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ENERGY LEVELS OF LIGHT NUCLEI $A = 13$–15*

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Abstract: Compilation of energy levels of $A = 13$, 14 and 15 nuclei, with emphasis on material leading to information about the structure of the $A = 13$, 14 and 15 systems.

Introduction

The first two sections [1,2] in the present generation of review papers summarizing the information on the light nuclei covered $A = 5$-12. The reader is referred to ref. [1]) for an exposition of the style, format and conventions used here. We list below some other recent compilations of similar character:

$A = 3$ and 4: Tilley and Weller [3,4]),
$A = 11$-12; 16-17; 18-20: Ajzenberg-Selove [5,6]),
$A = 21$-44: Endt and Van der Leun [7]).

Information about mass chains with $A > 44$ can be found in *Nuclear Data Sheets.*

This is the last of the present series of articles. I am pleased to report that Professors D.R. Tilley and H.R. Weller of TUNL plan to continue to review the light nuclei.

The initiator of this series of reviews on the light nuclei was Tom Lauritsen (1915-1973). It was a great honor to work with him from 1952 until 1973. It was also an enormous pleasure for he was a most wonderful man [8]).

In ending this 38-year series of papers I want to thank members of my family who fostered in me the desire to learn, to work and to be of service, and who gave me so much love: Misha and Olga Ajzenberg, Yvette and Ziutek Louria, Sara and Isaac Naiditch and Lida Vernant.

Over the years this work would not have been possible without the intelligence, the patience and the good humour of five remarkable women: Catherine L. Busch, Glenda C. Marshall, Mary Jane Potter, Jan Rasmussen and Barbara Zimmerman. Nor would the articles have been as useful without the detailed comments and pithy remarks of P.M. Endt, E.G. Fuller, A.H. Wapstra and E.K. Warburton, and, in particular, of F.C. Barker. Fred Barker has contributed greatly to the sense and accuracy of these reviews. I am also indebted to many other colleagues whose names

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In the past 35 years none of this work could have been done without the patience, the love and the support of my husband,

WALTER SELOVE,

to whom I dedicate this paper.

References to Introduction

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TABLE 1

Parameters of the ground states of the light nuclei with $A = 13$–15

Nucleus	Atomic mass [a]) excess (keV)	$\tau_{1/2}$ [b])	Decay [b])	J^π; T [b,c])
^{13}Li	see text		n	$(\frac{3}{2}^-)$; $\frac{7}{2}$
^{13}Be	35000 ± 500 [b])		n	$(\frac{1}{2}, \frac{5}{2})$; $\frac{5}{2}$
^{13}B [d])	16562.5 ± 1.1 [e])	17.36 ± 0.16 ms	β^-	$\frac{3}{2}^-$; $\frac{3}{2}$
^{13}C [f])	3125.032 ± 0.010 [e])		stable	$\frac{1}{2}^-$; $\frac{1}{2}$
^{13}N [g])	5345.52 ± 0.27 [e])	9.965 ± 0.004 min	β^+	$\frac{1}{2}^-$; $\frac{1}{2}$
^{13}O	23113 ± 10 [e])	8.58 ± 0.05 ms	β^+	$(\frac{3}{2}^-)$; $\frac{3}{2}$
^{13}F	see text			$(\frac{1}{2}, \frac{5}{2})$; $\frac{5}{2}$
^{13}Ne	see text			$(\frac{3}{2}^-)$; $\frac{7}{2}$
^{14}Li	see text		n	$\pi = -$; $T = 4$
^{14}Be	39740 ± 140 [e])	4.35 ± 0.17 ms	β^-	0^+; 3
^{14}B	23664 ± 21 [e])	13.8 ± 1.0 ms	β^-	2^-; 2
^{14}C	3019.908 ± 0.016 [e])	5730 ± 40 y	β^-	0^+; 1
^{14}N [h])	2863.433 ± 0.015 [e])		stable	1^+; 0
^{14}O	8006.54 ± 0.08 [e])	70.606 ± 0.018 s	β^+	0^+; 1

TABLE 1—continued

Nucleus	Atomic mass [a]) excess (keV)	$\tau_{1/2}$ [b])	Decay [b])	J^{π}; T [b,c])
^{14}F	see text		p	(2^-); 2
^{14}Ne	see text		(p)	0^+; 3
^{15}Li	see text		n	$(\frac{3}{2}^-)$; $\frac{9}{2}$
^{15}Be	see text		n	$\pi = +$; $\frac{7}{2}$
^{15}B	28970 ± 22 [e])	10.5 ± 0.3 ms	β^-	$(\frac{3}{2}^-)$; $\frac{5}{2}$
^{15}C	9873.2 ± 0.8 [e])	2.449 ± 0.005 s	β^-	$\frac{1}{2}^+$; $\frac{3}{2}$
^{15}N [i])	101.496 ± 0.024 [e])	stable		$\frac{1}{2}^-$; $\frac{1}{2}$
^{15}O [j])	2855.4 ± 0.5 [e])	122.24 ± 0.16 s	β^+	$\frac{1}{2}^-$; $\frac{1}{2}$
^{15}F	16770 ± 130 [b])	$\Gamma = 1.0 \pm 0.2$ MeV	p	$(\frac{1}{2}^+)$; $\frac{3}{2}$

[a]) The values of the mass excesses shown here were used to calculate Q_m.
[b]) From data reviewed in this article.
[c]) J^{π} values in parentheses are derived from systematics.
[d]) $\mu = +3.17778(51)$ n.m., $Q = 0.0478(46)$ b (Le 78n).
[e]) (Wa 88b) and A.H. Wapstra, private communication.
[f]) $\mu = +0.702411(1)$ n.m. (Le 78n).
[g]) $\mu = -0.32224(35)$ n.m. (Le 78n).
[h]) $\mu = +0.4037607(2)$ n.m. (Le 78n), $Q = +0.0193(8)$ b (Wi 80r).
[i]) $\mu = -0.283188842(45)$ n.m.: see (Ra 89g).
[j]) $\mu = 0.7189(8)$ n.m. (Le 78n).

TABLE 2

Electromagnetic transitions in $A = 13$-15 [a])

Nucleus	$E_{xi} \rightarrow E_{xf}$ (MeV)	$J_i^{\pi}(T_i) \rightarrow J_f^{\pi}(T_f)$	Γ_{γ} (eV)	Mult.	S (W.u.)
^{13}C [b])	$3.09 \rightarrow 0$	$\frac{1}{2}^+ \rightarrow \frac{1}{2}^-$	0.43 ± 0.04	E1	$(3.9 \pm 0.4) \times 10^{-2}$
	$3.68 \rightarrow 0$	$\frac{3}{2}^- \rightarrow \frac{1}{2}^-$	0.41 ± 0.04	M1	0.39 ± 0.04
			$(3.6 \pm 0.8) \times 10^{-3}$	E2	3.5 ± 0.8
	$\rightarrow 3.09$	$\rightarrow \frac{1}{2}^+$	$(3.1 \pm 0.5) \times 10^{-3}$	E1	$(3.9 \pm 0.6) \times 10^{-2}$
	$3.85 \rightarrow 0$	$\frac{5}{2}^+ \rightarrow \frac{1}{2}^-$	$(3.33 \pm 0.07) \times 10^{-5}$	M2	0.472 ± 0.010
			$(4.8 \pm 2.0) \times 10^{-7}$	E3	10 ± 4
	$\rightarrow 3.09$	$\rightarrow \frac{1}{2}^+$	$(6.4 \pm 0.3) \times 10^{-6}$	E2	1.6 ± 0.08
	$\rightarrow 3.68$	$\rightarrow \frac{3}{2}^-$	$(1.93 \pm 0.04) \times 10^{-5}$	E1	$(1.06 \pm 0.02) \times 10^{-2}$
	$6.86 \rightarrow 0$	$\frac{5}{2}^+ \rightarrow \frac{1}{2}^-$	$(6.9 \pm 3.6) \times 10^{-5}$	M2	$(5.5 \pm 3.0) \times 10^{-2}$
	$7.55 \rightarrow 0$	$\frac{5}{2}^- \rightarrow \frac{1}{2}^-$	1.0×10^{-5}	M3	34
			0.115 ± 0.007	E2	3.1 ± 0.2
	$8.86 \rightarrow 0$	$\frac{1}{2}^- \rightarrow \frac{1}{2}^-$	3.36 ± 0.47	M1	0.23 ± 0.03
	$9.90 \rightarrow 0$	$\frac{3}{2}^- \rightarrow \frac{1}{2}^-$	$(6.3 \pm 1.1) \times 10^{-3}$	E2	$(4.4 \pm 0.8) \times 10^{-2}$
			0.324 ± 0.038	M1	$(1.6 \pm 0.2) \times 10^{-2}$
	$11.08 \rightarrow 0$	$\frac{1}{2}^- \rightarrow \frac{1}{2}^-$	1.02 ± 0.12	M1	$(3.6 \pm 0.5) \times 10^{-2}$
	$15.11 \rightarrow 0$	$\frac{3}{2}^- (\frac{3}{2})$	22.4 ± 1.5	M1	0.31 ± 0.02
		$\rightarrow \frac{1}{2}^- (\frac{1}{2})$	0.6 ± 0.1	E2	0.50 ± 0.10
	$\rightarrow 3.09$	$\rightarrow \frac{1}{2}^+ (\frac{1}{2})$	4.12 ± 0.74	E1	$(6 \pm 1) \times 10^{-3}$
	$\rightarrow 3.68$	$\rightarrow \frac{3}{2}^- (\frac{1}{2})$	18.2 ± 2.4	M1	0.58 ± 0.08

TABLE 2—continued

Nucleus	$E_{xi} \to E_{xf}$ (MeV)	$J_i^\pi(T_i) \to J_f^\pi(T_f)$	Γ_γ (eV)	Mult.	S (W.u.)
^{13}N [c])	$2.37 \to 0$	$\frac{1}{2}^+ \to \frac{1}{2}^-$	0.50 ± 0.04	E1	0.10 ± 0.01
	$3.50 \to 0$	$\frac{3}{2}^- \to \frac{1}{2}^-$	0.64	M1	0.70
	$\to 2.37$	$\to \frac{1}{2}^+$	0.06	E1	0.1
	$3.55 \to 0$	$\frac{5}{2}^+ \to \frac{1}{2}^-$	$<2 \times 10^{-3}$	M2	<43
	$11.74 \to 0$	$\frac{3}{2}^+ \to \frac{1}{2}^-$	~ 4.2	E1	~ 0.007
	$13.5 \to 0$	$\frac{3}{2}^+ \to \frac{1}{2}^-$	$\geqslant 1100$	E1	$\geqslant 1.2$
	$14.05 \to 0$	$\frac{3}{2}^+ \to \frac{1}{2}^-$	3.7 ± 1.0	E1	$(3.6 \pm 1.0) \times 10^{-3}$
	$15.06 \to 0$	$\frac{3}{2}^- (\frac{3}{2})$	24.2 ± 1.5	M1	0.34 ± 0.02
		$\to \frac{1}{2}^- (\frac{1}{2})$	0.32 ± 0.12	E2	0.28 ± 0.10
	$\to 2.37$	$\to \frac{1}{2}^+ (\frac{1}{2})$	$\leqslant 2.8 \pm 0.3$	E1	$<(3.7 \pm 0.4)$
	$\to 3.50$	$\to \frac{3}{2}^- (\frac{1}{2})$	19.6 ± 1.4	M1	0.60 ± 0.05
	$15.3 \to 0$	$(\frac{3}{2}^+) \to \frac{1}{2}^-$	$\geqslant 0.5$	(E1)	$\geqslant 4 \times 10^{-4}$
^{14}C [d])	$6.09 \to 0$	$1^- \to 0^+$	>0.066	E1	$>7.3 \times 10^{-4}$
	$6.59 \to 6.09$	$0^+ \to 1^-$	$(1.5 \pm 0.2) \times 10^{-4}$	E1	$(3.2 \pm 0.4) \times 10^{-3}$
	$6.73 \to 0$	$3^- \to 0^+$	$(6.6 \pm 0.8) \times 10^{-6}$	E3	2.4 ± 0.3
	$\to 6.09$	$\to 1^-$	$(2.5 \pm 1.0) \times 10^{-7}$	E2	1.5 ± 0.6
	$6.90 \to 6.09$	$0^- \to 1^-$	$(1.8 \pm 0.2) \times 10^{-2}$	M1	1.6 ± 0.2
	$7.01 \to 0$	$2^+ \to 0^+$	$(5.0 \pm 1.0) \times 10^{-2}$	E2	1.8 ± 0.3
	$\to 6.09$	$\to 1^-$	$(7.0 \pm 3.6) \times 10^{-4}$	E1	$(2.3 \pm 1.2) \times 10^{-3}$
	$7.34 \to 0$	$2^- \to 0^+$	$(6.9 \pm 2.9) \times 10^{-4}$	M2	0.38 ± 0.15
	$\to 6.09$	$\to 1^-$	$(2.0 \pm 0.8) \times 10^{-3}$	M1	$(4.9 \pm 2.0) \times 10^{-2}$
	$\to 6.73$	$\to 3^-$	$(1.4 \pm 0.5) \times 10^{-3}$	M1	0.29 ± 0.10
	$11.31 \to 0$	$1^+ \to 0^+$	6.8 ± 1.4	M1	0.22 ± 0.05
^{14}N [e])	$2.31 \to 0$	$0^+ (1) \to 1^+ (0)$	$(6.7 \pm 0.3) \times 10^{-3}$	M1	$(2.6 \pm 0.1) \times 10^{-2}$
	$3.95 \to 0$	$1^+ \to 1^+$	4×10^{-4}	M1	3×10^{-4}
			3×10^{-3}	E2	2
	$\to 2.31$	$\to 0^+ (1)$	0.091 ± 0.030	M1	1.0 ± 0.3
	$4.92 \to 0$	$0^- \to 1^+$	$(8.4 \pm 1.6) \times 10^{-2}$	E1	$(1.8 \pm 0.4) \times 10^{-3}$
	$5.11 \to 0$	$2^- \to 1^+$	$(8.00 \pm 0.18) \times 10^{-5}$	E1	$(1.52 \pm 0.03) \times 10^{-6}$
			$(2.05 \pm 0.51) \times 10^{-6}$	M2	$(6.8 \pm 1.7) \times 10^{-3}$
			$(1.80 \pm 0.51) \times 10^{-6}$	E3	4.4 ± 1.3
	$\to 2.31$	$\to 0^+ (1)$	$(2.04 \pm 0.13) \times 10^{-5}$	M2	1.38 ± 0.09
	$\to 3.95$	$\to 1^+ (1)$	$(7.4 \pm 4.2) \times 10^{-7}$	E1	$(1.2 \pm 0.7) \times 10^{-6}$
	$5.69 \to 0$	$1^- \to 1^+$	$(0.9 \pm 0.5) \times 10^{-2}$	E1	$(1.2 \pm 0.7) \times 10^{-4}$
	$\to 2.31$	$\to 0^+ (1)$	$(1.7 \pm 0.8) \times 10^{-2}$	E1	$(1.1 \pm 0.5) \times 10^{-3}$
	$5.83 \to 0$	$3^- \to 1^+$	$(4.8 \pm 1.4) \times 10^{-6}$	M2	$(8.2 \pm 2.4) \times 10^{-3}$
			$(6.9 \pm 1.5) \times 10^{-6}$	E3	6.7 ± 1.5
	$\to 5.11$	$\to 2^-$	$(4.32 \pm 0.11) \times 10^{-5}$	M1	$(5.33 \pm 0.14) \times 10^{-3}$
			$(7^{+8}_{-5}) \times 10^{-8}$	E2	0.2 ± 0.2
	$6.20 \to 0$	$1^+ \to 1^+$	$(9.0 \pm 1.0) \times 10^{-3}$	M1	$(1.8 \pm 0.2) \times 10^{-3}$
			$(3.2 \pm 0.9) \times 10^{-4}$	E2	$(2.1 \pm 0.6) \times 10^{-2}$
	$\to 2.31$	$\to 0^+ (1)$	$(3.2 \pm 0.4) \times 10^{-3}$	M1	$(2.6 \pm 0.4) \times 10^{-3}$
	$6.45 \to 0$	$3^+ \to 1^+$	$(7.4 \pm 0.7) \times 10^{-4}$	E2	$(4.0 \pm 0.4) \times 10^{-2}$
	$\to 3.95$	$\to 1^+$	$(2.1 \pm 0.3) \times 10^{-4}$	E2	1.3 ± 0.2
	$\to 5.11$	$\to 2^-$	$(7.0 \pm 1.0) \times 10^{-5}$	E1	$(7.4 \pm 1.1) \times 10^{-5}$
	$\to 5.83$	$\to 3^-$	$(4.0 \pm 1.0) \times 10^{-5}$	E1	$(4.4 \pm 1.1) \times 10^{-4}$
	$7.03 \to 0$	$2^+ \to 1^+$	$(9.1 \pm 1.3) \times 10^{-2}$	M1	$(1.2 \pm 0.2) \times 10^{-2}$
			$(5.0 \pm 1.2) \times 10^{-2}$	E2	1.8 ± 0.4
	$\to 2.31$	$\to 0^+ (1)$	$(6.2 \pm 1.4) \times 10^{-4}$	E2	0.16 ± 0.04
	$\to 3.95$	$\to 1^+$	$<(1.1 \pm 0.3) \times 10^{-3}$	M1	$<(1.8 \pm 0.6) \times 10^{-3}$

TABLE 2—continued

Nucleus	$E_{xi} \to E_{xf}$ (MeV)	$J_i^\pi(T_i) \to J_f^\pi(T_f)$	Γ_γ (eV)	Mult.	S (W.u.)
	$8.06 \to 0$	$1^-(1) \to 1^+(0)$	9.9 ± 2.5	E1	$(4.8 \pm 1.2) \times 10^{-2}$
	$\to 2.31$	$\to 0^+(1)$	0.17 ± 0.05	E1	$(2.3 \pm 0.7) \times 10^{-3}$
	$\to 3.95$	$\to 1^+(0)$	1.56 ± 0.40	E1	$(5.7 \pm 1.5) \times 10^{-2}$
	$\to 4.92$	$\to 0^-(0)$	0.23 ± 0.06	M1	0.35 ± 0.09
	$\to 5.11$	$\to 2^-(0)$	$(3.0 \pm 2.0) \times 10^{-2}$	M1	$(5.6 \pm 3.7) \times 10^{-2}$
	$\to 5.69$	$\to 1^-(0)$	0.43 ± 0.12	M1	1.5 ± 0.4
	$8.49 \to 5.11$	$4^- \to 2^-$	$(6.1 \pm 1.5) \times 10^{-3}$	E2	8.3 ± 2.0
	$\to 5.83$	$\to 3^-$	$(1.3 \pm 0.4) \times 10^{-3}$	M1	$(3.3 \pm 1.0) \times 10^{-3}$
	$8.62 \to 0$	$0^+(1) \to 1^+(0)$	1.20	M1	0.089
	$\to 3.95$	$\to 1^+(0)$	1.26	M1	0.59
	$\to 5.69$	$\to 1^-(0)$	0.69	E1	6.9×10^{-2}
	$8.78 \to 0$	$0^-(1) \to 1^+(0)$	46 ± 12	E1	0.17 ± 0.05
	$8.91 \to 0$	$3^-(1) \to 1^+(0)$	$(1.10 \pm 0.17) \times 10^{-3}$	M2	2.3 ± 0.4
	$\to 5.11$	$\to 2^-(0)$	$(1.6 \pm 0.3) \times 10^{-2}$	M1	$(1.4 \pm 0.3) \times 10^{-2}$
	$\to 5.83$	$\to 3^-(0)$	0.32 ± 0.04	M1	0.53 ± 0.07
	$\to 6.45$	$\to 3^+(0)$	$(2.0 \pm 0.3) \times 10^{-2}$	E1	$(3.4 \pm 0.5) \times 10^{-3}$
	$\to 7.03$	$\to 2^+(0)$	$(1.3 \pm 0.2) \times 10^{-2}$	E1	$(5.0 \pm 0.8) \times 10^{-3}$
	$8.96 \to 6.44$	$5^+ \to 3^+$	$(1.2 \pm 0.2) \times 10^{-3}$	E2	7.2 ± 1.2
	$9.13 \to 0$	$3^+ \to 1^+$	$(8.5 \pm 1.0) \times 10^{-3}$	E2	$(8.1 \pm 1.0) \times 10^{-3}$
	$\to 5.83$	$\to 3^-$	$(9 \pm 3) \times 10^{-4}$	E1	$(6.4 \pm 2.1) \times 10^{-5}$
	$\to 6.45$	$\to 3^+$	$(9 \pm 3) \times 10^{-4}$	M1	$(2.2 \pm 0.7) \times 10^{-3}$
	$9.17 \to 0$	$2^+(1) \to 1^+(0)$	5.4 ± 0.3	M1	0.33 ± 0.02
	$\to 2.31$	$\to 0^+(1)$	$(5.4 \pm 0.6) \times 10^{-2}$	E2	2.2 ± 0.2
	$\to 5.69$	$\to 1^-(0)$	$(3.2 \pm 0.7) \times 10^{-2}$	E1	$(1.9 \pm 0.4) \times 10^{-3}$
	$\to 5.83$	$\to 3^-(0)$	$(3.9 \pm 0.6) \times 10^{-2}$	E1	$(2.7 \pm 0.4) \times 10^{-3}$
	$\to 6.45$	$\to 3^+(0)$	0.56 ± 0.06	M1	1.3 ± 0.2
			$(5.4 \pm 1.7) \times 10^{-4}$	E2	2.2 ± 0.7
	$\to 7.03$	$\to 2^+(0)$	0.20 ± 0.03	M1	0.97 ± 0.15
			$(2.8 \pm 1.7) \times 10^{-4}$	E2	3.8 ± 2.3
	$9.51 \to 0$	$2^-(1) \to 1^+(0)$	$(2.6 \pm 0.6) \times 10^{-2}$	E1	$(7.7 \pm 1.8) \times 10^{-5}$
	$\to 3.95$	$\to 1^+(0)$	0.26 ± 0.04	E1	$(3.8 \pm 0.6) \times 10^{-3}$
	$\to 5.11$	$\to 2^-(0)$	3.02 ± 0.36	M1	1.7 ± 0.2
	$\to 5.83$	$\to 3^-(0)$	0.67 ± 0.10	M1	0.64 ± 0.10
	$9.70 \to 0$	$1^+(0) \to 1^+(0)$	$(1.8 \pm 0.4) \times 10^{-2}$	M1	$(9.4 \pm 2.1) \times 10^{-4}$
	$\to 2.31$	$\to 0^+(1)$	$(4.3 \pm 0.5) \times 10^{-2}$	M1	$(5.1 \pm 0.6) \times 10^{-3}$
	$10.10 \to 0$	$2^+, 1^+(0)$	0.21 ± 0.02	M1	$(9.7 \pm 0.9) \times 10^{-3}$
		$\to 1^+(0)$			
	$10.43 \to 0$	$2^+(1) \to 1^+(0)$	10.8 ± 0.6	M1	0.45 ± 0.03
	$\to 5.11$	$\to 2^-(0)$	0.31 ± 0.03	E1	$(5.2 \pm 0.5) \times 10^{-3}$
	$\to 5.69$	$\to 1^-(0)$	0.21 ± 0.05	E1	$(5.0 \pm 1.2) \times 10^{-3}$
	$\to 6.45$	$\to 3^+(0)$	0.85 ± 0.06	M1	0.64 ± 0.05
	$\to 7.03$	$\to 2^+(0)$	0.85 ± 0.06	M1	1.0 ± 0.1
	$10.81 \to 6.45$	$5^+ \to 3^+$	$(1.6 \pm 0.7) \times 10^{-2}$	E2	6.1 ± 2.7
	$11.05 \to 0$	$3^+ \to 1^+$	0.12 ± 0.02	E2	0.44 ± 0.07
	$\to 3.95$	$\to 1^+$	$(9.0 \pm 2.0) \times 10^{-2}$	E2	3.0 ± 0.7
^{15}C [f])	$0.74 \to 0$	$\frac{5}{2}^+ \to \frac{1}{2}^+$	$(1.75 \pm 0.05) \times 10^{-7}$	E2	0.44 ± 0.01
^{15}N [g])	$5.27 \to 0$	$\frac{5}{2}^+ \to \frac{1}{2}^-$	$(2.5 \pm 0.2) \times 10^{-4}$	M2	0.68 ± 0.07
			$(4 \pm 1) \times 10^{-6}$	E3	7 ± 2
	$5.30 \to 0$	$\frac{1}{2}^+ \to \frac{1}{2}^-$	$(2.6 \pm 0.7) \times 10^{-2}$	E1	$(4.3 \pm 1.1) \times 10^{-4}$
	$6.32 \to 0$	$\frac{3}{2}^- \to \frac{1}{2}^-$	3.07 ± 0.08 [i])	M1	0.578 ± 0.015
			$(5.34 \pm 0.44) \times 10^{-2}$	E2	2.91 ± 0.24

TABLE 2—continued

Nucleus	$E_{xi} \to E_{xf}$ (MeV)	$J_i^\pi(T_i) \to J_f^\pi(T_f)$	Γ_γ (eV)	Mult.	S (W.u.)
	$7.16 \to 0$	$\frac{5}{2}^+ \to \frac{1}{2}^-$	$(8.6 \pm 1.0) \times 10^{-6}$	E3	1.7 ± 0.2
	$\to 5.27$	$\to \frac{5}{2}^+$	$(3.7 \pm 1.6) \times 10^{-2}$	M1	0.26 ± 0.11
	$7.30 \to 0$	$\frac{3}{2}^+ \to \frac{1}{2}^-$	1.08 ± 0.08	E1	$(6.7 \pm 0.05) \times 10^{-2}$
			$(3.1 \pm 1.7) \times 10^{-4}$	M2	0.16 ± 0.09
	$\to 5.27$	$\to \frac{5}{2}^+$	$(1.6 \pm 0.7) \times 10^{-2}$	M1	$(9 \pm 4) \times 10^{-2}$
	$\to 5.30$	$\to \frac{1}{2}^+$	$(5 \pm 3) \times 10^{-3}$	M1	$(3 \pm 2) \times 10^{-2}$
	$7.57 \to 0$	$\frac{7}{2}^+ \to \frac{1}{2}^-$	$(1.84 \pm 0.16) \times 10^{-5}$	E3	2.50 ± 0.22
	$8.31 \to 0$	$\frac{1}{2}^+ \to \frac{1}{2}^-$	0.3 ± 0.2	E1	$(1.3 \pm 0.8) \times 10^{-3}$
	$8.57 \to 0$	$\frac{3}{2}^+ \to \frac{1}{2}^-$	$(2.0 \pm 1.3) \times 10^{-2}$	E1	$(7.7 \pm 5.0) \times 10^{-5}$
			$(1.4 \pm 1.0) \times 10^{-4}$	M2	$(3.3 \pm 2.4) \times 10^{-2}$
	$\to 5.27$	$\to \frac{5}{2}^+$	$(3.9 \pm 2.5) \times 10^{-2}$	M1	$(5.2 \pm 3.3) \times 10^{-2}$
			$(3.2 \pm 2.3) \times 10^{-4}$	E2	0.45 ± 0.32
	$\to 6.32$	$\to \frac{3}{2}^-$	$(1.8 \pm 1.4) \times 10^{-3}$	E1	$(3.8 \pm 3.0) \times 10^{-4}$
	$9.05 \to 0$	$\frac{1}{2}^+ \to \frac{1}{2}^-$	1.2 ± 0.2	E1	$(3.9 \pm 0.7) \times 10^{-3}$
	$\to 5.27$	$\to \frac{5}{2}^+$	$(4.6 \pm 1.5) \times 10^{-2}$	E2	33 ± 11
	$\to 6.32$	$\to \frac{3}{2}^-$	$(5.8 \pm 2.1) \times 10^{-2}$	E1	$(6.9 \pm 2.5) \times 10^{-3}$
	$\to 7.30$	$\to \frac{3}{2}^+$	$(1.6 \pm 0.6) \times 10^{-2}$	M1	0.14 ± 0.05
	$9.152 \to 0$	$\frac{3}{2}^- \to \frac{1}{2}^-$	0.47 ± 0.12	M1	$(2.9 \pm 0.8) \times 10^{-2}$
	$9.155 \to 5.27$	$\frac{5}{2}^+ \to \frac{5}{2}^+$	$(9.1 \pm 5.9) \times 10^{-3}$ [j])	M1	$(7.4 \pm 4.8) \times 10^{-3}$
	$\to 5.30$	$\to \frac{1}{2}^+$	$(8.2 \pm 5.3) \times 10^{-3}$	E2	5.3 ± 3.4
	$\to 6.32$	$\to \frac{3}{2}^-$	$(1.8 \pm 1.2) \times 10^{-2}$	E1	$(1.9 \pm 1.3) \times 10^{-3}$
	$\to 7.16$	$\to \frac{5}{2}^+$	$(4.7 \pm 2.9) \times 10^{-2}$	M1	0.28 ± 0.17
	$9.23 \to 0$	$\frac{1}{2}^- \to \frac{1}{2}^-$	$> 1 \times 10^{-3}$	M1	$> 6 \times 10^{-5}$
	$\to 5.30$	$\to \frac{1}{2}^+$	$> 2 \times 10^{-3}$	E1	$> 8 \times 10^{-5}$
	$\to 6.32$	$\to \frac{3}{2}^-$	$> 2 \times 10^{-3}$	M1	$> 4 \times 10^{-3}$
	$9.76 \to 0$	$\frac{5}{2}^- \to \frac{1}{2}^-$	0.20 ± 0.05	E2	1.3 ± 0.3
	$9.83 \to 5.27$	$\frac{7}{2}^- \to \frac{5}{2}^+$	0.03	E1	8×10^{-4}
	$\to 6.32$	$\to \frac{3}{2}^-$	$(8.6 \pm 5.0) \times 10^{-4}$	E2	0.9 ± 0.5
	$\to 7.16$	$\to \frac{5}{2}^+$	$(9.3 \pm 5.6) \times 10^{-4}$	E1	$(1.2 \pm 0.7) \times 10^{-4}$
	$\to 7.30$	$\to \frac{3}{2}^+$	$(1.4 \pm 0.7) \times 10^{-3}$	M2	149 ± 74 [k])
	$\to 7.57$	$\to \frac{7}{2}^+$	$(2.8 \pm 1.3) \times 10^{-3}$	E1	$(5.9 \pm 2.7) \times 10^{-4}$
	$9.93 \to 0$	$\frac{3}{2}^- \to \frac{1}{2}^-$	1.6 ± 0.2	M1	$(7.8 \pm 1.0) \times 10^{-2}$
	$10.07 \to 0$	$\frac{3}{2}^+ \to \frac{1}{2}^-$	6.3 ± 0.4	E1	$(1.5 \pm 0.9) \times 10^{-2}$
	$10.45 \to 5.27$	$\frac{5}{2}^- \to \frac{5}{2}^+$	$> 1.2 \times 10^{-2}$	E1	$> 2 \times 10^{-4}$
	$\to 6.32$	$\to \frac{3}{2}^-$	$> 6.6 \times 10^{-3}$	M1	$> 4.5 \times 10^{-3}$
			$> 2.3 \times 10^{-3}$	E2	> 1
	$\to 7.16$	$\to \frac{5}{2}^+$	$> 1.1 \times 10^{-3}$	E1	$> 7.4 \times 10^{-5}$
			$> 1.9 \times 10^{-5}$	M2	> 0.54
	$\to 8.57$	$\to \frac{3}{2}^+$	$> 8.0 \times 10^{-4}$	E1	$> 2.9 \times 10^{-4}$
	$\to 9.152$	$\to \frac{3}{2}^-$	$> 9.9 \times 10^{-4}$	M1	$> 2.1 \times 10^{-2}$
			$> 1.0 \times 10^{-4}$	E2	> 15
	$10.53 \to 5.27$	$\frac{5}{2}^+ \to \frac{5}{2}^+$	$(1.3 \pm 0.1) \times 10^{-2}$	M1	$(4.3 \pm 0.3) \times 10^{-3}$
			$(9.5 \pm 2.0) \times 10^{-4}$	E2	0.13 ± 0.03
	$\to 6.32$	$\to \frac{3}{2}^-$	$(2.6 \pm 0.3) \times 10^{-3}$	E1	$(8.5 \pm 1.0) \times 10^{-5}$
			$(2.0 \pm 0.7) \times 10^{-6}$	M2	$(1.7 \pm 0.6) \times 10^{-2}$
	$\to 7.16$	$\to \frac{5}{2}^+$	$(6.6 \pm 0.7) \times 10^{-3}$	M1	$(8.2 \pm 0.9) \times 10^{-3}$
	$\to 7.30$	$\to \frac{3}{2}^+$	$(1.1 \pm 0.1) \times 10^{-2}$	M1	$(1.6 \pm 0.2) \times 10^{-2}$
			$(4.8 \pm 1.0) \times 10^{-5}$	E2	$(7.5 \pm 1.6) \times 10^{-2}$
	$\to 8.57$	$\to \frac{3}{2}^+$	$(8.2 \pm 0.9) \times 10^{-4}$	M1	$(5.2 \pm 0.6) \times 10^{-3}$
			$(1.2 \pm 0.8) \times 10^{-7}$	E2	$(2.3 \pm 0.2) \times 10^{-3}$

TABLE 2—continued

Nucleus	$E_{xi} \rightarrow E_{xf}$ (MeV)	$J_i^\pi(T_i) \rightarrow J_f^\pi(T_f)$	Γ_γ (eV)	Mult.	S (W.u.)
	$\rightarrow 9.152$	$\rightarrow \frac{3}{2}^-$	$(1.0 \pm 0.4) \times 10^{-4}$	E1	$(9.2 \pm 0.4) \times 10^{-5}$
			$(4.0 \pm 2.0) \times 10^{-6}$	M2	8.8 ± 4.4
	$10.69 \rightarrow 5.27$	$\frac{9}{2}^+ \rightarrow \frac{5}{2}^+$	$> 2.5 \times 10^{-2}$	E2	> 3
	$\rightarrow 7.16$	$\rightarrow \frac{5}{2}^+$	$> 8.4 \times 10^{-4}$	E2	> 0.85
	$\rightarrow 7.57$	$\rightarrow \frac{7}{2}^+$	1.5×10^{-2}	M1	> 0.02
			$> 2 \times 10^{-4}$	E2	> 0.4
	$10.70 \rightarrow 0$	$\frac{3}{2}^- \rightarrow \frac{1}{2}^-$	0.19 ± 0.04	M1	$(7.4 \pm 1.6) \times 10^{-3}$
			$(6.2 \pm 1.5) \times 10^{-3}$	E2	$(2.4 \pm 0.6) \times 10^{-2}$
	$\rightarrow 5.27$	$\rightarrow \frac{5}{2}^+$	0.14 ± 0.03	E1	$(2.1 \pm 0.5) \times 10^{-3}$
			$(8.1 \pm 2.4) \times 10^{-5}$	M2	0.19 ± 0.06
	$\rightarrow 5.30$	$\rightarrow \frac{1}{2}^+$	$(3.0 \pm 0.7) \times 10^{-3}$	E1	$(4.6 \pm 1.0) \times 10^{-5}$
			$(5 \pm 3) \times 10^{-5}$	M2	0.12 ± 0.07
	$\rightarrow 6.32$	$\rightarrow \frac{3}{2}^-$	$(1.4 \pm 0.3) \times 10^{-2}$	M1	$(7.9 \pm 1.6) \times 10^{-3}$
			$(2.6 \pm 0.9) \times 10^{-4}$	E2	$(8.9 \pm 3.1) \times 10^{-2}$
	$\rightarrow 7.16$	$\rightarrow \frac{5}{2}^+$	$(1.5 \pm 0.5) \times 10^{-3}$	E1	$(8.2 \pm 2.7) \times 10^{-5}$
	$\rightarrow 7.30$	$\rightarrow \frac{3}{2}^+$	$(8.5 \pm 1.7) \times 10^{-3}$	E1	$(5.3 \pm 1.1) \times 10^{-4}$
	$\rightarrow 8.31$	$\rightarrow \frac{1}{2}^+$	$(3.0 \pm 0.6) \times 10^{-3}$	E1	$(5.4 \pm 1.1) \times 10^{-4}$
	$\rightarrow 9.05$	$\rightarrow \frac{1}{2}^+$	$(7.4 \pm 3.8) \times 10^{-4}$	E1	$(4.0 \pm 2.1) \times 10^{-4}$
	$\rightarrow 9.152$	$\rightarrow \frac{3}{2}^-$	$(7.4 \pm 3.8) \times 10^{-4}$	M1	$(9.5 \pm 4.9) \times 10^{-3}$
			$(9.0 \pm 6.0) \times 10^{-6}$	E2	0.56 ± 0.37
	$\rightarrow 9.23$	$\rightarrow \frac{1}{2}^-$	$(5.6 \pm 1.4) \times 10^{-3}$	M1	$(8.3 \pm 2.1) \times 10^{-2}$
			$(1.3 \pm 0.4) \times 10^{-5}$	E2	1.0 ± 0.3
	$10.80 \rightarrow 0$	$\frac{3}{2}^+ \rightarrow \frac{1}{2}^-$	$(1.8 \pm 0.8) \times 10^{-2}$	M2	1.3 ± 0.6
	$11.62 \rightarrow 0$	$\frac{1}{2}^+ (\frac{3}{2})$	19.2 ± 0.4	E1	$(2.96 \pm 0.06) \times 10^{-2}$
		$\rightarrow \frac{1}{2}^- (\frac{1}{2})$			
	$\rightarrow 5.30$	$\rightarrow \frac{1}{2}^+ (\frac{1}{2})$	1.6 ± 0.4	M1	0.30 ± 0.08
	$\rightarrow 6.32$	$\rightarrow \frac{3}{2}^- (\frac{1}{2})$	0.4 ± 0.3	E1	$(6.6 \pm 5.0) \times 10^{-3}$
	$12.52 \rightarrow 0$	$\frac{5}{2}^+ (\frac{3}{2})$	$(5.2 \pm 2.0) \times 10^{-2}$	M2	1.9 ± 0.7
		$\rightarrow \frac{1}{2}^- (\frac{1}{2})$			
	$\rightarrow 5.27$	$\rightarrow \frac{5}{2}^+ (\frac{1}{2})$	4.3 ± 0.6	M1	0.54 ± 0.08
	$\rightarrow 6.32$	$\rightarrow \frac{3}{2}^- (\frac{1}{2})$	0.27 ± 0.05	E1	$(2.8 \pm 0.6) \times 10^{-3}$
	$13.39 \rightarrow 0$	$\frac{3}{2}^+ \rightarrow \frac{1}{2}^-$	3.0 ± 0.9	E1	$(3.0 \pm 0.9) \times 10^{-3}$
^{15}O [h])	$5.18 \rightarrow 0$	$\frac{1}{2}^+ \rightarrow \frac{1}{2}^-$	0.08 ± 0.01	E1	$(1.4 \pm 0.2) \times 10^{-3}$
	$5.24 \rightarrow 0$	$\frac{5}{2}^+ \rightarrow \frac{1}{2}^-$	$(2.0 \pm 0.2) \times 10^{-4}$	M2	0.55 ± 0.06
			$(2 \pm 1) \times 10^{-6}$	E3	4 ± 2
	$6.18 \rightarrow 0$	$\frac{3}{2}^- \rightarrow \frac{1}{2}^-$	> 0.26 [i])	M1	$> 5.3 \times 10^{-2}$
			$> 4.5 \times 10^{-3}$	E2	> 0.28
	$6.79 \rightarrow 0$	$\frac{3}{2}^+ \rightarrow \frac{1}{2}^-$	$> 2.4 \times 10^{-2}$	E1	$> 1.9 \times 10^{-4}$
	$6.86 \rightarrow 5.24$	$\frac{5}{2}^+ \rightarrow \frac{5}{2}^+$	$(4.1 \pm 0.6) \times 10^{-2}$	M1	0.46 ± 0.07
	$7.28 \rightarrow 0$	$\frac{7}{2}^+ \rightarrow \frac{1}{2}^-$	$(3.6 \pm 1.4) \times 10^{-5}$	E3	6.4 ± 2.5
	$\rightarrow 5.24$	$\rightarrow \frac{5}{2}^+$	$(9.1 \pm 1.8) \times 10^{-4}$	M1	$(5.1 \pm 1.0) \times 10^{-3}$
	$7.56 \rightarrow 0$	$\frac{1}{2}^+ \rightarrow \frac{1}{2}^-$	1.5×10^{-3}	E1	8.5×10^{-6}
	$\rightarrow 5.18$	$\rightarrow \frac{1}{2}^+$	6.7×10^{-3}	M1	2.4×10^{-3}
	$\rightarrow 6.18$	$\rightarrow \frac{3}{2}^-$	2.4×10^{-2}	E1	2.2×10^{-2}
	$\rightarrow 6.79$	$\rightarrow \frac{3}{2}^+$	1.0×10^{-2}	M1	1.0
	$8.28 \rightarrow 0$	$\frac{3}{2}^+ \rightarrow \frac{1}{2}^-$	0.53	E1	2.3×10^{-3}
	$\rightarrow 5.24$	$\rightarrow \frac{5}{2}^+$	0.41	M1	0.69
	$\rightarrow 6.18$	$\rightarrow \frac{3}{2}^-$	0.02	E1	5×10^{-3}
	$\rightarrow 6.86$	$\rightarrow \frac{5}{2}^+$	0.01	M1	0.2
	$8.74 \rightarrow 5.18$	$\frac{1}{2}^+ \rightarrow \frac{1}{2}^+$	0.32	M1	0.34
	$\rightarrow 6.18$	$\rightarrow \frac{3}{2}^-$	0.16	E1	2.3×10^{-2}

TABLE 2—continued

Nucleus	$E_{xi} \to E_{xf}$ (MeV)	$J_i^\pi(T_i) \to J_f^\pi(T_f)$	Γ_γ (eV)	Mult.	S (W.u.)
	9.49 → 0	$\frac{5}{2}^- \to \frac{1}{2}^-$	2.1	E2	15
	→ 5.24	$\to \frac{5}{2}^+$	0.15	E1	4.8×10^{-3}
	→ 6.18	$\to \frac{3}{2}^-$	0.22	M1	0.29
	→ 6.86	$\to \frac{5}{2}^+$	0.08	E1	1.1×10^{-2}
	→ 7.28	$\to \frac{7}{2}^+$	0.11	E1	2.5×10^{-2}
	9.61 → 0	$\frac{3}{2}^- \to \frac{1}{2}^-$	4.0	M1	0.21
	→ 5.24	$\to \frac{5}{2}^+$	1.0	E1	2.9×10^{-2}
	→ 6.18	$\to \frac{3}{2}^-$	0.1	M1	0.1
	10.94 → 0	$\frac{1}{2}^+ \to \frac{1}{2}^-$	14 ± 4	E1	$(2.6 \pm 0.8) \times 10^{-2}$
	→ 5.18	$\to \frac{1}{2}^+$	11 ± 2	M1	2.7 ± 0.5
	→ 6.18	$\to \frac{3}{2}^-$	7 ± 2	E1	0.16 ± 0.05
	11.03 → 0	$\frac{1}{2}^- \to \frac{1}{2}^-$	1.4 ± 0.4	M1	$(5 \pm 2) \times 10^{-2}$
	11.22 → 0	$\frac{3}{2}^+ \to \frac{1}{2}^-$	5.5 ± 0.5	E1	$(9.5 \pm 1.0) \times 10^{-3}$
	→ 5.18	$\to \frac{1}{2}^+$	1.0 ± 0.2	M1	0.22 ± 0.05
	→ 5.24	$\to \frac{5}{2}^+$	0.9 ± 0.2	M1	0.20 ± 0.04
	11.57 → 0	$\frac{5}{2}^- \to \frac{1}{2}^-$	0.3 ± 0.2	E2	0.8 ± 0.5
	→ 5.24	$\to \frac{5}{2}^+$	1.2 ± 0.1	E1	$(1.2 \pm 0.1) \times 10^{-2}$
	→ 6.18	$\to \frac{3}{2}^-$	0.4 ± 0.2	M1	0.12 ± 0.06
	11.75 → 5.24	$\frac{5}{2}^+ \to \frac{5}{2}^+$	5 ± 1	M1	0.9 ± 0.2
	→ 6.18	$\to \frac{3}{2}^-$	5 ± 1	E1	$(7.1 \pm 1.4) \times 10^{-2}$
	11.85 → 5.24	$\frac{5}{2}^- \to \frac{5}{2}^+$	1.4 ± 0.6	E1	$(1.1 \pm 0.5) \times 10^{-2}$

[a]) See also (En 79a). The last column gives the γ-ray strengths expressed in Weisskopf units (see D.H. Wilkinson, in *Nuclear spectroscopy B*, ed. F. Ajzenberg-Selove (Academic Press, New York, 1960)). The Weisskopf estimates (Γ_W in eV, E_γ in MeV) are

$$\Gamma_W(E1) = 6.8 \times 10^{-2} A^{2/3} E_\gamma^3,$$

$$\Gamma_W(E2) = 4.9 \times 10^{-8} A^{4/3} E_\gamma^5,$$

$$\Gamma_W(E3) = 2.3 \times 10^{-14} A^2 E_\gamma^7,$$

$$\Gamma_W(M1) = 2.1 \times 10^{-2} E_\gamma^3,$$

$$\Gamma_W(M2) = 1.5 \times 10^{-8} A^{2/3} E_\gamma^5,$$

$$\Gamma_W(M3) = 6.8 \times 10^{-15} A^{4/3} E_\gamma^7.$$

The values for these γ-ray strengths are occasionally different from those listed in other tables of this paper because different values of r were used. In this table $r_0 = 1.2$ fm is used consistently. We acknowledge with deep appreciation the very helpful criticisms of P.M. Endt. For mixing ratios see table 2 in (Aj 81) except when changed values are footnoted.

