJ01, 1986AJ01). See also (1987BRZV) and (1984BE23; theor.).

21. (a) ^{11}B(^{6}Li, α)^{13}C $Q_{\rm m} = 17.2040$
(b) ^{11}B(^{7}Li, ^{5}He)^{13}C $Q_{\rm m} = 9.06$

For reaction (a) see (1981AJ01). For reaction (b) see ^{5}He in (1988AJ01) and (1990DA03).

22. ^{12}C(n, γ)^{13}C $Q_{\rm m} = 4.94635$

The thermal capture cross section is 3.53 ± 0.07 mb. The capture is $(67.47 \pm 0.92)\%$, $(0.16 \pm 0.01)\%$ and $(32.36 \pm 0.44)\%$ via ^{13}C*(0, 3.09, 3.68): see (1986AJ01) for references and additional information. Based on unpublished measurements quoted in (1986AJ01), the energies of the γ-rays involved in C $\rightarrow$ 0, C $\rightarrow$ 3.68 and 3.68 $\rightarrow$ 0 are 4946.362 ± 0.021, 1261.855 ± 0.006 and 3684.507 ± 0.019 keV. The branching ratios for the decay of ^{13}C*(3.68) to ^{13}C*(0, 3.09) are $(99.3 \pm 2.0)\%$ and $(0.74 \pm 0.05)\%$, respectively: see (1986AJ01). (1990WA22) proposes 3683.915 ± 0.015 keV for $E_\gamma[3.68 \rightarrow 0]$.

Differential cross sections for γ_0 (90°) have been studied for $E_\mathrm{n} = 6.5$ to 18.5 MeV (1987AU02), 7.0 to 19.5 MeV (1986BE17) and at 7.8, 9.3 and 10.8 MeV (1990HA19). Broad structures are seen at ≈ 9 and 17.2 MeV (^{13}C*(13.2, 20.8)) [the latter has $\Gamma \approx 2.5$ MeV]. It should be noted that the cross sections reported by (1987AU02) are substantially higher than those reported in the other two references. The variation of the cross section with energy is similar to that from the ^{13}C(γ, n_0) reaction but the magnitudes of the cross section are smaller: see, for instance, (1990HA19). Angular distributions and analyzing powers of γ_0 for $E_\mathrm{n} = 12.0$ to 18.8 MeV suggest two doorway states at $E_\mathrm{x} = 21.1 \pm 0.6$ and 20.52 ± 0.07 MeV with $\Gamma = 4.2 \pm 0.4$ and 0.51 ± 0.07 MeV, respectively (1984WO05). See also (1989HU15). For work to 50 MeV see (1988DO1E; prelim.). See also (1986MU1B, 1986RA1B, 1986WE1D, 1988MCZT), (1988MA1U, 1989GU1J; astrophysics) and (1987HO23, 1987LY01: theor.).

23. (a) ^{12}C(n, n)^{12}C $\qquad E_\mathrm{b} = 4.94635$
    (b) ^{12}C(n, n′)^{12}C*
    (c) ^{12}C(n, n′)3^{4}He $\qquad Q_\mathrm{m} = -7.27473$
    (d) ^{12}C(n, 2n)^{11}C $\qquad Q_\mathrm{m} = -18.7215$

The coherent scattering length (thermal, bound) $a_\mathrm{coh} = 6.6535 \pm 0.0014$ fm; $\sigma_\mathrm{scatt} = 4.7456 \pm 0.0020$ (1979KO26).

Total cross sections have been measured in the range $E_\mathrm{n} = 1$ keV to 273 GeV/c [see (1981AJ01, 1986AJ01)] and at 0.14, 1.3 and 2.1 MeV (1988KO18) and 160 to 575 MeV (1988FR23): see the compilation of (1988MCZT). See also (1986BA40). Various elastic, inelastic and non-elastic cross sections have been reported over a wide range of energies: [see (1986AJ01, 1988MCZT)], most recently at 6.23 to 13.75 MeV (1986BO1M; prelim.; elastic and inelastic scattering cross sections), from 16.5 to 22.0 MeV (1989OL02, 1989OL1C; σ_t, σ_el and σ to ^{12}C*(4.4, 7.7, 9.6)) and from threshold to 25 MeV (1988WE06; prelim.; cross section for scattering to ^{12}C*(4.4)). Polarization measurements have been reported for $E_\mathrm{n} = 1.5$ to 16.3 MeV [see (1976AJ04, 1981AJ01, 1986AJ01)] and at $E_\mathrm{n} = 15.55$ to 17.35 MeV (1987TO03, 1987TO07) and 18.2 MeV (1988TO01). See also (1986BE2D, 1987BEYP).

Observed resonances are displayed in Table 13.10 here, and in Table 13.13 in (1981AJ01) [the latter for (n, n′$\gamma_{4.4}$)]. In Table 13.10 the assignment of the broad states above $E_\mathrm{x} = 11.7$ MeV are from phase-shift analyses ($\sigma(\theta)$ and A_y) referred to here and in (1986AJ01). Five weak anomalies in the total cross section are thought to be due to $T = \frac{3}{2}$ states (1987HI03).

Table 13.10: Resonances in ^{12}C(n, n)^{12}C [a]

$E_{\rm res}$ (MeV $\pm$ keV)	$\Gamma_{\rm c.m.}$ (keV)	^{13}C* (MeV)	J^π	$\Gamma_{\rm n}/\Gamma$
2.079 ± 3	6	6.864 [e]	$\frac{5}{2}^+$	
2.819 ± 3	1.2 ± 0.3	7.546 [e]		
2.94 ± 10	124 ± 7	7.66 [e]	$\frac{3}{2}^+$	
3.472 ± 15	1000 ± 50	8.149	$\frac{3}{2}^+$	
4.259 ± 15	210 ± 15	8.874	$\frac{1}{2}^-$	1.00
4.93707 ± 0.07 [b]	1.9 ± 0.15 [b]	9.4998 [e]	$(\frac{9}{2}^+)$	1.00
5.368 ± 5	26 ± 3	9.897	$\frac{3}{2}^-$	0.70 ± 0.10
6.294 ± 5	53 ± 4	10.751	$\frac{7}{2}^-$	0.70 ± 0.10
6.5		10.9		
6.558 ± 8	37 ± 4	10.994	$(\frac{1}{2}^+)$	0.40 ± 0.10
6.7		11.1		
7.35 ± 50	129 ± 40	11.72	$\frac{3}{2}^-$	0.80 ± 0.08
7.62 ± 90	494 ± 80	11.97	$\frac{5}{2}^+$	0.51 ± 0.06
7.78 ± 80	538 ± 65	12.12	$\frac{3}{2}^+$	0.28 ± 0.05
7.79 ± 50	77 ± 30	12.13	$\frac{5}{2}^-$	0.43 ± 0.06
7.80 ± 70	426 ± 70	12.14	$\frac{1}{2}^+$	0.50 ± 0.07
7.94 ± 70	186 ± 50	12.27	$\frac{3}{2}^-$	0.73 ± 0.08
8.12 ± 50	114 ± 40	12.43	$\frac{7}{2}^-$	0.42 ± 0.06
9.35	619 ± 50	13.57	$\frac{7}{2}^-$	0.18 ± 0.03
9.96		14.13	$\frac{3}{2}^-$	
10.88	450	14.98	$\frac{7}{2}^-$	
11.02 [c]		15.11	$\frac{3}{2}^-; T = \frac{3}{2}$	0.062 ± 0.016
11.20		15.27	$\frac{9}{2}^+$	
11.40		15.46	$\frac{3}{2}^-$	
12.1	230	16.1	$(\frac{5}{2}^- + \frac{7}{2}^-)$	
13.65 [c]	17 ± 6	17.533 ± 3		
14.25 [c]	12 ± 7	18.082 ± 3		
15.80 [d]	≥ 500	19.51	$\frac{5}{2}^-$	
16.39 [c]	11 ± 8	20.057 ± 4		
16.45 [d]	1090	20.11	$\frac{1}{2}^-$	0.16

Table 13.10: Resonances in ^{12}C(n, n)^{12}C[a] (continued)

E_{res} (MeV $\pm$ keV)	$\Gamma_{c.m.}$ (keV)	^{13}C* (MeV)	J^π	Γ_n/Γ
16.45 [d]	440	20.11	$\frac{5}{2}^+$	0.05
16.53 [d]	630	20.19	$\frac{7}{2}^+$	0.11
16.65 [d]	1560	20.30	$\frac{7}{2}^-$	0.08
16.70 [d]	320	20.34	$\frac{9}{2}^+$	0.06
16.90 [d]	≈ 500	20.53	$\frac{5}{2}^-$	
18.18 [c]	18 ± 9	21.703 ± 4		
19.6 ± 200	≈ 1000	23.0		

[a] For earlier references and additional information see Tables 13.10 in (1970AJ04), 13.16 in (1976AJ04), 13.12 in (1981AJ01) and 13.10 in (1986AJ01). See the discussions in (1982KN02, 1985TO02, 1987TO03).

[b] Derived from a lorentzian probability plot (1980CI03).

[c] Weak resonance anomaly attributed to $T = \frac{3}{2}$ state (1987HI03) [and see for $(J + \frac{1}{2})\ \Gamma_{n0}/\Gamma$].

[d] From phase-shift analysis by (1987TO03).

[e] For the decay of these states, reported in the interaction of ^{14}N ions (35 MeV/A) with a silver target, see (1989HE24).

For reactions (c) and (d) see reactions 23 and 24 in (1986AJ01) and (1988MCZT). For pion production see (1988BU16). See also ^{12}C in (1990AJ01) and (1984BE1L, 1985FI09, 1985KU1F, 1985ME16, 1985RA1E, 1986BAYL, 1986DR10, 1986ROZW, 1987NEZY, 1988AN1F, 1989SA1J), (1986AL1N, 1986WE1B, 1986WI1B, 1989OL1C; applied), (1988FR1M; astrophys.), (1987BR06, 1988MA1H) and (1985KO1U, 1985TI07, 1986BE2F, 1986LI16, 1988BA1P, 1988RU1C, 1989MI20, 1990LE1Q; theor.).

24. ^{12}C(n, p)^{12}B $\quad Q_m = -12.587 \quad E_b = 4.94635$

The cross section exhibits a weak resonance corresponding to $E_x \approx 20.5$ MeV and a stronger structure at $E_x \approx 21.5$ MeV: see (1976AJ04). See also the compilation of (1988MCZT). The excitation function for $E_n = 30$ to 150 MeV is being studied (1988RAZX; prelim.). For proton production for $E_n = 300$ to 580 MeV see (1987FR16). See also ^{12}B in (1990AJ01) and (1985AZ1A, 1986FO1E, 1989BE2P, 1989SOZY), (1986RO1F; applied), (1988FR1M; astrophysics), (1988MA1H) and (1986KO26, 1988PE01; theor.).

25. (a) ^{12}C(n, d)^{11}B $\quad Q_m = -13.7326 \quad E_b = 4.94635$

(b) ^{12}C(n, t)^{10}B $\quad Q_m = -18.9295$

For deuteron and triton emission at $E_n = 300$ to 580 MeV, see (1987FR16). See also (1986RO1F; applied), (1988FR1M; astrophysics), (1988MA1H) and (1986KO26; theor.).

26. ^{12}C(n, α)^{9}Be $\quad Q_m = -5.7012 \quad E_b = 4.94635$

The cross section for the α_0 group shows a broad structure at $E_n \approx 8$ MeV: see (1981AJ01). For other work see (1986AJ01, 1988MCZT). See also (1988CA1I), (1986RO1F, 1986WI1B; applied) and (1988MA1H).

27. ^{12}C(p, π^+)^{13}C $\quad Q_m = -135.4045$

Angular distributions have previously been reported for $E_p = 147$ to 250 MeV: see (1986AJ01). ^{13}C*(0, 3.09, 3.68, 3.85, 6.86, 9.50) have been populated. In the more recent work at $E_p = 354$ MeV it is found that at 21° the π^+ spectrum is dominated by the group to the (2p1h) $\frac{9}{2}^+$ state at 9.50 MeV. Angular distributions have been measured to ^{13}C*(0, $3.09 + 3.68 + 3.85$, 9.50) (1987HU08) [see also for a discussion of the energy dependence of the total cross section, and of the influence of the Δ-resonance]. (1987HO21) report a measurement of ground-state differential cross sections at $E_p = 186$ MeV.

At $E_{\vec{p}} = 200$ MeV angular distributions and A_y measurements have been reported to ^{13}C*(0, 3.09, 3.7 [u], 6.86, 7.5 [u], 9.5, 21.4) (1989KO21). For the strongly populated group to ^{13}C*(21.4) $A_y \approx 0$ at all angles. The results are suggestive of those for a $\frac{7}{2}^+$; $T = \frac{3}{2}$ state, but other explanations are also possible (1987KO01, 1989KO21). See also (1990JAZZ). For inclusive differential cross sections and A_y at $E_{\vec{p}} = 400$ and 450 MeV see (1986FA03). For other polarization measurements see (1986AJ01). For total cross sections at $E_p = 180$ and 201 MeV see (1985BI04). See also (1981AJ01), the "General" section, (1987SEZY, 1988SEZT), (1986JA1H) and (1985IQ01, 1986MI09, 1987KU06; theor.).

28. ^{12}C(d, p)^{13}C $\quad Q_m = 2.7218$

Measurements of proton groups and γ-rays are summarized in Table 13.11. Angular distributions have been studied at many energies to $E_d = 80.2$ MeV [see (1981AJ01, 1986AJ01)] as well as at $E_{\vec{d}} = 12$ MeV (1988LA03; to ^{13}C*(0, 3.09, 3.68, 3.85, 6.86, 7.50, 7.55, 7.69)) and at $E_d = 30$ MeV (1986OH01; to all even-parity states below $E_x = 10$ MeV and to ^{13}C*(0, 3.68, 7.55, 10.75, 11.08)). See also (1989BE2K, 1989IE01, 1989NA1R).