[b]) See tables 13.4, 13.5, 13.6 and 13.12.

[c]) See tables 13.5, 13.6, 13.14 and 13.17.

[d]) See tables 14.3 and 14.5, and table 14.4 in (Aj 86).

[e]) See tables 14.10, 14.11, 14.16, 14.19, and table 14.14 in (Aj 86).

[f]) See table 15.1.

[g]) See tables 15.4, 15.5, 15.11 and 15.15, and table 15.6 in (Aj 86).

[h]) See tables 15.16, 15.17 and 15.20.

[i]) $\delta = 0.132 \pm 0.004$.

[j]) Using $\tau_m = 8 \pm 5$ fs.

[k]) Too large for M2, see (En 79a) (W.B. Ewbank, private communication).

[l]) $\delta = 0.125 \pm 0.007$.

^{13}Li

(Not illustrated)

^{13}Li has not been observed: see (Aj 86). The calculated value of its mass excess is 60.34 MeV [see (Aj 81)]: ^{13}Li would then be unstable with respect to ^{11}Li + 2n by 3.34 MeV. (Po 85f) calculate [in a $(0+1)\ \hbar\omega$ model space] that the first four states of ^{13}Li at 0, 1.42, 2.09, 2.77 MeV have, respectively, $J^\pi = \frac{3}{2}^-, \frac{7}{2}^-, \frac{1}{2}^-, \frac{5}{2}^-$. See also (Pe 87d, Og 89a) and (Po 88d, Zv 88; 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 (Al 83i, Al 85m). 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 (Og 89a). See also (De 89v). ^{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 (Gi 86c). 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 $\frac{1}{2}^+$ (Po 85f). See also (Ga 85q, Do 86, Ga 86a; hypernuclei), (Pe 87d), (An 86u) and (Sa 87g, Po 89g; theor.).

^{13}B

(Figs. 1 and 4)

GENERAL[†]

Model calculations: (Wo 88, Po 89g, Wo 89c)

Complex reactions involving ^{13}B: (Bo 85t, Av 86, Bi 86f, Ut 86, An 87, Ba 87w, Sa 87m, Vi 87a, Ca 88, Ru 88, Sa 88h, Ki 89f, Sa 89g, Yo 89, Ha 90f)

Muon and neutrino capture and reactions: (Ko 85v)

Pion capture and reactions[‡]: (Sa 85s, Ha 88i, Je 89a)

Hypernuclei: (Fe 86b, Me 86c, Wu 86b, Ma 88f, Ba 89cc)

† See also (Aj 86).

‡ See also reactions 5 and 6.

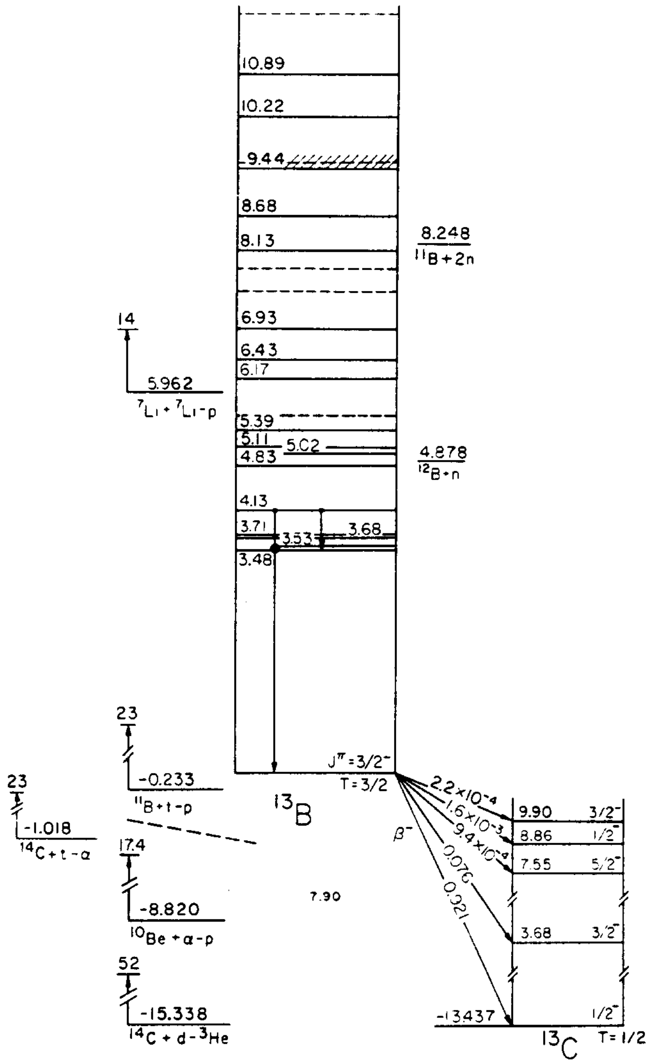


Fig. 1. Energy levels of ^{13}B. For notation see fig. 2.

Antinucleon interactions: (Ma 88z)

Other topics: (An 85e, An 86u)

Ground-state properties of ^{13}B: (An 85e, Va 88, Wo 88, Sa 89g, Wo 89c, Lo 90c)

$Q = 47.8 \pm 4.6$ mb (Le 78n). See also (Ra 89g).

$\mu = +3.17778(51)$ n.m. (Le 78n).

Interaction cross sections at 790 MeV/A for ^{13}B ions with Be, C and Al are reported by (Ta 88d). The interaction radius and the r.m.s. radius for the nucleon distribution in ^{13}B have also been derived (Ta 88d).

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

The half-life of ^{13}B is 17.36 ± 0.16 ms: see (Aj 81). See also (Sa 88a). 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 (Po 89g, Sa 89j, Wo 89c; theor.).

2. $^{7}Li(^{7}Li, p)^{13}B$ $Q_m = 5.962$

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

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

Observed proton groups are displayed in table 13.3.

4. $^{12}C(^{13}C, ^{12}N)^{13}B$ $Q_m = -30.776$

See (Vo 86, Vo 88a) and ^{12}N in (Aj 89).

TABLE 13.1

Energy levels of ^{13}B

E_x (MeV ± keV)	$J^\pi; T$	τ or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
g.s.	$\frac{3}{2}^-; \frac{3}{2}$	$\tau_{1/2} = 17.36 \pm 0.16$ ms	β^-	1→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 (Aj 81).
b) M.J. Martin, Private communication. I am very grateful to Dr. Martin for sending me his calculations.

5. $^{13}C(\gamma, \pi^+)^{13}B$ $Q_m = -153.006$

At $E_e = 195$ MeV the ^{13}B E_x region to 12 MeV has been studied by (Mi 83d): 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 $^{13}B_{g.s.}$ 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 (Mi 83d). [For $T = \frac{3}{2}$ states see table 13.6.] For other work on this reaction see (Aj 80). See also reaction 40 in ^{13}C, "General", p. 9 and (Si 86c; theor.).

6. $^{13}C(\pi^-, \gamma)^{13}B$ $Q_m = 126.131$

Gamma rays have been observed which are associated with the ^{13}B ground state; an unresolved doublet at $E_x \sim 3.5$–3.7 MeV; sharp states at $E_x \sim 6.5$ and 7.6 MeV; a broad level (or unresolved levels) at ~ 10.2 MeV (Ma 83e; see for radiative capture branching ratios). The analogs of the peaks at $E_x = 6.5$, 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 (Ma 83e). See also "General", p. 9.

7. $^{13}C(n, p)^{13}B$ $Q_m = -12.655$

The 0° ground-state differential cross section has been measured at $E_n = 198$ MeV (Ja 88). At $E_n = 65$ MeV, $^{13}B^*(0, 3.5)$ and the region from 6–10 MeV have been studied (Wa 86i; prelim.). See also (Fo 86e, Br 87q, So 89, So 89a) and (Al 86u).

8.† $^{13}C(d, 2p)^{13}B$ $Q_m = -14.880$

At $E_d = 70$ MeV the angular distribution to $^{13}B_{g.s.}$ has been reported. Structures at $E_x = 3.8, 5.2, 6.6$ MeV are also observed. For VAP measurements see ^{15}N (Mo 86m).

† Reactions on which no new work is reported are not necessarily discussed in this article: see (Aj 86).

9. $^{13}C(^{7}Li, ^{7}Be)^{13}B$ $Q_m = -14.299$

At $E(^{7}Li) = 21$ MeV/A, forward angular distributions are reported to $^{13}B_{g.s.}$ and to unresolved structures at 3.5, 4.0, 5.1, 6.3, 7.0 and 7.6 MeV, and to a broad ($\Gamma \sim 2.3$ MeV) structure at 9.5 MeV. The latter is suggested to be due to the GDR (Na 90) [see for possible J^π assignments].

10. $^{14}C(\gamma, p)^{13}B$ $Q_m = -20.832$

See (Go 87c; theor.).

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)	$\Gamma_{c.m.}$ (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 (Aj 81).
[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 ± 10)%, (25 ± 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, (Aj 78a), p. 1289.
[h]) Not observed.
[i]) $L \geq 4$.

11. $^{14}C(t, \alpha)^{13}B$ $Q_m = -1.017$

See (Aj 86).

^{13}C

(Figs. 2 and 4)

GENERAL[†]

Nuclear models: (Kw 85, Ki 87e, Mi 88j, Wo 88, Am 89a, Po 89g, Wo 89c, Fe 90a, Ho 90c, Va 90a)

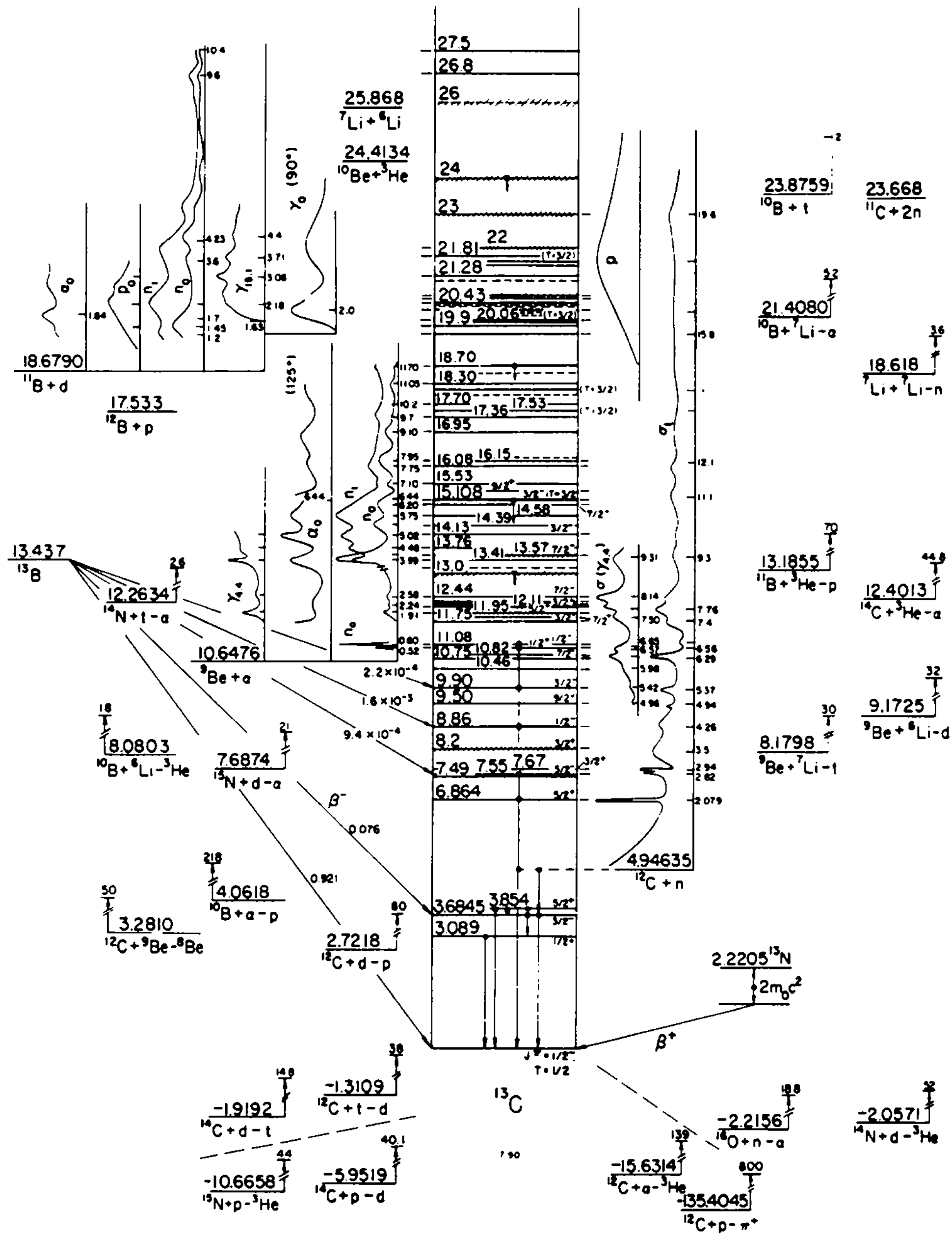
Special states: (Ko 84z, Go 85v, Ro 85m, Sh 85o, An 86u, Xu 86b, Ki 87e, Kw 88, Mi 88j, Ro 88q, Zh 88a, Am 89a, Or 89a, Ro 89d, Ho 90c)

Electromagnetic transitions and giant resonances: (Va 84, Go 85v, Ad 86, Er 86, Ki 87e, Am 89a)

Astrophysical questions: (Bu 82m, Ca 82h, Gr 82n, Wo 82h, Br 85g, Ha 85y, He 85d, Mi 85i, Pr 85e, Ri 85d, Do 86a, Fr 86f, Go 86o, La 86o, Ma 86jj, Sn 86, Sn 86c, Wi 86n, Ar 87i, Au 87d, Be 87w, Bo 87a, Br 87n, Do 87e, Ha 87e, Ha 87p, Kr 87j, Ma 87, Ma 87ee, Pi 87d, Pr 87, So 87f, Wa 87g, Wa 87n, Zi 87b, Ap 88, Ar 88g, As 88c, Cr 88, De 88i, Ja 88a, Ju 88b, Pi 88b, Sc 88, Tr 88g, Ab 89d, Ba 89v, Ba 89y, Bo 89n, Br 89d, Br 89h, Ch 89t, Ch 89v, Fr 89g, Gi 89c, Gu 89k, Ha 89c, Ho 89c, Ji 89, Ka 89b, Lo 89a, Lo 89b, Me 89, No 89, Sm 89, St 89h, We 89b, Wh 89a, Wy 89, Ca 90b, Fu 90b, Ho 90d, Mo 90d, Pi 90a, Tu 90, We 90)

[†] See also (Aj 86).

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 c.m. 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
23.8759
¹⁰B + t
23.668
¹¹C+2n
21.81
22
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
14.39
14.58
14.13
13.76
13.41
13.57
13.0
12.44
12.11
11.95
11.75
11.08
10.82
10.75
10.46
9.90
9.50
8.86
8.2
7.49
7.55
7.67
6.864
3.6845
3.854
3.089
18.6790
¹¹B+d
17.533
¹²B+p
18.618
⁷Li+⁷Li-n
21.4080
¹⁰B+⁷Li-α
13.437
¹³B
12.2634
¹⁴N+t-α
10.6476
⁹Be+α
13.1855
¹¹B+³He-p
12.4013
¹⁴C+³He-α
9.1725
⁹Be+⁶Li-d
8.1798
⁹Be+⁷Li-t
8.0803
¹⁰B+⁶Li-³He
7.6874
¹⁵N+d-α
4.94635
¹²C+n
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
Jπ=1/2⁻
T=1/2
¹³C
-1.3109
¹²C+t-d
-1.9192
¹⁴C+d-t
-10.6658
¹⁵N+p-³He
-5.9519
¹⁴C+p-d
-2.2156
¹⁶O+n-α
-2.0571
¹⁴N+d-³He
-15.6314
¹²C+α-³He
-135.4045
¹²C+p-π⁺

Applied work: (Br 86w, Bu 86g, Do 86c, Dr 86b, En 86d, Fo 86d, Fr 86h, Ge 86, He 86c, Ki 86a, Kn 86b, Kr 86c, Ma 86e, Ma 86s, Ni 86d, No 86a, Sr 86, St 86l, Xu 86, Bo 87s, Du 87, Ki 87d, Na 87m, St 87c, Ar 88f, Bu 88b, Do 88c, Fa 88, Go 88i, Ma 88, Pu 88a, Sc 88b, Ce 89b, Gr 89, Ku 89m, Mu 89, Ra 89k, Do 90, Fr 90)

Complex reactions involving ^{13}C: (Bo 84q, Ki 85h, Kw 85a, Po 85d, Po 85e, Ut 85a, Av 86, Gr 86m, Ha 86bb, Ho 86n, Ma 86k, Ma 86z, Me 86d, Mo 86j, Po 86d, Sa 86ee, So 86d, Ut 86, Xu 86b, Xu 86c, Ar 87f, Ba 87w, Be 87o, Bu 87e, Ga 87g, Ge 87, Ly 87b, Na 87, Pe 87c, Po 87f, Ri 87b, Si 87b, Sn 87, St 87, Vi 87a, Ya 87l, Be 88ii, Ca 88, Ga 88c, Ha 88a, Jo 88a, Ki 88d, Ru 88, Sa 88h, Aj 89a, Ba 89cc, Ch 89p, Gi 89a, Gr 89e, Ho 89e, Ki 89f, Po 89c, Pr 89b, Sa 89g, Se 89b, Te 89b, Ch 90d)

Muon and neutrino capture and reactions: (De 85t, Ko 85v, Mi 85r, Is 86, Mi 86j, Mi 86s, Su 87a, Ch 90g, Fu 90b, Lu 90, Mi 90c)

Pion capture and reactions involving pions and ρ-mesons[†]: (Ma 83e, Bo 84q, Ch 84s, Sa 85s, Bo 86u, Ce 86, Do 86, Er 86, Ko 86t, Li 86e, Li 86f, Mi 86s, Si 86c, Si 86f, Si 86j, Su 86i, Du 87d, Gi 87f, Mi 87i, Pi 87a, Bu 88i, Ch 88h, Ch 88k, Ch 88m, Gi 88c, Ha 88i, Ki 88e, Pe 88e, Pe 88g, Po 88g, Po 88h, Us 88b, Ch 89w, Ge 89b, It 89, Je 89a, Jo 89a, Ki 89a, Mo 89b, Pi 89g, Be 90b, Ch 90f, Er 90c, Er 90d, Fe 90a, Ko 90f, Ta 90d, Ti 90)

Kaon capture and reactions: (Bo 84q, Ga 85q, Do 86, Fe 86b, Ga 86a, Ma 86f, Ma 86g, Fa 87, Pi 87a, Po 87e, Fa 88a, Pe 88e, Pe 88g, Po 88g, Zh 88g, Ch 89aa, Do 89i, Pi 89g, Fe 90a)

Hypernuclei: (Bo 84q, Zh 84b, Ba 85ee, Ba 85ff, Ga 85q, Ko 85s, Ko 85cc, Ya 85j, An 86s, Ba 86tt, Da 86a, Da 86b, Do 86, Er 86, Fe 86b, Ga 86a, Ko 86i, La 86j, Ma 86f, Ma 86g, Me 86c, Wu 86, Wu 86b, Ya 86e, Co 87d, Fa 87, Ma 87h, Mi 87b, Pi 87b, Po 87e, Ch 88f, Fa 88a, Ga 88, Ga 88h, It 88, Ma 88f, Ma 88w, Mo 88k, Pe 88g, Po 88g, Ta 88a, Wa 88a, Zh 88g, Ba 89cc, Ba 89hh, Ch 89aa, Do 89i, Do 89m, Fe 89f, It 89, Ki 89a, Ko 89h, Ko 89z, Ko 89bb, La 89c, La 89d, Ma 89f, Mi 89a, Pi 89g, Fe 90a, It 90, Os 90)

Other topics: (An 85e, Sh 85o, An 86u, Kw 88, Fu 89g, Or 89a, Mu 90a)

Ground state of ^{13}C: (An 85e, Go 85v, Gl 86g, Si 86j, Ab 87a, Fu 87h, Gi 87f, Ki 87e, Sa 87g, Ar 88h, Ke 88a, Va 88, Wa 88c, Wo 88, Am 89a, An 89c, Fu 89g, Go 89b, Wo 89c, Va 90a)

$$\mu = +0.702411(1) \text{ n.m. (Le 78n)}$$

$$\langle r^2 \rangle^{1/2} = 2.4628(39) \text{ fm (De 85t) [charge radius, from muonic } ^{13}\text{C]}$$

[†] See also reactions 27 and 41, and reaction 23 in ^{13}N.

[The neutron r.m.s. radius is 2.35(3) fm (Jo 79g)]

Natural abundance: (1.10 ± 0.03)% (De 84q)

$^{13}C^*(3.85)$: $g=-0.558 \pm 0.015$ (Ru 81). From the γ-ray due to the transition $^{13}C^*(3.85 \to 3.68)$, $\Delta E_x = 169.356 \pm 0.020$ keV: see (Aj 86). See also (Ra 89g).

TABLE 13.4

Energy levels of ^{13}C [a])

E_x in ^{13}C (MeV ± keV)	J^{π}; T	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
g.s.	$\frac{1}{2}^-$; $\frac{1}{2}$		stable	5 → 8, 10, 11, 13 → 15, 19 → 22, 27 → 65, 67 → 73
3.089443 ± 0.020	$\frac{1}{2}^+$	$\tau_m = 1.55 \pm 0.15$ fs [c])	γ	5 → 8, 11, 13, 19 → 22, 27 → 29, 31, 32, 35, 36, 40 → 47, 50, 59 → 65, 67, 69, 71
3.684507 ± 0.019	$\frac{3}{2}^-$	1.59 ± 0.13 fs [c])	γ	5 → 8, 11, 13, 14, 19 → 22, 27 → 29, 31, 32, 34, 37, 40 → 48, 59 → 64, 67, 69
3.853807 ± 0.019	$\frac{5}{2}^+$	12.4 ± 0.2 ps [d])	γ	5 → 8, 11, 13, 19 → 21, 27 → 30, 32, 34, 37, 40 → 46, 50, 59, 60, 62, 64, 69, 71
6.864 ± 3 [f])	$\frac{5}{2}^+$	$\Gamma = 6$	γ, n	5 → 8, 11 → 13, 19, 21, 23, 27 → 29, 40, 43, 45, 46, 59, 61, 64, 67
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 → 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 → 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 [h])	$\frac{9}{2}^+$	≤ 5	γ, n	5, 8, 12, 19, 23, 27, 28 → 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

^{13}C MASTER TABLE

TABLE 13.4—continued

E_x in ^{13}C (MeV ± keV)	J^π; T	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
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
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 [c])	$\frac{3}{2}^-; \frac{3}{2}$	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, 40, 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
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

TABLE 13.4—continued

E_x in ^{13}C (MeV ± keV)	$J^\pi; T$	$\Gamma_{c.m}$ (keV)	Decay	Reactions
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 (Aj 81).
[d]) Weighted mean of values displayed in table 13.5 in (Aj 81) and in (Ru 81).
[e]) See table 13.6.
[f]) See also footnote [c]) in table 13.11.

TABLE 13.5

Summary of results on the total radiation widths of the 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 (Aj 81).

[b]) $E_x = 3089.443 \pm 0.020$ keV, $E_\gamma = 3089.049 \pm 0.020$ keV* (Wa 80k: 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 ± 0.04)% (Wa 80k), (0.74 ± 0.05)% (Mu 82e). $E_x = 3684.482 \pm 0.023$ keV, $E_\gamma = 3683.921 \pm 0.023$ keV. $\delta(E2/M1) = -0.094 \pm 0.009$. E_γ for the transition to $^{13}C^*(3.09)$ is 595.013 ± 0.011 keV (Wa 80k).

[d]) Branching ratios for cascades via $^{13}C^*(3.68, 3.09)$ are (36.3 ± 0.6)% and (1.20 ± 0.04)%, respectively (Wa 80k). $E_x = 3853.783 \pm 0.022$ 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* (Wa 80k) [169.356 ± 0.020 keV* (Sc 84)].

[e]) The ground-state branching ratio is (62.5 ± 0.6)% (Wa 80k) and $\delta(E3/M2) = +0.12 \pm 0.03$ (Po 66f).

[f]) Branching ratio for cascade via $^{13}N^*(2.37)$ is (8 ± 1)% (Ro 74n). See also footnote [g]) in table 13.17.

[g]) See the discussion in (Ba 85mm).

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

The yield curves for d_0 ($E(^6\text{Li}) = 4$ to 14 MeV), 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 $p_0 \to p_2$, p_{3+4}, p_5; $d_0 \to d_3$, d_{4+5}, d_6; $t_0 \to t_2$; and α_0: the total cross sections generally increase smoothly with energy without showing any structure: see (Aj 81). For reaction (b) see (Sc 87c).

2. (a) ^{9}Be(α, n)^{12}C $Q_m = 5.7012$ $E_b = 10.6476$
   (b) ^{9}Be(α, 2n)^{11}C $Q_m = -13.021$

Resonances for n_0 and 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 n_0 and 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 $E_x = 15.11$ MeV: see tables 13.6 and 13.7 (Hi 78e). For thick target yields see (We 82k). See also (He 89). For polarization measurements (E_α to 100 MeV) see (Aj 81). Reaction (b) has been studied at a number of energies for $E_\alpha = 17$ to 44 MeV: see (Aj 81, Aj 86). See also ^{12}C in (Aj 90), (El 87a, Cr 89c; applied) and (Ca 85t; astrophysics).

3. (a) ^{9}Be(α, d)^{11}B $Q_m = -8.0314$ $E_b = 10.6476$
   (b) ^{9}Be(α, t)^{10}B $Q_m = -13.2283$

Excitation curves have been measured for $E_\alpha = 15$ to 27.5 MeV for reaction (a) [involving d_0, d_1 and at the higher energies d_2, d_3, d_{4+5}, d_6] and at 26.0 to 27.5 MeV for reaction (b) [t_0, t_1, t_3]: no structures are observed: see (Aj 81). See also ^{11}B in (Aj 90) and ^{10}B in (Aj 88).

4. ^{9}Be(α, α)^{9}Be $E_b = 10.6476$

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 $E_x = 15.11$ MeV: see table 13.6 for the

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	≤2.82 ± 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 (Aj 81).

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

[c]) Widths for ^{13}C*(15.11) → $^{12}C_{g.s.}+n_0$ or ^{13}N*(15.06) → $^{12}C_{g.s.}+p_0$ [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) → $^{9}Be_{g.s.}+\alpha_0$ or ^{13}N*(15.06) → $^{9}B_{g.s.}+\alpha_0$ [α_1 and α_2 refer to the decays to ^{9}B*((1.6), 2.4)].

[e]) $\delta=-0.15\pm0.07$. Here $\delta=B(^{13}\mathrm{C})/B(^{13}\mathrm{N})-1$.

[f]) $\delta=1.0\pm0.6$.

[g]) $\delta\geq0.83\pm0.29$.

[h]) $\delta=-0.04\pm0.14$.

[i]) Based on measured branching ratios and on $\Gamma_{c.m.}=0.932\pm0.028$ 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 ± 8)%. It is apparent from the character of the decay modes of this state that 2s1d shell isospin admixtures are important.

parameters of that state. For a measurement of the total reaction cross section at $E_\alpha=100$ MeV see (Du 86m). See also (Bu 87k) and (Sa 86ee; theor.).

5. ^{9}Be(^{6}Li, d)^{13}C $\qquad Q_m=9.1725$

Angular distributions have been studied at $E(^{6}\mathrm{Li})=32$ 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 $E_x=10.75\pm0.018$ MeV, with $\Gamma=130$ keV [suggesting

TABLE 13.7

Resonances in $^9Be(\alpha, n)^{12}C$ [a]

E_α [b] (MeV)	E_α [c] (MeV)	E_α [d] (MeV)	$\Gamma_{c.m.}$ (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 (Aj 81).
[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.

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 (As 89a; see for spectroscopic factors).

6. $^9Be(^7Li, t)^{13}C$ $\qquad Q_m = 8.1798$

Angular distributions for t_0, t_1, t_{2+3}, t_4 are reported at $E(^7Li) = 5.6$ to 6.2 MeV: see (Aj 76).

7. $^9Be(^9Be, n\alpha)^{13}C$ $\qquad Q_m = 9.0741$

Cross sections for gamma rays from the decay of $^{13}C^*(3.09, 3.68, 3.84)$ are reported by (La 88f) for $E(^9Be) = 2.8$ to 6 MeV.

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

E_α (MeV)	$\Gamma_{c.m.}$ (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]) (Go 73g): from analysis in the single-level approximation. This assumes the J^π ordering suggested by (Li 65c). See also (Aj 81).

[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 $\qquad Q_m = 3.2810$

Angular distributions have been measured for $E(^{12}\mathrm{C}) = 10.5$ to 15 MeV and at $E(^9\mathrm{Be}) = 20$ MeV: see (Aj 81, Aj 86).

9. (a) ^{10}B(t, p)^{12}B $\qquad Q_m = 6.342 \qquad E_b = 23.8759$
   (b) ^{10}B(t, d)^{11}B $\qquad Q_m = 5.1969$
   (c) ^{10}B(t, α)^{9}Be $\qquad Q_m = 13.2282$

Yields have been measured for $E_t = 0.5$ to 2.0 MeV. There is no evidence of resonance behavior: see (Aj 81). In the range $E_t = 3.0$ to 7.3 MeV a broad structure is reported in the activation cross section (reaction (a)) at $E_t \sim 5.5$ MeV, $\Gamma \sim 2.7$ MeV (Ab 851). See also ^{9}Be in (Aj 88).

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

At $E(^3\mathrm{He}) = 260$ and 280 MeV, ^{13}C$_{g.s.}$ and an unresolved group at $E_x \sim 3.6$ MeV are observed: see (Aj 86).

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

Angular distributions have been measured at many energies up to $E_\alpha = 31.2$ MeV: see (Aj 70, Aj 86). 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 (Bi 87; prelim.). For a study of high E_x states see (Br 87j, Mi 87q, Br 88b; prelim.). See also ^{14}N, (Br 89e) and (Ba 86ag; axion search).

12. $^{10}B(^6Li, ^3He)^{13}C$ $Q_m = 8.0803$

Comparisons of the relative intensities of the ^3He groups in this reaction and of the triton groups in the mirror reaction (see reaction 6 in ^{13}N) at $E(^6Li) = 18$ 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_x is in ^{13}C, the second in ^{13}N]: see (Aj 81).

13. $^{10}B(^7Li, \alpha)^{13}C$ $Q_m = 21.4080$

Angular distributions have been measured at $E(^7Li) = 5.20$ MeV for the α_0, α_1, α_{2+3} and α_4 groups: see (Aj 81).

14. $^{10}B(^{14}N, ^{11}C)^{13}C$ $Q_m = 1.139$

At $E(^{10}B) = 100$ MeV angular distributions are reported for the transitions to $^{13}C^*(0, 3.7, 7.5, 11.8)$: see (Aj 81).

15. $^{11}B(d, \gamma)^{13}C$ $Q_m = 18.6790$

The 90° γ_0 excitation curve measured for $E_d = 1.0$ to 12.0 MeV shows resonant structure at $E_d = 2.0 \pm 0.1$ and 4.0 ± 0.1 MeV, $\Gamma \sim 0.6$ and ~ 1 MeV, corresponding to states at $E_x = 20.4$ and 22.1 MeV: see table 13.9 and (Aj 86). More recently (Au 85d) have studied the 90° γ_0 differential cross sections at $E_d = 1.65$ to 3.5 MeV, angular distributions at 1.6, 1.8, 2.0 and 4.0 MeV, and analyzing powers at $E_d = 2.0$ and 4.0 MeV (90°) and 1.6 and 1.8 MeV (125°). The data are interpreted in terms of two doorway states at $E_x = 20.57 \pm 0.84$ and 20.20 ± 0.07 MeV with $\Gamma_{c.m.} = 5.64 \pm 0.43$ and 0.56 ± 0.09 MeV, respectively (Au 85d). See also reaction 22 and (Ho 90f).

16. (a) $^{11}B(d, n)^{12}C$ $Q_m = 13.7326$ $E_b = 18.6790$
(b) $^{11}B(d, 2n)^{11}C$ $Q_m = -4.989$

The yields of neutrons and 15.1 MeV γ-rays have been measured in the range $E_d = 0.2$ to 11 MeV: see table 13.9. At $E_d = 79$ MeV, VAP measurements are reported for $^{12}C^*(0, 4.4, 9.6, 12.7, 15.1)$ (Fo 87d, Fo 86h). See also (Aj 81). The thick-target yield in reaction (b) has been measured for $E_d = 7.00$ to 16.01 MeV: see (Aj 86). See also ^{12}C in (Aj 89).

17. (a) $^{11}B(d, p)^{12}B$ $Q_m = 1.145$ $E_b = 18.6790$
(b) $^{11}B(d, d)^{11}B$

For reaction (a) see (Aj 81, Aj 86). For $E_d = 2.99$ to 6.99 MeV the activation cross section does not show any evidence of structure (Ab 851). For reaction (b) see (Aj 81). See also ^{12}B in (Aj 90).

18. $^{11}B(d, \alpha)^9Be$ $Q_m = 8.0314$ $E_b = 18.6790$

TABLE 13.9

Resonant structure in ^{11}B + d [a])

Resonant structure in yield of (MeV ± keV)							$\Gamma_{c.m.}$ (keV)	E_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 (Aj 81).
[b]) Yield of α_0, α_1, α_2, α_3.
[c]) (Ka 81h): part of the GDR. More recent work (see reaction 15) suggest two states at $E_x = 20.20 \pm 0.07$ and 20.57 ± 0.84 MeV with $\Gamma_{c.m.} = 0.56 \pm 0.09$ and 5.64 ± 0.43 MeV, respectively (Au 85d).
[d]) $J^\pi = \frac{5}{2}^-$ is suggested.

At low energies the excitation functions for α_0 and α_1 increase monotonically: see (Aj 70). Then at $E_d = 1.85$ 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 $E_d = 1.0$ to 3.2 MeV: see (Aj 81). See also ^{9}Be in (Aj 88).

19. ^{11}B(^{3}He, p)^{13}C $\qquad Q_m = 13.1855$

Levels derived from proton groups are displayed in table 13.11 of (Aj 81). [The only level parameters included in the values of table 13.4 are $E_x = 7500 \pm 12$ keV and $\Gamma_{c.m.} < 5$, 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$_{g.s.}$ (99 ± 9)% and (100 ± 20)% for the first two states, and to ^{12}C*(0, 4.4) (67 ± 16)% and (33 ± 8)% for the third (Ad 73b). The decay parameters for the first $T = \frac{3}{2}$ state, ^{13}C*(15.11), are shown in table 13.6. See also (Aj 86).

20. ^{11}B(α, d)^{13}C $\qquad Q_m = -5.1677$

Angular distributions have been measured at $E_\alpha = 15.1$ to 31.2 MeV: see (Aj 81, Aj 86). See also (Br 87j) and (Be 84bb; theor.).

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

For reaction (a) see (Aj 81). For reaction (b) see ^{5}He in (Aj 88) and (Da 90).

22. $^{12}C(n, \gamma)^{13}C$ $\qquad Q_m = 4.94635$

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 (Aj 86) for references and additional information. Based on unpublished measurements quoted in (Aj 86), the energies of the γ-rays involved in $C \to 0$, $C \to 3.68$ and $3.68 \to 0$ 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 (Aj 86). (Wa 90b) proposes 3683.915 ± 0.015 keV for E_γ [$3.68 \to 0$].

Differential cross sections for γ_0 (90°) have been studied for $E_n = 6.5$ to 18.5 MeV (Au 87), 7.0 to 19.5 MeV (Be 86q) and at 7.8, 9.3 and 10.8 MeV (Ha 90j). 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 (Au 87) 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 $^{13}C(\gamma, n_0)$ reaction but the magnitudes of the cross section are smaller: see, for instance, (Ha 90j). Angular distributions and analyzing powers of γ_0 for $E_n = 12.0$ to 18.8 MeV suggest two doorway states at $E_x = 21.1 \pm 0.6$ and 20.52 ± 0.07 MeV with $\Gamma = 4.2 \pm 0.4$ and 0.51 ± 0.07 MeV, respectively (Wo 84b). See also (Hu 89f). For work to 50 MeV see (Do 88d; prelim.). See also (Mu 86, Ra 86, We 86b, Mc 88e), (Ma 88u, Gu 89i; astrophysics) and (Ho 87p, Ly 87; theor.).

23. (a) $^{12}C(n, n)^{12}C$ $\qquad E_b = 4.94635$
(b) $^{12}C(n, n')^{12}C^*$
(c) $^{12}C(n, n')3^4He$ $\qquad Q_m = -7.27473$
(d) $^{12}C(n, 2n)^{11}C$ $\qquad Q_m = -18.7215$

The coherent scattering length (thermal, bound) $a_{coh} = 6.6535 \pm 0.0014$ fm; $\sigma_{scatt} = 4.7456 \pm 0.0020$ (Ko 79w).

Total cross sections have been measured in the range $E_n = 1$ keV to 273 GeV/c [see (Aj 81, Aj 86)] and at 0.14, 1.3 and 2.1 MeV (Ko 88k) and 160 to 575 MeV (Fr 88k): see the compilation of (Mc 88e). See also (Ba 86u). Various elastic, inelastic and non-elastic cross sections have been reported over a wide range of energies: [see (Mc 88e, Aj 86)], most recently at 6.23 to 13.75 MeV (Bo 86m; prelim.; elastic and inelastic scattering cross sections), from 16.5 to 22.0 MeV (Ol 89, Ol 89b; σ_t, σ_{el} and σ to $^{12}C^*(4.4, 7.7, 9.6)$) and from threshold to 25 MeV (We 88a; prelim.; cross section for scattering to $^{12}C^*(4.4)$). Polarization measurements have been reported for $E_n = 1.5$ to 16.3 MeV [see (Aj 76, Aj 81, Aj 86)] and at $E_n = 15.55$ to 17.35 MeV (To 87a, To 87) and 18.2 MeV (To 88a). See also (Be 86a, Be 87e).

Observed resonances are displayed in table 13.10 here, and in table 13.13 in (Aj 81) [the latter for $(n, n'\gamma_{4.4})$]. In table 13.10 the assignment of the broad states above $E_x = 11.7$ MeV are from phase-shift analyses ($\sigma(\theta)$ and A_y) referred to here and in (Aj 86). Five weak anomalies in the total cross section are thought to be due to $T = \frac{3}{2}$ states (Hi 87a).

TABLE 13.10

Resonances in $^{12}C(n, n)^{12}C$ [a])

E_{res} (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	$^{13}C^*$ (MeV)	J^π	Γ_n/Γ
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
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 (Aj 70), 13.16 in (Aj 76), 13.12 in (Aj 81) and 13.10 in (Aj 86). See the discussions in (Kn 82, To 85b, To 87a).

[b]) Derived from a lorentzian probability plot (Ci 80).

[c]) Weak resonance anomaly attributed to $T = \frac{3}{2}$ state (Hi 87a) [and see for $(J + \frac{1}{2})$ Γ_{n_0}/Γ].

[d]) From phase-shift analysis by (To 87a).

[e]) For the decay of these states, reported in the interaction of ^{14}N ions (35 MeV/A) with a silver target, see (He 89h).

For reactions (c) and (d) see reactions 23 and 24 in (Aj 86) and (Mc 88e). For pion production see (Bu 88k). See also ^{12}C in (Aj 90) and (Be 84aa, Fi 85c, Ku 85e, Me 85i, Ra 85i, Ba 86gg, Dr 86e, Ro 86d, Ne 87, An 88f, Sa 89c), (Al 86q, We 86f, Wi 86d, Ol 89b; applied), (Fr 88l; astrophys.), (Br 87r, Ma 88g) and (Ko 85gg, Ti 85a, Be 86kk, Li 86m, Ba 88p, Ru 88b, Mi 89o, Le 90h; theor.).

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

The cross section exhibits a weak resonance corresponding to $E_x \sim 20.5$ MeV and a stronger structure at $E_x \sim 21.5$ MeV: see (Aj 76). See also the compilation of (Mc 88e). The excitation function for $E_n = 30$ to 150 MeV is being studied (Ra 88b; prelim.). For proton production for $E_n = 300$ to 580 MeV see (Fr 87e). See also ^{12}B in (Aj 90) and (Az 85, Fo 86e, Be 89mm, So 89), (Ro 86l; applied), (Fr 88l; astrophysics), (Ma 88g) and (Ko 86t, Pe 88a; theor.).

25. (a) $^{12}C(n, d)^{11}B$ $Q_m = -13.7326$ $E_b = 4.94635$
(b) $^{12}C(n, t)^{10}B$ $Q_m = -18.9295$

For deuteron and triton emission at $E_n = 300$ to 580 MeV, see (Fr 87e). See also (Ro 86l; applied), (Fr 88l; astrophysics), (Ma 88g) and (Ko 86t; theor.).

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

The cross section for the α_0 group shows a broad structure at $E_n \sim 8$ MeV: see (Aj 81). For other work see (Mc 88e, Aj 86). See also (Ca 88h), (Ro 86l, Wi 86d; applied) and (Ma 88g).

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

Angular distributions have previously been reported for $E_p = 147$ to 250 MeV: see (Aj 86). $^{13}C^*(0, 3.09, 3.68, 3.85, 6.86, 9.50)$ 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 $^{13}C^*(0, 3.09+3.68+3.85, 9.50)$ (Hu 87c) [see also for a discussion of the energy dependence of the total cross section, and of the influence of the Δ-resonance]. (Ho 87m) 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 $^{13}C^*(0, 3.09, 3.7\ [u], 6.86, 7.5\ [u], 9.5, 21.4)$ (Ko 89m). For the strongly populated group to $^{13}C^*(21.4)$ $A_y \sim 0$ 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 (Ko 87, Ko 89m). See also (Ja 90). For inclusive differential cross sections and A_y at $E_{\vec{p}} = 400$ and 450 MeV see (Fa 86). For other polarization measurements see (Aj 86). For total cross sections at $E_p = 180$ and 201 MeV see (Bi 85g). See also (Aj 81), "General", p. 16, (Se 87, Se 88f), (Ja 86i) and (Iq 85, Mi 86j, Ku 87c; theor.).

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

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 (Aj 81, Aj 86)] as well as at $E_d = 12$ MeV (La 88; to $^{13}C^*$(0, 3.09, 3.68, 3.85, 6.86, 7.50, 7.55, 7.69)) and at $E_d = 30$ MeV (Oh 86; 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 (Be 89hh, Ie 89, Na 89n).

For τ_m measurements see table 13.5 and for γ-decay see table 13.6. For work at very high energies see (Az 87b, Av 89b). See also ^{14}N, (Li 85e, Vi 88a, Vi 89a, Ch 90c; applied), (Si 86a; computer program) and (Bl 84h, Is 86f; theor.).

TABLE 13.11

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

^{13}C(MeV ± keV)	$\Gamma_{c.m.}$ (keV)	l_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 (Aj 81) and 13.11 in (Aj 86).

[b]) DWBA fit at $E_d = 30$ MeV (Oh 86). For earlier results see (Aj 81, Aj 86).

[c]) (Wa 80k): E_γ for the 3.85 → 3.68 transition is 169.300 ± 0.004 keV. Using $E_x = 3684.507 \pm 0.019$ keV [see reaction 22] and this value for E_γ, E_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 "General", p. 17. (Pi 90b) report $E_x = 3089.42 \pm 0.07$, 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 (Oh 86).

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

29. $^{12}C(t, d)^{13}C$ $Q_m = -1.3109$

At $E_t = 38$ 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) (Si 88c). See also (Aj 81).

30. $^{12}C(^3He, 2p)^{13}C$ $Q_m = -2.7718$

At $E(^3\vec{He}) = 33$ MeV $^{13}C^*(3.85)$ is strongly populated. $^{13}C^*$(0, 8.0 (broad), 9.5) have also been studied (Ka 86aa). See also (Aj 81) and ^{15}O.

31. $^{12}C(\alpha, ^3He)^{13}C$ $Q_m = -15.6314$

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 $^{12}C(\alpha, t)^{13}N$, have also been compared: see (Aj 81). See also (Ku 89a; $E_\alpha = 94$ MeV; g.s.; prelim.) and (Ga 89d).

32. $^{12}C(^7Li, ^6Li)^{13}C$ $Q_m = -2.304$

At $E(^7Li) = 34$ MeV angular distributions have been studied to $^{13}C^*$(0, 3.09, 3.85). The analysis by FRDWBA leads to $S = 0.65 \pm 0.06, 0.75 \pm 0.08$ and 0.68 ± 0.10, respectively (Co 86). See also (Ke 88c; theor.). For the earlier work at $E(^7\vec{Li}) = 21.1$ and $E(^7Li) = 48$ MeV see (Aj 81, Aj 86).

33. $^{12}C(^8Li, ^7Li)^{13}C$ $Q_m = 2.9136$

At $E(^8Li) = 14.3$ MeV, an angular distribution is reported involving $^{13}C_{g.s.}$ (Be 89w): at $\theta_{lab} = 15°$, the differential cross section is $\simeq 15$ mb/sr.

34. $^{12}C(^{12}C, ^{11}C)^{13}C$ $Q_m = -13.7754$

Angular distributions have been reported at $E(^{12}C) = 72.5$ and 93.8 MeV [see (Aj 81, Aj 86)], at 240 MeV (Bo 851; $^{13}C^*$(0, 3.85)) and at 300, 420 and 600 MeV (Wi 88c, Wi 89a; $^{13}C_{g.s.}$). See also ^{11}C in (Aj 90) and (Sa 89p; theor.).

35. $^{12}C(^{14}N, ^{13}N)^{13}C$ $Q_m = -5.6071$

Angular distributions have been reported in the range $E(^{14}N) = 28$ to 154.8 MeV involving $^{13}C^*(0, 3.09, 3.85, 7.3 \pm 0.3)$: see (Aj 81). See also (Aj 86) and (Os 87c, Ka 88t; theor.).

36. (a) $^{12}C(^{17}O, ^{16}O)^{13}C$ $Q_m = 0.8029$
(b) $^{12}C(^{18}O, ^{17}O)^{13}C$ $Q_m = -3.0982$

Angular distributions involving $^{16}O_{g.s.} + ^{13}C_{g.s.}$ are reported at $E(^{17}O) = 40$ to 70 MeV (Fr 86b). For the earlier work see (Aj 81). For reaction (b) see ^{18}O in (Aj 87).

37. $^{13}B(\beta^-)^{13}C$ $Q_m = 13.437$

See ^{13}B and table 13.2.

38. (a) $^{13}C(\gamma, n)^{12}C$ $\qquad Q_m = -4.94635$
(b) $^{13}C(\gamma, 2n)^{11}C$ $\qquad Q_m = -23.668$

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 $E_x =$ 13 MeV [on which peaks are superimposed at $E_x = 11.0$, 13.8, 16.5 and 17.8 MeV] and the giant resonance at $E_x = 24$ MeV ($\sigma_{max} = 9.5$ mb) [surrounded by shoulder resonances at $E_x = 20.8$ 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 $E_x = 7.70$ ($\frac{3}{2}^+$), 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 (Aj 81) for references and for additional information. See also the atlas in (Di 88), (Py 85, Be 88s, Ha 88i) and (Go 85v, Ki 87e; theor.). For comparisons with $^{12}C(n, \gamma)$ see reaction 22 and (Au 85d, Be 86q).

39. (a) $^{13}C(\gamma, p)^{12}B$ $\qquad Q_m = -17.533$
(b) $^{13}C(\gamma, d)^{11}B$ $\qquad Q_m = -18.6790$

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 $E_x \sim 23$ 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 (Zu 83a). For the earlier work see (Aj 81). See also (Ha 88i) and (Ki 87e; theor.). For the cross section of reaction (b) from detailed balance calculations from $^{11}B(d, \gamma)$ see reaction 15 and (Au 85d).

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

The elastic scattering has been studied for $E_e = 80$ to 750 MeV [see (Aj 81, Aj 86)] and (Hi 87c, Mi 89). The form factor for M1 elastic scattering is enhanced above $q \simeq 2.5$ fm^{-1} (Hi 82e, Hi 87c). See also (De 87c). A number of inelastic groups have been seen: see tables 13.12 and 13.13 (Wi 70a, Hi 86c, Hi 87c, Mi 89).

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 (Aj 81). See also (Ch 84s, Sa 85s, Ch 86aa, Do 86e, Ho 87p, Mi 88j, Am 89a, Wo 89c, Je 90; theor.).

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

Angular distributions have been measured at $E_\pi = 20$ to 180 MeV [see (Aj 81) and table 13.13 in (Aj 86)], at 65 MeV (Mi 88c; several states up to $E_x = 11.8$ MeV)

TABLE 13.12

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

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 ± 0.4 [c])	3.5
3.85	$\frac{5}{2}^+$	C3	6×10^{-8}	1.3 ± 0.2 [a])
6.86	$\frac{5}{2}^+$	M2	$(6.9\pm3.6)\times10^{-5}$ [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	$(6.3\pm2.1)\times10^{-3}$ [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]) (Mi 89) [see for form factors up to multipolarity three]. Table V in (Mi 89) shows $B(C\lambda,\uparrow)$. $B(C1,\downarrow)$ and $B(C3,\downarrow)$ are given here with errors double the statistical errors given in (Mi 89) [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 (Aj 81) and 13.12 in (Aj 86) [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 (Mi 89)].

[c]) (Wi 69d, Wi 70a).

[d]) $\Gamma = 190\pm35$ keV.

[e]) Monopole matrix element in fm^2.

[f]) For form factors see (Hi 86c, Hi 87c).

[g]) Unresolved doublet, $B(C3,\uparrow)\simeq 27.5$ W.u. [see (Mi 89)].

[h]) The low q (e, e′) data give a C2 transition strength of 0.5 W.u. (Wi 70a, Wi 69d). However, data points near the peak of the C2 form factor (Mi 89) suggest that $B(C2,\downarrow)$ 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 (Hi 86c) for discussion and for form factors].

and at $E_{\pi^-}=30$ and 50 MeV (Se 90c; 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

TABLE 13.13

Additional states of ^{13}C from $^{13}C(e, e')^{13}C^*$ (Mi 89) [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 (Mi 89).

$^{13}C^*(11.82)$ [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 $\frac{9}{2}^+$ (Se 82c, Se 83f). Analyzing powers for elastic scattering on $^{13}\vec{C}$ have been studied at $E_{\pi^\pm} =$ 100 MeV (Sm 90a) and 114 to 226 MeV (Ye 90a) [both preliminary]. See also "General", p. 16 and (Am 86a; theor.).

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

Angular distributions have been measured at $E_n = 4.5$ to 17.92 MeV [see (Aj 86)], at 4.55 to 10.99 MeV (Re 89; $n_0 \rightarrow n_3$) and at 24 MeV (Pe 85b; 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 $^{12}C_{g.s.}$ (Re 87). See also ^{14}C, (Re 88h; computer) and (Al 86e; theor.).

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

Angular distributions have been studied at $E_p = 1.37$ MeV to 1 GeV [see (Aj 81, Aj 86)] and at 30.95 MeV (Ba 88v; p_0), 35 MeV (Oh 86c; $p_0 \rightarrow p_3$), 71.8 MeV (Pr 89e, Pr 90; p_0; polarized protons), 135 MeV (Co 88b; to 33 states below $E_x = 23$ MeV), 500 MeV (Ho 90f; p_0; polarized protons), 0.8 GeV (Bl 85g; p_0) and 1 GeV (Al 85l; p_0). (Co 88b) 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 $^{13}C^*(12.19 \pm 0.01, 22.2 \pm 0.1)$ 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 (Co 88b, S. Collins, Ph.D. thesis, and B. Spicer, private communication). See also ^{14}N, (Pe 85b) and (Am 86a, Ra 86e, Be 87d, Be 87j, Go 88b, Ra 88a, Am 89a, Am 89b, Be 89jj, Go 89i, Ku 89i, Ku 89o, Ra 89m, Du 90; theor.).

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

Angular distributions (reaction (a)) have been measured at $E_d = 0.71$ to 56 MeV: see (Aj 81, Aj 86). 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 $E_t = 38$ MeV (Si 88c). See also (Aj 81).

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

Angular distributions of elastically scattered ^3He ions have been studied at $E(^3He) = 12$ to 41 MeV [see (Aj 81)] and at 39.6 MeV (Bu 87a; prelim.) as well as at $E(^3\overrightarrow{He}) = 33$ MeV (Dr 86). Angular distributions have also been reported at $E(^3He) = 43.6$ MeV for the ^3He 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 $^{13}C(^3He, t)^{13}N$ reaction] (Pe 81e). See also (De 891) and (Ze 86f, Ra 87p; theor.).

46. $^{13}C(\alpha, \alpha)^{13}C$

Angular distributions have been studied at $E_\alpha = 15$ to 40.5 MeV [see (Aj 81)], at $E_\alpha = 35.5$ MeV (Pe 81e; 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 (Ab 87a; α_0). For $^{13}C^*(7.69)$, $E_x = 7686 \pm 6$ keV, $\Gamma_{c.m.} = 70 \pm 5$ keV (Fu 80a; also line shapes). An angular correlation study at $E_\alpha = 24.35$ MeV of the $(\alpha, \alpha n)$ reaction to $^{12}C_{g.s.}$ has determined the substate population of $^{13}C^*(6.86)$, $J^\pi = \frac{5}{2}^+$ (De 84u). $\Gamma_\gamma/\Gamma \leq 3 \times 10^{-4}$ for $^{13}C^*(6.86)$. The evidence for states near 7.5 MeV is less clear cut (De 85v). See also (Bu 87k) and (Sh 85g; theor.).

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

Angular distributions of elastically scattered Li ions have been studied at $E(Li) = 4.5$ to 40 MeV [see (Aj 81, Aj 86)] as well as at $E(^7Li) = 34$ MeV (Co 87a, Co 87f). At $E(^7Li) = 34$ MeV angular distributions involving $^{13}C^*(3.09, 3.68, 7.55)$ are also reported (Co 87a). For the $(^6Li, \alpha d)$ breakup via states of ^{17}O see (Aj 86) and (Ca 87k, Wu 89c). For fusion and breakup cross sections see (Aj 86). See also (De 89s) and (De 88d, De 88f; theor.).

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

The elastic scattering has been studied at $E(^{13}C) = 28.1$ and 36.2 MeV [see (Aj 81)] and at $E(^9Be) = 50.5$ MeV (Ba 90e; also to $^{13}C^*(3.68, 7.55)$). For cross section measurements see (Da 84j, Cu 86a). See also (Mi 86n; 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 $E(^{10}B) = 18$ to 80.9 MeV: see (Aj 86). For fusion and other cross section measurements see (Aj 86) and (Ma 88b). See also (Cu 85a).

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 $E(^{12}C) = 10$ to 87 MeV and $E(^{13}C) = 12$ to 36 MeV [see (Aj 81, Aj 86)], and at $E(^{12}C) = 94.5$ MeV (Ba 86ae; elastic) and $E(^{13}C) = 16.3$ to 26.5 MeV (Vo 88; $^{13}C^*(0, 3.09, 3.85)$) and 260 MeV (Bo 85l; $^{13}C_{g.s.} + {}^{12}C^*(0, 4.4)$). Elastic distributions for reaction (b) have been studied at $E(^{13}C) = 15$ to 24 MeV [see (Aj 81)] and at 14 and 16 MeV (Tr 88d). Angular distributions for reaction (c) have been measured at $E(^{13}C) = 15$ MeV [see (Aj 81)] and at 20 to 27.5 MeV (Bi 88b; $^{13}C^*(0, 3.09, 3.85)$). For excitation functions, fusion and evaporation cross sections see (Aj 86) and (Ha 86aa, Tr 88d). For a spin-flip probability study see (By 85) and ^{12}C in (Aj 90).

See also (Ba 82oo, Ba 85t, Tr 88d; astrophysics), (Fr 84a, Be 85r, Cu 85a, Ko 85q, Sn 86b, St 86n, Gr 87o, Im 87d, Be 88v, Vo 89, Vo 90a) and (Hu 85, Im 85, Sa 85r, Ba 86oo, Ba 86uu, El 86a, Ha 86i, Ka 86gg, Sa 86kk, Vi 86c, Ar 87, Bo 87p, Fr 87b, Im 87, Ma 87k, Th 87a, Br 88q, Ja 88h, Ka 88t, Mi 88p, Pa 88f, Er 89, Fr 89f, Ha 89h, Ba 90a; 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 $E(^{14}N) = 19.3$ to 35 MeV and at $E(^{13}C) = 105$ MeV: see (Aj 81, Aj 86). See also (Be 89z: γ-ray yields, reaction (b)) and (Ba 86uu; 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 $E(^{16}O) = 10$ to 30 MeV and at $E(^{13}C) = 36$ and 105 MeV [see (Aj 81)] as well as at $E(^{16}O) = 42$ to 65 MeV (Fr 89a) and at 108.15 MeV (Ba 86ae). Those for reaction (b) are reported at $E(^{17}O) = 29.8$, 85.4, 120 and 140 MeV; and those for reaction (c) at $E(^{18}O) = 15$ to 31 MeV: see (Aj 81, Aj 86). For excitation functions, breakup yields and fusion measurements see (Aj 81, Aj 86) and (Fr 83f [see, however, Fr 88h], Be 85o, Be 85p, Ga 86d, Pa 86f). See also (Cu 85a, Hu 85, Ko 85q, Re 85b, St 86n, Be 89z, Sn 90) and (Mi 85o, Ba 86uu, Ci 86, Mi 86l, Pa 86b, Ar 87a, Ba 87c, Ch 87n, Da 87m, Nu 87a, Re 87f, Ch 89y, Th 89, Im 90; theor.).

53.[†] $^{13}C(^{24}Mg, ^{24}Mg)^{13}C$

See (Aj 86) and (Os 86e; theor.).

[†] We remind the reader that a number of reactions on which no new work has been reported are not discussed here: see (Aj 86).

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

For reaction (a) see (Sn 88). The elastic angular distribution for reaction (b) has been studied at $E(^{13}C) = 60$ MeV (Ya 88b). For the earlier work see (Aj 81, Aj 86). See also (Ch 89f; theor.).

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

For reaction (a) see (Me 90a); for (b) see (Go 88h, Ra 89i). See also (Aj 86).

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

See (Aj 81, Aj 86) and (El 85b, Os 86e; theor.).

57. ^{13}N(β^+)^{13}C $Q_m = 2.2205$

See ^{13}N.

58. ^{14}C(γ, n)^{13}C $Q_m = -8.1765$

See ^{14}C and (Py 85). See also (Go 87c; theor.).

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

At $E_p = 35.0$ 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) [$\frac{9}{2}^+$] (Ya 90). See also (Aj 81).

60. ^{14}N(γ, p)^{13}C $Q_m = -7.5506$

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 $E_{b.s.} = 15.5$ 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 (Aj 81). See also ^{14}N.

61. ^{14}N(n, d)^{13}C $Q_m = -5.3260$

Angular distributions have been determined at $E_n = 10.1$ to 14.7 MeV: see (Aj 81). See also (Yo 88c; $E_n = 60$ MeV; prelim.).

62. ^{14}N(p, 2p)^{13}C $Q_m = -7.5506$

At $E_p = 46$ MeV, the summed proton spectrum shows transitions to $^{13}C^*(0, 3.68, 7.5, 11.9)$: see (Aj 81). At $E_p = 50$ MeV $^{13}C^*(0, 3.1, 3.7)$ are populated (Vd 84b, Vd 86a). See also (Vd 87c).

63. $^{14}N(d, {}^3He)^{13}C$ $\quad Q_m = -2.0571$

At $E_d = 52$ MeV, angular distributions have been measured for the ^3He particles to $^{13}C^*(0, 3.09, 3.68, 6.86, 7.5, 8.86, 9.50, 11.9 \pm 0.15)$ 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 ^3He 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 ^3He and triton groups as well as groups to $^{13}C^*(8.9 + 9.5)$ and $^{13}N^*(9.2)$: see (Aj 81).

64. $^{14}N(t, \alpha)^{13}C$ $\quad Q_m = 12.2634$

Observed α groups at $E_t = 2.6$ MeV are displayed in table 13.22 of (Aj 76).

65. $^{14}N({}^6Li, {}^7Be)^{13}C$ $\quad Q_m = -1.945$

See (Aj 81, Aj 86).

66. $^{14}N({}^{10}B, {}^{11}C)^{13}C$ $\quad Q_m = 1.1390$

See (Os 87c; theor.).

67. $^{15}N(p, {}^3He)^{13}C$ $\quad Q_m = -10.6658$

At $E_p = 43.7$ MeV ^3He groups have been observed to eleven states of ^{13}C: see table 13.17 in (Aj 81).

68. $^{15}N(\alpha, {}^6Li)^{13}C$ $\quad Q_m = -14.6843$

At $E_\alpha = 42$ MeV the angular distribution to $^{13}C_{g.s.}$ has been measured: see (Aj 81). See also (Sh 88d; theor.).

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

Angular distributions have been measured for E_n to 18.8 MeV for $\alpha_0, \alpha_1, \alpha_{2+3}$: see (Aj 81). See also (Ma 87; astrophysics).

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

At $E_\alpha = 42$ MeV, angular distributions involving $^{13}C_{g.s.}$ have been measured: see (Aj 81).

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

Angular distributions are reported at $E(^{16}O) = 20.0$ to 28.3 MeV to $^{13}C^*(0, 3.09, 3.85)$ (We 88d). See also (Vo 89).

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 (Aj 86).

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 (Go 86r).

^{13}N

(Figs. 3 and 4)

GENERAL†

Nuclear models: (Am 89a)

Special states: (Ko 84z, Ro 85m, An 86u, Ro 88q, Ro 89d)

Electromagnetic transitions: (Va 84, Ho 87g)

Astrophysical questions: (Ta 85y, Ra 87m, St 89g)

Applied work: (Hi 86b, Ma 86m, Ma 86bb, We 86c, Bu 87f, Le 87g, Hi 88f, Vo 88c, Ar 89c, Ar 89h, Ar 89m, Tr 89a, Wo 89, Da 90e)

Complex reactions involving ^{13}N: (Ar 85h, Po 85d, Ha 86bb, Po 86d, Ut 86, Ba 87w, Fe 87, Na 87, Ri 87b, St 87, Sa 88h, Ba 89cc, Ki 89c, Ki 89f, Ly 89, Sa 89g, Ta 89l, Yo 89, Gl 90a, We 90a)

Muon and neutrino reactions: (Mi 85r, Fu 90b, Mi 90c)

Reactions involving pions, kaons and other mesons: (Sa 85s, Ku 86b, Li 86e, Si 86f, Si 86j, Su 86i, Mi 87i, Ab 88a, Bu 88i, Ch 88k, Ha 88i, Ko 88u, Ag 89a, Be 89ll, Be 90b, Ca 90f, Ko 90f, Ti 90)

Hypernuclei: (Ba 85ff, Ba 89hh)

Other topics: (An 85e, An 86u, Mu 90a)

Ground state of ^{13}N: (An 85e, Gl 86g, Si 86j, Fu 87h, Wa 88c, Am 89a, Sa 89g)

$$\mu = -0.32224\,(35)\ \text{n.m. (Le 78n). See also (Ra 89g)}$$

1. ^{13}N(β^+)^{13}C $Q_m = 2.2205$

The weighted mean of $\tau_{1/2}$ measurements is 9.965 ± 0.004 min. The decay is entirely to $^{13}C_{g.s.}$; $\log ft = 3.667 \pm 0.001$: see (Aj 81). See also (Ka 89k: $\tau_m = 9.962 \pm 0.020$ min),

† See also (Aj 86).

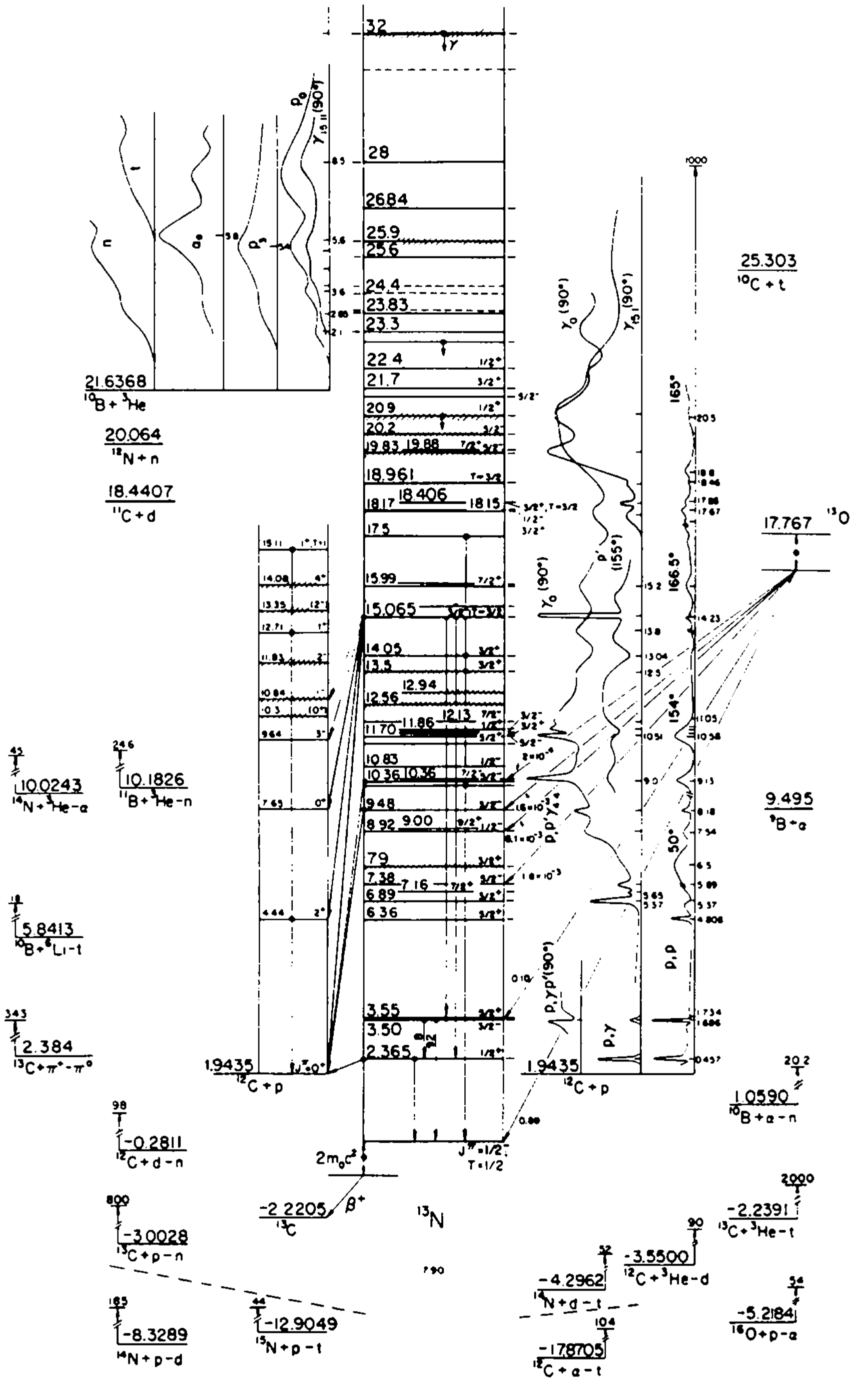


Fig. 3. Energy levels of ^{13}N. For notation see fig. 2.

TABLE 13.14

Energy levels of ^{13}N

E_x (MeV ± keV)	J^π; T	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
g.s.	$\frac{1}{2}^-$; $\frac{1}{2}$	$\tau_{1/2}$ = 9.965 ± 0.004 min	β^+	1, 2, 5, 7, 8, 13 → 31, 33 → 36
2.3649 ± 0.6	$\frac{1}{2}^+$	$\Gamma_{c.m.}$ = 31.7 ± 0.8	γ, p	5, 7 → 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 → 9, 13, 14, 17 → 19, 24 → 30, 34, 35
3.547 ± 4	$\frac{5}{2}^+$	47 ± 7	p	2, 5, 7, 9, 13, 14, 17 → 19, 24 → 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 → 30, 34
7.9	$\frac{3}{2}^+$	~1500	p	9, 14
8.918 ± 11	$\frac{1}{2}^-$	230	p	7, 9, 14, 27 → 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
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

TABLE 13.14—continued

E_x (MeV ± keV)	J^π; T	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
23			γ, p	8
23.3	$(\frac{3}{2}^-)$	400	p, ^{3}He	3, 4
23.83 ± 50	$(\frac{5}{2}^-)$	350 ± 50	p, ^{3}He	3, 4
(23.9)	$(\frac{11}{2}^-)$	20	^{3}He	4
(24.4)		700	p, ^{3}He	3
(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 → 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.

(Se 89c, Se 89e, St 90), (Ba 85q, Gr 86c, Ba 87j, Fr 87, Ri 87d, We 87a, Ba 88g, Ba 88z, Ba 99ee, Da 89f, Gu 89h, Ka 89l; astrophysics) and (Bo 84a, Si 86j, Am 89a, Sa 89j, Wo 89c; theor.).

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

The 90° cross sections for γ_0 and γ_{2+3} have been measured for $E(^3\mathrm{He}) = 4.8$ to 14 MeV: no pronounced structures are observed: see (Aj 81).

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

Activation cross sections (reaction (a)) have been reported for $E(^3\mathrm{He}) = 1$ 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 (Aj 81).

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

For observed resonances and anomalies see table 13.15. See also (Aj 81).

5. ^{10}B(α, n)^{13}N $\qquad Q_m = 1.0590$

Angular distributions have been measured in the range $E_\alpha = 1.5$ to 20.2 MeV: see (Aj 81). See also (El 87a; applied) and (Ca 88m; 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 (Aj 81). For ^{3}He elastic scattering anomalies see (Ba 87n).

[b]) (Ba 87n) report $\Gamma(^3He)/\Gamma = 0.5, 0.3$ and ~ 1 for ^{13}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 $\qquad Q_m = 5.8413$
   (b) ^{10}B(^{9}Be, ^{6}He)^{13}N $\qquad Q_m = 0.4606$

At $E(^6Li) = 18$ 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 (Ho 74d). For reaction (b) see (Ja 90).

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

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 (Aj 81).

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

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

TABLE 13.16
States of ^{13}N from $^{11}B(^3He, n)^{13}N$ [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 (Aj 81).
[b]) See also table 13.6.

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 (Aj 81). [A reanalysis of the data by (Ba 80) 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 $(8.5 \pm 3.3)\%$ (He 80c). At $E_p = 14.2$ MeV, capture radiation from the first $T = \frac{3}{2}$ state, $^{12}N^*(15.06)$ 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 (Sn 80): the E1 capture is found to be predominantly d-wave. See (Aj 81) 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 $^{13}N^*(3.55)$

TABLE 13.17

Resonances in $^{12}C(p, \gamma)^{13}N$ [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 (Aj 81) and 13.17 in (Aj 86).

[b]) (Ki 89i) [see for additional comments]. See also (Po 84l, Po 87h). *Please note*: The earlier work [see, e.g., Ro 74n] led to $E_p = 1699 \pm 2$ keV. It would be useful to confirm the new value of (Ki 89i). 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]) (Br 85b) 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. (Ki 89a) 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 (Ba 85mm).

[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}.

[$J^\pi = \frac{5}{2}^+$] 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 (Bl 84c) for $E_p \sim 25$ to 40 MeV. Differential cross sections (γ_0) have also been measured for $E_p = 28.35$ to 90 MeV (Ha 88b) [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 (Ej 86, Sh 86d; prelim.). See also (Zu 89).

The photon production cross section has been studied at $E_p = 168$ and 200 MeV (Pi 89a). For other high-energy γ-ray emission results see (Cl 90). The π^0 production cross section to $^{13}N_{g.s.}$ has been determined for $E_p = 154.5$ to 204 MeV (Ho 87m, Se 88f) and at 200 MeV (Be 89dd). See also (Ab 88a) [$E_p = 1$ GeV; charged pion production].

See also (An 82g, Na 84s, Iz 89), (Ha 86hh, Po 88f; applied), (Ar 85g, Ca 85t, Ro 87e, We 87a, Ca 88m, Ba 89ee, Gu 89i, Ka 89l; astrophysics), (Be 86q, Sn 86b, We 86b, He 87a, Bl 89a) and (Di 86, Mi 86j, Mi 86s, Re 87d, Ha 90f; theor.).

9. (a) ^{12}C(p, p)^{12}C — $E_b = 1.9435$
   (b) ^{12}C(p, 2p)^{11}B — $Q_m = -15.9572$
   (c) ^{12}C(p, pα)^{8}Be — $Q_m = -7.3666$

Yield 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 $E_p = 0.35$ to 0.55 MeV (Ho 86q), 1.6 to 1.9 MeV (Er 86d, Er 87b) and 5.0 to 7.5 MeV (Ro 87h; prelim.). A phase-shift analysis of the elastic scattering analyzing power for $E_{\vec{p}} = 11.5$ to 18.1 MeV shows four $T = \frac{1}{2}$ states with $E_x = 14.06$, 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 $E_{\vec{p}} = 19.15$ 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 $21 < E_x < 22$ 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 (Bl 85g, Op 89a, Ch 90) and (Sr 89b; theor.).

Cross sections for production of 4.4 MeV γ-rays have been determined for $E_p = 5.1$ to 23 MeV (Dy 81), 8.9, 20, 33, 40 and 50 MeV (Le 88b) and 22 to 85 MeV (La 87e, Sa 88e). 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., (La 87e). The cross sections for the (p, 2p) process (reaction (b)) from the $1p_{3/2}$ orbital and from the continuum have been measured at $E_p = 200$ MeV by (Co 89h, Pi 89i). See also (Te 89; prelim.). For other breakup processes see (Aj 86). For high-energy gamma-ray emission see (Cl 90). Total and inelastic cross sections have been measured at $E_p = 1.52$ and 1.8 GeV/c (Af 84). For a study of inclusive proton spectra at 150 MeV see (Se 85e). For π^+ emission see reaction 27 in ^{13}C. For an anti-proton study see (Ta 89aa). For a study at $E(^{12}\mathrm{C}) = 296$ to 1572 MeV/A see (We 90a).

The yield of bremsstrahlung and the shape of the energy spectrum have been studied for $E_p = 1.74$ to 1.93 MeV by (Er 86d, Er 87b, Er 90a). For other bremsstrahlung studies see (Aj 81, Aj 86) and (Ya 87h, Ya 88).

See also ^{12}C in (Aj 90), (Ba 85nn, Ch 86u, No 86, Sa 86gg, Vd 86a, Ba 87m, Li 87b, Mo 87, Ly 88, Ag 89a, Su 89e), (Ze 86c, Bo 90e; applied), (Ba 86nn, Ca 86b, Cl 86a, Gl 86, Mo 86o, St 86b, He 87a, Bo 88d, Hi 88h) and (Za 84c, Bo 85t, Pi 85c, Sh 85r, Zh 85b, De 86i, Ha 86, Ho 86d, Ka 86c, Lo 86, Sa 86ee, Vd 86c, Vi 86a, Za 86c, Zh 86, Ho 87a, Li 87, Mi 87, Pl 87b, Re 87b, Ro 87, Sc 87g, Za 87e, Zh 87a, Az 88a, Be 88g, Ho 88l, Ku 88i, Na 88c, Ru 88b, St 88f, Be 89y, Mi 89o, Ya 89c, Ca 90h, Ph 90a, Pi 90d; theor.).