For τ_m measurements see Table 13.5 in (1981AJ01) and for γ-decay see Table 13.6. For work at very high energies see (1987AZ1C, 1989AV02). See also ^{14}N, (1985LI1H, 1988VI1A, 1989VI1E, 1990CH1J; applied), (1986SI1D; computer program) and (1984BL21, 1986IS1F; theor.).

Table 13.11: Levels of ^{13}C from ^{12}C(d, p)^{13}C [a]

^{13}C (MeV ± keV)	$\Gamma_{\rm c.m.}$ (keV)	$l_{\rm n}$	J^π	S [b]
0		1	$\frac{1}{2}^-$	0.77
3.089443 ± 0.020 [c]		0	$\frac{1}{2}^+$	0.65
3.684482 ± 0.023 [c]		1	$\frac{3}{2}^-$	0.14
3.853783 ± 0.022 [c]		2	$\frac{5}{2}^+$	0.58
6.86		2	$\frac{5}{2}^+$	0.017
7.470 ± 20				
7.533 ± 20				0.009
7.641 ± 20	70 ± 15			0.11
8.4 ± 300	1100 ± 300	2	$\frac{3}{2}^+$	
8.86		1	$\frac{1}{2}^-$	[e]
9.500 ± 20		(1)	$(\frac{3}{2}^-)$ [f]	
9.897 ± 20		1	$\frac{3}{2}^-$	[e]
10.755 ± 5	56 ± 2			0.026
10.818 ± 5	24 ± 3			
10.997 ± 8	82 ± 15			
11.080 ± 5	< 8			
11.748 ± 10	107 ± 14			
11.851 ± 5	68 ± 4			
11.97 ± 40 [d]	≈ 260			
12.108 ± 5	81 ± 8			

[a] For references and additional information see Tables 13.14 in (1981AJ01) and 13.11 in (1986AJ01).

[b] DWBA fit at $E_{\rm d} = 30$ MeV (1986OH01). For earlier results see (1981AJ01, 1986AJ01).

[c] (1980WA24): E_γ for the $3.85 \rightarrow 3.68$ transition is 169.300 ± 0.004 keV. Using $E_{\rm x} = 3684.507 \pm 0.019$ keV [see reaction 22] and this value for E_γ, $E_{\rm x}$ for the higher state is 3853.807 ± 0.019 keV, which we adopt. I am indebted to Dr. E.K. Warburton for his comments. See also Table 13.5 and the "General" section. (1990PI05) report $E_{\rm x} = 3089.42 \pm 0.07$, 3684.50 ± 0.06, 3853.67 ± 0.20 and 6864.07 ± 0.46 keV from measurements of proton groups in a spectrograph.

[d] May correspond to unresolved states.

[e] Not observed (1986OH01).

[f] Known to be $\frac{9}{2}^+$.

29. ^{12}C(t, d)^{13}C $\quad Q_{\rm m} = -1.3109$

At $E_{\rm t} = 38$ MeV angular distributions have been measured to ^{13}C*(0, 3.09, 3.68, 3.85, 6.86, 7.5, 7.69, 8.2, 9.5, 10.7) (1988SI08). See also (1981AJ01).

30. ^{12}C(^{3}He, 2p)^{13}C $\quad Q_{\rm m} = -2.7718$

At $E(\vec{^{3}\rm He}) = 33$ MeV ^{13}C*(3.85) is strongly populated. ^{13}C*(0, 8.0 (broad), 9.5) have also been studied (1986KA44). See also (1981AJ01) and ^{15}O.

31. ^{12}C(α, ^{3}He)^{13}C $\quad Q_{\rm m} = -15.6314$

Angular distributions of the ^{3}He particles to the first three states of ^{13}C have been measured in the range $E_{\alpha} = 56$ to 139 MeV. The ground-state distributions in this, and in the mirror reaction ^{12}C(α, t)^{13}N, have also been compared: see (1981AJ01). See also (1989KU1E; $E_{\alpha} = 94$ MeV; g.s.; prelim.) and (1989GA1H).

32. ^{12}C(^{7}Li, ^{6}Li)^{13}C $\quad Q_{\rm m} = -2.304$

At $E(^{7}\rm Li) = 34$ MeV angular distributions have been studied to ^{13}C*(0, 3.09, 3.85). The analysis by FRDWBA leads to $S = 0.65 \pm 0.06$, 0.75 ± 0.08 and 0.68 ± 0.10, respectively (1986CO02). See also (1988KE07; theor.). For the earlier work at $E(^{7}\rm Li) = 21.1$ and $E(^{7}\rm Li) = 48$ MeV see (1981AJ01, 1986AJ01).

33. ^{12}C(^{8}Li, ^{7}Li)^{13}C $\quad Q_{\rm m} = 2.9136$

At $E(^{8}\rm Li) = 14.3$ MeV, an angular distribution is reported involving ^{13}C$_{\rm g.s.}$ (1989BE28): at $\theta_{\rm lab} = 15°$, the differential cross section is ≈ 15 mb/sr.

34. ^{12}C(^{12}C, ^{11}C)^{13}C $\quad Q_{\rm m} = -13.7754$

Angular distributions have been reported at $E(^{12}\rm C) = 72.5$ and 93.8 MeV [see (1981AJ01, 1986AJ01)], at 240 MeV (1985BO39; ^{13}C*(0, 3.85)) and at 300, 420 and 600 MeV (1988WI09, 1989WI07; ^{13}C$_{\rm g.s.}$). See also ^{11}C in (1990AJ01) and (1989SA44; theor.).

35. ^{12}C(^{14}N, ^{13}N)^{13}C $\quad Q_{\rm m} = -5.6071$

Angular distributions have been reported in the range $E(^{14}\text{N}) = 28$ to 154.8 MeV involving ^{13}C*(0, 3.09, 3.85, 7.3 ± 0.3): see (1981AJ01). See also (1986AJ01) and (1987OS1E, 1988KA27; theor.).

36. (a) ^{12}C(^{17}O, ^{16}O)^{13}C $\quad Q_{\rm m} = 0.8029$
(b) ^{12}C(^{18}O, ^{17}O)^{13}C $\quad Q_{\rm m} = -3.0982$

Angular distributions involving $^{16}\text{O}_{\text{g.s.}} + {}^{13}\text{C}_{\text{g.s.}}$ are reported at $E(^{17}\text{O}) = 40$ to 70 MeV (1986FR04). For the earlier work see (1981AJ01). For reaction (b) see ^{18}O in (1987AJ02).

37. ^{13}B(β^-)^{13}C $\quad Q_{\rm m} = 13.437$

See ^{13}B and Table 13.2.

38. (a) ^{13}C(γ, n)^{12}C $\quad Q_{\rm m} = -4.94635$
(b) ^{13}C(γ, 2n)^{11}C $\quad Q_{\rm m} = -23.668$

The main features of the cross sections are a sharp peak corresponding to the $T = \frac{3}{2}$ state ^{13}C*(15.11) [$\Gamma_{\gamma_0} = 19.7 \pm 2.0$ eV], the broad pigmy resonance at $E_{\rm x} = 13$ MeV [on which peaks are superimposed at $E_{\rm x} = 11.0$, 13.8, 16.5 and 17.8 MeV] and the giant resonance at $E_{\rm x} = 24$ MeV ($\sigma_{\rm max} = 9.5$ mb) [surrounded by shoulder resonances at $E_{\rm x} = 20.8$ and ≈ 30 MeV, both of which appear to decay substantially to highly excited states of ^{12}C]. There is also some evidence for a weak resonance at ≈ 37 MeV superimposed on the high-energy tail of the GDR. A study of the angular distributions of n_0 suggests states at $E_{\rm x} = 7.70$ ($\frac{3}{2}^+$), 7.95 ($\frac{3}{2}^+$), 8.95(($\frac{1}{2}^-$)), 10.0 (($\frac{3}{2}^-$)), 11.0 (($\frac{1}{2}^+$)) and 12.05 MeV (($\frac{3}{2}^+$)). See (1981AJ01) for references and for additional information. See also the atlas in (1988DI02), (1985PY01, 1988BE1T, 1988HA12) and (1985GO1A, 1987KI1C; theor.). For comparisons with ^{12}C(n, γ) see reaction 22 and (1985AU10, 1986BE17).

39. (a) ^{13}C(γ, p)^{12}B $\quad Q_{\rm m} = -17.533$
(b) ^{13}C(γ, d)^{11}B $\quad Q_{\rm m} = -18.6790$

Table 13.12: Electromagnetic transitions in ^{13}C from ^{13}C(e, e′)^{13}C [a]

E_x (MeV)	J^π	Mult.	Γ_{γ_0} (eV)	$\Gamma_{\gamma_0}/\Gamma_w$ (W.u.)
3.09	$\frac{1}{2}^+$	C1	0.52	0.047 ± 0.010 [a]
3.68	$\frac{3}{2}^-$	M1	0.36 ± 0.05 [c]	0.34
		C2	$(3.6 \pm 0.4) \times 10^{-3}$ [c]	3.5
3.85	$\frac{5}{2}^+$	C3	6×10^{-8}	1.3 ± 0.2 [a]
6.86	$\frac{5}{2}^+$	M2	$(6.9 \pm 3.6) \times 10^{-5}$ [c]	0.055
		C3	3×10^{-7}	0.10 ± 0.06 [a]
7.55 [b]	$\frac{5}{2}^-$	C2	0.115 ± 0.006 [c]	3.2
8.86 [d]	$\frac{1}{2}^-$	C0	2.1 ± 0.4 [c, e]	
		M1	3.4 ± 0.5 [c]	0.23
9.50 [f]	$\frac{9}{2}^+$	M4		
9.90	$\frac{3}{2}^-$	M1	0.32 ± 0.05 [c]	0.016
		C2	$(6.3 \pm 2.1) \times 10^{-3}$ [c]	0.045
11.08	$\frac{1}{2}^-$	C0	2.6 ± 0.3 [c, e]	
		M1	1.0 ± 0.2 [c]	0.036
11.85 [g]	$\frac{7}{2}^+$	C3		
11.95 [g]	$(\frac{5}{2}^+)$	C3		
15.11	$\frac{3}{2}^-$	M1	22.7 ± 2.6 [c]	0.31
		C2	[h]	
16.08 [i]	$(\frac{7}{2}^+)$	M4		
21.47 [i]	$\frac{9}{2}^+$	M4		

[a] (1989MI01) [see for form factors up to multipolarity three]. Table V in (1989MI01) shows B(Cλ, ↑). B(C1, ↓) and B(C3, ↓) are given here with errors double the statistical errors given in (1989MI01) [see also footnote [g]]. I am greatly indebted to Dr. D.J. Millener for this table, which he prepared. For the earlier work see Tables 13.15 in (1981AJ01) and 13.12 in (1986AJ01) [see also footnotes [d,e]].

[b] The dominant 7.55 MeV $\frac{5}{2}^-$ level is not resolved from the much weaker 7.49 and 7.69 MeV levels [see (1989MI01)].

[c] (1969WI22, 1970WI04).

[d] $\Gamma = 190 \pm 35$ keV.

[e] Monopole matrix element in fm^2.

[f] For form factors see (1986HI06, 1987HI09).

[g] Unresolved doublet, B(C3, ↑) $\simeq$ 27.5 W.u. [see (1989MI01)].

[h] The low q (e, e′) data give a C2 transition strength of 0.5 W.u. (1969WI22, 1970WI04). However, data points near the peak of the C2 form factor (1989MI01) suggest that B(C2, ↓) is about a factor of two smaller, consistent with 0.28 ± 0.10 W.u. for the analog transition in ^{13}N (see Table 13.6).

[i] Probably unresolved [see (1986HI06) for discussion and for form factors].

Table 13.13: Additional states of ^{13}C from ^{13}C(e, e′)^{13}C* (1989MI01) [a]

E_x (MeV±keV)	$\Gamma_{c.m.}$ (keV)	E_x (MeV±keV)	$\Gamma_{c.m.}$ (keV)
11.845 ± 5	144 ± 5	16.080 ± 7	148 ± 13
12.187 ± 10	109 ± 48	(16.183 ± 28)	(40 ± 20)
12.438 ± 12	160 ± 37	(18.497 ± 10)	(91 ± 23)
14.390 ± 15	281 ± 65	18.699 ± 5	98 ± 11
14.582 ± 10	227 ± 41	20.021 ± 13	232 ± 27
14.983 ± 10	380 ± 53	20.429 ± 8	112 ± 23
15.526 ± 11	147 ± 23	21.466 ± 8	268 ± 14

[a] Some other states may also have been observed: see (1989MI01).

The integrated cross section (reaction (a)) from $E_\gamma = 17.5$ (threshold) to 28 MeV is 36 ± 5 MeV · mb. Resonances are observed at $E_x = 18.6$, (19.7), 20.7, (22), 23.5, 24.5 and (26) MeV. [σ_{max} at $E_x \approx 23$ MeV is 8 mb]. Below ≈ 18 MeV the cross section is dominated by transitions involving $T_<$ states. The states at 18.6 and 20.7 MeV have a significant $T_>$ component. The two isospin components of the GDR appear to be split by 6.8 MeV (1983ZU02). For the earlier work see (1981AJ01). See also (1988HA12) and (1987KI1C; theor.). For the cross section of reaction (b) from detailed balance calculations from ^{11}B(d, γ) see reaction 15 and (1985AU10).

40. ^{13}C(e, e)^{13}C

The elastic scattering has been studied for $E_e = 80$ to 750 MeV [see (1981AJ01, 1986AJ01)] and (1987HI09, 1989MI01). The form factor for M1 elastic scattering is enhanced above $q \approx 2.5$ fm^{-1} (1982HI07, 1987HI09). See also (1987DE43). A number of inelastic groups have been seen: see Tables 13.12 and 13.13 (1970WI04, 1986HI06, 1987HI09, 1989MI01).