10. (a) ^{12}C(p, n)^{12}N $\quad Q_m = -18.120 \quad E_b = 1.9435$
(b) ^{12}C(p, pn)^{11}C $\quad Q_m = -18.7215$

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 (Aj 81). 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 (An 82a), at 120, 160 and 200 MeV (Ra 81h) [see ref. 14 in (Wa 89c)], at 135 and 160 MeV (Wa 83u), at 144 MeV (Mo 79cc), at 200, 300 and 400 MeV (Wa 89c) and at 492 MeV (Ra 89b). Polarization measurements are reported at $E_{\vec{p}}$ = 160 MeV (Ta 84b; D_{NN}(0°); g.s.), 160 MeV

TABLE 13.18

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

E_p (MeV ± keV)	^{13}N* (MeV)	$\Gamma_{c.m.}$ (keV)	l_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	$\frac{7}{2}^-$	
					Γ_p/Γ =
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	$\frac{3}{2}^+$; $T=\frac{3}{2}$	
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	$\frac{5}{2}^-$; $T=\frac{1}{2}$	

TABLE 13.18—continued

E_p (MeV ± keV)	^{13}N* (MeV)	$\Gamma_{c.m.}$ (keV)	l_p	J^π	
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	22.4	~1000		$\frac{1}{2}^+$	
[h]					
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 (Aj 81) and 13.27 in (Aj 76).

[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 (Ba 80). 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 (Aj 81). See also (Ad 86b).

[d]) $\Gamma_p = 263 \pm 15$ eV (Th 80b). See discussion in (Br 81m): 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.

(Ra 87d; A_y; g.s.), 290 and 420 MeV (Hi 89c; A_y; quasifree), 494 MeV (Ta 88j, Ta 90c; A_y; quasielastic; prelim.) and at 590 MeV (Bi 89c). See also (Ga 89j) and (Aj 86). For continuum spectra at 200 MeV, see (Ni 88b; prelim.). For neutron yields at $E_p = 113$, 318 and 800 MeV, see (Me 86b, Me 86e, Me 89a; prelim.). For neutron production cross sections at $E_p = 585$ MeV, see (Ci 87, Fi 87a). See also reaction 9, and ^{12}C in (Aj 90).

Cross sections for reaction (b) have been measured to 300 GeV: see (Aj 81). See also ^{12}N in (Aj 90), (Na 84s, Ie 86a, Le 88b), (Ki 85k, Ta 87f, Hi 88f, Qu 90) and (Ba 88mm; theor.).

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

See (Aj 86).

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

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 $E_p = 17$ 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

TABLE 13.19

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

$E_{\vec{p}}$ (MeV)	A_y to ^{12}C* (MeV)	Refs.
21.1 → 83.8	g.s.	(Ie 87)
35	12.7, 15.1, 16.1	(Ie 90)
40	15.1	(Sh 86c) [b]
65	g.s.: spin rotation parameter	(Sa 86e) [b]
65	0, 4.4, 7.7, 9.6, 14.1	(Ka 85d)
71.2	g.s. [$A_y = 0.986 \pm 0.001$]	(Ev 90)
71.7	g.s.	(Pr 89e)
79 → 584	inclusive protons	(Mc 85b)
80	12.7, 15.1: spin transfer	(Ho 86a) [b]
156	(p, pα)	(Mu 89a) [b]
180, 190, 200	g.s. [D_{LL}, D_{SL}]	(We 90c) [b]
200	g.s.: spin rotation parameter	(St 85b, St 86d)
200	12.7: pol. transfer coeff.	(Wi 85e, Ol 86) [b]
250	g.s.	(Me 88)
290, 420	quasielastic; spin observables	(Ch 89c, Ch 90j)
300, 500	15.1: angular correlation	(Li 86g) [b]
303	inclusive	(Mo 87c)
319	inclusive inelastic [S_{nn}]	(Ba 90d)
400	12.7, 15.1, 16.1 [$P - A_y$]	(Hi 88)
500	g.s.	(Ho 90f)
500	12.7, 15.1, 16.1: pol. transfer observables	(Ch 90l) [b]
800	pol. transfer observables	(Fe 88c)
80 → 250 MeV/c	12.7: spin observables	(Op 89) [b]

[a]) For the earlier work see tables 13.26 in (Aj 70), 13.28 in (Aj 76), (Aj 81), and table 13.19 in (Aj 86).

[b]) Preliminary report.

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 (Aj 81). For polarization measurements see table 13.19 in (Aj 86). For α and ^{3}He emission at $E_p = 72$ MeV see (Wa 86n).

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

Angular distributions have been measured for $E_d = 0.5$ to 17 MeV [see (Aj 81, Aj 86)] and at 18 MeV (Ka 87i, Ka 88z: 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 (Aj 76). See also ^{14}N, (Ma 88q), (We 86c, Vi 88a, Ba 90i; applied) and (Bl 84h; theor.).

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

Angular distributions have been studied at $E(^3$He) to 81.4 MeV: see (Aj 81, Aj 86). The spectroscopic factors derived by (Pe 80i) 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 $^{13}N^{*}(9.0)$ (Pe 80i). For other values of S, see (Aj 81). 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 (Aj 81). For work at very high energies see (Ab 87e). See also (Aj 86) and (Bl 84h, Ka 89e; theor.).

15. $^{12}C(\alpha, t)^{13}N$ $\quad Q_m = -17.8705$

See (Aj 81) and (Ga 89d).

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

(Wo 88a) [and see reaction 9 in ^{5}He (Aj 88)].

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

Angular distributions have been obtained (reaction (a)) at $E(^{7}Li) = 36$ MeV [see (Aj 81)] and at 34 MeV (Co 86; $^{13}N^{*}(0, 3.5[u])$). $S_{g.s.} = 0.38 \pm 0.05$ (Co 86). See also (Al 88f). For reaction (b) see ^{12}B in (Aj 90).

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

At $E(^{12}C) = 93.8$ MeV angular distributions involving $^{13}N^{*}(0, 3.5[u])$ have been measured: see (Aj 86). See also (Wi 87, Ha 88m).

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

At $E(^{13}C) = 390$ MeV angular distributions have been studied involving $^{13}N^{*}(0, 3.5[u])$ and broad states at $E_x \sim 16$ 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 (Ad 87c, Vo 88e). See also the discussion in reaction 26 in ^{12}B (Aj 90) and (Le 89f).

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

See ^{13}C.

21. $^{13}C(\gamma, \pi^{-})^{13}N$ $\quad Q_m = -141.789$

Angular distributions have been studied at $E_{\gamma} = 163$ MeV (Sh 86e) and 223 MeV (Du 87d). (Sh 86e) find that the M1 component reproduces the experimental data, suggesting some suppression of the E0 component. See also (Aj 86) and (Er 90c; theor.).

22. $^{13}C(\pi^{+}, \pi^{0})^{13}N$ $\quad Q_m = 2.384$

The excitation function involving $^{13}N_{g.s.}$ (the isobaric analog state) has been studied at $E_{\pi^+} = 50$ to 343 MeV (Us 88b). An angular distribution is reported at $E_{\pi^+} = 165$ MeV involving the Δ-resonance (Ki 88e; prelim.). See also (Aj 86).

23. $^{13}C(\pi^+, \gamma)^{13}N$ $Q_m = 137.348$

Differential cross sections for γ_0 have been measured at $E_{\pi^+} = 115.5$ MeV: no evidence is observed for pion condensation (Ma 84w).

24. (a) $^{13}C(p, n)^{13}N$ $Q_m = -3.0028$
(b) $^{13}C(p, pn)^{12}C$ $Q_m = -4.94635$

Angular distributions have been measured for $E_p = 3.1$ to 800 MeV [see (Aj 81, Aj 86)] and at 18.6 MeV (Ka 88z; n_0, n_1), and 35 MeV (Oh 86c, Or 87; n_0, n_1, n_{2+3}) [also comparison with ^{13}C(p, p′) to mirror states], and at $E_{\bar{p}} = 160$ MeV (Ra 87d; n_0, n_{2+3}) [^{13}N*(11.7, 15.1) are also populated]. Forward-angle cross sections have been measured at $E_p = 318$ and 800 MeV (Ki 86c) and at 492 and 590 MeV (Ra 89b). For discussions of the Gamow–Teller strength see (Wa 85k, Ki 86c, Ta 87c, Ra 89b). For reaction (b) see (Aj 81). See also (Aj 86), ^{14}N, (Gu 85d, Al 87f, Ki 89c), (Ma 86n, Ar 89; applied), (Ca 88m; astrophysics), (Go 85m, Ca 86b, Ta 86b, Vo 86j, Be 87p, Go 87t, Li 87m, Ra 87k, Ta 87f, Ro 88n, Us 88b, Ra 89e) and (Pe 86h, Am 89a, Ra 89d; theor.).

25. $^{13}C(^3He, t)^{13}N$ $Q_m = -2.2391$

At $E(^3He) = 43.6$ 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 $^{13}C(^3He, ^3He)^{13}C$ 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 $E_x = 9.0$ MeV and with $\frac{1}{2}^-$ and $\frac{7}{2}^+$ for ^{13}N*(10.83, 16.02) (Pe 81e). An angular distribution has also been determined at $E(^3He) = 39.6$ MeV (Bu 87b; t_0). Cross sections (0°) involving ^{13}N*(0, 3.5) have been measured for $E(^3He) = 0.6$ to 2.3 GeV (Be 87p; see for ratios of the isovector strengths). For the earlier work see (Aj 81). See also (De 89l, Ja 89) and (Ro 88n).

26. (a) $^{13}C(^6Li, ^6He)^{13}N$ $Q_m = -5.727$
(b) $^{13}C(^7Li, ^7He)^{13}N$ $Q_m = -13.42$

Angular distributions to ^{13}N*(0, 3.50+3.55) have been measured at $E(^6Li) = 31.8$ MeV: see (Aj 81). These two reactions have been studied at $E(^6Li) = 93$ MeV and $E(^7Li) = 78$ MeV by (Gl 84f): ^{13}N*(0, 3.5, 7.3) are most intensively populated. Angular distributions to ^{13}N*(0, 3.5[u]) have also been reported (De 89s; $E(^6Li) = 93$ MeV). See also (Go 87j; theor.).

27. $^{13}O(\beta^+)^{13}N$ $Q_m = 17.767$

See ^{13}O and table 13.20.

28. $^{14}N(p, d)^{13}N$ $Q_m = -8.3289$

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 $E_p = 155.6$ MeV [see (Aj 81,

TABLE 13.20

Beta decay of ^{13}O [a]

Decay to		E_p (c.m.) (MeV) to		Relative intensity [a]	% of all β-decays [a]	$\log ft$ [b]
$^{13}N^*$ (MeV)	J^π	^{12}C(g.s.)	$^{12}C^*$(4.4)			
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		

[a]) (As 90). See also the earlier work by (Es 70). 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 intensity of 3.4 ± 1.4 to $^{12}C^*(4.4)$. I am indebted to Prof. F.C. Barker for this observation.

Aj 86)] and at $E_p = 18.6$ MeV (Va 87r, Be 89i; d_0). See also (Ar 89; applied), (Gu 89h; astrophysics) and (Gu 88c; theor.).

29. $^{14}N(d, t)^{13}N$ $\qquad Q_m = -4.2962$

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 $E_d = 52$ MeV and analyzed by DWBA. The spectroscopic factors for the ^{13}N states [and the mirror states reached in the $^{14}N(d, ^3He)^{13}C$ reaction] are in good agreement with theory and are additional evidence for the J^π assignments of $\frac{1}{2}^-, \frac{3}{2}^-, \frac{5}{2}^-, \frac{1}{2}^-, \frac{3}{2}^-$ and $\frac{3}{2}^-$ to these states: see (Aj 81). See also (Gu 87c, Gu 88c, Be 89i).

30. (a) $^{14}N(^3He, \alpha)^{13}N$ $\qquad Q_m = 10.0243$
(b) $^{14}N(^3He, p\alpha)^{12}C$ $\qquad Q_m = 8.0808$

Alpha-particle groups have been observed to the first seven excited states of ^{13}N, including two at $E_x = 7.166$ and 7.388 MeV [±8 keV]. Angular distributions have been studied at many energies up to $E(^3He) = 45$ MeV [see (Aj 81)] and at $E(^3He) =$ 22.7, 36.9 and 40.0 MeV (Va 87d, Be 89i; α_0). Reaction (b), studied at $E(^3He) =$ 8 MeV, appears to involve some states of ^{13}N, possibly $^{13}N^*(7.93, 8.92, 11.87)$: see (Aj 81). See also (Go 88d; theor.).

31. $^{14}N(^{6}Li, ^{7}Li)^{13}N$ $Q_m = -3.303$

An angular distribution has been measured at $E(^{6}Li) = 32$ MeV for the transition to $^{13}N_{g.s.}$ and $^{7}Li^*(0, 0.48)$. $^{13}N^*(2.36)$ was also populated: see (Aj 81).

32. $^{14}N(^{14}N, ^{15}N)^{13}N$ $Q_m = 0.2799$

See (Da 88f; theor.).

33. $^{15}N(\gamma, 2n)^{13}N$ $Q_m = -21.3868$

See ^{15}N (Mc 88a).

34. $^{15}N(p, t)^{13}N$ $Q_m = -12.9049$

At $E_p = 43.7$ MeV, angular distributions have been obtained for the tritons corresponding to the ground state of ^{13}N and the excited states at 3.50 ($\frac{3}{2}^-$), 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 (Aj 81) for references and other information.

35. $^{16}O(p, \alpha)^{13}N$ $Q_m = -5.2184$

Angular distributions of the α_0, α_1 and α_2 groups have been measured for E_p to 54.1 MeV: see (Aj 70, Aj 76). In addition the distribution of the α-particles to a state with $E_x = 12.13 \pm 0.06$ MeV, $\Gamma_{c.m.} \sim 300$ keV [$J^\pi = \frac{7}{2}^-$] is reported at 54.1 MeV: see (Aj 81). For additional work see (Aj 86). See also (Ki 89c), (Ar 89, Ba 90i; applied), (Ca 88m, Gu 89h; astrophysics) and (Ma 85l; theor.). For the (p, pt) reaction see (Go 86s; theor.).

36. $^{17}Ne(\beta^+)^{17}F \xrightarrow{\alpha} {}^{13}N$ $Q_m = 8.71$

See (Bo 88u).

^{13}O

(Figs. 3 and 4)

GENERAL† (An 85e, An 86u, Sa 87g, Ay 89a)

Mass of ^{13}O: We adopt the atomic mass excess of 23113 ± 10 keV of (Wa 88b). See also (Aj 81). ^{13}O is then bound with respect to $^{12}N + p$ and $^{11}C + 2p$ by 1.514 and 2.115 MeV, respectively.

† See also (Aj 86).

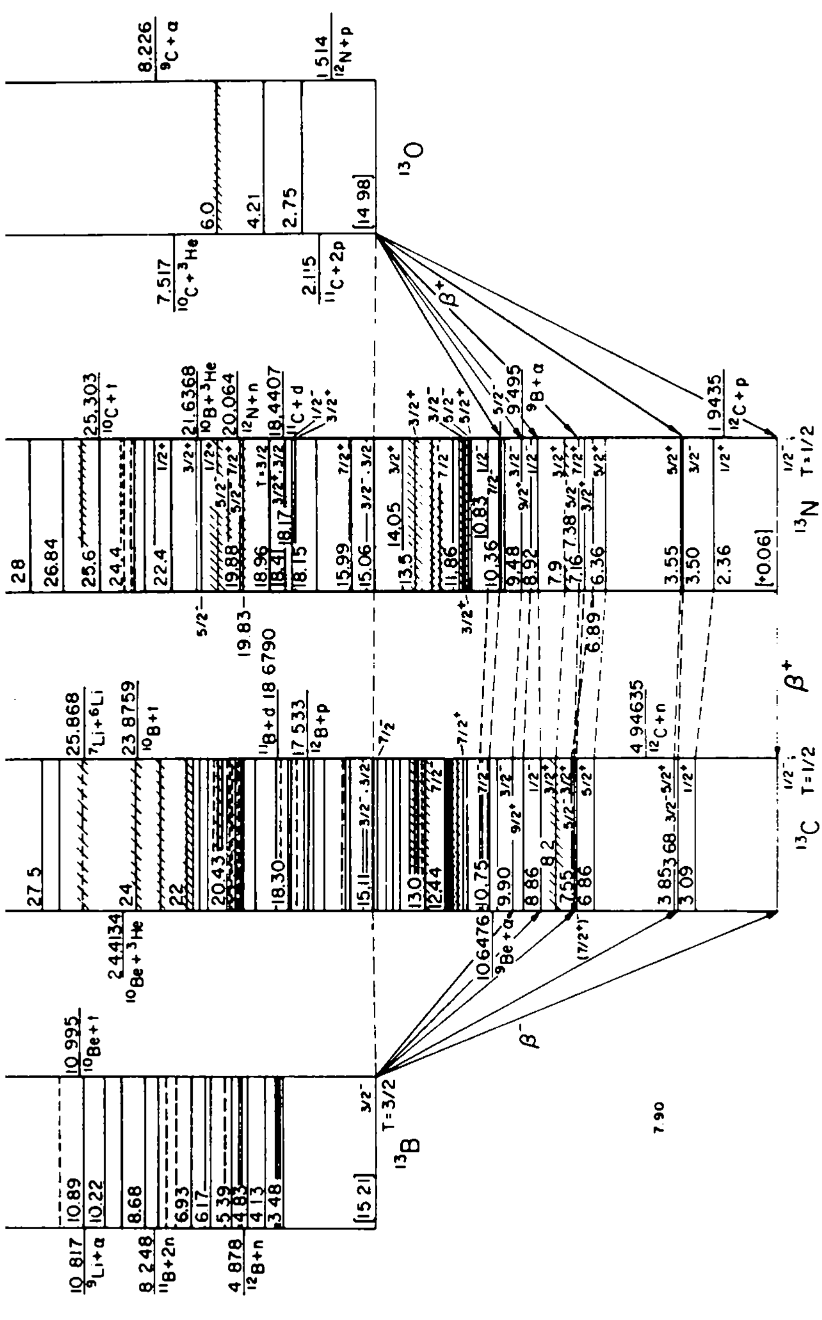


Fig. 4. Isobar diagram, $A = 13$. The diagrams for individual isobars have been shifted vertically to eliminate the neutron-proton mass difference and the Coulomb energy, taken as $E_c = 0.60Z(Z-1)/A^{1/3}$. Energies in square brackets represent the (approximate) nuclear energy, $E_N = M(Z,A) - ZM(H) - NM(n) - E_C$, 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 with dashed lines.

TABLE 13.21

Energy levels of ^{13}O

E_x in ^{13}O (MeV)	J^{π}; 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→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.

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

The half-life of ^{13}O has been reported to be 8.7 ± 0.4 ms (Mc 65g), 8.95 ± 0.20 ms (Es 70), 8.55 ± 0.05 ms (As 90): 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 (Wi 89c; astrophys.) and (Wo 89c; theor.).

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

At $E(^{13}C) = 380$ MeV ^{9}He*(0, 3.8) are populated (Bo 88k). The atomic mass excess of ^{9}He derived from this work is 41.5 ± 0.6 MeV. In calculating Q_m, we used the value 40.8 ± 0.1 MeV (Se 87a): see ^{9}He in (Aj 88).

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

At $E_p = 613$ MeV the ground state of ^{13}O and an excited state at $E_x = 2.82 \pm 0.24$ MeV are observed in addition to unresolved structures (Co 78m). [See fig. 4 for analog region in ^{13}B.] The angular distribution of the π^- to ^{13}O$_{g.s.}$ has been measured at $E_p = 200$ MeV (Ho 80m), as has A_y at $E_{\bar{p}} = 183$ MeV: see (Aj 86). For a study of inclusive pion production at $E_p = 180$ and 201 MeV see (Bi 85g). See also (Co 85d, Ku 86b, Ku 90a; theor.).

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

At $E_{\pi^+} = 164$ MeV excited states are reported at $E_x = 2.75 \pm 0.04$ and 4.21 MeV, as is a broad [$\Gamma = 1.2$ MeV] structure corresponding to one or more states at $E_x = 6.02 \pm 0.08$ 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}O$_{g.s.}$ and at 164 MeV to ^{13}O*(4.21) (Se 84g). 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 $E_x = 7.4 \pm 0.5$ MeV [$Q = -27.4 \pm 0.5$ MeV] (Mo 89b). See also (Mo 90).

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

See (Aj 81).

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

(Not illustrated)

These nuclei have not been observed. See (An 86u; theor.).

^{14}He

(Not illustrated)

^{14}He has not been observed: see (Og 89a).

^{14}Li

(Not illustrated)

^{14}Li has not been observed. The calculated mass excess is 72.29 MeV: see (Aj 81). ^{14}Li is then particle unstable with respect to decay into ^{13}Li + n and ^{12}Li + 2n by 3.9 and 3.2 MeV, respectively [see, however, ^{13}Li]. (Po 85f) calculate [in a $(0+1)\hbar\omega$ model space] that the first four states of ^{14}Li at 0, 0.75, 1.22 and 1.48 MeV have, respectively, $J^\pi = 2^-, 4^-, 3^-$ and 1^-. See also (Al 86g), (Og 89a) and (Po 88d; theor.).

^{14}Be

(Fig. 5)

^{14}Be has been observed in the ^{14}C(π^-, π^+)^{14}B reaction (Gi 84e), in the interaction of 30 MeV/A ^{18}O ions with ^{181}Ta (Cu 86) and in the spallation of thorium by 800 MeV protons (Wo 88c). See also (Aj 86). The atomic mass excess reported by (Gi 84e) is 40.10 ± 0.13 MeV but it is not clear that the ground state was observed. (Wo 88c) report an atomic mass excess of 39.74 ± 0.14 MeV which we adopt. ^{14}Be is then bound by 3.0 and 1.12 MeV, respectively, with respect to decay into ^{13}Be + n and ^{12}Be + 2n [see, however, ^{13}Be].

^{14}Be decays by β^- emission to states in ^{14}B. Its half-life is 4.2 ± 0.7 ms (Cu 86), 4.35 ± 0.17 ms (Du 88d). We adopt the latter value. The branching ratios for 0n, 1n and 2n emission are 0.14 ± 0.03, 0.81 ± 0.04 and 0.05 ± 0.02 (Du 88d). We remind the reader that the two bound states of ^{14}B are the ground state [$J^\pi = 2^-$] and an excited state with $J^\pi = (1^-)$. The binding energies of 1n and 2n in ^{14}B are, respectively, 0.97 and 5.85 MeV: see fig. 5.

The interaction cross section at 790 MeV/A for ^{14}Be ions on C is reported by (Ta 88d) who also derive the interaction and the r.m.s. radii for the nucleon distribution in ^{14}Be. See also (Be 89a; theor.) and (Sa 89g). A calculation in a $(0+1)\hbar\omega$ model space suggests that the first four states of ^{14}Be calculated to be at 0, 1.95, 3.67 and 5.30 MeV have $J^\pi = 0^+, 2^+, 4^+, 2^+$, respectively (Po 85f). See also (An 86u,

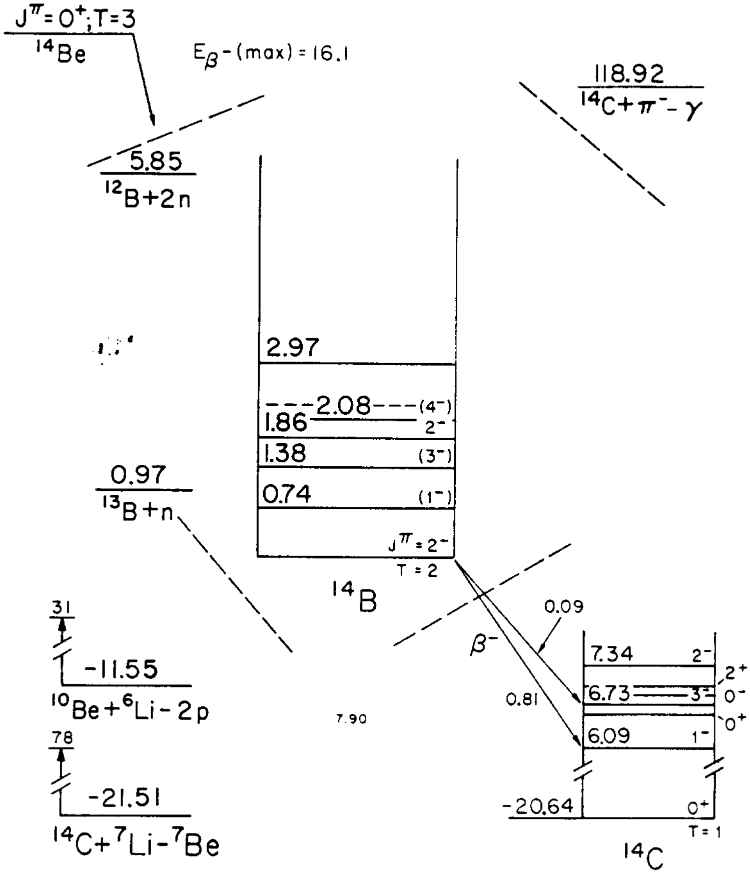


Fig. 5. Energy levels of ^{14}B. For notation see fig. 2.

Wi 86g, Aj 87a, Mi 88f, Ta 88n, Aj 89a, De 89v, Ta 89f, Ta 89q, Vo 89b) and (Bl 87j, Sa 87g, Ya 87l, Po 89g, Br 90c, Lo 90c; theor.).

^{14}B

(Figs. 5 and 9)

GENERAL[†]

Complex reactions involving ^{14}B: (Bi 86f, Sa 87m, As 88b, Ru 88, As 89, Yo 89)

Pion capture and reactions: (As 83, As 84a)

Hypernuclei: (Me 86c, Ma 88f, Ba 89cc)

[†] See also (Aj 86).

Other topics: (Va 84, An 86u, Po 89g, Re 90a)

Ground state of ^{14}B: (Va 87n, Lo 90c)

Interaction cross sections at 790 MeV/A for ^{14}B ions on Be, C and Al are reported by (Ta 88d) [see also for interaction and r.m.s. radii for the nucleon distribution in ^{14}B]. See also (Sa 89g).

1. $^{14}B(\beta^-)^{14}C$ $\qquad Q_m = 20.64$

^{14}B has a half-life of 16.1 ± 1.2 ms (Al 74), 12.8 ± 0.8 ms (Cu 86): the weighted mean is 13.8 ± 1.0 ms and we adopt it. The nature of the decay [see table 14.2] fixes J^π of ^{14}B to be 2^- (Al 74). See also (Po 89g; theor.).

2. $^{14}C(\pi^-, \gamma)^{14}B$ $\qquad Q_m = 118.92$

A single strong transition is observed in this pion capture cross section to a state in ^{14}B at $E_x = 2.15 \pm 0.17$ MeV, $\Gamma = 1.0 \pm 0.5$ MeV, with $J^\pi = 2^-$. The relative branching ratio of the ground state [2^-] to this second 2^- state is <0.1. The data are also suggestive of the population of 2^- and 1^- states in the $E_x = 5$-7 MeV region (Ba 83v).

3. $^{14}C(n, p)^{14}B$ $\qquad Q_m = -19.86$

Ground-state angular distributions have been reported at $E_n = 65$ MeV (Dr 86d, Dr 88a; prelim.).

4. $^{14}C(^7Li, ^7Be)^{14}B$ $\qquad Q_m = -21.51$

^{14}B states with $0 < E_x < 3$ MeV have been populated in this reaction at $E(^7Li) = 52$ MeV: see table 14.1. Similarities in the relative intensities of ^{14}B*(0, 0.74, 1.38,

TABLE 14.1
Energy levels of ^{14}B

E_x (MeV ± keV)	J^π; T	$\tau_{1/2}$ (ms) or Γ (MeV)	Decay	Reactions
g.s. [a])	2^-; 2	$\tau_{1/2} = 13.8 \pm 1.0$ ms	β^-	1, 3→5
0.74 ± 40	(1^-); 2			4
1.38 ± 30	(3^-); 2			4
1.86 ± 70 [b])	2^-; 2	$\Gamma = 1.0 \pm 0.5$ MeV		2, 4
2.08 ± 50	(4^-); 2			4
(2.32 ± 40)				4
2.97 ± 40				4
[c])				

[a]) See also footnote [c]) to table 14.3.

[b]) It is not clear that the states reported in reactions 2 and 4 are the same states. The level structure of ^{14}B should be studied further. I am indebted to Prof. F.C. Barker for his comments.

[c]) See reaction 2.

TABLE 14.2

Beta decay of ^{14}B [a])

Decay to $^{14}C^*$ (MeV)	J^π	Branch (%)	$\log ft$ [e])
0	0^+	(5 ± 3) [c])	(6.1 ± 0.3)
6.09 [b])	1^-	81 ± 9	4.16 ± 0.06
6.73	3^-	$8.6^{+1.7}_{-4.0}$	$5.04^{+0.27}_{-0.08}$
7.34	2^-	<11 [d])	>4.8

[a]) (Al 74).

[b]) $E_{\beta^-}(\max) = 14.0 \pm 0.7$ MeV to this state.

[c]) This branch has not been observed. It is assumed to be (5 ± 3)% in the calculation of the branching ratios to $^{14}C^*(6.09, 6.73)$.

[d]) This branch has not been observed: the upper limit is shown. In the calculations of the branching ratios to $^{14}C^*(6.09, 6.73)$ a value (5 ± 5)% was used.

[e]) M.J. Martin, private communication.

1.82, 2.08) and of $^{12}B^*(1.67, 2.62, 3.39, 4.30, 4.52)$ [populated in $^{12}C(^7Li, ^7Be)^{12}B$], and the similarity in the ΔE_x of these ^{12}B states with the E_x of the ^{14}B states suggest that they have the same J^π (Ba 731).

5. $^{14}C(^{14}C, ^{14}N)^{14}B$ $\qquad Q_m = -20.49$

The work quoted in (Aj 86) has not been published.

^{14}C

(Figs. 6 and 9)

GENERAL[†]

Nuclear models: (Kw 85, Mi 85s, Gu 86d, Ki 87e, Fl 88, Wo 88, Po 89g, Si 89c, Wo 89c)

Special states: (Ba 85mm, Go 85v, An 86u, Bl 87f, Bl 87j, Ki 87e, Am 89, Ra 89g)

Electromagnetic transitions and giant resonances: (Va 84, Go 85v, Er 86, Ho 87g, Ki 87e, Ra 87, Am 89, Ra 89f, Sp 89a)

Astrophysical questions: (Wo 82h, Co 86l, Ha 86cc, Ha 87q, Ma 87l, Ma 87w, Ap 88, Ap 88a, Be 88a, Bo 89h, Gu 89k, Ka 89b, Me 89, St 89, Wh 89a, Oe 90, Th 90a)

Applied work: (Ba 85ss, Go 85q, Ci 86a, Cs 86b, Do 86c, Ef 86, Ho 86o, Ki 86a, Ko 86r, Sr 86, Su 86a, Ar 87l, Ba 87jj, Ba 87kk, Bo 87s, Cu 87d, Du 87g, Ga 87d,

[†] See also (Aj 86).

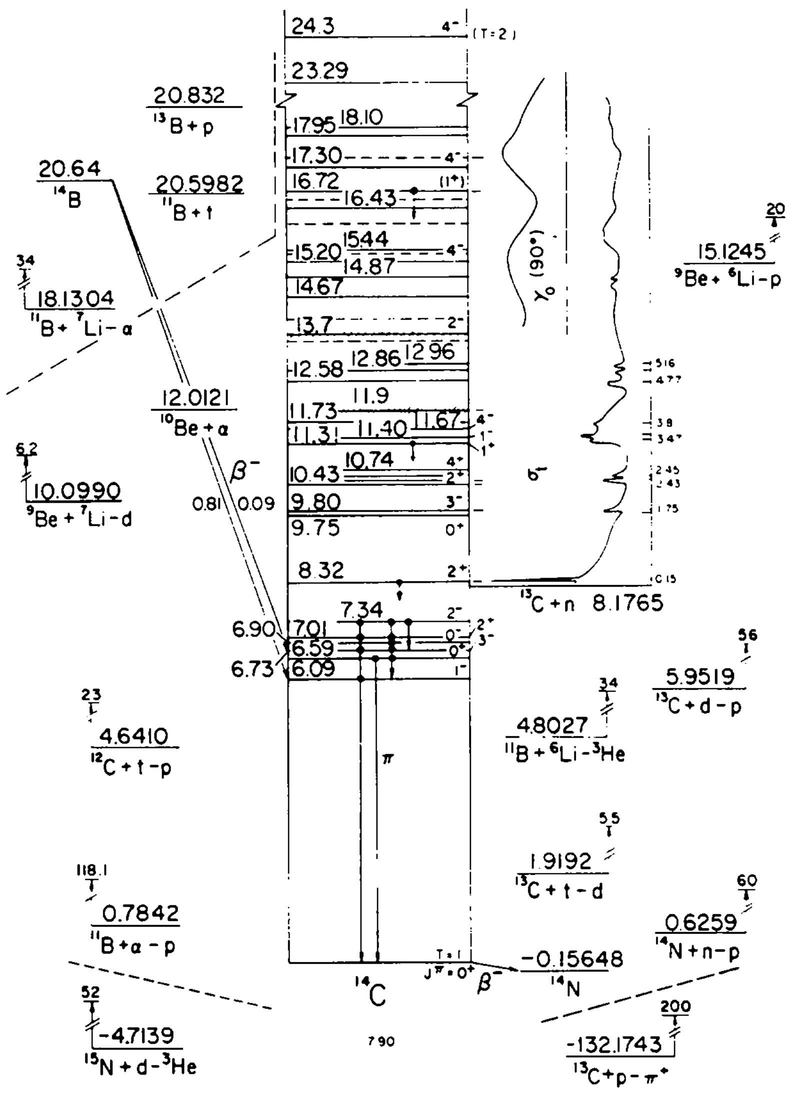


Fig. 6. Energy levels of ^{14}C. For notation see fig. 2.

Go 87u, He 87e, He 87f, Ho 87e, Ja 87e, Ki 87d, Ko 87u, Kr 87m, Ku 87b, Lo 87d, Ma 87bb, Na 87l, Na 87m, Oe 87, Os 87d, Po 87i, Re 87g, Se 87c, Sl 87, Ta 87g, Va 87p, Do 88c, El 88b, Ju 88a, Pu 88a, Su 88e, Lo 89d, Mu 89, Do 90, Sa 90a)

Complex reactions involving ^{14}C: (Al 85o, Ba 85ss, Be 85o, Br 85m, Ho 85l, Ka 85h, Ka 85i, Ka 85j, Ku 85j, Kw 85a, Po 85b, Po 85d, Po 85e, Si 85d, Vi 85a, Ba 86v, Bi 86f, Cs 86, De 86o, Ha 86bb, Ir 86a, Me 86d, Pa 86j, Pi 86d, Po 86d, Po 86k, Pr 86c, So 86d, Ut 86, Ba 87w, Bl 87b, Bu 87c, Bu 87e, Gu 87a, He 87g, Iv 87, Na 87, Po 87b, Po 87j, Pr 87d, Ri 87b, Ru 87b, Ru 87c, Sh 87a, Sn 87, Vi 87a, Ya 87l, Ba 88a, Be 88ii, Bl 88f, Ca 88, Iv 88b, Jo 88a, Pr 88a, Ru 88, Sa 88h, Sa 88p, Sa 88y, Sh 88i, Ba 89cc, Br 89n, Bu 89b, Bu 89c, Bu 89f, Bu 89g, Ci 89, Ci 89a, Fl 89, Gi 89a, Gr 89e, Gu 89, Ho 89e, Ki 89f, Ma 89c, Ma 89s, Po 89e, Po 89i, Pr 89b, Pr 89d, Pr 89f, Sa 89e, Sa 89g, Sa 89r, Sh 89o, Te 89b, Yo 89, Ar 90, Bu 90a, Bu 90b, Hu 90b, Og 90, Sh 90b, We 90b, Ya 90b)

Muon and neutrino capture and reactions†: (Ko 85v, Mu 89f, Ko 90b)

Pion and kaon capture and reactions‡: (Al 85g, Ba 85z, Ch 85n, Ko 85z, Tu 85e, Ba 86kk, Be 86l, Bo 86u, Ce 86, Dy 86, Er 86, Fe 86b, Fo 86c, Ge 86b, Gi 86a, Ma 86f, Si 86e, Su 86i, Wu 86b, Ba 87z, Bl 87f, Do 87, Gi 87f, Jo 87a, Ka 87cc, Ko 87q, Mi 87a, Ro 87b, Ba 88ee, Ba 88tt, Ha 88y, Ko 88u, Le 88f, Mi 88k, Oh 88a, Os 88, Pa 88e, Ro 88l, Ti 88, Yu 88, Ch 89w, Di 89a, Do 89i, Jo 89a, Le 89c, Si 89a, Si 89c, Ha 90b)

Hypernuclei: (Zh 84b, An 86s, Da 86b, Fe 86b, Ko 86i, Ma 86f, Wu 86b, Mi 87b, Po 87e, Ma 88f, Ba 89cc, Ba 89hh, Do 89i, Ge 89b)

Other topics: (An 85e, Ma 85r, An 86u, Aj 87a, Fl 88, Aj 89a, De 89j, Po 89h, Ya 90)

Ground state of ^{14}C: (An 85e, Go 85v, Mi 85s, He 86h, Bl 87j, Ki 87e, Sa 87g, Va 87n, Va 88, Wo 88, Wr 88, An 89c, Go 89b, Sa 89g, Ta 89, Wo 89c)

$$\langle r^2 \rangle^{1/2} = 2.4962(19)\ \text{fm (Sc 82e)}.$$

Adopted values from (Ra 87, Ra 89f):

$$B(E2)\uparrow\ (\text{to } ^{14}C^*(7.01)) = 0.00187(25)\ e^2 \cdot b^2,$$

$$Q_0 = 0.137(9)\ b.$$

1. $^{14}C(\beta^-)^{14}N$ $\qquad Q_m = 0.15648$

The adopted value of the half-life is 5730 ± 40 y: see (Aj 76). Using Q_m, $\log ft = 9.04$ (Go 71t). For discussions of the lifetime of ^{14}C see (Aj 59, Aj 70, Aj 76). See also (Ji 88c, Wr 88, Do 89l, Po 89g, Sa 89j, Wo 89c; theor.). For the internal bremsstrahlung spectrum see (Ra 88n).

2. (a)	$^7Li(^7Li, n)^{13}C$	$Q_m = 18.618$	$E_b = 26.794$
(b)	$^7Li(^7Li, p)^{13}B$	$Q_m = 5.962$	
(c)	$^7Li(^7Li, d)^{12}B$	$Q_m = 3.309$	
(d)	$^7Li(^7Li, t)^{11}B$	$Q_m = 6.196$	
(e)	$^7Li(^7Li, \alpha)^{10}Be$	$Q_m = 14.782$	
(f)	$^7Li(^7Li, ^7Li)^7Li$		

† See also reaction 32 in (Aj 86).

‡ See also reactions 15, 23, 31 and 32.

TABLE 14.3

Energy levels of ^{14}C [a])

E_x in ^{14}C (MeV ± keV)	J^π; T	τ or $\Gamma_{c.m}$	Decay	Reactions
g.s.	0^+; 1	$\tau_{1/2}=5730\pm40$ y	β^-	1, 3, 4, 6→12, 15→28, 30→39
6.0938 ± 0.2 [b])	1^-	$\tau_m<10$ fs	γ	3, 4, 6→8, 12, 15, 16, 18, 20, 22, 23, 26, 35, 38
6.5894 ± 0.2 [b])	0^+	4.3 ± 0.6 ps	γ	3, 4, 6, 8, 12, 16
6.7282 ± 1.3 [b])	3^-	96 ± 11 ps $\lvert g\rvert=0.272\pm0.007$	γ	3, 4, 6→9, 15, 16, 18, 20, 22→24, 26, 28, 35, 38
6.9026 ± 0.2 [b])	0^-	36 ± 4 fs	γ	3, 4, 7, 8, 12, 16, 18, 22
7.0120 ± 4.2 [b])	2^+	13 ± 2 fs	γ	3, 4, 6→8, 15, 16, 18, 22→24, 26, 38, 39
7.3414 ± 3.1 [b])	2^-	160 ± 60 fs	γ	3, 4, 7, 8, 15, 16, 18, 20, 22, 26, 35, 38
8.3179 ± 0.8	2^+	$\Gamma=3.4\pm0.7$ keV	γ, n	3, 4, 6→9, 12, 13, 15, 16, 22, 23, 26, 32, 34, 35, 39
9.746 ± 7	0^+			8, 38
9.801 ± 6	3^-	45 ± 12	γ, n	3, 6→8, 13, 15, 16, 22, 26, 38
10.425 ± 5	2^+		n	3, 6, 8, 13, 15, 16, 22, 26, 38
10.449 ± 7	≥1		n	3, 6→8, 13, 15, 38
10.498 ± 4	(3^-)	26 ± 8	n	3, 7, 8, 13, 15, 16, 23, 38
10.736 ± 5	4^+	20 ± 7		3, 6→9, 15, 16, 26, 32
11.306 ± 15	1^+	46 ± 12	γ, n	3, 6, 13, 21, 22, 26, 38
11.395 ± 8	1^-	22 ± 7	n	3, 6→8, 16, 26
(11.5)	1^-+2^-	broad	n	13
11.666 ± 10	4^-	20 ± 7	γ	3, 6→9, 15, 16, 22→24, 26, 38
11.730 ± 9	(5^-)			3, 6→9, 15, 23
11.9 ± 300	(1^-)	950 ± 300	n	13, 16
12.583 ± 10	$(2^-, 3^-)$	95 ± 15	n	3, 7, 8, 13, 16, 23, 26, 38
12.863 ± 8		30 ± 10	n	3, 7, 8, 13, 16, 22
12.963 ± 9	(3^-)	30 ± 10	n	3, 7, 8, 13, 16, 26
(13.50 ± 100)		<200		15
13.7	2^-	~1800	n	13
(14.05 ± 100)		<200		15
14.667 ± 20	(4^+)	57 ± 15	n	3, 6, 7, 13
14.868 ± 20	$(6^+, 5^-)$			3, 6→9, 15, 38
15.20 ± 23	4^-			3, 6, 7, 15, 22, 23
(15.37 ± 30)				3
15.44 ± 40	(3^-)		n	3, 13
(16.02 ± 50)	(4^+)		n	3, 13
16.43 ± 16				3, 6→8
(16.57 ± 40)				3
16.715 ± 30	(1^+)	~200	γ, n	3, 6, 12
17.30 ± 30	4^-		γ	3, 6, 7, 22→24
(17.5)	(1^+)	≃200	γ, n	12
17.95 ± 40				3
18.10 ± 40				3
18.5		broad		15

TABLE 14.3—continued

E_x in ^{14}C (MeV ± keV)	J^{π}; T	$\Gamma_{c.m.}$	Decay	Reactions
20.4		wide		33
(21.4)				6
22.1 ± 100	(2^-; $T=2$) [c]		γ	22
23.288 ± 15 [d]		~50		6, 15
24.4 ± 100	4^-; ($T=2$)	<300	γ	22, 23
24.5		wide		15, 23

[a]) See also tables 14.4 here and in (Aj 86), as well as tables 14.8 and 14.9 and reaction 22.
[b]) See also reaction 16.
[c]) If this is the isobaric analog state of $^{14}B_{g.s.}$ then the ^{14}B-^{14}C Coulomb energy difference is calculated to be 2.25 ± 0.10 MeV (Pl 89c).
[d]) See also reactions 6 and 15.

TABLE 14.4

Branching ratios of γ-rays in ^{14}C [a])

E_i (MeV)	J_i^{π}	E_f (MeV)	Branch (%)
6.09	1^-	0	100
6.59	0^+	0	1.1 ± 0.1 [b])
		6.09	98.9 ± 0.1 [c])
6.73	3^-	0	96.4 ± 1.2
		6.09	3.6 ± 1.2
6.90	0^-	6.09	100 [d])
7.01	2^+	0	98.6 ± 0.7
		6.09	1.4 ± 0.7
7.34	2^-	0	16.7 ± 3.5
		6.09	49.0 ± 3.1 [e,f])
		6.73	34.3 ± 3.5 [e])

[a]) For references see table 14.5 in (Aj 81). For the decay of ^{14}C*(8.32) see reaction 12.
[b]) Internal pairs. $\Gamma_{\pi}/\Gamma = (1.1 \pm 0.1) \times 10^{-2}$, $\langle M \rangle_{\pi} = 0.36 \pm 0.06$ fm^2.
[c]) $E_{\gamma} = 495.35 \pm 0.10$ keV (Ko 81d).
[d]) $E_{\gamma} = 808.7 \pm 1.0$ keV.
[e]) δ(M2/E1) = −0.04 ± 0.09 and +0.07 ± 0.30, respectively.
[f]) $E_{\gamma} = 1248 \pm 3$ keV.

For $E(^7\text{Li}) = 2.3$ to 5.8 MeV, the cross section for emission of α_0, α_1 and α_{2+3+4} is found to increase monotonically with energy. There is a report of several broad structures in the 0° yield of α_0 and α_1 for $E(^7\text{Li}) = 2$ to 20 MeV: it is suggested that they are due to a forward-direction cluster transfer process: see (Aj 76) for references. For other work see (Aj 70, Aj 86). For reaction (a) see also (Sc 87c).

3. ^{9}Be(^{6}Li, p)^{14}C $Q_m = 15.1245$

Observed proton groups are displayed in table 14.5. See also ^{15}N.

4. ^{9}Be(^{7}Li, d)^{14}C $Q_m = 10.0990$

TABLE 14.5

Levels of ^{14}C from ^{9}Be(^{6}Li, p)^{14}C [a])

E_x (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	$2J_f+1$ [b])	J^{π} [c])
6.089 ± 10		2.5 [3]	
6.588 ± 10		1.0 [1]	
6.726 ± 10		7.6 [7]	
6.899 ± 10		1.1 [1]	
7.016 ± 10		4.5 [5]	
7.341 ± 10		5.2 [5]	
8.318 ± 10	22 ± 6	5.1	2^+
9.796 ± 10	45 ± 12	7.7	3
10.441 ± 15		10.8	$2^+ + 3$
10.512 ± 15	26 ± 8	9.1	4
10.743 ± 15	20 ± 7	15.4	
11.306 ± 15	46 ± 12	2.4	1^-
11.397 ± 15	22 ± 7	6.2	$2^+, 3$
11.667 ± 15	20 ± 7	12.4	5^-
11.74 ± 20			
12.57 ± 25	80 ± 20	15.1	
12.867 ± 20	30 ± 10	10.4	4, 5
12.970 ± 20	30 ± 10	7.8	3, 4
14.667 ± 20	57 ± 15		$2^+, 3, 4, 5, 6^+$
14.867 ± 25			
15.19 ± 30			
(15.37 ± 30)			
15.44 ± 40			
(16.02 ± 50)			
16.411 ± 20			
(16.57 ± 40)			
16.715 ± 30			
(17.28 ± 40)			
17.95 ± 40			
18.10 ± 40			

[a]) (Aj 73b): $E(^{6}\text{Li}) = 20$ MeV. See table 14.6 in (Aj 81) for additional information on cross sections and reduced widths.

[b]) The first number gives $2J_f+1$, based on a best fit to the experimentally determined values for the cross section of the states with known spins. These $2J_f+1$ values are determined to ±10%, except for the last six values which are determined to ±20%. The second number, in brackets, gives $2J_f+1$ derived from the J_f assignments shown in table 14.3.

[c]) Suggested from the $2J_f+1$ rule and comparison of predicted neutron width with observed $\Gamma_{c.m.}$ assuming $0.01 < \theta_n^2 < 1.0$.

Angular distributions have been measured at $E(^7Li) = 5.6$ to 6.2 MeV for the deuterons to ^{14}C*(0, 6.09, 6.59+6.73, 6.90+7.01, 7.34, 8.32). Gamma rays with $E_\gamma = 6094.5 \pm 3.2$, 6728.1 ± 1.4 and 7011.7 ± 5.2 keV have been reported: see (Aj 81) for references. For τ_m and E_γ measurements see tables 14.4 in (Aj 86) and 14.4 here (Ko 81d) [see this reference for an extensive study of electromagnetic transitions in ^{14}C and ^{14}N].

5. (a) $^{11}B(t, n)^{13}C$ $Q_m = 12.4217$ $E_b = 20.5982$
   (b) $^{11}B(t, \alpha)^{10}Be$ $Q_m = 8.5861$

For possible resonant structure in (a) see (Aj 76). For reaction (b) see (Aj 81, Aj 86). See also (Ha 90f).

6. $^{11}B(\alpha, p)^{14}C$ $Q_m = 0.7842$

Angular distributions of p_0 have been measured at $E_\alpha = 1.43$ to 31.2 MeV: see (Aj 76, Aj 81, Aj 86). At $E_\alpha = 118.1$ MeV angular distributions have been studied [DWBA analysis] to ^{14}C*(6.09, 6.59, 6.73, 7.01, 8.32, 9.80, 10.43 [u], 10.74, 11.38 [u], 11.7 [u], 14.67, 14.87, 15.20, 16.43, 16.72, 17.30, 21.40 [u?]). It is suggested that one of the states at 11.7 MeV has $J^\pi = 4^-$ and the other $J^\pi = (1, 2, 3)^-$, and that the state at 16.43 has $J^\pi = 6^-$ (An 87a). At $E_\alpha = 48$ MeV an angular distribution is reported to a state at $E_x = 23.288 \pm 0.015$ MeV with $\Gamma_{lab} = 70 \pm 3$ keV. The sharpness of the state suggests that J is large, and that perhaps it is a 7^- state (Br 88l, and J.D. Brown, private communication). A search has been made for an 8^- state up to 26 MeV (at 20°): the upper limit for its strength is 0.2 that for the 23.29 MeV state (J.D. Brown, private communication). See also ^{15}N, (Br 89e) and (Ca 88m; astrophys.).

7. (a) $^{11}B(^6Li, ^3He)^{14}C$ $Q_m = 4.8027$
   (b) $^{11}B(^7Li, \alpha)^{14}C$ $Q_m = 18.1304$

Below $E_x = 10.4$ MeV, ^{14}C*(6.09, 6.73, 6.90+7.01, 7.34, 8.32, 9.78) are observed in both reactions at $E(Li) = 34$ MeV (Cl 84a): the states observed at higher excitation energies are displayed in table 14.6. The intensities of the ^{3}He and α groups in the two reactions are significantly different. Comparison of the angular distributions in reaction (a) and in the analog reaction $^{11}B(^6Li, t)^{14}N$, as well as other data, leads to the assignment of analog pairs: see reaction 11 in ^{14}N. It is suggested that ^{14}C*(11.73) and not ^{14}C*(11.67) is populated in the inelastic pion scattering (Cl 84a). For the earlier work on reaction (b), see (Aj 76).

8. $^{12}C(t, p)^{14}C$ $Q_m = 4.6410$

Observed proton groups are displayed in table 14.7. Angular distributions have been measured at $E_t = 5.5$ to 23 MeV [see (Aj 81)] and at 33 MeV (Co 86o; prelim.; to ^{14}C*(6.09, 6.6 [u], 7.01, 8.31, 10.5 [u], 14.87, 16.43). For other results see (Aj 86). See also ^{15}N.

TABLE 14.6

States in ^{14}C from ^{11}B(^{6}Li, ^{3}He) and ^{11}B(^{7}Li, α) [a])

E_x (MeV ± keV) [b])	E_x (MeV ± keV) [b])
10.47 ± 15 [c])	12.96 ± 30
10.74 ± 15 [d])	14.67 ± 30
11.40 ± 20 [e])	14.87 ± 30
11.66 ± 15	15.21 ± 30
11.73 ± 15	16.45 ± 25 [e])
12.58 ± 30	17.32 ± 40
12.86 ± 30	

[a]) (Cl 84a): E(Li) = 34 MeV. See for angular distributions and for discussion of analog states in ^{14}N. See also reaction 11 in ^{14}N.

[b]) States below E_x = 10.4 MeV are not displayed here.

[c]) Unresolved.

[d]) Differential cross section at 10° in ^{11}B(^{6}Li, ^{3}He) is much higher than in ^{11}B(^{7}Li, α).

[e]) More strongly populated in ^{11}B(^{7}Li, α).

9. ^{12}C(α, 2p)^{14}C $\qquad Q_m = -15.1731$

At $E_\alpha = 65$ MeV angular distributions have been measured to ^{14}C*(0, 6.73 ± 0.02, 8.40 ± 0.14, 10.69 ± 0.05, 11.69 ± 0.06[u], 14.84 ± 0.4). The two most strongly populated states (or groups of states) are ^{14}C*(6.73, 10.69). $J^\pi = 1^-$ and $(6^+, 5^-)$ are favored for ^{14}C*(11.69, 14.84). For the latter 4^+ is considered to be very unlikely: see (Aj 86). See also (Aj 81) for the earlier work.

10. ^{12}C(^{14}N, ^{12}N)^{14}C $\qquad Q_m = -17.495$

See (Ba 86k, El 86d, Ro 86a).

11. ^{12}C(^{18}O, ^{12}C)^{18}O* $\xrightarrow{\alpha}$ ^{14}C $\qquad Q_m = -6.2270$

See ^{18}O in (Aj 87).

12. ^{13}C(n, γ)^{14}C $\qquad Q_m = 8.1765$

The thermal capture cross section is 1.37 ± 0.04 mb (Mu 82e). The decay is primarily to ^{14}C*(0, 6.59) [(84.0 ± 2.3)%, (8.5 ± 0.5)%] with weaker branches to ^{14}C*(6.09, 6.90) [(2.5 ± 0.5)%, (4.9 ± 1)%]. Gamma rays with E_γ = 8173.92, 6092.4 ± 0.2, 2082.6 ± 0.3, 1586.8 ± 0.2, 1273.9 ± 0.2, 808.9 ± 0.2 and 495.4 ± 0.3 keV have been observed: E_x = 6093.8 ± 0.2, 6589.4 ± 0.2 and 6902.6 ± 0.2 keV are reported for ^{14}C*(6.09, 6.59, 6.90). The neutron capture yield for E_n = 95 to 235 keV shows a resonance at E_n = 152 ± 1 keV, Γ_{lab} = 5 ± 1 keV: see table 14.8 in (Aj 81). A revised value of Γ_γ is 2.4 ± 0.9 eV [see R.L. Macklin quoted in (Ra 90a)]. A recent remeasurement of the on- and off-resonance capture determines the following Γ_γ (in meV)

TABLE 14.7

^{14}C states from $^{12}C(t,p)^{14}C$ [a])

E_x [b]) (MeV ± keV)	E_x [c]) (MeV ± keV)	L [b,c])	J^{π}
−0.006 ± 10	0	0	0^+
6.087 ± 10	6.099 ± 10	1	1^-
6.577 ± 10	6.589 ± 10	0	0^+
6.725 ± 10	6.731 ± 10	3	3^-
6.895 ± 10	6.899 ± 10	weak	
≡7.012	7.017 ± 10	2	2^+
7.336 ± 10	7.342 ± 10	weak	
8.307 ± 12	8.315 ± 10	2	2^+
9.746 ± 7 [d])		0	0^+
9.809 ± 10 [d])	9.80 ± 20 [e])	(1)	(1^-)
10.425 ± 6 [d])	10.419 ± 20	2	2^+
10.448 ± 10			
10.498 ± 4 [d])	10.492 ± 20	(3)	(3^-) [f])
10.736 ± 5 [d])	10.730 ± 20	4	4^+
11.398 ± 10	11.377 ± 20	1	1^-
11.665 ± 13	11.647 ± 30	(1)	(1^-)
11.727 ± 10	[e])	(5)	(5^-)
12.580 ± 12		(2, 3)	$(2^+, 3^-)$
12.867 ± 10	12.849 ± 20	2, 3	$2^+, 3^-$
12.963 ± 10	12.945 ± 30	(1)	(1^-)

[a]) See also tables 14.5 in (Aj 76) and 14.7 in (Aj 81), and (Fo 82a), and reaction 8.

[b]) $E_t = 18$ MeV (Mo 78h, Mo 78k).

[c]) $E_t = 23$ MeV (Aj 78a).

[d]) The widths for $^{14}C^*$(9.75, 9.81, 10.43, 10.50, 10.74) are, respectively 18, 40, 14, 18 and 15 keV (Mo 78h, Mo 78k).

[e]) Very weak at all angles.

[f]) See also the note added in proof on p. 476 of (Mo 78k).

for the listed transitions: 8.32 → g.s. = 34^{+13}_{-6}; 8.32 → 6.09 = 151^{+76}_{-33}; 8.32 → 6.73 = 30^{+30}_{-13}. Thus the total radition width for $^{14}C^*$(8.32)is 215^{+84}_{-35} meV. The off-resonance capture cross section is 20 ± 9 μb (Ra 90a). The decrease by an order of magnitude in the Γ_γ of $^{14}C^*$(8.32) has an important bearing on nucleosynthesis and appears to significantly reduce the production of $A \geq 14$ nuclei in the non-standard Big Bang (Ra 90a).

Angular distributions of cross sections and A_y and the 90° γ_0 cross sections have been measured in the range $E_{\vec{n}} = 5.6$ to 17 MeV. M1 resonances are indicated at $E_n \sim 9.2$ and 10.1 MeV ($\Gamma \simeq 200$ keV) [$E_x = 16.7$ and 17.5 MeV]. σ(E2) is less than 2% of the total capture cross section for $E_n = 5.6$ to 17 MeV (Wr 85a). See also (Ma 88u, De 89q; astrophysics) and (We 85c, Ho 86s, Ly 87, Ho 88a, Ho 88f, Ra 88f; theor.).

TABLE 14.8

R-matrix analysis of ^{13}C(n, n) [a])

E_n (keV)	E_x (MeV)	$\Gamma_{c.m.}$ (keV)	J^π
152.9 ± 1.4	8.3184 ± 0.9	3.4 ± 0.7	
1736	9.79	14	3^-
1754	9.80	38	1^-
2426	10.43	9	$3^{(-)}$
2445	10.45	7	$(1^+, 2)$
2504	10.50	≪ 5	≥ 1
3358	11.292	170	1^+
3500	11.4	2700	1^-
3700	11.6	1300	2^-
4330	12.19	370	1^-
4770	12.60	180	2^-
5050 [b])	12.86		
5162 [b])	12.97		
6000	13.7	1800	2^-
6950	14.62	390	(1^-)
7048	14.716	90	4^+
7260	14.91	250	(1^+)
7950	15.55	270	3^-
8300	15.9	630	(1^-)
8340	15.91	330	4^+
9100	16.6	780	(1^+)
10200	17.6	1300	(1^+)

[a]) For the 153 keV resonance see table 14.8 in (Aj 81); for the structures at $E_n < 3$ MeV see (Aj 81) and (La 81) [quoted in table 14.9 of (Aj 86)]; for higher energy structures see (Re 89).

[b]) See table 14.9 in (Aj 86).

13. (a) ^{13}C(n, n)^{13}C $E_b = 8.1765$
    (b) ^{13}C(n, 2n)^{12}C $Q_m = -4.94635$

The coherent scattering length (thermal, bound) is 6.19 ± 0.09 fm, $\sigma_{scatt} =$ 4.16 ± 0.13 b (Ko 79w) [see, however, (Aj 86)]. $a_{j=1} = 5.5 \pm 0.1$ fm; $a_{j=0} = 6.6 \pm 0.4$ fm: see (Ly 87). The total cross section has been measured from 0.1 to 23 MeV: see (Mc 88e, Aj 81).

The results of an R-matrix analysis based on $\sigma(\theta)$ for neutrons scattered to ^{13}C*(0, 3.09, 3.68, 3.85) for $4.5 \le E_n \le 11$ MeV and on some other work are shown in table 14.8 (Re 89).

The cross section for reaction (b) has been studied for $E_n = 7.5$ to 14.8 MeV: see unpublished work quoted in (Re 87). Double differential cross sections have been studied at $4.55 \le E_n \le 10.99$ MeV: evidence is found for the excitation of ^{14}C states [$E_x = 15.8$–18.4 MeV] which decay to $^{12}C_{g.s.}$ via ^{13}C*(7.55) [$J^\pi = \frac{5}{2}^-$] (Re 87).

14. (a) $^{13}C(n, p)^{13}B$ $Q_m = -12.655$ $E_b = 8.1765$
(b) $^{13}C(n, t)^{11}B$ $Q_m = -12.4217$
(c) $^{13}C(n, \alpha)^{10}Be$ $Q_m = -3.8356$

For reaction (a) see ^{13}B and (So 89). For reaction (b) see (Mc 88e). For reaction (c) see (Re 89).

15. $^{13}C(p, \pi^+)^{14}C$ $Q_m = -132.1743$

At $E_p = 185$ and 200 MeV the angular distributions of π^+ and π^- to the ground states of ^{14}C and ^{14}O are very different: see (Aj 86). Angular distributions and A_y measurements have been reported at $E_{\vec{p}} = 200$ MeV by (Ko 89m, Ko 87) to $^{14}C^*$(0, 6.09, 6.9 [u], 7.34, 8.32, 9.8 [u], 10.4 [u], 10.7 [u], 11.7 [u], (13.0, 13.6), 14.87 [u], 18.5 [broad], 23.2). The latter state has an energy of 23.2 ± 0.1 MeV and $\Gamma \lesssim 85$ keV: it is not clear whether this is the same state as that reported in the $^{11}B(\alpha, p)^{14}C$ reaction at 23.29 MeV (Dr. S. Vigdor, private communication). $A_y \approx 0$ at all angles for this state (Ko 87, Ko 89m). Assuming that the $\pi^\pm$ groups to $^{14}C^*(6.9)$ and $^{14}O^*(6.3)$ correspond to single states, and that the first populates $^{14}C^*(6.73)$ [$J^\pi = 3^-$], then $^{14}O^*$ (6.27) is assigned $J^\pi = 3^-$ also. A similar comparison of $^{14}C^*(14.87)$ with $^{14}O^*(14.15)$, and with $^{14}N^*(16.91)$ [$J^\pi = 5^-$; 1] suggests $J^\pi = 5^-$ for these ^{14}C and ^{14}O states (Ko 89m). (Hu 88a) report differential cross sections at $E_p = 250$, 354 and 489 MeV to $^{14}C^*$(0, 6.09, 6.7 [u], 7.34, 8.32, 9.80 [u], 10.5 [u], 11.7 [u], 14.87, 23.2) and to previously unreported states at $E_x = 13.50$ and 14.05 MeV: The (p, π^+) reactions show an enchancement of the $\sigma(\theta)$ near the invariant mass of the Δ_{1232}, in contrast with the (p, π^-) reactions. A broad structure near $E_x = 25$ MeV is also observed (Hu 88b) [see also for a continuum study]. (R.D. Bent and G.M. Huber, private communication) report that, from their measurements, $E_x = 23.2 \pm 0.6$ MeV and $\Gamma_{c.m.} < 200$ keV. The assignment of $J^\pi = 5^-$ to $^{14}N^*(14.87)$ [see fig. 2 of (Hu 88a)] is tentative. The uncertainties in the $E_x = 13.50$ and 14.05 MeV states are ± 100 keV and their $\Gamma_{c.m.}$ are <200 keV. I am greatly indebted to Drs. Bent and Huber for their comments. See also reaction 5 in ^{14}O, (Ja 86i, Hu 88c) and (Ku 87c; theor.).

16. (a) $^{13}C(d, p)^{14}C$ $Q_m = 5.9519$
(b) $^{13}C(t, d)^{14}C$ $Q_m = 1.9192$

Observed proton groups are displayed in table 14.10 of (Aj 86). Recent measurements of proton groups, using a spectrograph, give $E_x = 6094.05 \pm 0.11$, 6589.58 ± 0.39, 6731.58 ± 0.11, 6902.24 ± 0.18, 7011.4 ± 0.8 and 7342.65 ± 0.32 keV (Pi 90b). Angular distributions have been measured at a number of deuteron energies up to 17.7 MeV: see (Aj 81, Aj 86).

Gamma rays are exhibited in table 14.4: studies of these, of the angular distributions analyzed by DWBA, and of $p\gamma$ correlations lead to the following J^π assignments [see reaction 14 in (Aj 70) for a full discussion of the evidence and a listing of the relevant references]. *$^{14}C^*(6.09)$* is 1^- (decay is E1); *$^{14}C^*(6.59)$* is 0^+ (internal pairs only); *^{14}C*(6.73)* is 3^- (γ_0 is E3; $l_n = 2$); *^{14}C*(6.90)* is 0^- (no γ_0; 0.81 MeV cascade via 6.09 is predominantly dipole; $\gamma_{0.8} + \gamma_{6.1}$ correlation is only consistent with $J = 0$, and plane polarization leads to negative parity); *^{14}C*(7.34)* is 2^- (strength of cascade decay and angular correlation results). For a study of the pair decay of ^{14}C*(6.90) [$J^\pi = 0^-$] see (Pa 86k). See also ^{15}N, (Ab 87) and (Me 85d; applied).

In reaction (b) at $E_t = 38$ MeV angular distributions have been studied to ^{14}C*(0, 6.09, 6.6 [u], 7.0 [u], 7.34, 8.32, 9.8, 10.4 [u]) (Si 88c).

17. ^{13}C(^{6}Li, ^{5}Li)^{14}C $\qquad Q_m = 2.51$

(Wo 88a) [and see reaction 9 in (Aj 88)].

18. ^{13}C(^{7}Li, ^{6}Li)^{14}C $\qquad Q_m = 0.926$

At $E(^7\mathrm{Li}) = 34$ MeV angular distributions have been studied to ^{14}C*(0, 6.09, 6.73, 7.34): $S = 1.70, 0.43, 0.59, 0.55$ (Co 87f). See also (Aj 86).

19. ^{13}C(^{13}C, ^{12}C)^{14}C $\qquad Q_m = 3.2302$

See (Aj 86). See also (Gr 87o) and (Th 87a; theor.).

20. ^{14}B(β^-)^{14}C $\qquad Q_m = 20.64$

^{14}B decays primarily to ^{14}C*(6.09, 6.73): see table 14.2. The half-life is 13.8 ± 1.0 ms: see ^{14}B.

21. (a) ^{14}C(γ, n)^{13}C $\qquad Q_m = -8.1765$
    (b) ^{14}C(γ, 2n)^{12}C $\qquad Q_m = -13.1229$
    (c) ^{14}C(γ, p)^{13}B $\qquad Q_m = -20.832$

The cross sections for reactions (a) and (b) have been measured with monochromatic photons to $E_\gamma = 36$ MeV (and the (γ, Tn) cross section has been derived) by (Py 85). A sharp state is observed [with $\sigma \sim 3$ mb] at $E_x = 11.25 \pm 0.05$ MeV (Py 85) [also observed in the (γ, n$_0$) work of (Ku 85) and showing a pronounced E1-M1 interference], sitting on a 1 mb tail of the GDR. The integrated value of the cross section is 1.1 ± 0.1 MeV · mb, yielding $\Gamma_{\gamma_0} = 12 \pm 1$ eV. Most of the M1 strength of the ^{12}C core is concentrated at 11.3 MeV (Py 85). While other states in ^{14}C affect the (γ, n) cross section at higher energies there is no evidence of pigmy resonances. The next major peak is at 15.5 MeV ($\sigma \sim 9.1$ mb), whose decay is by neutrons to ^{12}C$_{\mathrm{g.s.}}$. Above 17.5 MeV the neutron decay becomes more complex (Py 85). Reaction (b) has little strength below 23.3 MeV. Above that energy, states of ^{14}C ($T_>$) can decay to ^{13}C*(15.1) [$T = \frac{3}{2}$], which subsequently decays by neutron emission (Py 85). See also the (γ, n$_0$) work of (Ku 85), (Di 88) and (Go 85v, Go 87c, Ki 87e; theor.).

22. ^{14}C(e, e)^{14}C

The charge radius of ^{14}C, $r_{\mathrm{r.m.s.}} = 2.56 \pm 0.05$ fm (Kl 73b). At $E_e = 37$-60 MeV ($\theta =$ 180°) inelastic groups are reported to ^{14}C*(7.01, 7.34, 8.32, 9.80, 10.5, 11.31 ± 0.02, 12.96, 14.67) with the 11.3 MeV state [1^+, $\Gamma = 207 \pm 13$ keV, $\Gamma_{\gamma_0} = 6.8 \pm 1.4$ eV] dominant (Cr 77). At $E_e = 81.9$ to 268.9 MeV ($\theta = 180°$) (Pl 89c, Pl 84) find the dominant strength to be to 4^- states at 11.7, 17.3 and 24.4 MeV [±0.1 MeV]. The first two of these are $T = 1$ states reported in the (π, π) reaction below, the third is suggested to have $T = 2$ (and to be unresolved from a 2^- state). The M4 form factors account for 41% and 37% of the $T = 1$ and $T = 2$ single-particle (e, e′) cross section, respectively. The observed transitions to the $T = 1$ states exhaust 33-45% of the total isovector transition strength and 1-15% of the isoscalar transition strength. Magnetic electron scattering is most sensitive to isovector transitions (Pl 84). The population of ^{14}C*(6.1, 6.7, 7.0, 8.3, 9.84 ± 0.05, 10.50 ± 0.05, 12.2 ± 0.1, 12.9 ± 0.1, 13.6 ± 0.1, 14.0 ± 0.1, 14.9 ± 0.1, 15.2 ± 0.1, 16.5 ± 0.1, 22.1 ± 0.1) is also reported (Pl 89c, Pl 84). See also (De 87c, Hi 86c, Aj 89a) and (Li 86o, Go 87d, Ki 87e, Li 87k, Cl 88a, Ho 88f, Cl 90a, Ga 90g; theor.).

23. ^{14}C($\pi^{\pm}$, $\pi^{\pm}$)^{14}C

Elastic angular distributions have been measured at $E_{\pi^{\pm}} = 50$ MeV (Mi 85p), 65 and 80 MeV (Bl 83g) and 164 MeV (Ha 86g). At $E_{\pi^{\pm}} = 164$ MeV, the differential cross sections for the transition to ^{14}C*(7.01) [$J^{\pi} = 2_1^+$] are nearly the same for π^+ and π^-. Angular distributions have also been studied to the 2_2^+ state, ^{14}C*(8.32), and to an unresolved group at $E_x = 10.4$ MeV [the latter results are consistent with a $J^{\pi} = 3^-$ distribution] (Ha 88f) [see for discussion of B(E2)]. In earlier work at $E_{\pi^{\pm}} = 164$ MeV angular distributions had been obtained to states at $E_x = 6.7$, 11.7, 15.2, 17.3 MeV [±0.1 MeV] with $J^{\pi} = 3^-, 4^-, 4^-, 4^-$. In addition a broad structure ($\Gamma \sim 1.7$ MeV) had been observed near 24.5 MeV. It may include a narrower peak at 24.4 MeV (Ho 85b): see also the Erratum (Ho 90b). The population of ^{14}C*(6.1, 12.6) has also been reported: see (Aj 86). See also (Aj 89a).

24. (a) ^{14}C(p, p)^{14}C
(b) ^{14}C(d, d)^{14}C

At $E_p = 497$ MeV ^{14}C*(11.7, 17.3) [$J^{\pi} = 4^-$] are populated (Cr 89a; prelim.). Elastic angular distributions are reported at $E_p = 35$ and 40.1 MeV (Ya 90). See also (Aj 81, Aj 86) [the work quoted in (Aj 86) has not been published.]

25. ^{14}C(^{3}He, ^{3}He)^{14}C

Elastic angular distributions have been studied at $E(^3\text{He}) = 4.5$ to 18 MeV [see (Aj 76)], at 22 MeV (Ad 88a; prelim.) and 72 MeV (De 88k, Er 89b) and at 39.6 MeV (Bu 87a; prelim.). See also (De 89l, Ga 89e) and (Ze 86f; theor.).

26. ^{14}C(α, α)^{14}C

Elastic angular distributions have been studied at $E_{\alpha} = 22$, 24 and 28 MeV [see (Aj 76)] and at $E_{\alpha} = 35.5$ MeV (Pe 84f). At the latter energy many inelastic groups

TABLE 14.9

States of ^{14}C from $^{14}C(\alpha, \alpha')$ [a]

E_x (MeV) [b]	L [c]	J^π	β^2 [d]
6.09	1	1^-	0.050
6.73	3	3^-	0.158
7.01 [e]	2	2^+	0.086
7.34		2^-	
8.32 [e]	2	2^+	0.049
9.80	3	3^-	0.068
10.44 ± 0.06 [e]	2	2^+	0.038
10.74	4	4^+	0.018
11.32 ± 0.06	2	2^+	0.014
11.62 ± 0.08		4^-	
12.58	3	3^-	0.041
12.96	(3)	(3^-)	0.033
13.58	1	1^-	0.068
14.82	3	3^-	0.079
15.66	3	3^-	0.096

[a]) (Pe 84f): $E_\alpha = 35$ MeV.

[b]) Excitation energies without uncertainties are from table 14.3, except for the last three values.

[c]) Microscopic DWBA analysis.

[d]) Collective deformations.

[e]) Isoscalar transition rates $B(02)$ are 168, 96 and 74 fm^4 for $^{14}C^*(7.01, 8.32, 10.44)$.

have also been studied: see table 14.9 (Pe 84f). See also ^{18}O in (Aj 87) and (Um 85; theor.).

27. $^{14}C(^6Li, ^6Li)^{14}C$

Elastic angular distributions have been obtained at $E(^6Li) = 93$ MeV (Br 86r, De 87, De 88g, De 89s) and 210 MeV (Wi 87b; forward angles).

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

The elastic scattering for reaction (a) has been studied at $E(^{14}C) = 20$ to 40.3 MeV (St 86a; prelim.) and 31 to 56 MeV (Ko 85e); that for reaction (b) has been studied at $E(^{13}C) = 20$ to 27.5 MeV (Bi 88b) [see also reaction 50 in ^{13}C]; and that for reaction (c) is reported at $E(^{14}C) = 31$ to 56 MeV: see (Aj 86). For the earlier work see (Aj 76). For yield and fusion studies see (Aj 86) and (St 86a). The yields of γ-rays from $^{14}C^*(6.73)$ [$J^\pi = 3^-$] have been measured for $E(^{14}C) = 25$ to 70 MeV: see (Aj 86). See also (Vo 90a) and (Ba 86uu; theor.).

29. $^{14}C(^{15}N, ^{15}N)^{14}C$
See (Ba 86uu; theor.).

30. (a) $^{14}C(^{16}O, ^{16}O)^{14}C$
(b) $^{14}C(^{17}O, ^{17}O)^{14}C$
(c) $^{14}C(^{18}O, ^{18}O)^{14}C$

The elastic scattering has been studied in reaction (a) at $E(^{16}O) = 20$, 25 and 30 MeV [see (Aj 81)] and at $E(^{14}C) = 20$ to 43 MeV (St 86a; prelim.); that for reaction (c) has been studied for $E(^{14}C) = 20$ to 30 MeV (St 86a). The α-breakup in reaction (c) is being investigated at $E(^{18}O) = 33.5$ to 64 MeV (Al 88e; prelim.). For excitation functions see (Aj 86) and (St 86a). See also (Ci 89a) and (Ba 86uu; theor.).

31. $^{14}N(\gamma, \pi^+)^{14}C$ $Q_m = -139.725$

Differential cross sections to $^{14}C_{g.s.}$ have been measured at $E_\gamma = 173$ MeV (Ro 85a, Ro 87j), at 200 MeV (Co 85g), at 230, 260 MeV and 320 MeV (Te 86b, Gh 90) and at 320 and 400 MeV (Di 90; prelim.). The transitions to the 2^+ states at 7.01 + 8.32 [u] and 10.7 MeV have been studied by (Su 87m) [see for $B(M1)$]. See also (Be 85w, Hu 87, Ya 87g), (Wi 86j, Ti 88, Er 90c; theor.) and p. 60.

32. $^{14}N(\pi^-, \gamma)^{14}C$ $Q_m = 139.412$

The photon spectrum from stopped pions is dominated by peaks corresponding to $^{14}C^*(6.7 + 6.9 + 7.0$ [u], 8.32, 10.7) and branching ratios have been obtained for these and the g.s. transition. That to $^{14}C^*(6.7 + 6.9 + 7.0)$ is $(6.22 \pm 0.40)\%$ (absolute branching ratio per stopped pion) (Pe 86b). For the earlier work see (Aj 81). See also p. 60.

33. $^{14}N(n, p)^{14}C$ $Q_m = 0.6259$

The p_0 angular distribution has been measured at $E_n = 14$ MeV: see (Aj 81). At $E_n = 60$ MeV the strongest transitions are to $^{14}C^*(7.0 + 8.3$, 11.3, 15.4) and to the giant resonance peak, centered at ~20.4 MeV, and angular distributions have been studied to these groups: see (Aj 86). For cross sections of astrophysical interest see ^{15}N. A study of P-odd and left-right asymmetries with polarized thermal neutrons is reported by (An 88i). See also (Bo 86g, El 88b; applied).

34. $^{14}N(d, 2p)^{14}C$ $Q_m = -1.5987$

Angular distributions have been measured at $E_d = 70$ MeV to $^{14}C^*(7.0$ [u], 8.3). The ground state is very weakly populated (Mo 86m). See also (He 88h).

35. $^{14}N(t, ^3He)^{14}C$ $Q_m = -0.13788$

At $E_t = 33.4$ MeV $^{14}C^*(0, 6.09, 6.73, 7.34, 8.32)$ are populated (Cl 88).

36. $^{14}N(^7Li, ^7Be)^{14}C$ $Q_m = -1.018$

See (Go 86g; prelim.; $E(^{14}N) = 150$ MeV).

37. $^{15}N(\gamma, p)^{14}C$ $Q_m = -10.2074$

See (Aj 81), ^{15}N and (Go 88a; theor.).

38. $^{15}N(d, ^3He)^{14}C^\dagger$ $Q_m = -4.7139$

The parameters of ^{14}C states observed in this reaction are displayed in table 14.9 of (Aj 76).

39. $^{16}O(^6Li, ^8B)^{14}C$ $Q_m = -16.592$

At $E(^6Li) = 93$ MeV $^{14}C^*$(0, 7.01, 8.32, 10.45) are populated, the first two of these strongly: see (Aj 81).

^{14}N

(Figs. 7 and 9)

GENERAL‡

Nuclear models: (Kw 85, Ze 86, Ki 87e, Wo 88, Ta 89, Wo 89c, Ha 90e, Va 90a)

Special states: (Ad 85d, Ba 85mm, Go 85v, Ad 86c, An 86u, Go 86t, Ba 87ee, Bl 87f, Ki 87e, Su 87c, Kw 88, Wr 88, Am 89, Or 89a, Su 89d, Ta 89)

Electromagnetic transitions and giant resonances: (Va 84, Go 85v, Go 85w, Er 86, Ba 87ee, Ki 87e, Ji 88c, Wr 88, Am 89)

Astrophysical questions: (Ca 82h, Wo 82h, Br 85g, Dw 85, Pr 85e, Ch 86v, Do 86a, Ha 86cc, La 86o, Ma 86gg, Sm 86c, Tr 86e, Wo 86a, Al 87j, Ar 87g, Ar 87i, Au 87d, Bo 87a, Cu 87, Dw 87, Me 87, Mu 87c, Pr 87, Ra 87m, Wa 87g, Ba 88g, Cu 88, Du 88a, Du 88f, Ep 88, Kr 88f, Wa 88h, Ab 89d, Bo 89h, Ch 89t, Ch 89v, De 89c, Du 89, Gu 89b, Gu 89h, Gu 89i, Gu 89k, Ho 89c, Ji 89, Ka 89b, Ke 89c, Me 89, No 89, Pr 89c, Wy 89, Ha 90e, Ho 90d, Ro 90a, Si 90, We 90)

Complex reactions involving ^{14}N: (Ma 84ee, Xi 84a, Be 85o, Kw 85a, Po 85d, Ro 85k, Sh 85s, St 85h, St 85k, Wa 85n, Ai 86, Bo 86t, Gr 86m, Gr 86n, Ha 86bb, Ma 86j, Ma 86k, Me 86d, Pl 86a, Po 86d, Sa 86ee, Sh 86h, Sh 86u, Va 86n, We 86, Ba 87w, Be 87aa, Be 87s, Bo 87z, Bu 87e, Fe 87, Ge 87a, Go 87f, Hi 87b, Ja 87a, Ko 87b, Ly 87b, Mu 87e, Na 87, Pa 87, Ri 87b, Ro 87f, Sh 87j, St 87, Te 87b, Ay 88, Ca 88f, Ga 88d, Ha 88dd, Ka 88l, Ly 88a, Mi 88h, Pa 88i, Po 88, Po 88e, Sa 88h, Sh 88, Si 88, Te 88, Ut 88a, Ba 89cc, Br 89b, Ca 89e, Ce 89a, Ge 89, Ki 89f, Ma 89r,

† For other reactions on which no new work has been reported see (Aj 86).