A distinct splitting of the giant resonance into two large peaks near $E_x = 20.5$ and 24.5 MeV, with widths of ≈ 3 and ≈ 4 MeV, respectively, is observed. It is suggested that these are groupings of narrower peaks. The $E_x = 20.5$ and 24.5 MeV groups are probably $T = \frac{1}{2}$ and $T = \frac{3}{2}$, although the 4 MeV splitting is somewhat smaller than expected: see (1981AJ01). See also (1984CH1K, 1985SA06, 1986CH2E, 1986DO11, 1987HO23, 1988MI1J, 1989AM02, 1989WO1E, 1990JE1B; theor.).

41. ^{13}C($\pi^\pm$, $\pi^\pm$)^{13}C

Angular distributions have been measured at $E_\pi = 20$ to 180 MeV [see (1981AJ01) and Table 13.13 in (1986AJ01)], at 65 MeV (1988MI02; several states up to $E_x = 11.8$ MeV) and at

$E_{\pi^-} = 30$ and 50 MeV (1990SE04; elastic). Enhanced in π^- scattering are ^{13}C*(0, 3.09, 3.85, 9.50, 21.60 ± 0.05), the latter very strongly but with a large uncertainty. Enhanced in π^+ scattering are ^{13}C*(3.68, 7.55, 8.86, 11.82, 16.05 ± 0.05, 17.92 ± 0.05, 21.37 ± 0.05). The data for ^{13}C*(9.50, 21.60, 16.05, 21.37) indicate pure neutron particle-hole excitations for the first two states and pure proton excitation for the latter two, however with large uncertainties except for ^{13}C*(9.5). Spin assignments are $\frac{9}{2}^+$ for ^{13}C*(9.50); $\frac{7}{2}^+$ or $\frac{9}{2}^+$ for ^{13}C*(16.05, 17.92, 21.37, 21.60); $\frac{5}{2}^+$ and/or $\frac{7}{2}^+$ for ^{13}C(11.82) [unresolved doublet?]. The π^-/π^+ asymmetry near 21.5 MeV suggests that there is isospin mixing between $T = \frac{1}{2}$ and $\frac{3}{2}$ states of $J^\pi = \frac{7}{2}^+$ and/or $\frac{9}{2}^+$ (1982SE04, 1983SE15). Analyzing powers for elastic scattering on $^{13}\vec{C}$ have been studied at $E_{\pi^\pm} = 100$ MeV (1990SM1B) and 114 to 226 MeV (1990YE1C) [both preliminary]. See also the "General" section and (1986AMZX; theor.).

42. ^{13}C(n, n)^{13}C

Angular distributions have been measured at $E_n = 4.5$ to 17.92 MeV [see (1986AJ01)], at 4.55 to 10.99 MeV (1989RE01, $n_0 \rightarrow n_3$) and at 24 MeV (1985PE10; n_0). At $E_n = 8.1$ to 11 MeV ^{13}C*(7.55) [$J^\pi = \frac{5}{2}^-$] is involved in the sequential decay to $^{12}C_{g.s.}$ (1987RE01). See also ^{14}C, (1988RE09; computer) and (1986AL1L; theor.).

43. ^{13}C(p, p)^{13}C

Angular distributions have been studied at $E_p = 1.37$ MeV to 1 GeV [see (1981AJ01, 1986AJ01)] and at 30.95 MeV (1988BA30); p_0), 35 MeV (1986OH03: $p_0 \rightarrow p_3$), 71.8 MeV (1989VO05, 1990VO02; p_0; polarized protons), 135 MeV (1988CO05, to 33 states below $E_x = 23$ MeV), 500 MeV (1990HO06; p_0; polarized protons), 0.8 GeV (1985BL22; p_0) and 1 GeV (1985AL16; p_0). (1988CO05) assign $\frac{7}{2}^+$ for ^{13}C*(11.85) [in agreement with the (e, e) work]. ($\frac{5}{2}^+$) for ^{13}C*(11.95, 14.98), $\leq \frac{5}{2}$ for ^{13}C*(12.11, 12.19), ($\frac{7}{2}$, $\frac{9}{2}$)$^+$ for ^{13}C*(14.58, 21.47), ($\frac{7}{2}^+$) for ^{13}C*(16.08), ($\frac{3}{2}$, $\frac{5}{2}$) for ^{13}C*(17.70), ($\frac{3}{2}$, $\frac{5}{2}$)$^+$ for ^{13}C*(18.70), ($\frac{7}{2}$, $\frac{9}{2}$)$^+$ for ^{13}C*(21.47), $\geq \frac{5}{2}$ for ^{13}C*(21.81) and $\leq \frac{5}{2}$ for ^{13}C*(22.2, 23). The widths of ^{13}C*(12.19 ± 0.01, 22.2 ± 0.1) are 110 ± 50 keV and 1100 ± 500 keV, respectively. [The widths for ^{13}C*(11.95, 12.11, 12.19) are appreciably smaller than those reported in Table 13.10.] A state at $E_x = 20.93 \pm 0.1$ MeV with $\Gamma = 240 \pm 100$ keV is suggested (1988CO05, S. Collins, Ph.D. thesis, and B. Spicer, private communication). See also ^{14}N, (1985PE10) and (1986AMZX, 1986RA05, 1987BE1M, 1987BE1P, 1988GOZH, 1988RA08, 1989AM02, 1989AM05, 1989BEXT, 1989GO14, 1989KU14, 1989KU32, 1989RA1O, 1990DU01; theor.).

44. (a) ^{13}C(d, d)^{13}C
(b) ^{13}C(t, t)^{13}C

Angular distributions (reaction (a)) have been measured at $E_{\rm d} = 0.71$ to 56 MeV: see (1981AJ01, 1986AJ01). See also ^{15}N. Angular distributions for the tritons to ^{13}C*(0, 3.09, 3.68, 3.85, 7.55) have been studied at $E_{\rm t} = 38$ MeV (1988SI08). See also (1981AJ01).

45. ^{13}C(^{3}He, ^{3}He)^{13}C

Angular distributions of elastically scattered ^{3}He ions have been studied at $E(^{3}\text{He}) = 12$ to 41 MeV [see (1981AJ01)] and at 39.6 MeV (1987BUZR; prelim.) as well as at $E(^{3}\text{He}) = 33$ MeV (1986DR03). Angular distributions have also been reported at $E(^{3}\text{He}) = 43.6$ MeV for the ^{3}He ions to ^{13}C*(3.09, 3.68, 3.85, 6.86, $7.49 + 7.55$, 7.69, 8.86, 9.50, 9.90, $10.75 + 10.82$, 11.08, 11.85, 15.11, 16.0) [and these have been compared to the analog states reached in the ^{13}C(^{3}He, t)^{13}N reaction] (1981PE08). See also (1989DE1Q) and (1986ZE04, 1987RA36; theor.).

46. ^{13}C(α, α)^{13}C

Angular distributions have been studied at $E_\alpha = 15$ to 40.5 MeV [see (1981AJ01)], at $E_\alpha = 35.5$ MeV (1981PE08; to ^{13}C*(3.09, 3.68, 3.85, 6.86, $7.49 + 7.55$, 7.69, 8.86, 9.50, 11.08, 11.85)) as well as at $E_\alpha = 48.7$ and 54.1 MeV (1987AB03; α_0). For ^{13}C*(7.69), $E_{\rm x} = 7686 \pm 6$ keV, $\Gamma_{\rm c.m.} = 70 \pm 5$ keV (1980FU04; also line shapes). An angular correlation study at $E_\alpha = 24.35$ MeV of the (α, αn) reaction to ^{12}C$_{\rm g.s.}$ has determined the substate population of ^{13}C*(6.86), $J^\pi = \frac{5}{2}^+$ (1984DE44). $\Gamma_\gamma/\Gamma \leq 3 \times 10^{-4}$ for ^{13}C*(6.86). The evidence for states near 7.5 MeV is less clear cut (1985DE11). See also (1987BU27) and (1985SH1D; theor.).

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

Angular distributions of elastically scattered Li ions have been studied at $E(\text{Li}) = 4.5$ to 40 MeV [see (1981AJ01, 1986AJ01)] as well as at $E(^{7}\text{Li}) = 34$ MeV (1987CO02, 1987CO16). At $E(^{7}\text{Li}) = 34$ MeV angular distributions involving ^{13}C*(3.09, 3.68, 7.55) are also reported (1987CO02). For the (^{6}Li, αd) breakup via states of ^{17}O see (1986AJ01) and (1987CA30, 1989WUZX). For fusion and breakup cross sections see (1986AJ01). See also (1989DE34) and (1988DEZU, 1988DE1F; theor.).

48. ^{13}C(^{9}Be, ^{9}Be)^{13}C

The elastic scattering has been studied at $E(^{13}\mathrm{C}) = 28.1$ and 36.2 MeV [see (1981AJ01)] and at $E(^{9}\mathrm{Be}) = 50.5$ MeV (1990BA16; also to ^{13}C*(3.68, 7.55)). For cross section measurements see (1984DA17, 1986CU02). See also (1986MI24; theor.).

49. (a) ^{13}C(^{10}B, ^{10}B)^{13}C
    (b) ^{13}C(^{11}B, ^{11}B)^{13}C

Elastic angular distributions have been measured at $E(^{10}\mathrm{B}) = 18$ to 80.9 MeV: see (1986AJ01). For fusion and other cross section measurements see (1986AJ01) and (1988MA07). See also (1985CU1A).

50. (a) ^{13}C(^{12}C, ^{12}C)^{13}C
    (b) ^{13}C(^{13}C, ^{13}C)^{13}C
    (c) ^{13}C(^{14}C, ^{14}C)^{13}C

Angular distributions for reaction (a) have been reported for $E(^{12}\mathrm{C}) = 10$ to 87 MeV and $E(^{13}\mathrm{C}) = 12$ to 36 MeV [see (1981AJ01, 1986AJ01)], and at $E(^{12}\mathrm{C}) = 94.5$ MeV (1986BA80; elastic) and $E(^{13}\mathrm{C}) = 16.3$ to 26.5 MeV (1988VO01; ^{13}C*(0, 3.09, 3.85)) and 260 MeV (1985BO39; $^{13}\mathrm{C}_{\mathrm{g.s.}} + {}^{12}$C*(0, 4.4)). Elastic distributions for reaction (b) have been studied at $E(^{13}\mathrm{C}) = 15$ to 24 MeV [see (1981AJ01)] and at 14 and 16 MeV (1988TR01). Angular distributions for reaction (c) have been measured at $E(^{13}\mathrm{C}) = 15$ MeV [see (1981AJ01)] and at 20 to 27.5 MeV (1988BI11; ^{13}C(0, 3.09, 3.85)). For excitation functions, fusion and evaporation cross sections see (1986AJ01) and (1986HA30, 1988TR01). For a spin-flip probability study see (1985BY01) and ^{12}C in (1990AJ01).

See also (1982BA1D, 1985BA1T, 1988TR01; astrophysics), (1984FR05, 1985BE1A, 1985CU1A, 1985KO1J, 1986SN1B, 1986ST1A, 1987GR1K, 1987IM1C, 1988BE1W, 1989VO1D, 1990VO1E) and (1985HU04, 1985IM1B, 1985SA1D, 1986BA1D, 1986BA69, 1986EL02, 1986HA13, 1986KA1B, 1986SA1D, 1986VI08, 1987AR1E, 1987BO48, 1987FR06, 1987IM01, 1987MA22, 1987TH04, 1988BR29, 1988JA14, 1988KA27, 1988MI25, 1988PA07, 1989ER1B, 1989FR08, 1989HA19, 1990BA03; theor.).

51. (a) ^{13}C(^{14}N, ^{14}N)^{13}C
    (b) ^{13}C(^{15}N, ^{15}N)^{13}C

Elastic angular distributions have been measured at $E(^{14}\mathrm{N}) = 19.3$ to 35 MeV and at $E(^{13}\mathrm{C}) = 105$ MeV: see (1981AJ01, 1986AJ01). See also (1989BEZC: γ-ray yields, reaction (b)) and (1986BA69; theor.).

52. (a) ^{13}C(^{16}O, ^{16}O)^{13}C
(b) ^{13}C(^{17}O, ^{17}O)^{13}C
(c) ^{13}C(^{18}O, ^{18}O)^{13}C

Elastic angular distributions have been measured for reaction (a) at $E(^{16}\mathrm{O}) = 10$ to 30 MeV and at $E(^{13}\mathrm{C}) = 36$ and 105 MeV [see (1981AJ01)] as well as at $E(^{16}\mathrm{O}) = 42$ to 65 MeV (1989FR04) and at 108.15 MeV (1986BA80). Those for reaction (b) are reported at $E(^{17}\mathrm{O}) = 29.8$, 85.4, 120 and 140 MeV; and those for reaction (c) at $E(^{18}\mathrm{O}) = 15$ to 31 MeV: see (1981AJ01, 1986AJ01). For excitation functions, breakup yields and fusion measurements see (1981AJ01, 1986AJ01) and (1983FR17 [see, however, 1988FR15], 1985BE40, 1985BE37, 1986GA13, 1986PA10). See also (1985CU1A, 1985HU04, 1985KO1J, 1985RE1C, 1986ST1A, 1989BEZC, 1990SN1A) and (1985MI13, 1986BA69, 1986CI01, 1986MI1A, 1986PA04, 1987AR13, 1987BA01, 1987MO27, 1987DA34, 1987NU02, 1987RE1C, 1989CH2B, 1989TH1A, 1990IM01; theor.).

53. ^{13}C(^{24}Mg, ^{24}Mg)^{13}C

See (1986AJ01) and (1986OS05; theor.).

54. (a) ^{13}C(^{27}Al, ^{27}Al)^{13}C
(b) ^{13}C(^{28}Si, ^{28}Si)^{13}C

For reaction (a) see (1988SN1A). The elastic angular distribution for reaction (b) has been studied at $E(^{13}\mathrm{C}) = 60$ MeV (1988YA06). For the earlier work see (1981AJ01, 1986AJ01). See also (1989CH1K; theor.).