‡ See also (Aj 86).

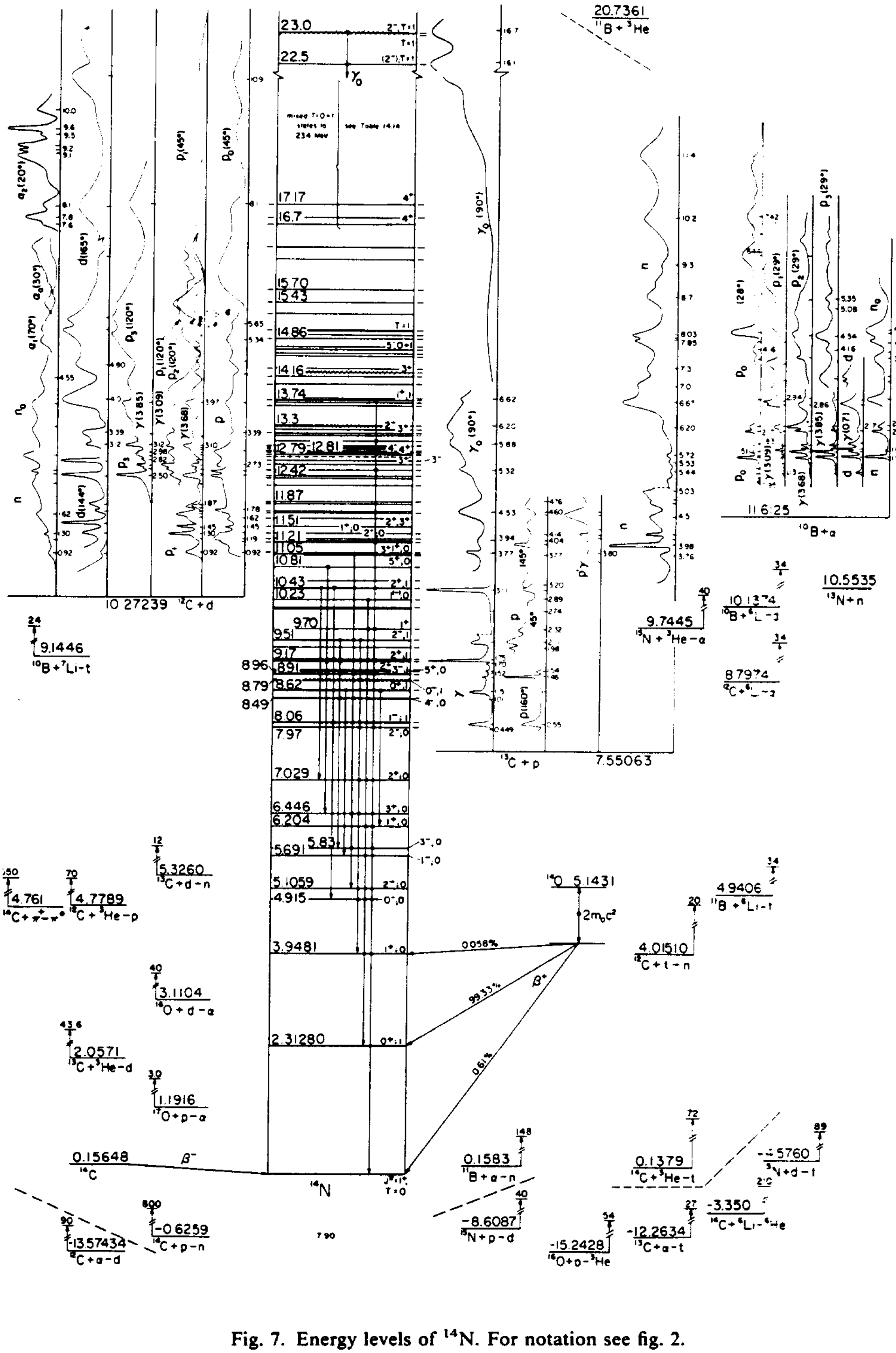


Fig. 7. Energy levels of ^{14}N. For notation see fig. 2.

Po 89b, Po 89d, Pr 89b, Sa 89g, Vo 89e, Yo 89, Zh 89e, Bo 90a, De 90g, Gl 90a, Le 90e, Pa 90, We 90a, Ye 90)

Applied work: (Go 85o, Ko 85i, Bo 86l, Co 86c, He 86c, No 86a, Ph 86a, St 86l, Za 86a, Si 87c, Za 87, Al 88k, Go 88l, Il 88, Ro 88e, Ro 88k, Za 88, Ko 90e)

Muon and neutrino capture and reactions: (Ag 85a, Ko 85v, Is 86, Su 87a, Al 88g, Bu 88, Mu 89f, Na 89, Ch 90g, Gr 90a)

Pion capture and reactions: (As 83, As 84a, Be 85f, Gi 85h, Ko 85z, La 85h, Ro 85f, Tu 85e, Ar 86f, Be 86l, Ce 86, Dy 86, Er 86, Ge 86b, Ko 86e, La 86d, Pe 86b, Ra 86p, Ro 86, Su 86i, Ah 87, Bl 87f, Bo 87f, Bo 87g, Do 87, Gi 87c, Gi 87f, Go 87a, Ka 87cc, Ko 87h, Le 87b, Na 87e, Ro 87j, Gi 88c, Ko 88u, Mi 88k, Oh 88a, Ti 88, Ba 89ii, Ch 89w, Di 89a, Do 89j, Ga 89f, Ge 89b, Gi 89, Gi 89a, It 89, Kh 89b, Na 89, Ri 89c, Be 90f, Ch 90f, Ch 90m, Di 90, Er 90c, Er 90d, Gh 90)

Kaon capture and reactions: (Be 85y, Be 86ee, Da 86a, Fe 86b, Ma 86f, Wu 86, Be 89l, Be 89p, Do 89g, Do 89i, Si 89e)

Antinucleon reactions: (Ba 86ai, Ko 86w, Ro 86s, Sp 86, Ah 87, Gr 87f, Ha 87z, Po 87a, Ri 89c, Jo 90)

Hypernuclei: (Bo 84q, Zh 84b, Fe 86b, Ga 86m, Ma 86f, Wu 86, Ya 86a, Ma 88f, Mo 88k, Ba 89cc, Ba 89hh, Do 89i, It 89, Ko 89z, It 90)

Other topics: (Ad 85d, An 85e, Ad 86c, An 86u, Ba 87ee, Gu 88b, He 88f, Kw 88, De 89j, Or 89a, Po 89g, Mu 90a, Pr 90a)

Ground state of ^{14}N: (An 85e, Go 85v, Zi 85b, Gl 86g, Ro 86, Wi 86g, Ab 87a, Ki 87e, Va 87n, Bi 88, Va 88, Wo 88, Wr 88, Am 89, An 89c, Go 89b, Sa 89g, Wo 89c, Be 90f, Va 90, Va 90a)

$\mu = +0.4037607$ (2) n.m. (Le 78n),

$Q = +0.0193$ (8) b (Wi 80r). See also (Ha 86ii) and (Ra 89g),

$\langle r^2 \rangle^{1/2} = 2.560$ (11) fm (Sc 80g),

Natural abundance: $(99.634 \pm 0.009)\%$ (De 84q)

1. $^9Be(^7Li, 2n)^{14}N$ $\quad Q_m = 7.249$

The energy of the $5.83 \to 5.11$ γ transition is $E_\gamma = 728.34 \pm 0.10$ keV. When corrected for the nuclear recoil and added to $E_x = 5105.89 \pm 0.10$ keV, $E_x = 5834.25 \pm 0.14$ keV for $^{14}N^*(5.83)$ (Ko 81d) [recalculated]. For branching ratios see table 14.11. See (Ko 81d) also for a general discussion of electromagnetic transitions in ^{14}C and ^{14}N, and comparison with theory.

^{14}N MASTER TABLE

TABLE 14.10

Energy levels of ^{14}N [a])

E_x in ^{14}N [b]) (MeV ± keV)	J^π; T	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
g.s.	1^+; 0	stable	-	6→10, 18→25, 31→65
2.312798 ± 0.011	0^+; 1	τ_m = 98.7 ± 4.5 fs [c])	γ	8, 10, 18→21, 24, 25, 31→34, 36→39, 42, 44, 45, 47, 57→61, 64, 65
3.94810 ± 0.20	1^+; 0	7.0 ± 2.5 fs [d])	γ	6→8, 10, 18→21, 25, 31→34, 37→39, 43, 44→48, 57→61
4.9151 ± 1.4	0^-; 0	7.6 ± 1.4 fs	γ	6, 7, 18→21, 31→34, 38, 43→48, 59→61
5.10589 ± 0.10	2^-; 0	6.27 ± 0.07 ps $\|g\|$ = 0.66 ± 0.04	γ	1, 6→8, 10, 18→21, 31→34, 38, 39, 43→48, 59→61, 64
5.69144 ± 0.13	1^-; 0	16 ± 8 fs	γ	6, 7, 18→21, 25, 31, 32, 34, 38, 43→48, 59→61
5.83425 ± 0.14	3^-; 0	11.98 ± 0.23 ps	γ	1, 6, 7, 11, 18→21, 23, 24, 31, 32, 34, 38, 39, 43→48, 59→61
6.2035 ± 0.6	1^+; 0	160 ± 20 fs	γ	6, 7, 18→21, 25, 31, 32, 38, 39, 45→48, 59→61
6.44617 ± 0.10	3^+; 0	620 ± 60 fs	γ	6, 7, 18→21, 25, 31, 32, 38, 45, 46, 48, 59→61
7.02912 ± 0.12	2^+; 0	5.4 ± 0.5 fs	γ	6, 7, 18→21, 25, 31, 32, 34, 38, 39, 43→48, 59→61
7.9669 ± 0.5	2^-; 0	$\Gamma = (2.5 \pm 0.7) \times 10^{-3}$	γ, p	6, 7, 18→21, 25, 32, 45, 48, 59→61
8.062 ± 1.0	1^-; 1	23 ± 1	γ, p	18, 19, 25, 26, 31, 32, 41, 45, 47, 59, 61
8.490 ± 2	4^-; 0	τ_m = 19 ± 3 fs	γ, p	6, 7, 18→21, 25, 31, 32, 39, 43, 45, 48, 60
8.618 ± 2	0^+; 1	Γ = 3.8 ± 0.3	γ, p	8, 18, 19, 25, 26, 31, 32, 45, 59, 61
8.776 ± 7	0^-; 1	410 ± 20	γ, p	25, 26, 32
8.907 ± 3	3^-; 1	16 ± 2	γ, p	19, 25, 26, 31, 32, 42, 45, 59, 61
8.964 ± 2	5^+; 0	τ_m = 105 ± 17 fs	γ, p	7, 11, 19→21, 23, 25, 31, 32, 52, 59
8.980 ± 3	2^+; (0)	Γ = 8 ± 2	γ, p	6, 7, 19, 25, 26, 31, 32, 59
9.1290 ± 0.5 [e])	3^+; 0	τ_m = 13 ± 5 fs	γ, p	6, 7, 19, 20, 25, 31, 32, 48
9.17225 ± 0.12	2^+; 1	Γ = 0.122 ± 0.008 [h])	γ, p	19, 25, 31, 32, 42, 45, 59→61
9.388 ± 3	2^-; 0	13 ± 3	p	6, 7, 19→21, 26, 31, 32, 45, 48, 59→61
9.509 ± 3	2^-; 1	41 ± 2	γ, p	19, 25, 26, 31, 32, 45, 59→61

TABLE 14.10—continued

E_x in ^{14}N [b]) (MeV ± keV)	J^π; T	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
9.703 ± 4	1^+; 0	15 ± 3	p	6, 19, 21, 25, 26, 31, 32, 45, 59 → 61
10.079 ± 10	(3^+)	< 10		6, 7, 11, 19, 21, 32
10.101 ± 15	2^+, 1^+; 0	12 ± 3	γ, p	19, 21, 25, 26, 32, 45, 59, 60
10.226 ± 8	$1^{(-)}$; 0	80 ± 15	γ, p	19, 21, 25, 26, 32, 59
10.432 ± 7	2^+; 1	33 ± 3	γ, p	11, 19, 25, 26, 38, 42, 59 → 61
10.534 ± 20	(1^-)	140	p	19, 26, 32
10.812 ± 15	5^+; 0	$(0.39 \pm 0.16) \times 10^{-3}$	γ	6, 7, 11, 19 → 21, 32, 48
11.00 ± 30		165 ± 30	γ, p	25
11.050 ± 5	3^+	1.2 ± 0.4	γ, p	6, 7, 11, 19, 21, 25, 32, 59, 60
11.07	1^+; 0	100	n, p, d	13, 26, 27
11.21 ± 30	$T = 1$	220 ± 30	γ, p, d	13
11.24 ± 15	3^-; 0	11	γ, n, p	11, 19, 26, 27, 32, 42, 43, 45 → 48, 59
11.27 ± 15	2^-; 0	180	n, p, d	6, 13, 14, 21, 26, 27, 32, 59
11.357 ± 15	1^+; 0	30	n, p, d	13, 14, 19, 26, 27, 59
11.5135 ± 1.5	2^+, 3^+	7.0 ± 0.5	p, d	6, 7, 11, 13, 14, 19, 21, 32, 42, 59, 60
11.676 ± 18	1^-, 2^-	150 ± 20	n, p, d	13, 14, 27, 32, 59
11.741 ± 6	1^-, 2^-	40 ± 9	(γ), p, d	13
11.761 ± 6	3^-, 4^-	78 ± 6	(γ), p, d	13
11.807 ± 7	2^-, (1^+)	119 ± 9	n, p, d	13, 14
11.874 ± 6	2^-, (1^-)	101 ± 9	n, p, d	13, 27
12.20 ± 19	1^-, 2^-	300 ± 30	n, p, d	13, 14, 27, 59
12.408 ± 3	(4^-)	34 ± 3	n, p, d, α	3, 4, 13, 14, 21, 38
12.418 ± 3	3^-, 4^-	41 ± 4	p, d	6, 11, 13, 19, 38
12.495 ± 9	$(1^+; 1)$	39 ± 5	γ, n, p, d, α	3, 13, 19, 25, 42, 59 → 61
12.594 ± 3	3^+	48 ± 2	(n), p, d, α	3, 13, 14, 19, 27, 48, 59
12.690 ± 5	3^-	18 ± 5	n, p, d, α	3 → 7, 11, 13, 14, 19, 21, 27, 48
(12.708 ± 9)		(43 ± 15)	p, d	13
12.789 ± 5	4^+	16 ± 3	n, p, d, α	3 → 5, 7, 11, 13, 14, 19, 45 → 48, 59
12.813 ± 4	4^-	5 ± 2	γ, p, d, α	3, 4, 6, 7, 13, 14, 38, 42, 43, 45 → 48, 59, 60
12.826 ± 6		11 ± 3	n, p, d	13, 14
12.857 ± 6		78 ± 10	n, p, d	13, 21, 27
12.883 ± 8		134 ± 11	p, d	13
12.922 ± 5	4^+	22 ± 4	p, d, α	3, 4, 11, 13, 14
13.007 ± 17		120 ± 30	γ, p	6, 7, 25
13.167 ± 5	1^+	15 ± 5	γ, n, p, d, α	3 → 6, 19, 42, 59
13.192 ± 9	3^+	65 ± 10	α	5, 11, 59
13.243 ± 10	2^-	92 ± 5	γ, n, p, α	2, 3, 27, 42, 48, 59
13.30 ± 40	(2^-); 1	1000 ± 150	γ, p	25

TABLE 14.10—continued

E_x in ^{14}N [b] (MeV ± keV)	J^{π}; T	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
13.656 ± 5	(2^+, 3^+)	~90	n, p, d, α	3, 5, 13, 14
13.714 ± 5	2^-, 3^+	105 ± 25	γ, n, p, d, α	2 → 4, 6, 11
13.74 ± 10	1^+; 1	180 ± 20	(γ), n, p, d, α	2, 3, 5, 13, 14, 25, 27, 37, 42, 59 → 61
13.77 ± 10	(1^+)	120	p, α	3
14.04 ± 30		100	n, p, d, α	2, 3, 13, 14, 27
14.16 ± 30		230	n, p, d, α	2, 3, 13, 14
14.25 ± 50	3^+	420 ± 100	p, α	3, 5
14.30 ± 20		150	p, α	3
14.56 ± 20		100	n, p, α	2, 3, 11
14.59 ± 30		50	n, p, α	2, 3, 11
14.66 ± 10	5^-; 0	100 ± 20	α	5, 43
14.73 ± 25	(2^-; 1)	125	γ, n, p, α	2, 3
14.86 ± 30		140	n, p, d, α	2, 3, 6, 11, 13, 14, 16, 21, 27
14.92 ± 30		43 ± 8	n, p, α	2, 3, 11, 19, 27
15.02 ± 20	3^-, 4^-; 1	~60	γ, n, p, α	2, 6, 20, 27, 42, 43
15.24 ± 20		100	p, d, α	3, 6, 7, 11, 13, 14
15.43 ± 20		100	n, p, d, α	2, 3, 13, 16, 21
15.70 ± 50		350	γ, n, p, d, α	6, 13, 14, 16, 19, 21, 27, 42
16.21 ± 20		125	n, p, α	2, 3, 21, 27, 60
16.40 ± 20		150	p, d, α	3, 16
16.65 ± 25 [f]	4^+; 0 + 1	240 ± 25	d, α	16
16.91 ± 20	5^-; 1	170 ± 25	γ	11, 42, 43
16.91 ± 30	4^+; 0 + 1	290 ± 30	p, d, α	16
16.92 ± 20 [g]	2^+; 0 + 1	830 ± 170	d, α	16
17.03 ± 50	3^-; 0 + 1	245 ± 50	d, α	16
17.17 ± 30	1^-; 0 + 1	300 ± 30	γ, p, d, α	11, 16, 21, 42
17.31 ± 30	4^+; 0 + 1	275 ± 30	d, α	16, 60
17.40 ± 25	4^+; 0 + 1	245 ± 25	d, α	16
17.46	5^-; 0			43
17.85 ± 50 [g]	4^+; 0 + 1	475 ± 50	d, α	16
17.85 ± 50 [g]	3^-; 0 + 1	440 ± 50	d, α	16
17.93 ± 70 [g]	2^+; 0 + 1	340 ± 70	d, α	16
18.02 ± 60	3^-; 0 + 1	570 ± 60	d, α	16
18.14 ± 50	4^+; 0 + 1	480 ± 50	d, α	16
18.35 ± 60	1^-; 0 + 1	560 ± 60	d, α	16
18.43 ± 65	4^+; 0 + 1	315 ± 65	d, α	16
18.50 ± 10	5^-; 0 + 1	62 ± 10	d, α	16, 42
18.53 ± 80	2^+; 0 + 1	410 ± 80	d, α	16
18.53 ± 60	3^-; 0 + 1	310 ± 60	d, α	16
18.64 ± 70	3^-; 0 + 1	675 ± 70	d, α	16, 43
18.78 ± 35	1^-; 0 + 1	315 ± 35	d, α	16
18.88 ± 50	4^+; 0 + 1	475 ± 50	d, α	16
18.93 ± 50	2^+, 3^-; 0 + 1	450 ± 50	d, α	16
19.10 ± 90	3^-; 0 + 1	870 ± 90	d, α	16

TABLE 14.10—continued

E_x in ^{14}N [b]) (MeV ± keV)	J^π; T	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
19.90 ± 60	2^+; 0+1	575 ± 60	d, α	16
19.99 ± 50	1^-; 0+1	510 ± 50	d, α	16
(20.11 ± 20)	3^-, 4^-; 0+1	120 ± 20	γ	42, 43
20.63 ± 110	4^+; 0+1	1100 ± 110	d, α	16
20.65 ± 60	5^-; 0+1	610 ± 60	d, α	16
21.24 ± 50	4^+; 0+1	415 ± 50	d, α	16
21.51 ± 25	3^-; 0+1	235 ± 25	d, α	16
21.53 ± 75	5^+; 0+1	360 ± 75	d, α	16
21.68 ± 40	4^+; 0+1	360 ± 40	d, α	16
21.8	4^+; 0+1	650	γ, ^{3}He	9
22.26 ± 15	4^+; 0+1	65 ± 15	d, α	16
22.31 ± 60	5^-; 0+1	570 ± 60	d, α	16
22.5	2^-; 1		γ, p	25
23.0	2^-; 1	~3000	γ, n, p	25, 40
23.40 ± 70	5^-; 0+1	640 ± 70	d, α	16
24.0		~1000	n, ^{3}He, α	9

a) See also tables 14.13 and 14.14, and footnote b) in table 14.15 here (Wa 86h).

b) I am indebted to E.K. Warburton for sending me a reanalysis of the E_x of many of the states in ^{14}N with $E_x < 9.4$ MeV: see, e.g., footnote b) in table 14.15.

c) Weighted mean of values displayed in table 14.14 of (Aj 86) but not using the value 79 ± 7 fs which has not been published, and including the value 97.7 ± 5.5 fs (Zi 87a).

d) Adopted value, based on values shown in table 14.14 (Aj 86) and on 5.6 ± 1.1 fs (Zi 87a).

e) The present evidence (Wa 86h) only supports the presence of one state at $E_x \sim 9.13$ MeV, with $J^\pi = 3^+$. The only remaining evidence for a doublet is the ^{12}C(^{3}He, p')^{14}N (p) ^{13}C$_{g.s.}$ work by (No 74).

f) With the exception of ^{14}N*(16.91, 17.46, 21.8, 22.5, 23.0, 24.0), this state and all the higher states were derived from an S-matrix analysis of the ^{12}C(d, α_1) reaction by (Jo 81e).

g) See, however, tables 14.20 and 14.21.

h) See reaction 41.

2. ^{10}B(α, n)^{13}N $\quad Q_m = 1.0590 \quad E_b = 11.6125$

Observed resonances are displayed in table 14.12. For thick target yields see (He 89). See also (Ca 85t; astrophys.).

3. ^{10}B(α, p)^{13}C $\quad Q_m = 4.0618 \quad E_b = 11.6125$

Excitation functions have been measured to $E_\alpha = 26$ MeV. Observed resonances are displayed in table 14.12. (Wi 75b) has expanded the angular distributions of the $p_0 \rightarrow p_3$ groups into Legendre polynomials and fitted the coefficients at resonances corresponding to ^{14}N*(13.16, 13.24, 13.67, 13.76) obtaining $J^\pi = 1^+, 2^-$, 2 or 3^+, and 1, respectively, for these states. However, an R-matrix analysis by (Cs 83c) suggests $J^\pi = 2^-, 3^+, 1^+$ for ^{14}N*(13.69, 13.74, 13.77). (Wi 75b) finds that a surprising proportion of states have a higher cross section for neutron than for proton emission: the fluctuations of σ_n/σ_p at low E_α suggest sizeable isospin impurities in the ^{14}N states.

TABLE 14.11

Radiative decays in ^{14}N [a])

E_i (MeV)	$J_i^\pi; T$	E_f (MeV)	$J_f^\pi; T$	Branch (%)	Γ_γ (eV)
2.31	$0^+; 1$	0	$1^+; 0$	100	$(6.7 \pm 0.3) \times 10^{-3}$
3.95	$1^+; 0$	0	$1^+; 0$	3.9 ± 0.2	(M1)4×10^{-4} (E2)3×10^{-3}
		2.31	$0^+; 1$	96.1 ± 0.3	0.091 ± 0.030
4.92	$0^-; 0$	0	$1^+; 0$	97 ± 3	$(8.4 \pm 1.6) \times 10^{-2}$
		2.31	$0^+; 1$	<1	
		3.95	$1^+; 0$	[b])	
5.11	$2^-; 0$	0	$1^+; 0$	79.9 ± 1.0	(E1)$(8.00 \pm 0.18) \times 10^{-5}$ [c]) (M2)$(2.05 \pm 0.51) \times 10^{-6}$ [c,d]) (E3)$(1.80 \pm 0.51) \times 10^{-6}$ [c,d])
		2.31	$0^+; 1$	19.4 ± 1.2	$(2.04 \pm 0.13) \times 10^{-5}$ [c])
		3.95	$1^+; 0$	(0.7 ± 0.4)	$(7.4 \pm 4.2) \times 10^{-7}$ [c])
5.69	$1^-; 0$	0	$1^+; 0$	36.1 ± 1.2 [e])	$(0.9 \pm 0.5) \times 10^{-2}$
		2.31	$0^+; 1$	63.9 ± 1.2 [e])	$(1.7 \pm 0.8) \times 10^{-2}$
5.83	$3^-; 0$	0	$1^+; 0$	21.3 ± 1.3 [f])	(M2)$(4.8 \pm 1.4) \times 10^{-6}$ [c]) (E3)$(6.9 \pm 1.5) \times 10^{-6}$ [c])
		5.11	$2^-; 0$	78.7 ± 1.3 [f])	(M1)$(4.32 \pm 0.11) \times 10^{-5}$ [c]) (E2)$(7^{+8}_{-5}) \times 10^{-8}$ [c])
6.20	$1^+; 0$	0	$1^+; 0$	23.1 ± 1.9 [e])	$(0.9 \pm 0.1) \times 10^{-3}$
		2.31	$0^+; 1$	76.9 ± 2.0 [e])	$(3.2 \pm 0.4) \times 10^{-3}$
6.45	$3^+; 0$	0	$1^+; 0$	70.1 ± 1.5 [e])	$(7.4 \pm 0.7) \times 10^{-4}$ [g])
		3.95	$1^+; 0$	19.7 ± 1.0 [e])	$(2.1 \pm 0.3) \times 10^{-4}$
		5.11	$2^-; 0$	6.5 ± 0.6 [e])	$(0.7 \pm 0.1) \times 10^{-4}$
		5.83	$3^-; 0$	3.7 ± 0.6 [e])	$(0.4 \pm 0.1) \times 10^{-4}$
7.03	$2^+; 0$	0	$1^+; 0$	98.6 ± 0.3	(M1)$(9.1 \pm 1.3) \times 10^{-2}$ [h]) (E2)$(5.0 \pm 1.2) \times 10^{-2}$
		2.31	$0^+; 1$	0.5 ± 0.1	(E2)$(6.2 \pm 1.4) \times 10^{-4}$
		3.95	$1^+; 0$	0.9 ± 0.25	$<(11 \pm 0.3) \times 10^{-4}$
7.97 [i])	$2^-; 0$	0	$1^+; 0$	55 ± 3	0.010
		3.95	$1^+; 0$	45 ± 3	0.008
8.06 [f])	$1^-; 1$	0	$1^+; 0$	80.3 ± 0.6	9.9 ± 2.5
		2.31	$0^+; 1$	1.40 ± 0.14	0.17 ± 0.05
		3.95	$1^+; 0$	12.7 ± 0.4	1.56 ± 0.40
		4.92	$0^-; 0$	1.86 ± 0.14	0.23 ± 0.06
		5.11	$2^-; 0$	0.25 ± 0.14	0.03 ± 0.02
		5.69	$1^-; 0$	3.5 ± 0.4	0.43 ± 0.12
8.49 [f])	$4^-; 0$	5.11	$2^-; 0$	83 ± 3	$(6.1 \pm 1.5) \times 10^{-3}$ [j])
		5.83	$3^-; 0$	17 ± 3	$(1.3 \pm 0.4) \times 10^{-3}$ [j])
8.62	$0^+; 1$	0	$1^+; 0$	23	1.20
		3.95	$1^+; 0$	24	1.26
		5.69	$1^-; 0$	13	0.69
		6.20	$1^+; 0$	40	
8.79 [f])	$0^-; 1$	0	$1^+; 0$	90 ± 10	46 ± 12
8.91 [n])	$3^-; 1$	0	$1^+; 0$	2.9 ± 0.3	$(11.0 \pm 1.7) \times 10^{-3}$
		5.11	$2^-; 0$	4.2 ± 0.5	$(1.6 \pm 0.3) \times 10^{-2}$
		5.83	$3^-; 0$	84.3 ± 0.9	0.32 ± 0.04
		6.45	$3^+; 0$	5.3 ± 0.6	$(2.0 \pm 0.3) \times 10^{-2}$
		7.03	$2^+; 0$	3.3 ± 0.5	$(1.3 \pm 0.2) \times 10^{-2}$

TABLE 14.11—continued

E_i (MeV)	$J_i^\pi; T$	E_f (MeV)	$J_f^\pi; T$	Branch (%)	Γ_γ (eV)
8.96	$5^+; 0$	0	$1^+; 0$	<1	
		6.45	$3^+; 0$	100	$(1.2 \pm 0.2) \times 10^{-3}$ [k]
9.13	$3^+; 0$	0	$1^+; 0$	82 ± 3	$(8.5 \pm 1.0) \times 10^{-3}$ [l]
		5.83	$3^-; 0$	9 ± 3	$(0.9 \pm 0.3) \times 10^{-3}$ [l]
		6.45	$3^+; 0$	9 ± 3	$(0.9 \pm 0.3) \times 10^{-3}$ [l]
9.17 [m]	$2^+; 1$	0	$1^+; 0$	85.9 ± 1.0 [e]	5.4 ± 0.3
		2.31	$0^+; 1$	0.86 ± 0.08 [e]	$(5.4 \pm 0.6) \times 10^{-2}$
		5.69	$1^-; 0$	0.50 ± 0.10 [e]	$(3.2 \pm 0.7) \times 10^{-2}$
		5.83	$3^-; 0$	0.62 ± 0.08 [e]	$(3.9 \pm 0.6) \times 10^{-2}$
		6.45	$3^+; 0$	8.9 ± 0.8 [e]	0.56 ± 0.06
		7.03	$2^+; 0$	3.2 ± 0.3 [e]	0.20 ± 0.03
9.51 [p]	$2^-; 1$	0	$1^+; 0$	0.6 ± 0.1	0.026 ± 0.006
		3.95	$1^+; 0$	6.6 ± 0.5	0.26 ± 0.04
		5.11	$2^-; 0$	75.9 ± 4.7	3.02 ± 0.36
		5.83	$3^-; 0$	16.8 ± 1.5	0.67 ± 0.10
9.70 [p]	$1^+; 0$	0	$1^+; 0$	30 ± 7	0.018 ± 0.004
		2.31	$0^+; 1$	70 ± 8	0.043 ± 0.005
10.10 [p]	$2^+, 1^+; 0$	0	$1^+; 0$	100	0.21 ± 0.02
10.23	$1^{(-)}; 0$	2.31	$0^+; 1$	~ 100	4 ± 1.3
10.43 [p]	$2^+; 1$	0	$1^+; 0$	83 ± 3	10.8 ± 0.6
		5.11	$2^-; 0$	2.4 ± 0.2	0.31 ± 0.03
		5.69	$1^-; 0$	1.6 ± 0.4	0.21 ± 0.05
		6.45	$3^+; 0$	6.5 ± 0.3	0.85 ± 0.06
		7.03	$2^+; 0$	6.5 ± 0.3	0.85 ± 0.06
10.81	$5^+; 0$	6.45	$3^+; 0$	100	$(1.6 \pm 0.7) \times 10^{-2}$ [o]
11.05	3^+	0	$1^+; 0$		0.12 ± 0.02
		3.95	$1^+; 0$		0.09 ± 0.02

a) See table 14.11 in (Aj 81) for the earlier references and for additional comments. See also table 14.14 in (Aj 86) and (Ko 81d) for additional discussions.

b) Two values have been reported: 1.3 ± 1.0 and $\leq 0.5\%$.

c) (Bh 82a).

d) $\delta(M2/E1) = -0.16 \pm 0.02$, $\delta(E3/E1) = -0.15 \pm 0.025$: see (Ko 81d).

e) Recalculated to sum to 100%: see table 14.11 in (Aj 81).

f) (Ko 81d).

g) $\delta(M3/E2) = -0.004 \pm 0.010$.

h) $\delta(E2/M1) \approx 0.74 \pm 0.09$.

i) $\Gamma_\gamma/\Gamma = (0.7 \pm 0.2)\%$; $(2J+1)\Gamma_p = 12.6 \pm 3.6$ eV; $\Gamma = 2.5 \pm 0.7$ eV.

j) $\Gamma = (3.5 \pm 0.5) \times 10^{-2}$ eV from table 14.14 in (Aj 86); $\Gamma_p/\Gamma = 3.7 \pm 1.1$ [see (Aj 81)] leads to $\Gamma_\gamma \approx 7.4 \pm 2.5$ meV.

k) $\Gamma = 6.3 \pm 1.0$ meV from table 14.14 (Aj 86); $\Gamma_p/\Gamma_\gamma = 4.1 \pm 0.5$.

l) $\Gamma_p = 43^{-15}_{+31}$ meV; $\delta(M3/E2) = -0.03 \pm 0.02$.

m) $\Gamma_\gamma = 6.3 \pm 0.3$ eV: see table 14.19.

n) (Zu 86). See also (Ko 81d, Pr 85f).

o) $\Gamma_\gamma/\Gamma = (4.1 \pm 0.8)\%$; $\Gamma = 0.39 \pm 0.16$ eV.

p) (Pr 85f).

TABLE 14.12

Resonances in $^{10}B+\alpha$ [a])

E_α (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Outgoing particle [b]) (x)	$^{14}N^*$ (MeV)	J^π
0.95		p_0	12.29	
1.13 ± 5	30 ± 5	$p_0 \rightarrow p_3$, d	12.42	4^-
1.20 ± 5	≈20	p_0, (p_2), p_3	12.47	
1.23 ± 5	35 ± 5	p_0, p_3	12.49	
1.40 ± 5	46 ± 4	p_1, p_2, (p_3)	12.61	3^+
1.507 ± 5	18 ± 5	n_0, p_0, p_1, p_2, p_3, d, α [c])	12.689	3^-
1.645 ± 5	16 ± 3	n_0, p_0, p_1, p_2, p_3, d, α [d])	12.787	4^+
1.68 ± 5	5 ± 2	p_1, p_2, p_3, d	12.812	4^-
1.83 ± 5	22 ± 4	$p_0 \rightarrow p_3$, d	12.919	4^+
2.174 ± 5	15 ± 5	n_0, $p_0 \rightarrow p_3$, d, α_1	13.165	1^+
2.21 ± 10	65 ± 10	α_0	13.191	3^+
2.281 ± 10	92 ± 5	n_0, $p_0 \rightarrow p_3$	13.241	2^-
2.86 ± 5	≈90	n_0, p_1, p_2, α_1	13.655	
2.94 ± 5	105 ± 25	n_0, $p_0 \rightarrow p_3$, d	13.712	2^-, 3^+
2.98 ± 10	180 ± 20	n_0, p_0, p_1, (p_2), α_0	13.74	3^+, $1^{(+)}$
3.02 ± 10	120	p_1, p_3	13.77	(1^+)
3.40 ± 30	100	n_0, p_1	14.04	
3.56 ± 30	230	n_0, (p_0), p_3	14.16	
3.69 ± 50	420 ± 100	p, α_0	14.25	3^+
3.76 ± 20	150	p_1	14.30	
3.98 ± 20	100	n_0, p_0, p_2	14.56	
4.16 ± 30	50	n_0, p_0, p_3	14.59	
4.26 ± 10	100 ± 20	α_0	14.65	2^-
4.36 ± 30	125	n_0, p_0, p_1, (p_2)	14.73	
4.54 ± 30	140	n_0, p_2, p_3	14.86	
4.633 ± 30	43 ± 8	n_0, n_{2+3}, p_0	14.92	
4.77 ± 20	~60	n_0, n_1	15.02	
5.08 ± 20	100	p_3	15.24	
5.35 ± 20	100	n_1, p_2, p_3	15.43	
6.44 ± 20	125	n_0, p_0, p_2	16.21	
6.70 ± 20	150	p_2	16.40	
7.42 ± 20		p_0	16.91	
7.78 ± 20	50	p_3	17.17	

[a]) See references in tables 14.13 in (Aj 81) and 14.15 in (Aj 86), as well as in (Aj 70, Aj 76).

[b]) n_0, n_1, n_{2+3} correspond to $^{13}N^*$(0, 2.37, 3.51 + 3.55); p_0, p_1, p_2, p_3 correspond to $^{13}C^*$(0, 3.09, 3.68, 3.85) and the corresponding γ-rays; α_1 corresponds to the transition to $^{10}B^*$(0.7). For θ_x^2 see table 14.8 in (Aj 70).

[c]) Γ_x = 4.3, 0.62, 0.17, 0.70, 5.6, 0.93, 1.7 keV for n_0, p_0, p_1, p_2, p_3, d, α.

[d]) Γ_x = ≤0.6, 0.18, 0.085, 0.44, 9.6, 2.0, 1.0 keV for n_0, p_0, p_1, p_2, p_3, d, α.

4. (a) $^{10}B(\alpha, d)^{12}C$ $\qquad Q_m = 1.3401 \qquad E_b = 11.6125$

(b) $^{10}B(\alpha, t)^{11}C$ $\qquad Q_m = -11.1244$

Excitation curves have been measured at E_α up to 27 MeV [see (Aj 70, Aj 76, Aj 81)]. The low energy resonances are exhibited in table 14.12. At the higher energies the yield curves are fairly smooth although broad resonances in the d_1 and d_0 yields corresponding to $^{14}N^*$ (23, 25), respectively have been reported as has a sharp rise in the 15.1 MeV γ yield ~1 MeV above the $^{12}C^*(15.1)+p+n$ threshold, a channel which is not isospin forbidden: see (Aj 81). For cross sections at $E_\alpha =$ 29.5 MeV (reaction (a)) and 25.0 and 30.1 MeV (reaction (b)) see (Va 83m). See also ^{12}C in (Aj 90) and (Va 89j).

5. $^{10}B(\alpha, \alpha)^{10}B$ $E_b = 11.6125$

The yield of α-particles [and of 0.7 MeV γ-rays for $E_\alpha = 2.1$ to 3 MeV] has been measured for E_α to 50.6 MeV: see (Aj 81). Observed resonances are displayed in table 14.12. In addition to two strong resonances in the α_0 yields at $E_\alpha = 2.21$ and 4.26 MeV ($^{14}N^*(13.19, 14.66)$), two other states ($^{14}N^*(13.72, 14.25)$) are required to fit the data: an R-matrix calculation leads to $J^\pi = 3^+, 1^+$ [see, however, (Wi 75b)], 3^+ and 2^- for $^{14}N^*(13.19, 13.72, 14.25, 14.66)$: see (Aj 81).

6. $^{10}B(^6Li, d)^{14}N$ $Q_m = 10.1374$

States with $E_x > 10$ MeV studied in this reaction at $E(^6Li) = 34$ MeV are displayed in table 14.13 (Cl 84a). In addition most of the lower-lying $T = 0$ states have been populated: see (Aj 70, Aj 81).

7. $^{10}B(^7Li, t)^{14}N$ $Q_m = 9.1446$

At $E(^7Li) = 24$ MeV angular distributions of the tritons to $^{14}N^*(3.95, 5.83, 6.45, 8.96, 9.13, 10.06, 10.81, 12.79+12.81, 13.03, 15.26)$ have been studied. $^{14}N^*(4.91, 5.11, 5.69, 6.20, 7.03, 7.97, 8.49, 8.98, 9.39, 11.05, 11.51, 12.42)$ are also populated: see (Aj 81).

8. $^{10}B(^9Be, \alpha n)^{14}N$ $Q_m = 10.0390$

For cross sections see (Cu 86a).

9. (a)	$^{11}B(^3He, \gamma)^{14}N$	$Q_m = 20.7361$	
(b)	$^{11}B(^3He, n)^{13}N$	$Q_m = 10.1826$	$E_b = 20.7361$
(c)	$^{11}B(^3He, p)^{13}C$	$Q_m = 13.1855$	
(d)	$^{11}B(^3He, d)^{12}C$	$Q_m = 10.4637$	
(e)	$^{11}B(^3He, t)^{11}C$	$Q_m = -2.001$	
(f)	$^{11}B(^3He, ^3He)^{11}B$		
(g)	$^{11}B(^3He, \alpha)^{10}B$	$Q_m = 9.1236$	
(h)	$^{11}B(^3He, ^6Li)^8Be$	$Q_m = 4.5721$	

The capture γ-rays [reaction (a)] have been studied at $E(^3He) = 0.9$ to 2.6 MeV ($\theta = 0°, 90°$). When the barrier penetration factor has been removed a single resonance is observed at $E(^3He) \sim 1.4$ MeV [$^{14}N^*(21.8)$], $\Gamma_{c.m.} = 0.65$ MeV.