55. (a) ^{13}C(^{32}S, ^{32}S)^{13}C
(b) ^{13}C(^{40}Ar, ^{40}Ar)^{13}C

For reaction (a) see (1990ME07); for (b) see (1988GO12, 1989RA1K). See also (1986AJ01).

56. (a) ^{13}C(^{40}Ca, ^{40}Ca)^{13}C
(b) ^{13}C(^{48}Ca, ^{48}Ca)^{13}C

See (1981AJ01, 1986AJ01) and (1985EL07, 1986OS05; theor.).

57. ^{13}N(β^+)^{13}C $\quad Q_{\rm m} = 2.2205$

See ^{13}N.

58. ^{14}C(γ, n)^{13}C $\quad Q_{\rm m} = -8.1765$

See ^{14}C and (1985PY01). See also (1987GO09; theor.).

59. (a) ^{14}C(p, d)^{13}C $\quad Q_{\rm m} = -5.9519$
(b) ^{14}C(d, t)^{13}C $\quad Q_{\rm m} = -1.9192$
(c) ^{14}C(^{3}He, α)^{13}C $\quad Q_{\rm m} = 12.4013$

At $E_{\rm p} = 35.0$ and 40.1 MeV angular distributions (reaction (a)) have been reported [and integrated cross sections and spectroscopic factors have been derived] for the deuterons to the $\frac{1}{2}^-$ states ^{13}C*(0, 8.86, 11.08), the $\frac{3}{2}^-$ states ^{13}C*(3.68, 9.90, 11.75, (13.28), 15.11), the $\frac{5}{2}^+$ states ^{13}C*(3.85, 6.86), the $\frac{1}{2}^+$ states ^{13}C*(3.09, 11.0), the $\frac{3}{2}^+$ states ^{13}C*(7.69, 8.2), ^{13}C*(7.5) [$J^\pi = \frac{5}{2}^-$] and ^{13}C*(9.50) [$\frac{9}{2}^+$] (1990YA01). See also (1981AJ01).

60. ^{14}N(γ, p)^{13}C $\quad Q_{\rm m} = -7.5506$

Angular distributions measured in the giant resonance region of ^{14}N are consistent with the proton decay of $(p_{1/2})^{-1}$ (2s1d) giant dipole states to $^{13}C_{g.s.}$ and of $(p_{3/2})^{-1}$ (2s1d) states to ^{13}C*(3.68). The population of ^{13}C*(3.09, 3.85) is also reported. For $E_{\rm b.s.} = 15.5$ to 29.5 MeV a large fraction of the neutron yield appears to be associated with sequential decay to ^{12}C via ^{13}C*(7.75, 8.86, 11.80): see (1981AJ01). See also ^{14}N.

61. ^{14}N(n, d)^{13}C $\quad Q_{\rm m} = -5.3260$

Angular distributions have been determined at $E_{\rm n} = 10.1$ to 14.7 MeV: see (1981AJ01). See also (1988YOZX; $E_{\rm n} = 60$ MeV; prelim.).

62. ^{14}N(p, 2p)^{13}C $\quad Q_{\rm m} = -7.5506$

At $E_{\rm p} = 46$ MeV, the summed proton spectrum shows transitions to ^{13}C*(0, 3.68, 7.5, 11.9): see (1981AJ01). At $E_{\rm p} = 50$ MeV ^{13}C*(0, 3.1, 3.7) are populated (1984VD02, 1986VDZY). See also (1987VD1A).

63. ^{14}N(d, ^{3}He)^{13}C $\qquad Q_{\rm m} = -2.0571$

At $E_{\rm d} = 52$ MeV, angular distributions have been measured for the ^{3}He particles to ^{13}C*(0, 3.09, 3.68, 6.86, 7.5, 8.86, 9.50, 11.9 ± 0.15) and analysed by DWBA: $J^{\pi} = \frac{5}{2}^{-}$, $\frac{1}{2}^{-}$, $\frac{3}{2}^{-}$ and $\frac{3}{2}^{-}$, respectively, are assigned to ^{13}C*(7.5, 8.86, 9.50, 11.9). [However, ^{13}C*(9.50) is known to have $J^{\pi} = \frac{9}{2}^{+}$.] As expected, angular distributions of ^{3}He and of tritons (from ^{14}N(d, t)^{13}N) to analog states are closely the same: this has been shown for the ground-state ^{3}He and triton groups as well as groups to ^{13}C*$(8.9 + 9.5)$ and ^{13}N*(9.2): see (1981AJ01).

64. ^{14}N(t, α)^{13}C $\qquad Q_{\rm m} = 12.2634$

Observed α groups at $E_{\rm t} = 2.6$ MeV are displayed in Table 13.22 of (1976AJ04).

65. ^{14}N(^{6}Li, ^{7}Be)^{13}C $\qquad Q_{\rm m} = -1.945$

See (1981AJ01, 1986AJ01).

66. ^{14}N(^{10}B, ^{11}C)^{13}C $\qquad Q_{\rm m} = 1.1390$

See (1987OS1E; theor.).

67. ^{15}N(p, ^{3}He)^{13}C $\qquad Q_{\rm m} = -10.6658$

At $E_{\rm p} = 43.7$ MeV ^{3}He groups have been observed to eleven states of ^{13}C: see Table 13.17 in (1981AJ01).

68. ^{15}N(α, ^{6}Li)^{13}C $\qquad Q_{\rm m} = -14.6843$

At $E_\alpha = 42$ MeV the angular distribution to $^{13}C_{g.s.}$ has been measured: see (1981AJ01). See also (1988SH1E; theor.).

69. $^{16}O(n, \alpha)^{13}C$ $Q_m = 2.2156$

Angular distributions have been measured for E_n to 18.8 MeV for α_0, α_1, α_{2+3}: see (1981AJ01). See also (1987MA1C; astrophysics).

70. $^{16}O(\alpha, ^{7}Be)^{13}C$ $Q_m = -21.2061$

At $E_\alpha = 42$ MeV the angular distributions involving $^{13}C_{g.s.}$ have been measured: see (1981AJ01).

71. $^{16}O(^{9}Be, ^{12}C)^{13}C$ $Q_m = 3.4856$

Angular distributions are reported at $E(^{16}O) = 20.0$ to 28.3 MeV to $^{13}C^*(0, 3.09, 3.85)$ (1988WE17). See also (1989VO1D).

72. (a) $^{18}O(d, ^{7}Li)^{13}C$ $Q_m = -5.678$
(b) $^{19}F(d, ^{8}Be)^{13}C$ $Q_m = 3.5817$

Angular distributions have been measured in both reactions at $E_d = 13.6$ MeV involving $^{13}C_{g.s.}$: see (1986AJ01).

73. $^{23}Na(d, ^{12}C)^{13}C$ $Q_m = 0.4785$

At $E_d = 13.6$ MeV an angular distribution has been reported by (1986GO26).

^{13}N

(Figs. 3 and 4)

GENERAL (See also 1986AJ01).

Nuclear models: (1989AM02)

Special states: (1984KO40, 1985RO1J, 1986AN07, 1988RO1R, 1989RO03)

Electromagnetic transitions: (1984VA06, 1987HO1L).

Astrophysical questions: (1985TA1A, 1987RA1D, 1989ST14).

Applied work: (1986HI1B, 1986MA2F, 1986MA1T, 1986WE1E, 1987BU12, 1987LE1H, 1988HI1F, 1988VO1D, 1989AR1J, 1989AR1N, 1989AR1Q, 1989TR1B, 1989WO1B, 1990DA1J)

Complex reactions involving ^{13}N: (1985AR09, 1985PO11, 1986HA1B, 1986PO06, 1986UT01, 1987BA38, 1987FE1A,1987NA01, 1987RI03, 1987ST01, 1988SA19, 1989BA92, 1989WA16, 1989KI13, 1989LYZY, 1989SA10, 1989TA1O, 1989YO02, 1990GL01, 1990WE14)

Muon and neutrino reactions: (1985MI21, 1990FU03, 1990MI1J)

Reactions involving pions, kaons and other mesons: (1985SA06, 1986KU1J, 1986LI1N, 1986SI13, 1986SI22, 1986SU18, 1987MI08, 1988AB05, 1988BU1I, 1988CH1L, 1988HA12, 1988KO1V, 1989AG1B, 1989BE2O, 1990BE12, 1990CA15, 1990KO19, 1990TI1B)

Hypernuclei: (1985BA2D, 1989BA93)

Other topics: (1985AN28, 1986AN07, 1990MU10)

Ground state of ^{13}N: (1985AN28, 1986GL1A, 1986SI22, 1987FU06, 1988WA08, 1989AM02, 1989SA10)

$\mu = -0.32224(35)$ nm (1978LEZA). See also (1989RA17).

1. ^{13}N(β^+)^{13}C $\qquad Q_{\rm m} = 2.2205$

The weighted mean of $\tau_{1/2}$ measurements is 9.965 ± 0.0004 min. The decay is entirely to $^{13}C_{g.s.}$; log $ft = 3.667 \pm 0.001$: see (1981AJ01). See also (1989KA1S: $\tau_{\rm m} = 9.962 \pm 0.020$ min), (1989SE1C, 1989SE1G, 1990ST08), (1985BA1N, 1986GR04, 1987BA89, 1987FR1C, 1987RI1E, 1987WE1C, 1988BA86, 1988BA1Y, 1988BA2D, 1989DA1H, 1989GU28, 1989KA24; astrophysics) and (1984BO03, 1986SI22, 1989AM02, 1989SA1P, 1989WO1E; theor.).

2. ^{10}B(^{3}He, γ)^{13}N $\qquad Q_{\rm m} = 21.6368$

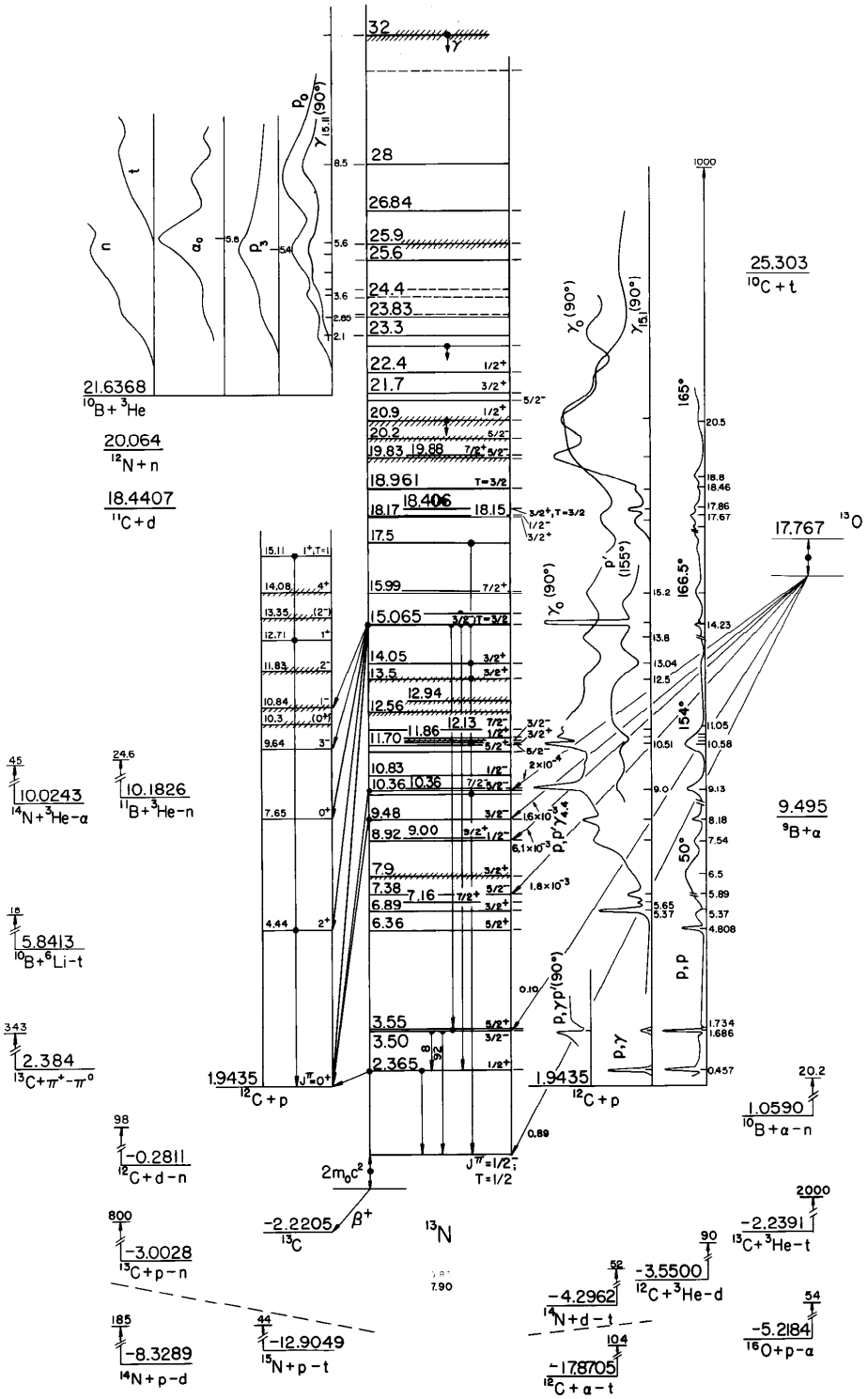


Fig. 3: Energy levels of ^{13}N. For notation see Fig. 2.

Table 13.14: Energy levels of ^{13}N

E_x (MeV±keV)	$J^\pi; T$	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
g.s.	$\frac{1}{2}^-; \frac{1}{2}$	$\tau_{1/2} = 9.965 \pm 0.004$ min	β^+	1, 2, 5, 7, 8, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 33, 34, 35, 36
2.3649 ± 0.6	$\frac{1}{2}^+$	$\Gamma_{c.m.} = 31.7 \pm 0.8$	γ, p	5, 7, 8, 9, 13, 14, 24, 25, 28, 30, 31, 35, 36
3.502 ± 2 [a]	$\frac{3}{2}^-$	62 ± 4 [a]	γ, p	2, 5, 7, 8, 9, 13, 14, 17, 18, 19, 24, 25, 26, 27, 28, 29, 30, 34, 35
3.547 ± 4	$\frac{5}{2}^+$	47 ± 7	p	2, 5, 7, 9, 13, 14, 17, 18, 19, 24, 25, 26, 28, 30
6.364 ± 9	$\frac{5}{2}^+$	11	p	6, 7, 9, 14, 25, 30, 34
6.886 ± 8	$\frac{3}{2}^+$	115 ± 5	p	6, 7, 9, 14, 25, 30
7.155 ± 5	$\frac{7}{2}^+$	9 ± 0.5	p	6, 7, 9, 14, 25, 30
7.376 ± 9	$\frac{5}{2}^-$	75 ± 5	p	6, 7, 9, 14, 25, 27, 28, 29, 30, 34
7.9	$\frac{3}{2}^+$	≈ 1500	p	9, 14
8.918 ± 11	$\frac{1}{2}^-$	230	p	7, 9, 14, 27, 28, 29, 34
9.00	$\frac{9}{2}^+$	280 ± 30		6, 14, 24, 25, 29
9.476 ± 8	$\frac{3}{2}^-$	30	p	6, 7, 9, 14, 25, 27, 29
10.25 ± 150	$(\frac{1}{2}^+)$	≈ 280	γ, p	8
10.36	$\frac{5}{2}^-$	30	p	6, 7, 9, 14, 25, 27
10.36	$\frac{7}{2}^-$	76	p	6, 7, 9, 14, 25
10.833 ± 9	$\frac{1}{2}^-$			6, 7, 14, 25, 34
11.530 ± 12	$\frac{5}{2}^+$	430 ± 35	p	6, 7, 9
11.70 ± 30	$\frac{5}{2}^-$	115 ± 30	p	9

Table 13.14: Energy levels of ^{13}N (continued)

E_x (MeV±keV)	$J^\pi; T$	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
11.74 ± 40	$\frac{3}{2}^+$	240 ± 30	γ, p	8, 9
11.74 ± 50	$\frac{3}{2}^-$	530 ± 80	p	7, 9, 28, 29, 34
11.86 ± 40	$\frac{1}{2}^+$	380 ± 50	p	9, 28
12.13 ± 50	$\frac{7}{2}^-$	250 ± 30	p	9, 35
12.558 ± 23		> 400		7
12.937 ± 24		> 400		7
13.5 ± 200	$\frac{3}{2}^+$	≈ 6500	γ, p	8, 9
14.05 ± 20	$\frac{3}{2}^+; \frac{1}{2}$	165 ± 20	γ, p, α	8, 9, 12
15.06457 ± 0.4 [b]	$\frac{3}{2}^-; \frac{3}{2}$	0.86 ± 0.12	γ, p, α	7, 8, 9, 12, 18, 24, 25, 34
15.3 ± 200	$(\frac{3}{2}^+)$	350 ± 150	γ, p	8
15.99 ± 30	$\frac{7}{2}^+; \frac{1}{2}$	135 ± 90	p, α	9, 12, 25
16.0		≈ 500	p	9
17.5			γ, p	8, 9
18.15 ± 30	$\frac{3}{2}^+; \frac{1}{2}$	320 ± 80	p	9
18.17 ± 20	$\frac{1}{2}^-; \frac{1}{2}$	225 ± 50	p, α	9, 12
18.406 ± 5	$\frac{3}{2}^+; \frac{3}{2}$	66 ± 8	p, α	7, 9, 12
18.961 ± 10	$\frac{3}{2}^-$ or $\frac{7}{2}^+; \frac{3}{2}$	23 ± 5	p, α	7, 9, 12
19.83	$\frac{5}{2}^-; \frac{1}{2}$	1000	p, α	9, 12
19.88	$\frac{7}{2}^+; \frac{1}{2}$	750	p	9
20.2	$\frac{5}{2}^-$	1000	p	9
20.9 ± 300	$\frac{1}{2}^+$	1200	γ, p	8, 9
21.4	$\frac{5}{2}^-$	750	p	9
21.7	$\frac{3}{2}^+$		p	9
22.4 ± 500	$\frac{1}{2}^+$		p	9
23			γ, p	8
23.3	$(\frac{3}{2}^-)$	400	p, ^{3}He	3, 4
23.83 ± 50	$(\frac{3}{2}^-)$	350 ± 50	p, ^{3}He	3, 4
(23.9)	$(\frac{11}{2}^-)$	20	^{3}He	4
(24.4)		700	p, ^{3}He	3

Table 13.14: Energy levels of ^{13}N (continued)

E_x (MeV±keV)	$J^\pi; T$	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
(24.6)		120	p, ^{3}He	3
25.6 ± 100	$(\frac{3}{2}^-)$	240 ± 80	p, ^{3}He	3, 9
25.9		1000	(n), p, d, ^{3}He, α	3, 4
26.84			p	9
28			(γ), p, ^{3}He, (α)	2, 3, 4
(31)			p	9
32		≈ 2000	γ, d, ^{3}He, α	2, 4, 8

[a] See also footnotes [b,f] in Table 13.17.

[b] See also Table 13.6.

The 90° cross sections for γ_0 and γ_{2+3} have been measured for $E(^3\text{He})$ = 4.8 to 14 MeV: no pronounced structures are observed: see (1981AJ01).

3. (a) ^{10}B(^{3}He, n)^{12}N $Q_m = 1.573$ $E_b = 21.6368$
   (b) ^{10}B(^{3}He, p)^{12}C $Q_m = 19.6933$

Activation cross sections (reaction (a)) have been reported for $E(^3\text{He})$ = 1 to 30.6 MeV: there is some evidence for broad structures. Observed resonances in the yield of proton groups and of 12.7 and 15.1 MeV γ-rays are displayed in Table 13.15. See also (1981AJ01).

4.(a) ^{10}B(^{3}He, d)^{11}C $Q_m = 3.1961$ $E_b = 21.6368$
   (b) ^{10}B(^{3}He, ^{3}He)^{10}B
   (c) ^{10}B(^{3}He, α)^{9}B $Q_m = 12.141$

For observed resonances and anomalies see Table 13.15. See also (1981AJ01).

5. ^{10}B(α, n)^{13}N $Q_m = 1.0590$

Angular distributions have been measured in the range $E_\alpha = 1.5$ to 20.2 MeV: see (1981AJ01). See also (1987EL1B; applied) and (1988CA26; astrophysics).

Table 13.15: Structures in ^{10}B + ^{3}He [a]

E_{res} (MeV ± keV)	Γ (keV)	Res. in	^{13}N* (MeV)
2.1 [b]	500	p_0, (p_1), ^{3}He	23.3
2.85 ± 50 [b]	450 ± 50	$\gamma_{15.1}$, ^{3}He	23.83
2.975 [b]	20	^{3}He	23.9
3.6 [b]	700	p_0, p_1	24.4
3.9	120	p_0	24.6
(4.6)	150	p_0, (p_1)	(25.2)
5.2 ± 100	240 ± 80	p_0, $\gamma_{15.1}$,p_2, p_3	25.6
5.6	1000 [d]	(n), p_0, p_2, p_3, $\gamma_{12.7}$, $\gamma_{15.1}$, d_0, α_0	25.9
8.5	[e]	(γ_0), p_0, $\gamma_{12.7}$, $\gamma_{15.1}$, (α_0)	28
13.5 [c]	≈ 2000	(γ_0), d_{4+5}, α_1	32

[a] For references and comments see Table 13.19 in (1981AJ01). For ^{3}He elastic scattering anomalies see (1987BA34).

[b] (1987BA34) report Γ(^{3}He)/Γ = 0.5, 0.3 and ≈ 1 for ^{3}N*(23.3, 23.83, 23.9); $J^\pi = \frac{3}{2}^-, \frac{3}{2}^-, \frac{11}{2}^-$ for these three states.

[c] This may correspond to more than one state.

[d] $J \geq \frac{3}{2}$.

[e] $J \geq \frac{7}{2}$.

6. (a) ^{10}B(^{6}Li, t)^{13}N $\quad Q_m = 5.8413$

   (b) ^{10}B(^{9}Be, ^{6}He)^{13}N $\quad Q_m = 0.4606$

At $E(^6\text{Li})$ = 18 MeV the known states of ^{13}N with $6.3 < E_x < 11.7$ MeV are observed, with the exception of ^{13}N*(7.9, 8.92). In addition, evidence is presented for a ^{13}N state at $E_x = 9.00$ MeV with $\Gamma_{c.m.} = 280 \pm 30$ keV: it is very strongly excited and its angular distribution is similar to that for ^{13}C*(9.50) in the mirror reaction (^{6}Li, ^{3}He), suggesting that these two states are analogs. Other analog assignments made on the basis of corresponding intensities in the mirror reaction are given in reaction 12 of ^{13}C. The widths of ^{13}N*(6.89, 7.38) are, respectively, 120 ± 30 and 70 ± 30 keV (1974HO06). For reaction (b) see (1990JAZZ).

7. ^{11}B(^{3}He, n)^{13}N $\quad Q_m = 10.1826$

Neutron groups have been observed to a number of states of ^{13}N: see Table 13.16. The parameters of the first $T = \frac{3}{2}$ state at $E_x = 15.06$ MeV are displayed in Table 13.6 where they are compared with the corresponding quantities for ^{13}C*(15.11): see (1981AJ01).

8. (a) ^{12}C(p, γ)^{13}N $\quad Q_m = 1.9435$
   (b) ^{12}C(p, π^0)^{13}N $\quad Q_m = -133.021$

Resonances for capture radiation are displayed in Table 13.17. No resonance is observed at $E_p = 1.73$ MeV [^{13}N*(3.55)]: $\omega\Gamma_\gamma < 0.006$ eV. Excitation functions have been measured for $E_p = 150$ to 2500 keV. In addition to the first two resonances, direct radiative capture is observed. The capture γ-ray yield, studied for $E_p = 610$ to 2700 keV, is dominated by a direct capture process to ^{13}N*(2.36). The cascade decay ^{13}N*(3.50 $\rightarrow$ 2.36) has an intensity of $(8 \pm 1)\%$. Extrapolating the cross section to $E_{c.m.} = 25$ keV yields a cross section factor $S = 1.45 \pm 0.20$ keV·b: see (1981AJ01). [A reanalysis of the data by (1980BA54) suggests $S = 1.54^{+0.15}_{-0.10}$ kev·b].

Differential cross sections for the transitions to the ground state have been measured for $E_{\vec{p}} = 10$ to 17 MeV. The total E2 capture cross section is ≈ 0.2 μb and no resonance effects are observed. The E2 energy-weighted sum rule depleted over this energy range is $(8.5 \pm 3.3)\%$ (1980HE04). At $E_p = 14.2$ MeV, capture radiation from the first $T = \frac{3}{2}$ state, ^{13}N*(15.06) is reported: see Table 13.6 for the parameters and the decay modes of this state. The angular distributions of the γ-rays determine $J = \frac{3}{2}$ for ^{13}N*(15.06). The interference between the M1(E2) $T = \frac{3}{2}$ resonance (^{13}N*(15.06)) and the E1 GDR has been studied by (1980SN01): the E1 capture is found to be predominantly d-wave. See (1981AJ01) for the earlier references.

Excitation functions for γ-rays have also been measured at $E_p = 8.7$ to 37 MeV (γ_0), 19.9 to 24.4 MeV (γ_1, γ_{2+3}) and 23 to 37 MeV (γ_{2+3}). At $E_p = 40$ to 100 MeV most of the γ-strength is due to transitions to ^{13}N*(3.5), probably to ^{13}N*(3.55) [$J^\pi = \frac{5}{2}^+$] because of its single-particle character. Transitions to higher states may also be indicated. Excitation functions, γ-ray angular distributions and analyzing powers for γ_0, γ_{2+3} are reported by (1984BL10) for $E_p \approx 25$ to 40 MeV. Differential cross sections (γ_0) have also been measured for $E_p = 28.35$ to 90 MeV (1988HA04) [also angular distribution and A_y at $E_{\vec{p}} = 28.35$ MeV]. At $E_p = 40$ to 80 MeV A_y measurements are reported for the γ_0 and "γ_1" transitions (1986EJ1A, 1986SH1Y; prelim). See also (1989ZU1A).

The photon production cross section has been studied at $E_p = 168$ and 200 MeV (1989PI02). For other high-energy γ-ray emission results see (1990CLZZ). The π^0 production cross section to ^{13}N$_{g.s.}$ has been determined for $E_p = 154.5$ to 204 MeV (1987HO21, 1988SEZT) and at 200 MeV (1989BE25). See also (1988AB05) [$E_p = 1$ GeV; charged pion production].

See also (1982AN1D, 1984NA1F, 1989IZ1A), (1986AI04, 1988PO1G; applied), (1985AR1A, 1985CA41, 1987RO25, 1987WE1C, 1988CA26, 1989BA2P, 1989GU1J, 1989KA24; astrophysics), (1986BE17, 1986SN1B, 1986WE1D, 1987HE1B, 1989BL1D) and (1986DI1C, 1986MI09, 1986MI1M, 1987RE11, 1990HA46; theor.).

Table 13.16: States of ^{13}N from ^{11}B(^{3}He, n)^{13}N [a]

E_x (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	L	J^π
0		2	$\frac{1}{2}^-$
2.358 ± 10		1	$\frac{1}{2}^+$
3.502 ± 10		0, 2	$\frac{3}{2}^-$
3.55 ± 18			
6.353 ± 9		1, 3	$\frac{5}{2}^+$
6.875 ± 10		1, 3	$\frac{3}{2}^+$
7.145 ± 9		3, 5	$\frac{7}{2}^+$
7.363 ± 8		2, 4	$\frac{5}{2}^-$
8.2 ± 22			
8.918 ± 11			
9.476 ± 8		0, 2	$\frac{3}{2}^-$
10.381 ± 8		2, 4	$\frac{5}{2}^-$
10.833 ± 9			
11.530 ± 12			
11.878 ± 12		0, 2	$\frac{3}{2}^-$
12.558 ± 23	> 400		
12.937 ± 24	> 400		
15.068 ± 8 [b]	< 15		$\frac{3}{2}^-; T = \frac{3}{2}$
18.44 ± 40			$T = \frac{3}{2}$
18.98 ± 20	40 ± 20		$T = \frac{3}{2}$

[a] For references see Table 13.20 in (1981AJ01).