The excitation function for reaction (b) has been measured for $E(^3He) = 1.5$ to 18 MeV [see (Aj 81)]. A broad peak at $E(^3He) = 4.15$ MeV may indicate the existence of $^{14}N^*(24)$, $\Gamma \simeq 1$ MeV.

Yield curves for protons (reaction (c)) have been measured for $E(^3He) = 3.0$ to 5.5 MeV (p_0, p_1, $p_1 + p_2 + p_3$): they are rather featureless. This is also true for the ground-state deuterons of reaction (d) in the same energy interval. Yield curves for reaction (e) have been measured for $E(^3He) = 6$ to 30 MeV: see (Aj 76). A_y measurements for t_0 and t_1 are reported at $E(^3\overrightarrow{He}) = 33$ MeV: see (Aj 86). See also ^{13}C and ^{13}N, and ^{11}B, ^{11}C, ^{12}C in (Aj 90).

The excitation functions for α-particle groups [reaction (g)] have been measured for $E(^3He) = 0.9$ to 5.5 MeV: see (Aj 76). No significant resonance behavior is seen except for the α_2 group which, in the 15° excitation function, exhibits a resonance at $E(^3He) = 4$ MeV, $\Gamma \simeq 1$ MeV. See also ^{10}B in (Aj 88).

The excitation function for reaction (h) to $^6Li_{g.s.} + ^8Be_{g.s.}$ has been measured for $E(^3He) = 1.4$ to 5.8 MeV: no pronounced structure is observed. At $E(^3He) = 25.20$ to 26.25 MeV the excitation functions for the transitions to $^8Be^*(0, 16.63, 16.91, 17.64)$ are smooth, indicating a predominantly direct reaction mechanism: see (Aj 76).

10. $^{11}B(\alpha, n)^{14}N$ $\qquad Q_m = 0.1583$

For angular distributions to $E_\alpha = 13.9$ MeV see (Aj 81). At $E_\alpha = 47.4$ MeV, $\theta = 0°$, unresolved groups are reported to $E_x = 5.2$, 8.6, 14.71, 16.84, 19.10, 20.52, 21.72, 22.38, 23.57 and 24.25 MeV (Lu 88a). [See for comments about dominant J^π: high-spin states are expected to be preferentially populated.] Uncertainties in E_x are ±0.35 MeV for 15 MeV neutrons to 1.5 MeV for 30 MeV neutrons. Widths could not be determined. A state at ~25 MeV was also populated [J.D. Brown, private communication]. See also ^{15}N, (Aj 86) and (Ca 88m; astrophys.).

11. $^{11}B(^6Li, t)^{14}N$ $\qquad Q_m = 4.9406$

States with $E_x > 10$ MeV studied in this reaction at $E(^6Li) = 34$ MeV are displayed in table 14.13 (Cl 84a).

12. $^{12}C(d, \gamma)^{14}N$ $\qquad Q_m = 10.27239$

At $E_d = 1.5$ MeV the capture cross section is <1 μb: see (Aj 70). See also (Na 84s). See also (Ha 90f).

13. (a) $^{12}C(d, n)^{13}N$ $\qquad Q_m = -0.2811$ $\qquad E_b = 10.27239$
(b) $^{12}C(d, p)^{13}C$ $\qquad Q_m = 2.7218$
(c) $^{12}C(d, 2p)^{12}B$ $\qquad Q_m = -14.812$

Resonances in the yields of neutrons and protons are displayed in table 14.14. The 0° yield of neutrons shows broad structures at $E_d \sim 7.2$ and 11.5 MeV [n_0] and 8 and (10.8) MeV [n_1] as well as a sharper structure at $E_d \sim 9.5$ MeV: see (Aj 86).

TABLE 14.13

States in ^{14}N from $^{10}B(^6Li, d)$, $^{11}B(^6Li, t)$, $^{12}C(^6Li, \alpha)$ ^a^)

E_x (MeV ± keV) ^b^)	$d\sigma/d\Omega_{c.m.}$ ($\mu b/sr$) ^c^)		
	A	B	C
10.07 ± 15	266	262	290
10.43 ± 15		88	
10.81 ± 15	234	164	
11.05 ± 15	82	64	770
11.24 ± 15		118	
11.27 ± 15	74		1510
11.51 ± 20	102	65	1170
11.79 ± 20	55		
12.42 ± 15	68	305	2702
12.66 ± 30	82	286	1175
12.79 ± 15		434	
12.81 ± 15	149		
12.85 ± 30			4960
12.92 ± 20		324	
13.00 ± 30	138		
13.19 ± 20	80	234	
13.71 ± 20	34	202	
14.57 ± 20	183	217	
14.81 ± 25		332	
14.85 ± 30	189		2325
14.95 ± 30		515	
15.00 ± 30	157		
15.24 ± 20	141	540	
15.40 ± 50			1653
15.70 ± 50	51		3530
16.20 ± 50			1830
16.80 ± 40		246	
16.91 ± 30		297	
17.17 ± 30		712	4860

A: $^{10}B(^6Li, d)$; $E(^6Li) = 34$ MeV.
B: $^{11}B(^6Li, t)$; $E(^6Li) = 34$ MeV.
C: $^{12}C(^6Li, \alpha)$; $E(^6Li) = 32$ MeV.

^a^) (Cl 84a): see for angular distributions and for discussion of analog states in ^{14}C.

^b^) States below $E_x = 10$ MeV are not displayed here.

^c^) At $\theta_{lab} = 10°$. Uncertainties in the differential cross sections are approximately ±20%.

Polarization measurements for both reactions (a) and (b) have been made at many energies. For the earlier work see (Aj 70, Aj 76, Aj 81, Aj 86). Recent studies have been reported for reaction (b) at $E_d = 0.25 \rightarrow 1.10$ MeV (Ko 86o; p_0) and at $E_d = 12$ MeV (La 88; ^{13}C states with $E_x < 7.7$ MeV; VAP, TAP), 56 MeV (Sa 86h; p_0, p_1; $K_{y'}^{y}$ and $K_{yy'}^{y'}$; prelim.), 2.1 GeV (Pe 87b, Pu 89; TAP; deuteron breakup), and

9.1 GeV/c (Ab 88c; TAP). For the breakup at high energies see also (Ko 84w, Av 89b, Be 89hh). For reaction (c) to $^{12}B^*(0, 4.4$ [u]) at $E_d = 70$ MeV see (Mo 86m, Mo 88b; VAP, TAP) [see (Mo 86m) for comment re lower energy measurement at 0°]. For a study of the Δ-region at $E_d = 2$ GeV see (El 89d).

For a study of the ($\vec{d}$, $\overline{pX}$) reaction at $E_d = 65$ MeV see (Ie 89). For a report on high-energy γ-ray production see (Ni 89a). For pion production see (Aj 86) and (Ag 87b). For total cross sections see (Aj 86) and (Ki 87f; prelim.; 2.0 to 4.0 GeV/c). See also (Na 84s, Na 89n) and (Ha 86hh; applied).

14. $^{12}C(d, d)^{12}C$ $E_b = 10.27239$

Reported resonances are displayed in table 14.14. For a listing of excitation function measurements see (Aj 76). A recent study is reported by (Ho 86q; $E_d = 0.60$

TABLE 14.14

Resonances in $^{12}C + d$ [a])

E_d (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Particles out	$^{14}N^*$ (MeV)	$J^\pi; T$
0.92	95	n, p_0, p_1	11.06	$1^+; 0$
1.13		p_0, p_1	11.24	$T = 1$
1.19	190	n, p_0, p_1, d	11.29	$2^-; 0$
1.23		p_0	11.33	(3^+)
1.30	30	n, p_0, p_1, d	11.39	$1^+; 0$
1.39		p_0	11.46	(2^-)
1.4495 ± 1.5	7.0 ± 0.5	p_0, p_1, d	11.5135	$2^+, 3^+$
1.55		p_0	11.60	(2^-)
1.640 ± 20	150 ± 20	n, p_1, d_0	11.68	$1^-, 2^-$
1.715 ± 6	40 ± 9	p_2	11.741	$1^-, 2^-$
1.738 ± 6	78 ± 6	p_1	11.761	$3^-, 4^-, (2^-)$
1.792 ± 7	119 ± 9	n, p_0, p_1, p_2, d_0	11.807	$2^-, (1^+)$
1.870 ± 6	101 ± 9	p_0, p_1, p_2	11.874	$2^-, (1^-)$
2.250 ± 19	300 ± 30	n, $p_0 \rightarrow p_3$, d_0	12.20	$1^-, 2^-$
2.494 ± 3 [b])	37 ± 4	n, $p_0 \rightarrow p_3$, d_0	12.408	$3^+, (3^-, 4^-)$
2.506 ± 3	41 ± 4	p_1	12.418	$3^-, 4^-, (2^+, 3^+)$
2.610 ± 20	30 ± 20	n, p_1, p_2, p_3	12.507	
2.712 ± 3	48 ± 2	(n), $p_0 \rightarrow p_3$, d_0	12.594	3^+
(2.817 ± 7)	27 ± 6	n, p_1, p_2, p_3, d_0	(12.684)	
2.844 ± 9	43 ± 15	p_2, p_3	12.708	
2.940 ± 10	30 ± 10	p_2, p_3, d	12.790	
2.967 ± 5	37 ± 6	p_1	12.813	
2.982 ± 6	11 ± 3	n, p_3, d	12.826	
3.018 ± 6	78 ± 10	n, p_0, p_1	12.857	
3.049 ± 8	134 ± 11	p_1	12.883	
3.100 ± 10	20 ± 14	p_1, p_2, p_3, d	12.927	$(3^-, 4^-)$
3.39 ± 12	47 ± 15	n, p_2, p_3, d	13.17	$(0^-, 1^-)$
3.97 ± 30	<200	p_0, p_2, p_3, (d)	13.67	$(2^+, 3^+)$
4.02^{+20}_{-10}	~235	n, (p), d	13.71	(1^+)
4.40		$p_0 \rightarrow p_3$, d	14.04	
4.55		n, p_2, d	14.17	

TABLE 14.14—continued

E_d (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Particles out	$^{14}N^*$ (MeV)	$J^\pi; T$
4.80		p_0, p_2, d	14.38	
5.17		d	14.70	
5.34	~100	$p_0 \rightarrow p_3$, d, α	14.84	
5.65		d	15.11	
5.83		p_1, p_3, d	15.26	
6.07		p_1, p_2, α	15.47	
6.3		p_0, p_3, d, α	15.7	
7.2		α	16.4	
7.448 [c])	1240	α_2	16.65 [d])	4^+
7.760 [d])	828	α_2	16.92	2^+
7.784	293	α_2	16.94	4^+
7.887	246	α_2	17.03	3^-
8.034	307	α_2	17.15	1^-
8.217	275	α_2	17.31	4^+
8.327	244	α_2	17.40	4^+
8.851	473	α_2	17.85	4^+
8.852	437	α_2	17.85	3^-
8.942 [d])	336	α_2	17.93	2^+
9.051	567	α_2	18.02	3^-
9.186	481	α_2	18.14	4^+
9.433	558	α_2	18.35	1^-
9.530 [d])	313	α_2	18.43	4^+
9.610	62	α_2	18.50	5^-
9.637 [d])	410	α_2	18.53	2^+
9.647 [d])	312	α_2	18.53	3^-
9.768	673	α_2	18.64	3^-
9.939	314	α_2	18.78	1^-
10.057	475	α_2	18.88	4^+
10.112	452	α_2	18.93	$2^+, 3^-$
10.306	872	α_2	19.10	3^-
11.237	575	α_2	19.90	2^+
11.348	506	α_2	19.99	1^-
12.094	1071	α_2, α_3	20.63	4^+
12.122	612	α_2	20.65	5^-
12.809	414	α_2	21.24	4^+
13.124	233	α_2	21.51	3^-
13.148 [d])	362	α_2	21.53	5^-
13.323	357	α_2	21.68	4^+
14.002 [d])	65	α_2	22.26	4^+
14.054	568	α_2	22.31	5^-
15.334	640	α_2	23.40	5^-

[a]) For references see table 14.15 in (Aj 76). See also table 14.10 in (Aj 70).

[b]) A study of this resonance shows that either f-shell components are present in the wave function or that the coupling is very strong or that both effects are present.

[c]) *S*-matrix analysis of α_2 by (Jo 81e) leads to the resonance parameters for the states shown below, all of which are isospin-mixed. See also table 14.14 in (Aj 81) and table 1 in (Jo 81e). Uncertainties in $\Gamma_{c.m.}$ and E_x are about 10% of $\Gamma_{c.m.}$.

[d]) Uncertainties in $\Gamma_{c.m.}$ and E_x are about 20% of $\Gamma_{c.m.}$.

to 1.10 MeV; d_0). For the earlier polarization measurements see (Aj 76, Aj 81, Aj 86). $A_y = 0.412 \pm 0.011$ at $E_d = 56$ MeV ($\theta = 47.5°$), and VAP and TAP have been studied for $E_d = 35$ to 70 MeV (Ka 85q, Ka 86g). Studies of VAP and TAP have also been carried out at $E_d = 56$ MeV (Ma 86ee; d_0) and 191 and 395 MeV (Ga 86h; inclusive scattering; on C). At $E_d = 400$ MeV, VAP and TAP measurements are reported for the groups to $^{12}C^*(4.4, 9.7, 12.7, 18.3)$ (Ar 87e; prelim.). For the (d, pn) reaction at $E_d = 56$ MeV see (Ok 89).

See also (Ca 87e), (Cl 86a, Bo 90f; applied), (Ya 86c) and (Go 89e; theor.).

15. (a) $^{12}C(d, t)^{11}C$ $\quad Q_m = -12.4645 \quad E_b = 10.27239$
    (b) $^{12}C(d, ^3He)^{11}B$ $\quad Q_m = -10.4637$

At $E_d = 89.1$ MeV A_y measurements are reported for $^{11}C^*(0, 2.3)$ (Sa 89h). For the earlier work see (Aj 86).

16. $^{12}C(d, \alpha)^{10}B$ $\quad Q_m = -1.3401 \quad E_b = 10.27239$

Reported resonances are displayed in table 14.14. The major interest in this reaction has been the study of the yield of the α_2 group to the $J^\pi = 0^+$, isospin "forbidden" $T = 1$ state. In particular, the work of (Sm 72d, Ri 71d) has shown that while the α_0, α_1 and α_3 yields show only weak fluctuations, the α_2 "forbidden" yield shows narrow resonances which implies that the source of the isospin mixing (at least in the region which they, and the subsequent work of (Jo 74) studied: $E_d = 7.2$ to 16 MeV) is due to states in the ^{14}N compound nucleus. The ratio of the σ_t for the α_2 group compared to the σ_t for the "allowed" groups is $\approx 1\%$, an order of magnitude greater than predicted by direct or multistep processes (Sm 72d). An S-matrix analysis leads to the resonance parameters shown in table 14.14 (Jo 81e). For polarization measurements see (Aj 86).

17. $^{12}C(d, ^6Li)^8Be$ $\quad Q_m = -5.8916 \quad E_b = 10.27239$

Polarization measurements have been reported at $E_d = 18$ and 22 MeV (Ta 87; VAP, TAP; g.s.) and 51.7 MeV (Ya 86o; VAP; $^8Be^*(0, 2.9, 11.4)$). See also (Aj 81).

18. $^{12}C(t, n)^{14}N$ $\quad Q_m = 4.01510$

Angular distributions have been measured to states below 8.7 MeV at $E_t = 1.12$ to 1.68 MeV and at 8 MeV: see (Aj 76).

19. $^{12}C(^3He, p)^{14}N$ $\quad Q_m = 4.7789$

Observed proton groups are displayed in table 14.15. Angular distributions have been measured for $E(^3He)$ to 25.3 MeV [see (Aj 70, Aj 76)] and at $E(^3\vec{He}) = 33$ MeV: see (Aj 86). For a discussion of $^{14}N^*$ (9.13) see (Wa 86h). For work at very high energies see (Ab 87e). See also (Sc 86a, To 90a; applied).

TABLE 14.15

States of ^{14}N from ^{12}C(^{3}He, p)^{14}N [a])

E_x (MeV ± keV)	L	J^π; T	E_x (MeV ± keV)	L	J^π; T
0	2		10.063 ± 15 [e])		3^+, ≥4
2.319 ± 15	0		10.101 ± 15		1^+, 2^+
3.9502 ± 1.5 [b])	0		10.23		1
4.9153 ± 1.4 [b])	1		10.441 ± 15	[g])	(2^+; 1) [h])
■ 5.10587 ± 0.18	1		10.53		1, 2
5.6888 ± 1.4 [b])	1		10.812 ± 15		5^+; 0
5.8324 ± 1.4 [b])	3		11.053 ± 15		
6.2025 ± 1.4 [b])	0		11.249 ± 15		
6.4449 ± 1.4 [b])	2		11.357 ± 15		
7.0279 ± 1.4 [b])	2		11.517 ± 15		
7.9649 ± 1.4 [b])	3		[f])		
8.072 ± 15	1		12.29 ± 15		
8.4864 ± 1.5 [b,c])	3	4^-; 0	12.425 ± 15		
8.6174 ± 4 [b])	0	(0^+; 1) [h])	12.506 ± 15		
8.9099 ± 1.9 [b,d])		(3^-; 1) [h])	12.608 ± 15		
8.9598 ± 1.4 [b])			12.69 ± 15		
8.9773 ± 4 [b])		(2^+; 0) [h])	12.80 ± 15		
9.1241 ± 1.5 [b])		(3^+; 0) [i])	12.90 ± 25 [f])		
9.1674 ± 1.4 [b])	[g])	(2^+; 1) [h])	13.15 ± 40		
9.3854 ± 1.6 [b,d])		2^-; 0 [j])	14.91 ± 60		
9.51		(2^-; 1) [h])	15.8 ± 200		
9.703 ± 15		(1^+; 0) [h])	17.4 ± 200		

[a]) See tables 14.14 in (Aj 70), 14.18 in (Aj 76) and 14.15 in (Aj 81) for references.

[b]) A re-evaluation by (Wa 86h) [based on an overall comparison with γ-ray values] of the E_x obtained by (Du 71) leads to $E_x = 3948.10 \pm 0.20, 4915.1 \pm 1.4, 5105.89 \pm 0.10, 5691.44 \pm 0.13, 5834.25 \pm 0.14, 6203.6 \pm 1.4, 6446.17 \pm 0.10, 7029.12 \pm 0.12, 7966.9 \pm 0.5, 8490 \pm 2, 8618 \pm 2, 8907 \pm 3, 8964 \pm 2, 8980 \pm 3, 9129.0 \pm 0.5, 9172.25 \pm 0.12$, and 9388 ± 3 keV.

[c]) $\Gamma_p/\Gamma = 0.73 \pm 0.10$.

[d]) The widths of ^{14}N*(8.91, 9.39) are, respectively, 19.7 ± 1.9 and 15.6 ± 2.0 keV.

[e]) $\Gamma < 10$ keV (J.W. Noe, private communication).

[f]) See table 14.15 in (Aj 81).

[g]) θ_p^2 $(l = 3) = (2.3 \pm 1.1) \times 10^{-3}$ and $< 1.6 \times 10^{-3}$ for ^{14}N*(9.17, 10.43).

[h]) Known from other data; consistent with the results in this reaction.

[i]) See discussion in (Wa 86h).

[j]) Or $J^\pi = 3^-$.

20. ^{12}C(α, d)^{14}N $\qquad Q_m = -13.57434$

Angular distributions of deuterons have been studied corresponding to the $T = 0$ states ^{14}N*(0, 3.95, 4.92, 5.11, 5.69, 5.83, 7.97, 8.49, 8.96, 9.13, 9.39, 10.81) [$E_\alpha = 34.5$, 42, 55 MeV; not all states at all energies]. At the higher energies the deuteron spectrum is dominated by very strong groups corresponding to the $(d_{5/2})^2$, $J^\pi = 5^+$ state at 8.96 MeV, and to a state at 15.1 ± 0.1 MeV: see table 14.19 in (Aj 76), and (Aj 81, Aj 86). At $E_\alpha = 50$ MeV the angular distributions of the singlet deuterons exciting the $T=1$ states ^{14}N*(2.31, 8.91[u]) have been studied by (Sa 86b): a state at 12.6 ± 0.3 MeV is also populated. See also (Ga 89d, Sh 89d).

21. ^{12}C(^{6}Li, α)^{14}N $Q_m=8.7974$

At $E(^6\text{Li})=20$ MeV [see table 14.19 in (Aj 76)] and 32 MeV [see table 14.13 here] many of the α-groups corresponding to $T=0$ states with $E_x<17.2$ MeV are observed. The 5^+ state, ^{14}N*(9.0), is strongly populated: see (Aj 70). Angular distributions have been measured at $E(^6\text{Li})=2$ to 33 MeV: see (Aj 81, Aj 86). Inclusive α-particle spectra have been studied at $E(^6\text{Li})=156$ MeV (Je 89). See also ^{18}F in (Aj 87), (Pa 87d) and (Ha 86k; theor.).

22. ^{12}C(^{9}Be, ^{7}Li)^{14}N $Q_m=-6.4227$

See (Go 88g).

23. ^{12}C(^{12}C, ^{10}B)^{14}N $Q_m=-14.9144$

This reaction has been studied at $E(^{12}\text{C})=114$ MeV: the spectrum is dominated by ^{14}N*(8.96) [$J^\pi=5^+$] but there is substantial population also of ^{14}N*(5.83) [3^-] and of a state at $E_x=11.2$ MeV. Angular distributions are reported at $E(^{12}\text{C})=49.0$ to 93.8 MeV: see (Aj 81, Aj 86).

24. ^{12}C(^{13}C, ^{11}B)^{14}N $Q_m=-8.4066$

At $E(^{13}\text{C})=390$ MeV angular distributions have been studied to ^{14}N*(0, 2.31, 5.8[u]) and to unresolved structures and continua. The spectra are dominated by the group to ^{14}N*(5.8) (Ad 87c, Vo 88e). See also (Vo 89).

25. (a) ^{13}C(p, γ)^{14}N $Q_m=7.55063$
(b) ^{13}C(p, p$'\gamma$)^{13}C $E_b=7.55063$

Observed resonances are displayed in table 14.16. The radiative decay is exhibited in table 14.11.

The low-energy capture cross section yields an extrapolated S-factor at $E_p=25$ keV (c.m.), $S_0=6.0\pm0.8$ keV · b. The capture cross section rises from $(7.7\pm1.8)\times10^{-10}$ b at $E_p=100$ keV to $(9.8\pm1.2)\times10^{-9}$ b at $E_p=140$ keV: see (Aj 70).

Following is a summary of the reasons for the assignments of J^π; T to some of the lower resonances displayed in table 14.16: for a fuller discussion and complete references see (Aj 70, Aj 76, Aj 81). *^{14}N*(7.97)*: angular distribution of the γ-rays is consistent with $J^\pi=2^-$. *^{14}N*(8.06)*: width of resonance, isotropy of γ-rays show $l_p=0$; $J^\pi=1^-$ from ^{13}C(p, p); E1 transition to g.s. is uninhibited; therefore, $T=1$ [but 1.4% 8.06→2.31 transition [$E_x=2312.6\pm0.3$ keV] shows $T=0$ admixture: $\alpha^2=0.046$]. The strong transition 8.06→5.69 [3.5%] permits either E1 or M1, $\Delta T=1$. Since 5.69→2.31 is seen *^{14}N*(5.69)* cannot have $J^\pi=0^+$, and 2^+ is excluded by the strength of the 8.62→5.69 transition. It is then $J^\pi=1^-$; $T=0$ [the isospin mixing $\alpha^2=0.09$]; $E_x=5691.55\pm0.13$ keV (Bi 81e). *^{14}N*(8.49, 8.96, 9.13)* correspond to anomalies in the cross section. The nature of their γ-decays [see table 14.11] and the angular distribution leads to $J^\pi = 4^-$, 5^+, 3^+ [all $T = 0$], respectively.

$^{14}N^*(8.62)$ [$J^\pi = 0^+$ from $^{13}C(p, p)$] shows strong transitions to $^{14}N^*(0, 3.95, 5.69)$: $T = 1$. The strength of the $8.62 \to 3.95$ decay shows it is dipole and therefore $J = 1$ for $^{14}N^*(3.95)$ [$E_x = 3947.6 \pm 0.4$ keV]. The strength of the transition $8.62 \to 6.20$ and the angular correlation $8.62 \to 6.20 \to$ g.s. is consistent with $J^\pi = 1^+$, $T = 0$ for *$^{14}N^*(6.20)$* [$E_x = 6203.7 \pm 0.6$ keV]. *$^{14}N^*(8.78)$* [$J^\pi = 0^-$ from $^{13}C(p, p)$] has a large Γ_γ consistent with E1 and $T = 1$. *$^{14}N^*(9.17)$*: angular correlation and angular distribution measurements indicate $J^\pi = 2^+$ for that state, 3^- for *$^{14}N^*(6.45)$* [see however table 14.10] and $J = 2$ for *$^{14}N^*(7.03)$*. For recent studies of *$^{14}N^*(9.17)$* see (Bi 81e, Wa 86h): $E_x = 9172.5 \pm 0.3$ keV from E_γ, $\Gamma_{\gamma_0}/\Gamma_\gamma = (79 \pm 4)\%$, Γ [from (p, p)] $= 135 \pm 8$ eV [135 ± 11 eV in (γ, γ)]. Other E_x determined by (Bi 81e) are 2312.90 ± 0.03, 3948.2 ± 0.2, 5105.9 ± 0.3, and 6446.3 ± 0.2 keV. See also tables 14.11 and 14.15.

The angular distribution of the γ-rays from $10.23 \to 2.31$ is consistent with $J^\pi = 1^+$ for *$^{14}N^*(10.23)$*: $T = 0$ from M^2(M1) [see, however, table 14.10]. The γ_0 angular distribution is consistent with $J = 2$ for *$^{14}N^*(10.43)$*: the similar decay characteristics of this state and of *$^{14}N^*(9.17)$* suggest that they are both $J^\pi = 2^+$, $T = 1$.

Below $E_p = 5.5$ MeV only γ_0 can be observed in the capture radiation. A number of resonances in the γ_0 yield and in the yield of the ground-state γ-rays from $^{13}C^*(3.09, 3.68, 3.85)$ have been observed: these are shown in table 14.16 in the range $E_p = 3.7$ to 6.6 MeV. Angular distributions and measurements of Γ_{γ_0} lead to the J^π values shown. Above $E_p = 7$ MeV the γ_0 yield shows broad structure and the giant dipole resonance at $E_x = 22.5$ and 23.0 MeV. Measurements of the γ_0 and γ_1 90° yields for $E_x = 23$ to 33 MeV find that the $T = 2$ resonances reported earlier at $E_x = 23.7$ and 24.2 MeV do not exist and that there is no evidence for the $T = 2$ GDR between $E_x = 25$ and 29 MeV. The 90° yields of γ-rays to $T = 0$ states ($4.9 < E_x < 5.9$ MeV) and to $T = 1$ states ($8.0 < E_x < 9.5$ MeV) have been measured from $E_x = 23$ and 26 MeV, respectively, to $E_x = 33$ MeV. A study of the 90° yield of γ_0 and γ_1 [and of analyzing powers] has been reported for $E_{\vec{p}} = 6.25$ to 17.0 MeV. The γ_0 results are in good agreement with those in the inverse reaction [$^{14}N(\gamma, p)^{13}C$]. Broad structures are observed at $E_p \sim 8$, 13, 14, 15 and 16.5 MeV. The γ_1 results indicate that the $T = 0$ strength is spread out fairly uniformly between $E_x = 13$ and 23 MeV. At $E_p = 25$ MeV strong transitions are observed to two groups of states centered near $E_x = 5.8$ and 8.9 MeV.

For searches for short-lived neutral particles in the decay of $^{14}N^*(9.17)$ see (Sa 86ff, Sa 88j). See also (Ab 85j), (Ro 86h, Ki 88c; applied), (Ca 85t, We 87a, Ca 88m, Ba 89ee, Ma 90f; astrophysics) and (We 86b, Mc 87) and (Ha 80f; theor.).

26. $^{13}C(p, p)^{13}C$ $E_b = 7.55063$

The elastic scattering has been studied for $E_p = 0.14$ MeV to 1 GeV: see (Aj 81) and ^{13}C here. For observed resonances see table 14.16. A_y measurements have been reported at $E_{\vec{p}} = 200$ and 547 MeV [see (Aj 86)], at 35 MeV (Oh 86c; $p_{0\to3}$), at 71.8 MeV (Pr 89e, Pr 90; p_0; and measurements of depolarization parameter, D), at 119 MeV (Co 88b; $p_0 \to p_4$ and p to ^{13}C*(7.55, 8.86, 9.5, 9.9)) and at 500 MeV (Ho 90f; p_0; A_y and rotation parameters). See (Ho 90h; prelim.) for measurements at $E_p =$ 497.5 MeV on $^{13}\vec{C}$. The 0^+-0^- doublet at $E_x \sim 8.7$ MeV has been studied by (Ad 84, Ad 86a, Sw 86, Ze 87, Ze 88a). For pion production see (Hu 88b). See also (Bl 85g, Ad 86c) and (Ra 86e, Be 87d, Be 87j, Ra 88a, Am 89b, Be 89jj, Go 89i, Ku 89e, Ku 89i, Ku 89o, Ra 89m, Du 90; theor.).

27. ^{13}C(p, n)^{13}N $\qquad Q_m = -3.0028 \qquad E_b = 7.55063$

Observed resonances are displayed in table 14.17. Polarization measurements are reported at $E_{\vec{p}} = 35$ MeV (Oh 86c; A_y; n_0, n_1, n_{2+3}) and 160 MeV (Ta 84b, Ra 87d; A_y; D_{NN} (0°); n_0, n_{2+3}, and n to ^{13}N*(15.1) [u]). Forward-angle cross sections have been measured at $E_p = 318$ and 800 MeV (Ki 86c) and at 492 and 590 MeV (Ra 89b). Cross sections for ^{13}N production have been studied for $E_p = 5.2$ to 30.6 MeV by (Ki 89c). For the earlier work see (Aj 86). See also ^{13}N, (Al 87f, Ta 90c), (Ha 86hh, Ar 89m; applied), (Ca 85t; astrophysics), (Al 86o, Ca 86b, Ta 86b, Ta 87f) and (Be 87l, Am 89a, Ra 89d; theor.).

28. ^{13}C(p, d)^{12}C $\qquad Q_m = -2.7218 \qquad E_b = 7.55063$

A_y measurements have been reported at $E_{\vec{p}} = 13.6$ to 530 MeV [see (Aj 86)] and at 119 MeV (Le 87j; to ^{12}C*(0, 4.4, 7.7, 9.6, 12.7, 14.1, 15.1, 16.1, 16.6, 17.8, 18.1, 18.8, 19.9, 20.3, 20.6)). For a measurement of the tensor polarization of ^{12}C*(15.1) at $E_p = 41.3$ MeV see (Ca 87i). For other work see (Aj 76, Aj 81) and ^{12}C in (Aj 90). See also (Ko 86b; theor.).

29. (a) ^{13}C(p, t)^{11}C $\qquad Q_m = -15.1863 \qquad E_b = 7.55063$
(b) ^{13}C(p, ^{3}He)^{11}B $\qquad Q_m = -13.1855$

See ^{11}B, ^{11}C in (Aj 90), and (Aj 86).

TABLE 14.16

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

E_p (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	l_p	$\omega\Gamma_\gamma$ (eV)	J^π; T	^{14}N* (MeV)
0.4485 ± 0.5	<0.37	2	0.022	2^-	7.9669
0.551 ± 1	23 ± 1 [p])	0	9.2	1^-; 1	8.062
1.012 ± 2	≤0.2	4	~0.01	(4^-); 0	8.490
1.152 ± 2 [b])	3.8 ± 0.3	1	1.3	0^+; 1	8.620
1.320 ± 7 [b])	410 ± 20	0	12.8	0^-; 1	8.776
1.462 ± 3	16 ± 2	2	0.67 ± 0.07 [c])	3^-; 1	8.907

TABLE 14.16—continued

E_p (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	l_p	$\omega\Gamma_\gamma$ (eV)	$J^\pi; T$	^{14}N* (MeV)
1.523 ± 2	<1		~0.003	$5^+; 0$	8.964
1.540 ± 3	8 ± 2	1, (3)	0.13	2^+	8.980
1.7005 ± 1 [j]	<1			$3^+; 0$	9.1287
1.7476 ± 0.9 [c,j]	135 ± 8 eV		[c]	$2^+; 1$	9.1724
1.980 ± 3	13 ± 3	2		$3^-, 2^-$	9.388
2.110 ± 3	41 ± 2	2	7.0 ± 1.0 [o]	$2^-; 1$	9.509
2.319 ± 4	15 ± 3	1	0.11 ± 0.01 [o]	1^+	9.703
2.743 [d]	12 ± 3	1	0.37 ± 0.03 [o]	$1^+, (2^+)$	10.096
2.885 ± 10 [d]	80 ± 15	0, 2		$1^{(-)}; 0$	10.228
3.105 ± 5 [d]	33 ± 3	1	22.8 ± 1.3 [o]	$2^+; 1$	10.432
3.20 [d]	140	0, 2		1^-	10.52
3.72 ± 30 [f]	165 ± 30				11.00
3.771 ± 5	1.2 ± 0.4		[k]	3^+	11.050
3.79	100			1^+	11.07
3.94 ± 30	220 ± 30				11.21
3.98 [d]	11	2		3^-	11.24
4.04 [d]	175	2		2^-	11.30
4.14 [d]	28	1		1^+	11.39
4.525 ± 15 [g]	115 ± 10		[l]	1^+	11.750
5.325 ± 10	48 ± 7		[m]		12.492
5.88 ± 20 [f]	120 ± 30				13.01
6.20 ± 100 [h]	1000 ± 150		[n]	$(2^-); 1$	13.30
6.62 ± 20 [f]					13.69
[i]					
16.1				$2^-; 1$	22.5
16.7				$2^-; 1$	23.0

[a]) See references in tables 14.16 in (Aj 70), 14.20 in (Aj 76) and 14.16 in (Aj 81).

[b]) See (Ad 86a).

[c]) See (Bi 81e): $E_x = 9172.5 \pm 0.3$ keV from γ-ray measurements. See also table 14.10, $\Gamma_{\gamma_0}/\Gamma_\gamma = (79 \pm 4)\%$; Γ_{γ_0} (from reaction 41 and table 14.19) $= 7.2 \pm 0.4$ eV; $\Gamma_{c.m.}$ from ^{13}C(p, p).

[d]) Reduced width for proton emission is of the order of 1% of the Wigner limit. For recent work on the $E_p = 3.11$ MeV resonance see (Wi 90; prelim.).

[e]) (Zu 86); $\Gamma_{\gamma_0} = (11.0 \pm 1.7) \times 10^{-3}$ eV: see table 14.11. See also (Pr 85f).

[f]) Weak resonance.

[g]) In the $\gamma_{3.09}$ channel the peak occurs 55 keV higher: interference effects may be present.

[h]) Part of the giant dipole resonance.

[i]) Some broad structures appear in the γ_0, $\gamma_{3.68}$ and $\gamma_{3.85}$ yields. See also reaction 26 and reaction 25 in (Aj 86).

[j]) See also (Wa 86h) and table 14.15.

[k]) $\Gamma_\gamma = 1.2 \pm 0.4$ keV; $\Gamma_p = 0.5\%$ of single-particle unit. J^π based on angular distribution of γ_0. For nature of γ-decay see table 14.11.

[l]) $(2J+1)\ \Gamma_\gamma = (18.5 \pm 4.2)\Gamma/\Gamma_p$ eV; if $J = 1$, $\Gamma_\gamma \geq 6$ eV.

[m]) $(2J+1)\ \Gamma_{\gamma_0} = 2.3\ \Gamma/\Gamma_p$ eV, if $\Gamma = 38$ eV is assumed.

[n]) $(2J+1)\ \Gamma_{\gamma_0} \geq 200$ eV: thus the transition is dipole and $T = 1$. The resonance is asymmetric and it is suggested that two states are involved, one with $J^\pi = 1^-$ at $E_x = 12.7$ MeV and the other one with 2^- at $E_x = 13.3$ MeV.

[o]) (Pr 85f).

[p]) (Sp 90).

TABLE 14.17

Resonances in $^{13}C(p, n)^{13}N$ (Da 61) [a]

E_p (MeV)	Γ (keV)	$^{14}N^*$ (MeV)
3.76 ± 0.05	100	11.04
3.98 ± 0.02	30	11.24
4.05		11.31
4.15 ± 0.02	40	11.40
4.5 ± 0.1	100	11.7
4.7 ± 0.1	150	11.9
5.03 [b]		12.22
(5.44 ± 0.03)	(60)	(12.60)
5.53 ± 0.03	50	12.68
5.72 ± 0.03	60	12.86
6.20 ± 0.04	70	13.30
6.67 ± 0.13 [c]	250	13.74
7.0 ± 0.1	150	14.0
7.3		14.3
7.85 ± 0.08	150	14.83
7.93 ± 0.03	50	14.91
8.03 ± 0.03	50	15.00
8.7 ± 0.2	350	15.6
9.3 ± 0.1	150	16.2
10.2 ± 0.2	400	17.0
11.4 ± 0.3	600	18.1

[a]) See also table 14.9 in (Aj 59).
[b]) (Gi 59).
[c]) See also (Ki 89c).

30. $^{13}C(p, \alpha)^{10}B$ $\qquad Q_m = -4.0618 \qquad E_b = 7.55063$

See (Aj 81).

31. $^{13}C(d, n)^{14}N$ $\qquad Q_m = 5.3260$

Observed neutron groups are displayed in table 14.18. See (Aj 70, Aj 76) for comments.

32. $^{13}C(^3He, d)^{14}N$ $\qquad Q_m = 2.0571$

Angular distributions have been reported at $E(^3\overline{He}) = 33$ MeV to $^{14}N^*(0, 2.31, 3.95, 5.11, 5.83, 8.91, 9.51)$ (Dr 86; also A_y). See table 14.18 here, and (Aj 81), for the earlier work.

33. $^{13}C(\alpha, t)^{14}N$ $\qquad Q_m = -12.2634$

See (Aj 81).

34. ^{13}C(^{7}Li, ^{6}He)^{14}N $Q_m = -2.424$

At $E(^{7}\text{Li}) = 34$ MeV angular distributions have been studied to ^{14}N*(0, 2.31, 3.95, 5.0[u], 5.7[u]). ^{14}N*(7.0, 8.9, 9.5) are also populated. $^{14}\text{N}_{\text{g.s.}}$ is dominant (Co 87f). See also (Aj 86), (Al 88f) and reaction 18 in ^{14}C.

35. ^{14}C(β^-)^{14}N $Q_m = 0.15648$

See ^{14}C. See also (Am 89; theor.).

36. ^{14}C(π^+, π^0)^{14}N $Q_m = 4.761$

Forward-angle differential cross sections for the isobaric-analog state (IAS) [^{14}N*(2.31)] have been measured at $E_{\pi^+} = 20$ MeV (Ir 87), 35 to 80 MeV (Ul 86a), 100 to 295 MeV (Ir 83a) and 300 to 550 MeV (Ro 88a). Angular distributions to the IAS are reported by (Ul 86a, Ir 87). See also (Ir 85b, Le 89g) and (St 89e; theor.).