[b] See also Table 13.6.

Table 13.17: Resonances in ^{12}C(p, γ)^{13}N [a]

E_p (MeV±keV)	$\Gamma_{c.m.}$ (keV)	Γ_{γ_0} (eV)	^{13}N* (MeV)	Res. in yield of	J^π
0.4568 ± 0.5	31.7 ± 0.8	0.50 ± 0.04 [g]	2.3649 ± 0.0006	γ_0	$\frac{1}{2}^+$
1.689 ± 2 [b]	62 ± 4 [f]	0.64	3.502	γ_0	$\frac{3}{2}^-$
9.01 ± 150	≈ 280		10.25	γ_0	$(\frac{1}{2}^+)$
10.62 ± 120	200 ± 50	≈ 4.2 [h]	11.74	γ_0	$\frac{3}{2}^+$
12.5 ± 200	6500	≥ 1100	13.5	γ_0	$\frac{3}{2}^+$
13.12 ± 90	160 ± 20	3.7 ± 1.0 [i]	14.04	γ_0	$\frac{3}{2}^+$
14.2	[see Table 13.6]		15.0	γ_0, γ_{2+3}	$\frac{3}{2}^-; T = \frac{3}{2}$
14.5 ± 200 [c]	350 ± 140	≥ 0.5	15.3	γ_1	$(\frac{3}{2}^+)$
16.9			17.5	γ_0	
20 [d]			20	γ_1, γ_{2+3}	
20.5 [e]	≈ 3700		20.8	γ_0	
23			23	γ_0	
24.5			24.5	γ_{2+3}	
32.5	broad		31.9	γ_0, γ_{2+3}	

[a] For references and other comments see Tables 13.21 in (1981AJ01) and 13.17 in (1986AJ01).

[b] (1989KI21) [see for additional comments]. See also (1984PO13, 1987PO09). *Please note*: The earlier work [see, e.g., 1974RO29] led to $E_p = 1699 \pm 2$ keV. It would be useful to confirm the new value of (1989KI21). I am indebted to Prof. Robert Zurmuhle for a very helpful discussion.

[c] This peak may be due to an unresolved doublet.

[d] Giant resonance for γ_1.

[e] Main dipole strength is concentrated in this peak.

[f] (1985BR06) have studied this resonance with polarized protons and analyzed the results with R-matrix theory: the E2/M1 mixing ratio is -0.102 ± 0.003 and the total width (lab.) is calculated to be 62 keV. An extranuclear direct capture background appears to be necessary to explain the data. (1989KI25) suggest 65.6 ± 1.8 keV but it is not clear whether that value is Γ_{lab} or $\Gamma_{c.m.}$.

[g] See the discussion in (1985BA75).

[h] A value of 0.30 ± 0.05 is assumed for Γ_{p_0}/Γ: see Table 13.18.

[i] A value of 126 keV is taken for Γ_{p_0}.

9. (a) ^{12}C(p, p)^{12}C $E_{\rm b} = 1.9435$

(b) ^{12}C(p, 2p)^{11}B $Q_{\rm m} = -15.9572$

(c) ^{12}C(p, pα)^{8}Be $Q_{\rm m} = -7.3666$

Yields curves for elastic protons, protons inelastically scattered to ^{12}C*(4.4, 7.7, 9.6, 12.7, 15.1) and for γ-rays from ^{12}C*(4.4, 12.7, 15.1) have been studied at many energies: see Table 13.18 for a display of the observed structure. Elastic excitation functions have recently been measured at $E_{\rm p} = 0.35$ to 0.55 MeV (1986HO26), 1.6 to 1.9 MeV (1986ER06, 1987ER01) and 5.0 to 7.5 MeV (1987RO1F; prelim.). A phase-shift analysis of the elastic scattering analyzing power for $E_{\vec{\rm p}} = 11.5$ to 18.1 MeV shows four $T = \frac{1}{2}$ states with $E_{\rm x} = 14.06$, 16.00, 18.16 and 18.18 MeV, with $J^\pi = \frac{3}{2}^+$, $\frac{7}{2}^+$, $\frac{3}{2}^+$, $\frac{1}{2}^-$: see Table 13.18. At $E_{\vec{\rm p}} = 19.15$ to 23.34 MeV, measurements of the elastic group and the protons to ^{12}C*(4.4, 12.7) locate $\frac{1}{2}^+$ (E1), $\frac{5}{2}^-$ (E2) and $\frac{7}{2}^+$ (E3) resonances below 21 MeV, $\frac{3}{2}^+$ (E1) and $\frac{5}{2}^-$ resonances with $21 < E_{\rm x} < 22$ MeV and $\frac{1}{2}^+$ and $\frac{3}{2}^+$ resonances above 22 MeV: see Table 13.18. For other polarization measurements see Table 13.19. See also (1985BL22, 1989OPZY, 1990CHZY) and (1989SR1C; theor.).

Cross sections for production of 4.4 MeV γ-rays have been determined for $E_{\rm p} = 5.1$ to 23 MeV (1981DY03), 8.9, 20, 33, 40 and 50 MeV (1988LE08) and 22 to 85 MeV (1987LA11, 1988SA1B). In the latter work, cross sections have also been measured for the 15.1 MeV γ-ray, and for the 2.1 MeV γ-ray [unresolved; from the decay of the first excited states of ^{11}B/^{11}C reached in the (p, 2p) and (p, pn) reactions]. These measurements are of considerable interest in astrophysics: see, e.g., (1987LA11). The cross sections for the (p, 2p) process (reaction (b)) from the $1p_{3/2}$ orbital and from the continuum have been measured at $E_{\rm p} = 200$ MeV by (1989CO17, 1989PI12). See also (1989TEZZ; prelim.). For other breakup processes see (1986AJ01). For high-energy gamma-ray emission see (1990CLZZ). Total and inelastic cross sections have been measured at $E_{\rm p} = 1.52$ and 1.8 GeV/c (1984AF1A). For a study of inclusive proton spectra at 150 MeV see (1985SE15). For π^+ emission see reaction 27 in ^{13}C. For an anti-proton study see (1989TA24). For a study at $E(^{12}{\rm C}) = 296$ to 1572 MeV/A see (1990WE14).

The yield of bremsstrahlung and the shape of the energy spectrum have been studied for $E_{\rm p} = 1.74$ to 1.93 MeV by (1986ER06, 1987ER01, 1990ER02). For other bremsstrahlung studies see (1981AJ01, 1986AJ01) and (1987YAZZ, 1988YAZZ).

See also ^{12}C in (1990AJ01), (1985BA2F, 1986CH2H, 1986NO1E, 1986SA2F, 1986VDZY, 1987BA33, 1987LIZZ, 1987MOZZ, 1988LYZZ, 1989AG1B, 1989SU1F), (1986ZE1E, 1990BO10; applied), (1986BA88, 1986CA1N, 1986CL1C, 1986GL1G, 1986MO1L, 1986ST1F, 1987HE1B, 1988BO46, 1988HI1H) and (1984ZA1D, 1985BO1A, 1985PI11, 1985SH1H, 1985ZH07, 1986DEZK, 1986HA1K, 1986HO10, 1986KA1Y, 1986LO1A, 1986SA30, 1986VD01, 1986VI1D, 1986ZA06, 1986ZH04, 1987HO1G, 1987LI01, 1987MI01, 1987PL1C, 1987RE03, 1987RO02, 1987SCZV, 1987ZA1F, 1987ZH08, 1988AZ1B, 1988BEYI, 1988HO1K, 1988KU16, 1988NA04, 1988RU1C, 1988ST1G, 1989BE2B, 1989MI20, 1989YA10, 1990CA1S, 1990PH02, 1990PI06; theor.).

10. (a) ^{12}C(p, n)^{12}N $Q_{\rm m} = -18.120$ $E_{\rm b} = 1.9435$

(b) ^{12}C(p, pn)^{11}C $\qquad Q_{\rm m} = -18.7215$

Table 13.18: ^{13}N levels from ^{12}C(p, p), ^{12}C(p, p′), ^{12}C(p, α) [a]

$E_{\rm p}$ (MeV ± keV)	^{13}N* (MeV)	$\Gamma_{\rm c.m.}$ (keV)	$l_{\rm p}$	J^π	[b]
0.461 ± 3	2.369 [c]	31 [c]	0	$\frac{1}{2}^+$	$\theta^2 = 0.54$
1.686 ± 6	3.499 [c]	60 [c]	1	$\frac{3}{2}^-$	0.031
1.734 ± 6	3.543 [c]	50 [c]	2	$\frac{5}{2}^+$	0.21
4.808 ± 10	6.378	11	2	$\frac{5}{2}^+$	0.0031
5.370 ± 10	6.896	115 ± 5	2	$\frac{3}{2}^+$	0.13
5.65 ± 10	7.155	9 ± 0.5	4	$\frac{7}{2}^+$	0.016
5.891	7.38	75 ± 5	3	$\frac{5}{2}^-$	0.069
6.5	7.9	≈ 1500	2	$\frac{3}{2}^+$	0.14
7.54	8.90	230	1	$\frac{1}{2}^-$	0.02
8.18	9.49	30	1	$\frac{3}{2}^-$	0.001
9.13	10.36	30	3	$\frac{5}{2}^-$	
9.13	10.36	76	3	$\frac{7}{2}^-$	
					$\Gamma_{\rm p}/\Gamma =$
10.35 ± 50	11.49	430 ± 35	2	$\frac{5}{2}^+$	0.70 ± 0.05
10.58 ± 30	11.70	115 ± 30	3	$\frac{5}{2}^-$	0.60 ± 0.04
10.62 ± 40	11.74	250 ± 30	2	$\frac{3}{2}^+$	0.30 ± 0.05
10.62 ± 50	11.74	530 ± 80	1	$\frac{3}{2}^-$	0.55 ± 0.05
10.75 ± 40	11.86	380 ± 50	0	$\frac{1}{2}^+$	0.35 ± 0.05
11.05 ± 50	12.13	250 ± 30	3	$\frac{7}{2}^-$	0.30 ± 0.05
12.5	13.5	≈ 500			
13.13 ± 20	14.05	180 ± 35	2	$\frac{3}{2}^+; T = \frac{1}{2}$	0.29 ± 0.07
14.23075 ± 0.2	15.06457 ± 0.4	0.932 ± 0.028 [d]	1	$\frac{3}{2}^-; T = \frac{3}{2}$	
15.24 ± 40 [e]	15.99	135 ± 90	4	$\frac{7}{2}^+; T = \frac{1}{2}$	0.05 ± 0.04
15.2	16.0	≈ 500			
16.8 [e]	17.4				
17.58 ± 30	18.15	322 ± 75	2	$\frac{3}{2}^+; T = \frac{1}{2}$	0.08 ± 0.02
17.60 ± 20	18.17	225 ± 50	1	$\frac{1}{2}^-; T = \frac{1}{2}$	0.24 ± 0.06
17.857 ± 5 [f]	18.406	66 ± 8	2	$\frac{3}{2}^+; T = \frac{3}{2}$	

Table 13.18: ^{13}N levels from ^{12}C(p, p), ^{12}C(p, p′), ^{12}C(p, α) [a] (continued)

E_p (MeV ± keV)	^{13}N* (MeV)	$\Gamma_{c.m.}$ (keV)	l_p	J^π	
18.460 ± 10 [f]	18.961	23 ± 5		$\frac{3}{2}^-$ or $\frac{7}{2}^+$; $T = \frac{3}{2}$	
19.40 [g]	19.83	1000	3	$\frac{5}{2}^-$; $T = \frac{1}{2}$	
19.46	19.88	750	4	$\frac{7}{2}^+$; $T = \frac{1}{2}$	
19.8 [f]	20.2	1000		$\frac{5}{2}^-$	
20.6 ± 300 [e, f]	20.9	1200		$\frac{1}{2}^+$	
21.1	21.4	750		$\frac{5}{2}^-$	
21.4	21.7			$\frac{3}{2}^+$	
22.2 ± 500 [h]	22.4	≈ 1000		$\frac{1}{2}^+$	
24.0	24.1	≤ 500			
25.7	25.6			$(\frac{3}{2}^-)$	
27.02	26.84				
32 [g]	31				

[a] For references see Tables 13.22 in (1981AJ01) and 13.27 in (1976AJ04).

[b] A dispersion analysis leads to a spectroscopic factor of 0.53 ± 0.08 for $^{13}N_{g.s.}$.

[c] The older values for ^{13}N*(3.50, 3.54) have been reanalyzed by (1980BA54). An R-matrix analysis had led to $E_x = 2.367$, 3.501 and 3.547 MeV, and $\Gamma_{c.m.} = 33$, 55 and 50 keV for these states. $^{13}N_{g.s.}$ appears to have an appreciable effect on the low-energy scattering: see (1981AJ01). See also (1986ADZY).

[d] $\Gamma_p = 263 \pm 15$ eV (1980TH05). See discussion in (1981BR24): if the ^{12}C nucleus were part of an atom the width of the resonance would be smeared out by an amount of the order of ≈ 0.5 keV (A.M. Lane, private communication). See also Table 13.6.

[e] Resonance in yield of 12.7 MeV γ-rays.

[f] Resonance in yield of 15.1 MeV γ-rays.

[g] Resonance in yield of 4.4 MeV γ-rays.

[h] A $\frac{3}{2}^+$ state is indicated in this region.

The cross section for reaction (a) has been measured from threshold to $E_p = 50$ MeV. Resonant structure is observed corresponding to $E_x = 21$, 24 and, possibly, ≈ 27 MeV: see (1981AJ01). The cross section at 0° for the transition to $^{12}N_{g.s.}$ has been measured at $E_p = 62$, 99 and 120 to 160 MeV (1982AN08), at 120, 160 and 200 MeV (1981RA12) [see ref. 14 in (1989WA15)], at 135 amd 160 MeV (1983WA29), at 144 MeV (1979MO16), at 200, 300 and 400 MeV (1989WA15) and at 492 MeV (1989RA09). Polarization measurements are reported at $E_{\vec{p}} = 160$ MeV (1984TA07; $D_{NN}(0^o)$; g.s.), 160 MeV (1987RA15; A_y; g.s.), 290 and 420 MeV (1989HI10; A_y, quasifree), 494 MeV (1988TAZY, 1990TA1J; A_y, quasielastic; prelim.) and at 590 MeV (1989BI06). See

Table 13.19: Polarization measurements in ^{12}C(p, p) [a]

E_p (MeV)	A_y to ^{12}C* (MeV)	Refs.
2.1→83.8	g.s.	(1987IE01)
35	12.7, 15.1, 16.1	(1990IE01)
40	15.1	(1986SH1X) [b]
65	g.s.: spin rotation parameter	(1986SA1J) [b]
65	0, 4.4, 7.7, 9.6, 14.1	(1985KA10)
71.2	g.s. [$A_\gamma = 0.968 \pm 0.001$]	(1990EV01)
71.7	g.s.	(1989VO05)
79→584	inclusive protons	(1985MC07)
80	12.7, 15.1: spin transfer	(1986HO1H) [b]
156	(p, pα)	(1989MUZZ) [b]
180, 190, 200	g.s. [D_{LL}, D_{SL}]	(1990WEZY) [b]
200	g.s.: spin rotation parameter	(1985STZW, 1986ST1G)
200	12.7: pol. transfer coeff.	(1985WIZW, 1986OL1A) [b]
250	g.s.	(1988ME02)
290, 420	quasielastic; spin observables	(1989CH01, 1990CH16)
300, 500	15.1: angular correlation	(1986LI1Q) [b]
303	inclusive	(1987MO04)
319	inclusive inelastic [S_{nn}]	(1990BA14)
400	12.7, 15.1, 16.1 [$P - A_y$]	(1988HI03)
500	g.s.	(1990HO06)
500	12.7, 15.1, 16.1: pol. transfer observables	(1990CH1R) [b]
800	pol. transfer observables	(1988FE09)
80→250 MeV/c	12.7: spin observables	(1989OPZZ) [b]

[a] For earlier work see Tables 13.26 in (1970AJ04), 13.28 in (1976AJ04), (1981AJ01), and Table 13.19 in (1986AJ01).

[b] Preliminary report.

also (1989GA1N) and (1986AJ01). For continuum spectra at 200 MeV, see (1988NI1C; prelim.). For neutron yields at $E_p = 113$, 318 and 800 MeV, see (1986MEZZ, 1986ME1K, 1989ME1D; prelim.). For neutron production cross sections at $E_p = 585$ MeV, see (1987CI08, 1987FI09). See also reaction 9, and ^{12}C in (1990AJ01).

Cross sections for reaction (b) have been measured to 300 GeV: see (1981AJ01). See also ^{12}N in (1990AJ01), (1984NA1F, 1986IE1A, 1988LE08), (1985KI1A, 1987TA22, 1988HI1F, 1990QU1B) and (1988BA83; theor.).

11. ^{12}C(p, d)^{11}C $\quad Q_m = -16.4972 \quad E_b = 1.9435$

See (1986AJ01).

12. ^{12}C(p, α)^{9}B $\quad Q_m = -7.552 \quad E_b = 1.9435$

Yield curves for α_0 have been measured over the 14.2 MeV resonance, corresponding to the first $T = \frac{3}{2}$ state at $E_x = 15.06$ MeV, and from $E_x = 17$ to 20 MeV. The yield for the α_1 group has been determined for $E_p = 17$ to 21.5 MeV. Parameters of observed resonances are displayed in Table 13.18. Excitation functions for α_0 have also been measured for $E_p = 18.5$ to 44 MeV at a number of angles: they exhibit structures which are typically 1 MeV broad: see (1981AJ01). For polarization measurements see Table 13.19 in (1986AJ01). For α and ^{3}He emission at $E_p = 72$ MeV see (1986WA26).

13. (a) ^{12}C(d, n)^{13}N $\quad Q_m = -0.2811$
(b) ^{12}C(d, pn)^{12}C $\quad Q_m = -2.24585$

Angular distributions have been measured at $E_d = 0.5$ to 17 MeV [see (1981AJ01, 1986AJ01)] and at 18 MeV (1987KAZL, 1988KA30: n_0, n_1). Reaction (b) is dominated at $E_d = 5.0$ to 6.5 MeV and at 9.20 and 9.85 MeV by sequential decay via ^{13}N*(3.50 + 3.55). At the lower energies ^{13}N*(2.36) participates also: see (1976AJ04). See also ^{14}N, (1988MAZP), (1986WE1E, 1988VI1A, 1990BA1S; applied) and (1984BL21; theor.).

14. ^{12}C(^{3}He, d)^{13}N $\quad Q_m = -3.5500$

Angular distributions have been studied at $E(^3\text{He})$ to 81.4 MeV: see (1981AJ01, 1986AJ01). The spectroscopic factors derived by (1980PE13) for ^{13}N*(0, 2.36, 3.55, 6.36, 6.89, 7.16, 7.38, 8.0, 8.92, 9.0, 9.48, 10.36, 10.78) are $S = 0.48$, 0.14, 0.53, 0.007, 0.015, < 0.009, 0.024, 0.13, $<$

0.005, < 0.005, < 0.002, < 0.001, 0.064, respectively. Evidence is presented for the assignment of $J^\pi = \frac{9}{2}^+$ to ^{13}N*(9.0) (1980PE13). For other values of S, see (1981AJ01). The energies and widths for the first three excited states are $E_x = 2368.2 \pm 2.8$, 3507.8 ± 7.6 and 3549.1 ± 5.0 keV, with $\Gamma_{c.m.} = 36.1 \pm 2.8$, 54.8 ± 11.5 and 46.5 ± 7.1 keV respectively: see (1981AJ01). For work at very high energies see (1987AB1J). See also (1986AJ01) and (1984BL21, 1989KA1N; theor.).

15. ^{12}C(α, t)^{13}n $\qquad Q_m = -17.8705$

See (1981AJ01) and (1989GA1H).

16. ^{12}C(^{6}Li, ^{5}He)^{13}N $\qquad Q_m = -2.65$

(1988WO10) [and see reaction 9 in ^{5}He (1988AJ01)].

17. (a) ^{12}C(^{7}Li, ^{6}He)^{13}N $\qquad Q_m = -8.031$
(b) ^{12}C(^{13}C, ^{12}B)^{13}N $\qquad Q_m = -15.590$

Angular distributions have been obtained (reaction (a)) at $E(^7\text{Li}) = 36$ MeV [see (1981AJ01)] and at 34 MeV (1986CO02; ^{13}N*(0, 3.5[u])). $S_{g.s.} = 0.38 \pm 0.05$ (1986CO02). See also (1988AL1G). For reaction (b) see ^{12}B in (1990AJ01).

18. ^{12}C(^{12}C, ^{11}B)^{13}N $\qquad Q_m = -14.0134$

At $E(^{12}\text{C}) = 93.8$ MeV angular distributions involving ^{13}N*(0, 3.5[u]) have been measured: see (1986AJ01). See also (1987WIZW, 1988HA23).

19. ^{12}C(^{13}C, ^{12}B)^{13}N $\qquad Q_m = -15.590$

At $E(^{13}\text{C}) = 390$ MeV angular distributions have been studied involving ^{13}N*(0, 3.5[u]) and broad states at $E_x \approx 16$ and 22 MeV. It is suggested that the latter are the $\frac{5}{2}^+$ and $\frac{3}{2}^+$ components of the giant dipole resonance in ^{13}N (1987AD07, 1988VO08). See also the discussion in reaction 26 in ^{12}B (1990AJ01) and (1989LE14).

20. ^{12}C(^{14}N, ^{13}C)^{13}N $\quad Q_{\rm m} = -5.6071$

See ^{13}C.

21. ^{13}C(γ, π^-)^{13}N $\quad Q_{\rm m} = -141.789$

Angular distributions have been studied at $E_\gamma = 163$ MeV (1986SH13) and 223 MeV (1987DU08). (1986SH13) find that the M1 component reproduces the experimental data, suggesting some supression of the E0 component. See also (1986AJ01) and (1990ER03; theor.).

22. ^{13}C(π^+, π^0)^{13}N $\quad Q_{\rm m} = 2.384$

The excitation function involving ^{13}N$_{\rm g.s.}$ (the isobaric analog state) has been studied at $E_{\pi^+} = 50$ to 343 MeV (1988US01). An angular distribution is reported at $E_{\pi^+} = 165$ MeV involving the Δ-resonance (1988KIZW; prelim.). See also (1986AJ01).

23. ^{13}C(π^+, γ)^{13}N $\quad Q_{\rm m} = 137.348$

Differential cross sections for γ_0 have been measured at $E_{\pi^+} = 115.5$ MeV: no evidence is observed for pion condensation (1984MA45).

24. (a) ^{13}C(p, n)^{13}N $\quad Q_{\rm m} = -3.0028$
(b) ^{13}C(p, pn)^{12}C $\quad Q_{\rm m} = -4.94635$

Angular distributions have been measured for $E_{\rm p} = 3.1$ to 800 MeV [see (1981AJ01, 1986AJ01)] and at 18.6 MeV (1988KA30; n_0, n_1), and 35 MeV (1986OH03, 1987OR01; n_0, n_1, n_{2+3}) [also comparison with ^{13}C(p, p$'$) to mirror states], and at $E_{\vec{\rm p}} = 160$ MeV (1987RA15; n_0, n_{2+3}) [^{13}N*(11.7, 15.1) are also populated]. Forward-angle cross sections have been measured at $E_{\rm p} = 318$ and 800 MeV (1986KI12) and at 492 and 590 MeV (1989RA09). For discussions of the Gamow-Teller strength see (1985WA24, 1986KI12, 1987TA13, 1989RA09). For reaction (b) see (1981AJ01). See also (1986AJ01), ^{14}N, (1985GU1C, 1987ALZW, 1989WA16), (1986MA1P, 1989AR1G; applied), (1988CA26; astrophysics), (1985GO1Q, 1986CA1N, 1986TA1E, 1986VO1G, 1987BE25, 1987GO1V, 1987LI29, 1987RA32, 1987TA22, 1988RO17, 1988US01, 1989RA1G) and (1986PE1E, 1989AM02, 1989RA15; theor.).

25. ^{13}C(^{3}He, t)^{13}N $\quad Q_{\rm m} = -2.2391$

At $E(^{3}\mathrm{He}) = 43.6$ MeV angular distributions are reported to ^{13}N*(0, 2.36, 3.50 + 3.55, 6.36, 6.89, 7.16, 7.38, 9.0, 9.48, 10.36, 10.83, 11.8, 15.07, 16.02). The results are compared with those from the reaction ^{13}C(^{3}He, ^{3}He)^{13}C to the analog states [see reaction 45 in ^{13}C]; they are consistent with $J^{\pi} = \frac{9}{2}^{+}$ for one of the unresolved states at $E_{\rm x} = 9.0$ MeV and with $\frac{1}{2}^{-}$ and $\frac{7}{2}^{+}$ for ^{13}N*(10.83, 16.02) (1981PE08). An angular distribution has also been determined at $E(^{3}\mathrm{He}) = 39.6$ MeV (1987BUZQ; t_0). Cross sections (0°) involving ^{13}N*(0, 3.5) have been measured for $E(^{3}\mathrm{He}) = 0.6$ to 2.3 GeV (1987BE25; see for ratios of the isovector strengths.). For the earlier work see (1981AJ01). See also (1989DE1Q, 1989JAZY) and (1988RO17).

26. (a) ^{13}C(^{6}Li, ^{6}He)^{13}N $\quad Q_{\rm m} = -5.727$

(b) ^{13}C(^{7}Li, ^{7}He)^{13}N $\quad Q_{\rm m} = -13.42$

Angular distributions to ^{13}N*(0, 3.50 + 3.55) have been measured at $E(^{6}\mathrm{Li}) = 31.8$ MeV: see (1981AJ01). These two reactions have been studied at $E(^{6}\mathrm{Li}) = 93$ MeV and $E(^{7}\mathrm{Li}) = 78$ MeV by (1984GL06): ^{13}N*(0, 3.5, 7.3) are most intensely populated. Angular distributions to ^{13}N*(0, 3.5[u]) have also been reported (1989DE34; $E(^{6}\mathrm{Li}) = 93$ MeV). See also (1987GOZM; theor.).

27. ^{13}O(β^{+})^{13}N $\quad Q_{\rm m} = 17.767$

See ^{13}O and Table 13.20.

28. ^{14}N(p, d)^{13}N $\quad Q_{\rm m} = -8.3289$

Angular distributions have been measured for deuteron groups to ^{13}N*(0, 2.36, 3.50 + 3.55, 7.38, 8.92, 11.86) at many energies up to $E_{\rm p} = 155.6$ MeV [see (1981AJ01, 1986AJ01)] and at $E_{\rm p} = 18.6$ MeV (1987VA28, 1989BE1N; d_0). See also (1989AR1G; applied), (1989GU28; astrophysics) and (1988GUZW; theor.).

29. ^{14}N(d, t)^{13}N $\quad Q_{\rm m} = -4.2962$

Angular distributions of the tritons to ^{13}N*(0, 3.50, 7.38, 8.92 + (9.00) + 9.48, 11.8) have been obtained at $E_{\rm d} = 52$ MeV and analyzed by DWBA. The spectroscopic factors for the ^{13}N states [and the mirror states reached in the ^{14}N(d, ^{3}He)^{13}C reaction] are in good agreement with theory and are additional evidence for the J^{π} assignments of $\frac{1}{2}^{-}$, $\frac{3}{2}^{-}$, $\frac{5}{2}^{-}$, $\frac{1}{2}^{-}$, $\frac{3}{2}^{-}$ and $\frac{3}{2}^{-}$ to these states: see (1981AJ01). See also (1987GUZZ, 1988GUZW, 1989BE1N).

30. (a) ^{14}N(^{3}He, α)^{13}N $Q_{\rm m} = 10.0243$

(b) ^{14}N(^{3}He, pα)^{12}C $Q_{\rm m} = 8.0808$

Alpha-particle groups have been observed to the first seven excited states of ^{13}N, including two at $E_{\rm x} = 7.166$ and 7.388 MeV [$\pm$ 8 keV]. Angular distributions have been studied at many energies up to $E(^{3}\text{He}) = 45$ MeV [see (1981AJ01)] and at $E(^{3}\text{He}) = 22.7$, 36.9 and 40.0 MeV (1987VA1I, 1989BE1N; α_0). Reaction (b), studied at $E(^{3}\text{He}) = 8$ MeV, appears to involve some states of ^{13}N, possibly ^{13}N*(7.93, 8.92, 11.87): see (1981AJ01). See also (1988GOZB; theor.).

31. ^{14}N(^{6}Li, ^{7}Li)^{13}N $Q_{\rm m} = -3.303$

An angular distribution has been measured at $E(^{6}\text{Li}) = 32$ MeV for the transition to $^{13}\text{N}_{\rm g.s.}$ and ^{7}Li*(0, 0.48). ^{13}N*(2.36) was also populated: see (1981AJ01).

32. ^{14}N(^{14}N, ^{15}N)^{13}N $Q_{\rm m} = 0.2799$

See (1988DA12; theor.).

33. ^{15}N(γ, 2n)^{13}N $Q_{\rm m} = -21.3868$

See ^{15}N (1988MC01).

34. ^{15}N(p, t)^{13}N $Q_{\rm m} = -12.9049$

At $E_{\rm p} = 43.7$ MeV, angular distributions have been obtained for the tritons corresponding to the ground state of ^{13}N and the excited states at 3.50 ($\frac{3}{2}^-$), 6.38 ± 0.03 ($\frac{5}{2}^+$), 7.38 ($\frac{5}{2}^-$), 8.93 ± 0.05 ($\frac{1}{2}^-$), 10.78 ± 0.06 ($\frac{1}{2}^-$), 11.88 ± 0.04 ($\frac{3}{2}^-$) and 15.06 ($\frac{3}{2}^-$; $T = \frac{3}{2}$) MeV [J^π values in parentheses, as determined by DWBA analyses using intermediate-coupling wave functions to obtain the two-nucleon structure factors]. Detailed comparisons have been made with the (p, ^{3}He) reaction to the mirror states in ^{13}C: see (1981AJ01) for references and other information.

35. ^{16}O(p, α)^{13}N $Q_{\rm m} = -5.2184$

Angular distributions of the α_0, α_1 and α_2 groups have been measured for $E_{\rm p}$ to 54.1 MeV: see (1970AJ04, 1976AJ04). In addition the distribution of the α-particles to a state with $E_{\rm x} = 12.13 \pm 0.06$ MeV, $\Gamma_{\rm c.m.} \approx 300$ keV [$J^\pi = \frac{7}{2}^-$] is reported at 54.1 MeV: see (1981AJ01). For additional work see (1986AJ01). See also (1989WA16), (1989AR1G, 1990BA1S; applied), (1988CA26, 1989GU28; astrophysics) and (1985MAZG; theor.). For the (p, pt) reaction see (1986GO28; theor.).

36. ^{17}Ne(β^+)^{17}F$\stackrel{\alpha}{\rightarrow}{}^{13}$N $\qquad\qquad$ $Q_{\rm m} = 8.71$

See (1988BO39).

^{13}O

(Fig. 4)

GENERAL (1985AN28, 1986AN07, 1987SA15, 1989AYZU). (See also (1986AJ01)).

Mass of ^{13}O: We adopt the atomic mass excess of 23113 ± 10 keV of (1988WO1C). See also (1981AJ01). ^{13}O is then bound with respect to ^{12}N + p and ^{11}C + 2p by 1.514 and 2.115 MeV, respectively.

1. ^{13}O(β^+)^{13}N $\qquad Q_{\rm m} = 17.767$

The half-life of ^{13}O has been reported to be 8.7 ± 0.4 ms (1965MC09), 8.95 ± 0.20 ms (1970ES03), 8.55 ± 0.05 ms (1990AS01): the weighted mean is 8.58 ± 0.05 ms and we adopt it. ^{13}O decays to a number of states of ^{13}N, some of which subsequently decay to ^{12}C* (0, 4.4): see Table 13.20. See also (1989WI24; astrophys.) and (1989WO1E; theor.).

2. ^{9}Be(^{13}C, ^{9}He)^{13}O $\qquad Q_{\rm m} = -49.440$

At $E(^{13}\text{C}) = 380$ MeV ^{9}He* (0, 3.8) are populated (1988BO20). The atomic mass excess of ^{9}He derived from this work is 41.5 ± 0.6 MeV. In calculating $Q_{\rm m}$, we used the value 40.8 ± 0.1 MeV (1987SE05): see ^{9}He in (1988AJ01).

3. ^{12}C(p, π^-)^{13}O $\qquad Q_{\rm m} = -155.392$

At $E_{\rm p} = 613$ MeV the ground state of ^{13}O and an excited state at $E_{\rm x} = 2.82 \pm 0.24$ MeV are observed in addition to unresolved structures (1978CO15). [See Fig. 4 for analog region in ^{13}B.] The angular distribution of the π^- to $^{13}\text{O}_{\text{g.s.}}$ has been measured at $E_{\rm p} = 200$ MeV (1980HO20), as has $A_{\rm y}$ at $E_{\vec{\rm p}} = 205$ MeV: see (1986AJ01). For a study of inclusive pion production at $E_{\rm p} = 180$ and 201 MeV see (1985BI04). See also (1985CO11, 1986KU1J, 1990KU1H; theor.).

4. ^{13}C(π^+, π^-)^{13}O $\qquad Q_{\rm m} = -19.988$

At $E_{\pi^+} = 164$ MeV excited states are reported at $E_{\rm x} = 2.75 \pm 0.04$ and 4.21 MeV, as is a broad [$\Gamma = 1.2$ MeV] structure corresponding to one or more states at $E_{\rm x} = 6.02 \pm 0.08$ MeV. At $E_{\pi^+} = 292$ MeV these states are not observed. Angular distributions have been studied at $E_{\pi^+} = 164$ and 292 MeV to $^{13}\text{O}_{\text{g.s.}}$ and at 164 MeV to ^{13}O* (4.21) (1984SE15). At $E_{\pi^+} = 292$ MeV ($\theta = 5°$) a structure with a width of 2.0 ± 1.0 MeV is suggested to be due to a state at $E_{\rm x} = 8.4 \pm 0.5$ MeV $Q = -27.4 \pm 0.5$ MeV] (1989MO09). See also (1990MO02).

Table 13.20: Beta decay of ^{13}O [a]

Decay to		E_p (c.m.) (MeV) to		Relative	% of all	log ft [b]
^{13}N* (MeV)	J^π	^{12}C (g.s.)	^{12}C*(4.4)	intensity [a]	β-decays [a]	
g.s.	$\frac{1}{2}^-$				89.2 ± 2.2	4.08 ± 0.02 [c]
3.50	$\frac{3}{2}^-$	observed		100	9.8 ± 2.0	4.55 ± 0.09
7.38	$\frac{5}{2}^-$	5.48 ± 0.05		0.17 ± 0.07	0.18 ± 0.09	5.56 ± 0.22
			0.99	1.7 ± 0.8 [d]		
8.92	$\frac{1}{2}^-$	observed		4.83 ± 0.51		
					0.61 ± 0.14	4.66 ± 0.10
			2.56 ± 0.05	1.44 ± 0.25		
9.48	$\frac{3}{2}^-$	observed		0.98 ± 0.14		
					0.16 ± 0.04	5.09 ± 0.11
			3.12 ± 0.05	0.61 ± 0.15		
10.36	$\frac{5}{2}^-$	not seen		0.05 ± 0.03 [e]		
					0.02 ± 0.01	$5.7^{+0.3}_{-0.2}$
			3.97 ± 0.05	0.12 ± 0.08 [d]		

[a] (1990AS01). See also the earlier work by (1970ES03). I am indebted to Dr. A.M. Poskanzer for his comments.

[b] M.J. Martin, private communication.

[c] Estimated.

[d] Calculated value from the known ratio of the elastic and inelastic widths.

[e] Includes a calculated relative itensity of 3.4 ± 1.4 to ^{12}C*(4.4). I am indebted to Prof. F.C. Barker for this observation.

Table 13.21: Energy levels of ^{13}O

E_x in ^{13}O (MeV)	$J^\pi; T$	$\tau_{1/2}$ (ms) or Γ (MeV)	Decay	Reactions
g.s.	$(\frac{3}{2}^-); \frac{3}{2}$	$\tau_{1/2} = 8.58 \pm 0.05$	β^+	1, 2, 3, 4, 5
2.75 ± 0.04				3, 4
4.21				4
6.02 ± 0.08 [a]		$\Gamma = 1.2$ MeV		4

[a] Corresponds to broad or unresolved states.

5. ^{16}O(^{3}He, ^{6}He)^{13}O $\qquad Q_{\rm m} = -30.511$

See (1981AJ01).

^{13}F, ^{13}Ne, ^{13}Na

(Not illustrated)

These nuclei have not been observed. See (1986AN07; theor.).

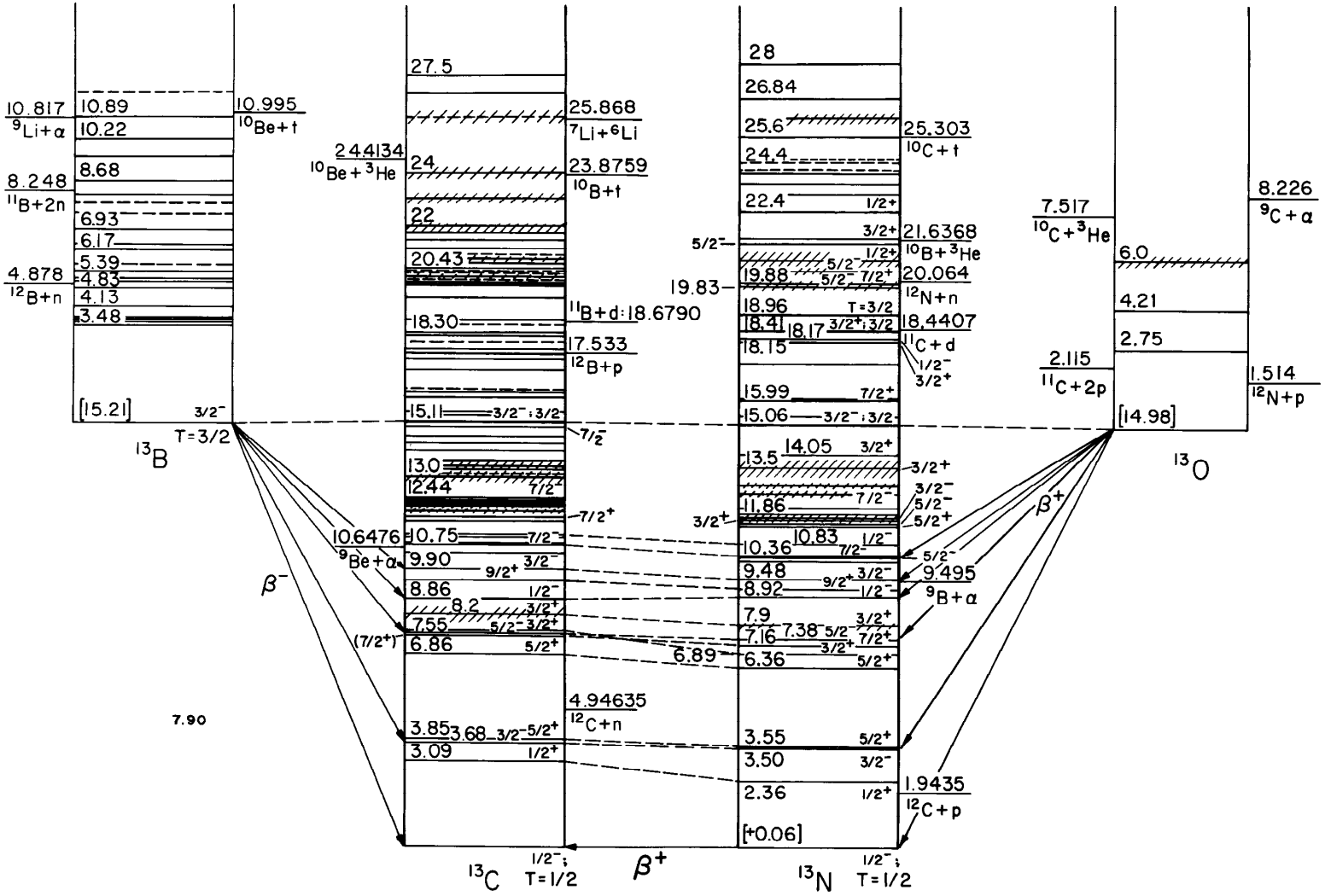


Fig. 4: Isobar diagram, $A = 13$. The diagrams for individual isobars have been shifted vertically to eliminate the neutron-proton mass difference and the Coulomb energy, taken as $E_{\rm C} = 0.60Z(Z-1)/A^{1/3}$. Energies in square brackets represent the (approximate) nuclear energy, $E_{\rm N} = M(Z,A) - ZM({\rm H}) - NM({\rm n}) - E_{\rm C}$, minus the corresponding quantity for ^{13}C: here M represents the atomic mass excess in MeV. Levels which are presumed to be isospin multiplets are connected by dashed lines.

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