37. ^{14}C(p, n)^{14}N $Q_m = -0.6259$

Angular distributions, generally for the n_0, n_1 and n_2 groups, have been measured in the range $E_p = 2.45$ to 45 MeV [see (Aj 81, Aj 86)] and at $E_{\bar{p}} = 35$ MeV (Ie 90) and 160 MeV (Ra 87d). (Ta 84b) have measured the transverse spin-transfer coefficients [$D_{NN}(0°)$] at 160 MeV for the groups to ^{14}N*(0, 2.31[$D_{NN} = 1$], 3.95, 13.72). The main GT strength lies in the three 1^+ states and their D_{NN} values, which are consistent with $\frac{1}{3}$, are those expected for pure $L = 0$ transitions (Ta 84b). At $E_p = 60$ to 200 MeV the spectra are dominated by the neutrons to ^{14}N*(3.95) (Ta 87c). 0° differential cross sections have recently been obtained at $E_p = 60$ to 200 MeV (Ta 87c; n_0, n_1, n_2), 200, 300 and 450 MeV (Al 89; n_1, n_2) and 492 MeV (Ra 89b). See also (Ma 89o). For discussions of the Fermi and Gamow–Teller strengths see (Wa 85k, Ra 87d, Ta 87c, Ra 89b). See also ^{15}N, (Ta 85v, Su 89c), (Ca 88m, Ke 89a; astrophysics), (Al 86o, Ta 86b, Vo 86j, Be 87p, Go 87t, He 87h, Ra 87k, Ro 88n, Wa 88p, Ra 89e, Su 89i) and (Pe 86h, Lo 87a, Lo 87b, Am 89; theor.).

38. ^{14}C(^{3}He, t)^{14}N $Q_m = 0.1379$

At $E(^{3}\text{He}) = 44.8$ MeV, triton groups are observed corresponding to all known levels of ^{14}N with $E_x < 7.1$ MeV. Triton groups were also seen to unresolved states with $E_x = 8.0 \rightarrow 9.5$ MeV, to ^{14}N*(10.43) and to excited states with $E_x = 12.49 \pm 0.04$, 12.83 ± 0.05 and 13.70 ± 0.04 MeV. Angular distributions were obtained for nine of the triton groups and analyzed using a local two-body interaction with an arbitrary spin-isospin exchange mixture. Dominant $L = 0$ transitions are found to ^{14}N*(2.31, 3.95, 13.7), $L = 1$ to ^{14}N*(5.11), $L = 2$ to ^{14}N*(0, 7.03, 10.43) and $L = 3$ to ^{14}N*(5.83) (Ba 69f). Angular distributions have also been studied at $E(^{3}\text{He}) = 72$ MeV (De 88k, De 88g, Er 89b; t_0, t_1, t_2).

39. ^{14}C(^{6}Li, ^{6}He)^{14}N $Q_m = -3.350$

TABLE 14.18

^{14}N levels from ^{13}C(d, n) and ^{13}C(^{3}He, d) [a]

^{14}N* [b] (MeV ± keV)	$J^\pi; T$ [b]	l_p [c]	l_j [d]	$(2J_f+1)C^2S$ [d]
0	$1^+; 0$	1	$p_{1/2}$	2.27
2.31	$0^+; 1$	1	$p_{1/2}$	0.92
3.95	$1^+; 0$	1	$p_{3/2}$	1.10
4.92	$0^-; 0$	0	$s_{1/2}$	0.29
5.11	$2^-; 0$	2	$d_{5/2}$	1.79
5.69	$1^-; 0$	0	$s_{1/2}$	0.91
			$d_{3/2}$	0.29
5.83	$3^-; 0$	2	$d_{5/2}$	2.19
6.20	$1^+; 0$	1	$p_{1/2}$	0.032
6.45	$3^+; 0$	1	$f_{7/2}$	(0.1)
7.03	$2^+; 0$	1	$p_{3/2}$	0.31
7.97	$2^-; 0$		$d_{5/2}$	0.051
8.06	$1^-; 1$	0	$s_{1/2}$	0.10
			$d_{3/2}$	<0.006
8.49	$4^-; 0$	4 [h,i]		
8.62	$0^+; 1$	1 [j]	$p_{1/2}$	0.021
8.78	$0^-; 1$		$s_{1/2}$	<0.009
8.91	$3^-; 1$	2 [k]	$d_{5/2}$	3.32
8.98	$2^+; (0)$	(1, 2, 3)	$p_{3/2}$	<0.2
9.13	$(2^-; 0)$ [g]	2	$d_{5/2}$	0.14
9.17	$2^+; 1$	(1, 3)	$p_{3/2}$	<0.08
9.39	$2^-; 0$	2	$d_{5/2}$	0.62
9.51	$2^-; 1$	2	$d_{5/2}$	1.31
9.70	$1^+; 0$	1	$p_{1/2}$	0.039
10.085 ± 12	$(1\text{-}3)^-$ [e]		$d_{5/2}$	0.054
10.222 ± 12	$(0\text{-}2)^+$ [e]		$p_{1/2}$	0.16
10.534 ± 20	$(0\text{-}2)^+$ [e,f]		$p_{1/2}$	0.34
10.81	$5^+; 0$ [f]			
11.05	(3^+) [e,f]			
11.26 ± 50	$(0\text{-}2)^+$ [e,f]		$p_{1/2}$	0.22
11.49 ± 40	$(0\text{-}2)^+$ [e,f]		$p_{3/2}$	0.040
11.66 ± 40	$(0\text{-}2)^+$ [e,f]		$p_{1/2}$	0.092

a) See also table 14.18 in (Aj 81) and 14.23 in (Aj 76).

b) From table 14.10.

c) ^{13}C(d, n)^{14}N: $E_d = 4.5$ to 6.5 MeV.

d) ^{13}C(^{3}He, d)^{14}N: $E(^3\text{He}) = 43.6$ MeV: see (Aj 86).

e) From (^{3}He, d).

f) $\Gamma \sim 200, 50, 50, 80, 80$ and 100 keV for ^{14}N*(10.53, 10.81, 11.06, 11.26, 11.51, 11.66).

g) See, however, table 14.10.

h) Observed in (d, n) and (^{3}He, d).

i) $\Gamma_p < 9.9 \times 10^{-2}$ eV.

j) $\Gamma_p < 18$ keV.

k) $\Gamma_p = 12.1$ keV.

Angular distributions have been studied at $E(^6Li)=34$ and 62 MeV [see (Aj 86)], at 93 MeV (Br 86r, De 87, De 88g, De 89s; to $^{14}N^*(0, 3.95)$) and at 84, 150 and 210 MeV (Wi 87b, An 86n, An 88b; to $^{14}N^*(0, 2.31, 3.95)$). $^{14}N^*(3.95)$ dominates the spectra: see e.g. (Wi 87b). $^{14}N^*(5.11, 5.83, 6.20, 7.03, 8.49)$ are also populated (Wh 80c, Wi 87b). For studies of the GT strength see (Wh 80c, Wi 87b). See also (Au 87f, Au 88d, Ga 88m, Au 89) and (Aj 86).

40. (a) $^{14}N(\gamma, n)^{13}N$ $Q_m=-10.5535$
(b) $^{14}N(\gamma, p)^{13}C$ $Q_m=-7.55063$
(c) $^{14}N(\gamma, d)^{12}C$ $Q_m=-10.27239$
(d) $^{14}N(\gamma, \pi^+)^{14}C$ $Q_m=-139.725$

The total absorption over the range $E_\gamma=9$ to 31 MeV is dominated by a single peak at 22.5 MeV [estimated $\sigma \approx 29$ mb, $\Gamma \approx 2$-3 MeV] and appreciable strength extending beyond 30 MeV. The cross section cannot be accounted for solely by the (γ, n) and (γ, p_0) processes: particle-unstable excited states of ^{13}C, ^{13}N are involved. The combined (γ, n) and (γ, pn) cross section begins to rise rapidly above 18 MeV, reaches its maximum value of 15 mb at 23.3 MeV and exhibits structure at about 19, 20.5 and 26 MeV. The main peak ($\Gamma \sim 3.5$ MeV: see (Aj 70)) at 23.3 MeV appears to be split into two absorption levels: see (Aj 81). Maxima reported in other experiments and "breaks" in the (γ, n) activation curve are listed in (Aj 70). Most of the photon absorption in the giant resonance region forms $J^\pi=2^-$ states in ^{14}N which decay by d-wave neutron emission to $^{13}N_{g.s.}$. Some evidence is found for the existence of $J^\pi=0^-$ strength at the peak of the giant resonance and for a small amount of isospin $T=0$ mixing near 22.5 MeV: see (Aj 81). The cross section for the (γ, n) reaction has recently been measured from threshold to 15.5 MeV (Fa 87c). See also (Di 88).

The (γ, p_0) and (γ, p_2) cross sections and angular distributions have been measured in the giant resonance region. The giant dipole states $[(p_{3/2})^{-1}(2s1d)]$ which decay by p_0 emission to $^{13}C^*(3.68)$ appear to carry ~90% of the E1 strength and do not contribute substantially to the (γ, p_0) process which is populated by $(p_{1/2})^{-1}(2s1d)$ giant dipole states. Above $E_\gamma=22$ MeV d-wave emission from 2^- states appears to dominate the (γ, p_0) cross section: see (Aj 76). For reaction (c) see (Im 87a). For reaction (d) see ^{14}C. See also (Fu 85h) and (Go 85v, Wi 86j, Hu 87, Ki 87e, Lu 87a, Du 88g; theor.).

41. $^{14}N(\gamma, \gamma)^{14}N$

A measurement of the protons from the $^{14}N(\gamma, p)^{13}C$ reaction and a resonant absorption measurement lead to $\Gamma_{\gamma_0}/\Gamma=0.052\pm0.004$ for $^{14}N^*(9.17)$ and to $\Gamma=122\pm8$ eV (Va 89k). See also (Aj 86), table 14.19, (Be 85d, Be 87b) and (Du 86h; theor.).

42. (a) $^{14}N(e, e)^{14}N$
(b) $^{14}N(e, ep)^{13}C$ $Q_m=-7.55063$

TABLE 14.19
^{14}N states from $^{14}N(\gamma, \gamma')$ and $^{14}N(e, e')$ [a]

E_x (MeV ± keV)	Mult.	$J^\pi; T$	Γ_{γ_0} (eV)	Γ (keV)
8.06	E1	$1^-; 1$	10.5 ± 6	
8.91	M2	$3^-; 1$	$(6.6 \pm 2.2) \times 10^{-3}$	
9.17	M1	$2^+; 1$	7.2 ± 0.4 [b]) 6.3 ± 0.3 [c])	
10.43 [d])	M1	$2^+; 1$	9.6 ± 1.9 [e])	
11.24 [f])	C3	(3^-)		
12.54 ± 100 [e])	(M1, C2)	$J = 0 \rightarrow 3$	$\frac{14.7 \pm 3.2}{2J+1}$	
12.81 [f])	C3	4^-		
13.27 ± 100 [e])	(M1, M2, C2)	$J = 0 \rightarrow 3$		
13.76 ± 100 [e])	(M1, C1)	$J = 0 \rightarrow 2$	$(4 \pm 1) \times 10^{-3}$ [g])	
14.72 ± 30 [f])	M2	$(2^-; 1)$		~ 100
15.01 ± 30 [f])	M4	$3^-, 4^-; \sim 1$		~ 100
16.11 ± 100 [e])	(M2)	$J = 0 \rightarrow 3$		
16.91 ± 20 [f])	M4	$5^-; \sim 1$		170 ± 20
18.48 ± 40 [f])	M4	$5^-; \sim 1$		
20.11 ± 20 [f])	M4	$3^-, 4^-; \sim 1$		120 ± 20

[a]) See table 14.19 in (Aj 81) for references and additional information. See also table 14.11 here.
[b]) (Bi 81e).
[c]) A. Richter and G. Kuehner, private communication; adopted.
[d]) $\Gamma = 44$ keV, $\Gamma_{\gamma_0} = 8.8$ eV (A. Richter and G. Kuehner, private communication).
[e]) (En 79).
[f]) (Be 84g).
[g]) And $\Gamma = 105 \pm 20$ keV (A. Richter and G. Kuehner, private communication).

Form factors have been determined at many energies in the range $E_e = 60.7$ to 300 MeV: see (Aj 81, Aj 86) for the earlier references. In recent work at $E_e = 80.0$ to 372.6 MeV the form factors for $^{14}N^*(0, 2.31)$ have been determined [$q = 0.80$ to $3.55\ fm^{-1}$] (Hu 87; see for a discussion of the wave functions for these two states): see also (Am 89, Ta 89). A number of other excited states of ^{14}N have also been studied: see table 14.19. (Be 84g) have populated $^{14}N^*(12.50, 13.17, 13.71, 15.43, 15.7, 17.2, 17.8)$ but not the 5^- states at $E_x = 14.66$ and 17.46 MeV which are thus presumably $T = 0$. (Be 84g) report that within the triplet of 5^- states at 14.66, 16.91, 17.46 MeV, they can account for ~60% of the isovector 5^- strength but only 35% of the isoscalar strength. There is no other significant M4 strength up to $E_x \sim 28$ MeV (Be 84g).

See also (Li 86o, De 87c, Li 87k, Ro 87j) and (Ch 85k, Ch 85n, Go 85g, Do 86e, Er 86, Go 86t, Je 86, Ze 86, Go 87d, Al 88i, Go 88q, Ji 88c, Be 90f, Ga 90g; theor.).

43. $^{14}N(\pi^\pm, \pi^\pm)^{14}N$

Angular distributions at $E_{\pi^\pm} = 162$ MeV have been studied to the states listed in table 14.20 (Ge 83). See also "General", p. 75.

TABLE 14.20

States of ^{14}N from ^{14}N($\pi^{\pm}$, $\pi^{\pm}$) (Ge 83)

E_x (MeV)	J^{π}; T	Mult.	$B(E\lambda)$ ($e^2 \cdot fm^{2\lambda}$)
0			
3.95		E2	2.8 ± 0.4
4.92			
5.11		E3	74 ± 10
5.69			
5.83		E3	117 ± 18
7.03		E2	3.95 ± 0.7
8.49			
11.24		E3	110 ± 12
12.79		E3	151 ± 17
13.14		E3	31 ± 8 [b])
14.66	5^-; 0+1		
15.10			
15.57	2, 3, 4^-; 0	E3	$10(2J+1)$
16.06	3^-; 0		
16.86	5^-; 1+0		
17.46	5^-; 0+1		
17.89	$2^- + 4^-$; 0		
[a])			
18.70	(3^-); 0+1		
20.10	(3^-); 0+1		

[a]) States at $E_x = 18.2$ and 18.4 MeV are also populated.
[b]) $J^{\pi} = 2^-$ assumed.

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

Angular distributions of elastically and inelastically scattered neutrons are displayed in table 14.23 of (Aj 70). Recent work is reported at $E_n = 7.68$ to 13.50 MeV (Ch 86cc; prelim.; to ^{14}N*(0, 2.31, 3.95, 4.91, 5.11, 5.69, 5.83)), 11, 14 and 17 MeV (Te 85a; n_0; prelim.), 20 and 25 MeV (Pe 85b; n_0) and at 21.6 MeV (Ol 90; n to ^{14}N*(0, 5.83, 7.03) as well as at $E_{\vec{n}} = 10$, 12, 14 and 17 MeV (Li 86a; n_0; prelim.). See also (Aj 76), (Ge 86a, Li 89l) and (St 89f; applied).

45. (a) ^{14}N(p, p)^{14}N
(b) ^{14}N(p, 2p)^{13}C $Q_m = -7.55063$
(c) ^{14}N(p, pd)^{12}C $Q_m = -10.27239$
(d) ^{14}N(p, pα)^{10}B $Q_m = -11.6125$

Angular distributions of elastically and inelastically scattered protons have been studied at many energies up to $E_p = 800$ MeV [see (Aj 81, Aj 86)], at $E_{\vec{p}} = 35$ MeV (Ie 90; p_1) and 800 MeV (Bl 85g; elastic) and at $E_p = 1$ GeV (Al 85l; elastic). For a display of the observed ^{14}N states see table 14.24 in (Aj 86). For a study of the 1.6 and 2.3 MeV γ-rays [from ^{14}N*(2.31, 3.95)] see (Le 88b). For reaction (b) see

(Be 89k) and ^{13}C. For reaction (c) see (De 85f). For reaction (d) see ^{10}B in (Aj 88). See also (Be 89l), (Pe 85b, Vd 87c) and (Ao 86, Er 86, Hu 87, Vd 87b, Vd 88a, Am 89, Lo 89c; theor.).

46. ^{14}N(d, d)^{14}N

Angular distributions of elastically and inelastically scattered deuterons have been studied to $E_d = 52$ MeV: see table 14.20 in (Aj 81). The deuteron group to the 0^+, $T = 1$ state ^{14}N*(2.31) is isospin "forbidden": its cross section is 1-2 orders of magnitude less than that to ^{14}N*(3.95) [J^π; $T = 1^+$; 0]: see (Aj 81). See also (Ha 86k, Ao 86; theor.).

47. ^{14}N(^{3}He, ^{3}He)^{14}N

Angular distributions of elastically and inelastically scattered ^{3}He ions have been measured at $E(^3\mathrm{He})$ up to 44.6 MeV: see table 14.20 in (Aj 81). See also (De 89l).

48. ^{14}N(α, α)^{14}N

Angular distributions of elastically and inelastically scattered α-particles have been studied for $E_\alpha = 7.6$ to 104 MeV [see table 14.24 in (Aj 86)] and at $E_\alpha = 48.7$ and 54.1 MeV (Ab 87a; α_0). See also ^{18}F in (Aj 87), (Bu 87k, Be 89m), (Gu 89h; astrophysics), (Pa 88j; applied) and (Sh 85g; theor.).

49. (a) ^{14}N(^{6}Li, ^{6}Li)^{14}N
(b) ^{14}N(^{7}Li, ^{7}Li)^{14}N

Elastic angular distributions have been measured at $E(^6\mathrm{Li}) = 19.5$, 32 and 36 MeV and at $E(^7\mathrm{Li}) = 36$ MeV: see (Aj 81, Aj 86). For reaction (b) see also (Go 86h; $E(^{14}\mathrm{N}) = 150$ MeV; prelim.). See also (De 89l).

50. ^{14}N(^{9}Be, ^{9}Be)^{14}N

See (Aj 86) and (Ha 88t).

51. (a) ^{14}N(^{10}B, ^{10}B)^{14}N
(b) ^{14}N(^{11}B, ^{11}B)^{14}N

Elastic angular distributions have been measured for reaction (a) at $E(^{10}\mathrm{B}) = 100$ MeV and $E(^{14}\mathrm{N}) = 73.9$ to 93.6 MeV [see (Aj 81, Aj 86)] as well as at $E(^{14}\mathrm{N}) = 38.1$, 42.0, 46.0 and 50.0 MeV (Ta 88g); those for reaction (b) have been studied at $E(^{14}\mathrm{N}) = 41$, 77 and 113 MeV: see (Aj 81). For fusion and other yield measurements see (Aj 86). See also (Be 85r, Cu 85a) and (Ko 85q, Ro 86j; theor.).

52. (a) ^{14}N(^{12}C, ^{12}C)^{14}N
(b) ^{14}N(^{12}C, d^{12}C)^{12}C $\quad Q_m = -10.27239$

Elastic and inelastic angular distributions have been studied in the range $E(^{14}N) =$ 21.3 to 155 MeV [see (Aj 81)] and at 86 MeV (Ar 88k). For cross sections and fusion, fragmentation and evaporation residue studies see (Aj 81, Aj 86) and (Mo 86h, Go 87, St 87, Ki 89f, We 90a). For high-energy γ-emission see (St 86m). For neutron emission see (Ki 88d). For pion emission see (Su 89g). For reaction (b) see (Ar 87m). See also (Go 86h, Ve 87d, Ha 88t, Ar 89g), (Ba 82oo, Ba 85t; astrophys.), (Be 85r, Cu 85a, Ge 87) and (Hu 85, Ko 85q, Vi 85b, Ba 86ss, Ha 86i, Po 86g, Re 86d, Bi 87a, Re 87b, Re 87d, Ba 88rr, He 88e, Pr 88, Bl 89a, Ni 89, Ro 89f, Sh 89, Ca 90h, De 90f, Gh 90c, Pr 90b; theor.).

53. $^{14}N(^{13}C, ^{13}C)^{14}N$

Elastic angular distributions have been measured at $E(^{14}N) = 19.3$ to 35 MeV and at $E(^{13}C) = 105$ MeV: see (Aj 81, Aj 86) [see also for fusion studies].

54. $^{14}N(^{14}N, ^{14}N)^{14}N$

Elastic angular distributions have been studied for $E(^{14}N) = 5.0$ to 20.2 MeV: see (Aj 81). For fusion and other cross section measurements, see (Aj 81, Aj 86). See also (Be 85r, Cu 85a, St 86f, St 86n, Bo 88d) and (Ko 85q, Ro 86j; theor.).

55. (a) $^{14}N(^{16}O, ^{16}O)^{14}N$
(b) $^{14}N(^{19}F, ^{19}F)^{14}N$

Elastic angular distributions have been studied for $E(^{14}N) = 8.1$ to 155 MeV [reaction (a)]: see (Aj 81). For fusion cross section measurements, see (Aj 81, Aj 86). See also (Be 85r, Cu 85a) and (Hu 85, Ko 85q; theor.). For reaction (b), see (Ho 89f; theor.).

56. (a) $^{14}N(^{24}Mg, ^{24}Mg)^{14}N$
(b) $^{14}N(^{26}Mg, ^{26}Mg)^{14}N$
(c) $^{14}N(^{27}Al, ^{27}Al)^{14}N$
(d) $^{14}N(^{28}Si, ^{28}Si)^{14}N$
(e) $^{14}N(^{40}Ca, ^{40}Ca)^{14}N$
(f) $^{14}N(^{48}Ca, ^{48}Ca)^{14}N$

Elastic angular distributions have been measured at $E(^{14}N) \sim 53$ MeV for reactions (a), (c) and (d) [see (Aj 86)] and at 84 MeV (Ya 88b; reaction (d); also inelastic to $^{28}Si^*(1.78)$). For fusion and fragmentation studies see (Aj 86) and (Sh 86m, Be 87aa, Gu 87k, St 87, Yi 87, Sh 88, Br 89f, Go 90a). For reaction (e), see also (Go 88h). For pion production [reaction (c)], see (St 86e). See also (Sh 87), (Bl 87l) and (Bl 85f, Ce 85d, St 85h, Os 86e, Po 86g, Pr 86a, Ay 88, Bh 89, Ch 89f; theor.).

57. $^{14}O(\beta^+)^{14}N$ $Q_m = 5.1431$

$^{14}O_{g.s.}$ decays predominantly to its analog state $^{14}N^*(2.31)$: $E_x = 2312.798 \pm 0.011$ keV (Wa 82e): see reaction 1 in ^{14}O. See also (Am 89; theor.).

58. ^{15}N(γ, n)^{14}N $Q_m = -10.8333$

See (Mc 88a) in ^{15}N. See also (Aj 81) and (Go 88a; theor.).

59. ^{15}N(p, d)^{14}N $Q_m = -8.6087$

Angular distributions have been obtained at $E_p = 39.8$ MeV for the deuterons corresponding to ^{14}N*(0→8.06, 8.62, 8.91, 8.96+8.98, 9.17, 9.39, 9.51, 9.70, 10.10, 10.21, 10.43, 11.06, 11.23+11.30, 11.39, 11.51, 11.66, 11.74+11.80, 11.97, 12.21+12.29, 12.52, 12.61, 12.80+12.83, 13.17+13.23, 13.72). Spectroscopic factors were extracted by DWBA analysis of the $l_n = 1$ pickup angular distributions: see (Sn 69). See also (Aj 70).

60. ^{15}N(d, t)^{14}N $Q_m = -4.5760$

At $E_d = 89.1$ MeV (Sa 89h) have investigated the level structure of ^{14}N up to $E_x = 24$ MeV: see table 14.21. Above $E_x = 18.6$ MeV no discrete states appear. The observed summed spectroscopic strength is 88% of the shell-model sum rule. No significant $l = 3$ strength was seen (Sa 89h).

61. ^{15}N(^{3}He, α)^{14}N $Q_m = 9.7445$

Observed states in ^{14}N are displayed in table 14.28 of (Aj 76) together with the derived spectroscopic factors. Recently, angular distributions and A_y have been determined at $E(^3\text{He}) = 33$ MeV to ^{14}N*(0, 2.31, 3.95, 5.11, 5.83, 7.03, 9.17, 10.43, 12.5, 13.7) (Dr 86).

62. ^{15}N(^{13}C, ^{14}C)^{14}N $Q_m = -2.6568$

See (Aj 81).

63. ^{16}O(π^+, 2p)^{14}N $Q_m = 117.390$

At $E_{\pi^+} = 116$ MeV proton angular correlations, energy sharing and recoil momentum distributions have been studied to groups corresponding to ^{14}N*(0, 3.9 [u], 7.0 [u], 11.0 [u]). No evidence is seen for other narrow states. The upper limit for the excitation of ^{14}N*(2.31) [0^+; $T = 1$] is 5% (Sc 88d). See also (Sc 90e) and (Ch 89b; theor.). Work at $E_{\pi^+} = 165$ MeV suggests that the earlier work reports too low a cross section and underestimates the two-nucleon absorption mechanism (Hy 90). In this paper the fraction of the total absorption cross section which can be attributed to that mechanism is reported to be about 50% (Hy 90). See also (Ky 88, Ro 88l).

64. (a) ^{16}O(p, ^{3}He)^{14}N $Q_m = -15.2428$
(b) ^{16}O(p, pd)^{14}N $Q_m = -20.7363$

Angular distributions (reaction (a)) have been measured in the range $E_p = 27$ to 54.1 MeV: see (Aj 81). Comparisons have been made of the ratio of (p, ^{3}He) to the

TABLE 14.21

States of ^{14}N from $^{15}N(d, t)^{14}N$ [a]) (Sa 89h)

E_x (MeV ± keV)	l	J^π; T [b])	j	C^2S [c])
0	1		$\frac{1}{2}$	1.24 ± 0.09
			$\frac{3}{2}$	0.10 ± 0.08
2.312 ± 2	1		$\frac{1}{2}$	0.472 ± 0.009
3.946 ± 4	1		$\frac{1}{2}$	0.18 ± 0.04
			$\frac{3}{2}$	0.48 ± 0.04
4.910 ± 6	(0)		$\frac{1}{2}$	(0.008 ± 0.001)
5.102 ± 5	2			0.056 ± 0.007
5.689 ± 4	2		$\frac{3}{2}$	0.010 ± 0.001
5.832 ± 3	2		$\frac{5}{2}$	0.045 ± 0.012
6.202 ± 3	1		$\frac{3}{2}$	0.047 ± 0.007
6.443 ± 6	?			<(0.002)
7.028 ± 2	1		$\frac{3}{2}$	1.11 ± 0.03
7.966 ± 4	(2)			(0.017 ± 0.005)
8.491 ± 4	?			
9.173 ± 5	1		$\frac{3}{2}$	0.423 ± 0.008
9.388 ± 5	(2)			(0.022 ± 0.003)
9.522 ± 21	(2)			(0.007 ± 0.001)
9.708 ± 8	1		($\frac{3}{2}$)	(0.005 ± 0.001)
10.108 ± 6	1	$(2)^+$	$\frac{3}{2}$	(0.061 ± 0.003)
10.440 ± 6	1		$\frac{3}{2}$	0.388 ± 0.013
11.056 ± 8	?			<(0.017)
11.252 ± 9	(2)		$\frac{5}{2}$	(0.016 ± 0.001)
11.515 ± 10	?	(3^+)		<(0.006)
11.754 ± 11	2		$\frac{3}{2}$	(0.014 ± 0.001)
12.505 ± 10	1	$(1^+; 1)$	$\frac{3}{2}$	0.13 ± 0.01
12.812 ± 13	?			
13.186 ± 21	?			<(0.015)
13.732 ± 16	1		$\frac{3}{2}$	0.45 ± 0.01
14.57 ± 23	?			
14.90 ± 21	(2)		($\frac{5}{2}$)	(0.025 ± 0.002)
15.63 ± 70	(2)		($\frac{5}{2}$)	(0.037 ± 0.003)
16.15 ± 130	?			
16.99 ± 21	(2)		($\frac{5}{2}$)	(0.034 ± 0.003)
17.28 ± 40	?			<(0.017)
17.88 ± 30	(2)	(3^-)	($\frac{5}{2}$)	(0.045 ± 0.005)
18.51 ± 30	1	$(2^+; 1)$	$\frac{3}{2}$	0.043 ± 0.007

[a]) $E_d = 89$ MeV. Measured angular distributions and A_y; FRDWBA.

[b]) Only those J^π; T determined in this experiment are shown.

[c]) Errors shown refer only to statistics.

$T = 1$ state at 2.31 MeV and of (p, t) to the analog $^{14}O_{g.s.}$: see ^{17}F in (Aj 82). For cross sections for the production of γ-rays from the decay of $^{14}N^*(2.31, 5.11)$ at $E_p = 40$, 65 and 85 MeV see (La 87e). For reaction (b) see (Vd 86a, Vd 87c) and (Go 86s; theor.).

65. $^{16}O(d, \alpha)^{14}N$ $Q_m = 3.1104$

Angular distributions have been measured at many energies up to $E_d = 40$ MeV: see (Aj 81). The yield of the isospin forbidden α_1 group [to $^{14}N^*(2.31)$] has been studied for $E_d = 2$ to 15 MeV: the intensity of the group is strongly dependent on E_d and on the angle of observation. The α_1 reaction appears to proceed almost exclusively by a compound-nuclear process and its study leads to the determination of a large number of ^{18}F states: the average isospin impurity in ^{18}F for $10 \leq E_x \leq 20$ MeV is 3-10%. At $E_d = 50$ MeV, the intensity of $^{14}N^*(2.31)$ is 0.1-0.2% that of $^{14}N_{g.s.}$. See also ^{18}F in (Aj 87), (Ka 85q), (Ha 85s, Du 86c; applied) and (Si 86a; computer).

66. $^{17}O(p, \alpha)^{14}N$ $Q_m = 1.1916$

See (Ca 88m; astrophys.).

^{14}O

(Figs. 8 and 9)

GENERAL[†]

Nuclear models: (Ba 85mm, Bl 87f)

Electromagnetic transitions: (Ra 89f, Sp 89a)

Astrophysical questions: (Ta 85y, Ra 87m)

Applied work: (Ar 89c)

Complex reactions involving ^{14}O: (Pe 87d, St 88c, Ba 89cc, Dr 89a, Ki 89f)

Reactions involving pions[‡]: (Ba 86kk, Bo 86u, Fo 86c, Ge 86b, Si 86e, Bl 87f, Ka 87cc, Ko 87h, Ko 87q, Mi 87a, Pa 87f, Au 88c, Ha 88y, Yu 88, Ha 90b)

Hypernuclei: (Ba 89hh)

Other topics: (An 85e, An 86u)

Ground state of ^{14}O: (An 85e, He 86h, Sa 87g, Wr 88)

For searches for ^{4}n and ^{4}H involving the production of ^{14}O see (Be 86aa, Be 86gg, Be 88b).

† See also (Aj 86).

‡ See also reactions 5 and 7.

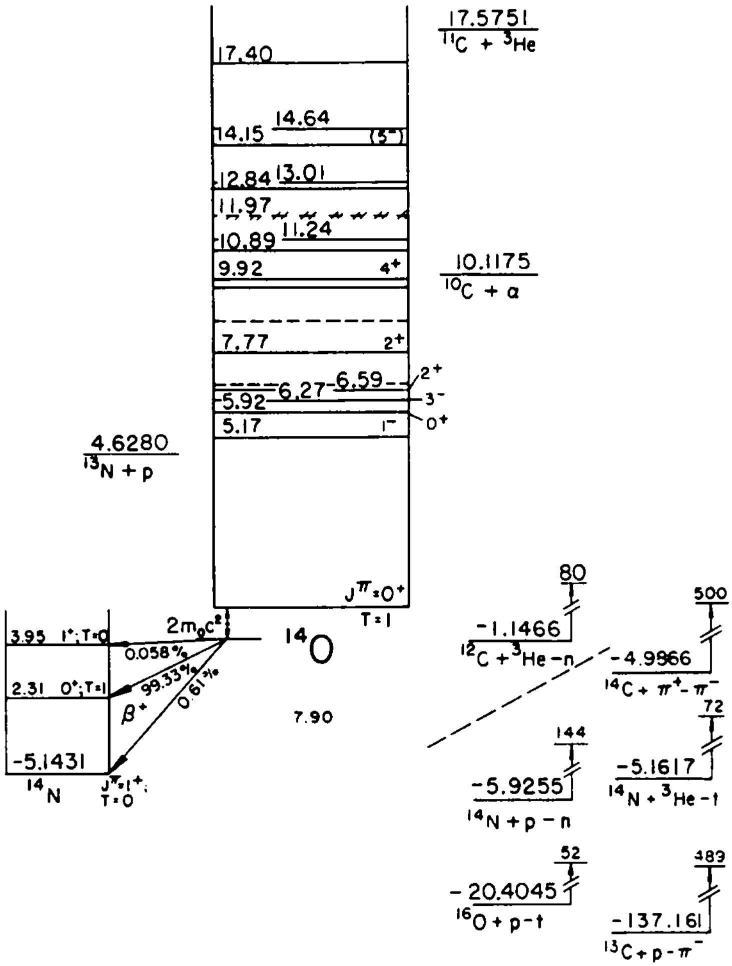


Fig. 8. Energy levels of ^{14}O. For notation see fig. 2.

1. ^{14}O(β^+)^{14}N $\qquad\qquad Q_m = 5.1431$

The best value of $\tau_{1/2} = 70.606 \pm 0.018$ s: see (Wi 78d). See also (Aj 76). ^{14}O decays predominantly to its analog state ^{14}N*(2.31) [J^π; $T = 0^+$; 1; $E_x = 2312.798$ (11) keV, $E_\gamma = 2312.593$ (11) keV (Wa 82e)]. The branching ratio to the state is (99.336 ± 0.010)%. This value is obtained by adopting (0.61 ± 0.01)% and (0.054 ± 0.002)% for the branching ratios to ^{14}N*(0, 3.95) [both 1$^+$; 0 states]. Log $f^R t = 3.4892$ (2) for the $0^+ \rightarrow 0^+$ transition (Wh 81c), using the Wapstra masses for the atomic mass excess of ^{14}N, ^{1}H and n; E_{thresh}. for the ^{14}N(p, n) threshold (Wh 81c) and E_x shown above for ^{14}N*(2.31) (Wa 82e). See (Or 89d, Or 89e) for other calculations of log ft [3.4884 (5)] and comments. Critical surveys of superallowed Fermi transitions lead to values for the first row of the Kobayashi-Maskawa matrix = 0.9970 ± 0.0021

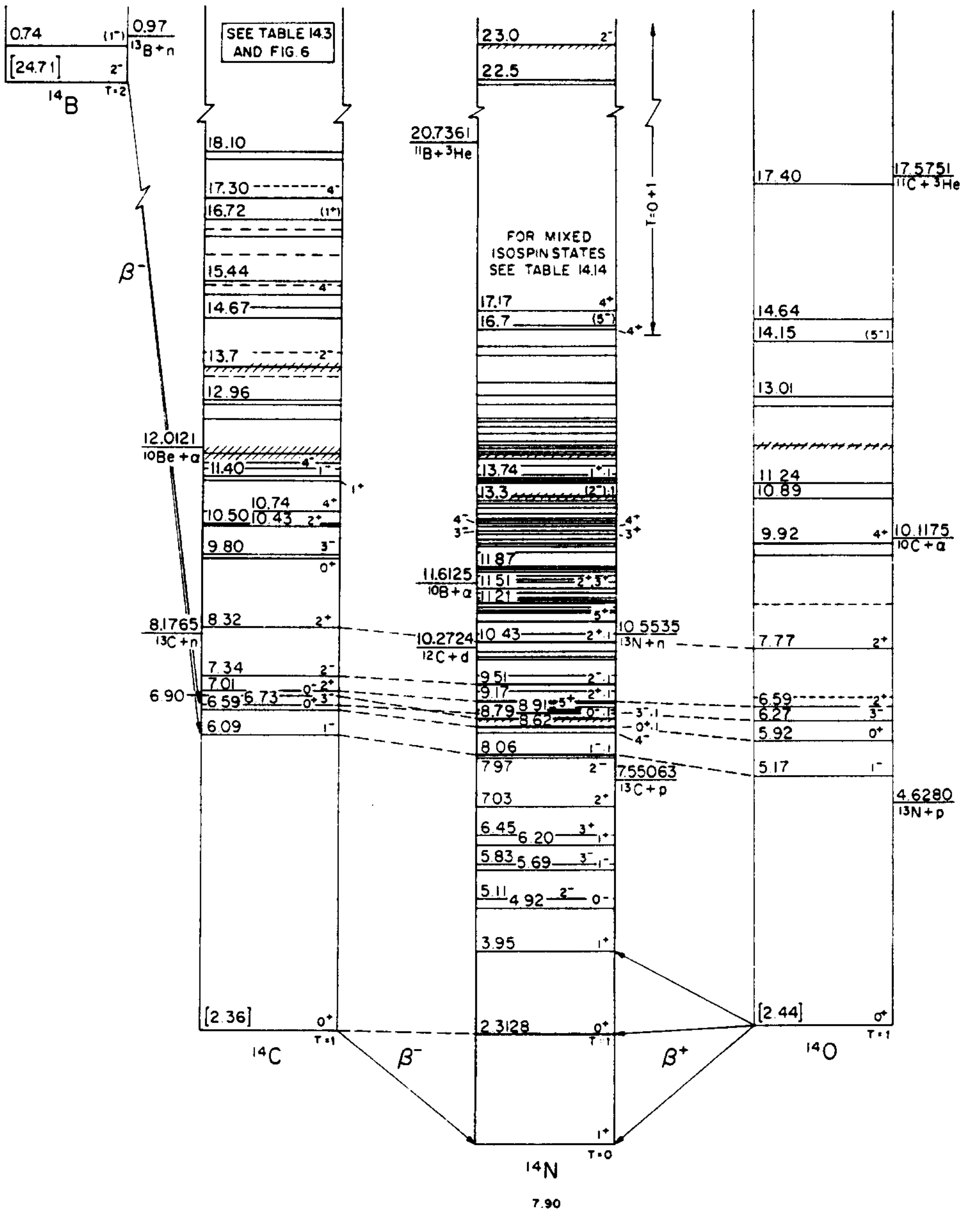


Fig. 9. Isobar diagram, $A = 14$. For notation see fig. 4.

TABLE 14.22
Energy levels of ^{14}O

E_x (MeV ± keV)	$J^\pi; T$	$\tau_{1/2}$ or $\Gamma_{c.m.}$ (s) (keV)	Decay	Reactions
g.s.	$0^+; 1$	$\tau_{1/2} = 70.606 \pm 0.018$ s	β^+	1 → 5, 7 → 10
5.173 ± 10	$1^-; 1$	$\Gamma = 38.1 \pm 1.8$ keV		3, 5, 6, 8 → 10
5.920 ± 10	$0^+; 1$	≤50	p	3, 9, 10
6.272 ± 10	$3^-; 1$	103 ± 6	p	3 → 5, 9, 10
6.590 ± 10	$2^+; 1$	≤60	p	3 → 5, 9, 10
(6.79 ± 30)	$\pi = -$			5, 9
7.768 ± 10	$2^+; 1$	76 ± 10	p	3, 5, 8 → 10
(8.72 ± 40)				9, 10
9.715 ± 20	$(2^+); 1$			3, 5, 10
9.915 ± 20	$4^+; 1$	100 ± 50		3 → 5, 9
10.89 ± 50				5, 9
11.24 ± 50				9
11.97 [a])				5, 9
12.84 ± 50				9
13.01 ± 50				9
14.15 ± 40	(5^-)			4, 5, 9
14.64 ± 60				5, 9
17.40 ± 60				5, 9

[a]) Possibly more than one level.

(Ha 90i), 0.9989 ± 0.0012 (Wi 90f, Wi 90e, Wi 90c) [and D.H. Wilkinson, private communication].

For the transitions to ^{14}N*(0, 3.95) log $ft = 7.266 \pm 0.009$ (Wi 80g) and 3.15 ± 0.02, respectively. The Q-value difference between the 0^+-0^+ transition in this decay and in the ^{26m}Al decay has been measured by (Ko 87s). For a study of the longitudinal polarization of the positrons see (Gi 88b, Ca 89i, Ca 90j). See also (Ha 89q, Ha 90a) and (Is 86e, Ja 86d, Si 86h, Ja 87b, Lo 88, Sa 89j, Wo 89c; theor.).

2. (a) ^{9}Be(^{13}C, ^{8}He)^{14}O $\quad Q_m = -25.13$
   (b) ^{9}Be(^{14}C, ^{9}He)^{14}O $\quad Q_m = -34.44$

For reaction (a) see (Bo 88k). For reaction (b) see (Be 88f).

3. ^{12}C(^{3}He, n)^{14}O $\quad Q_m = -1.1466$

Observed neutron groups are displayed in table 14.23. Angular distributions have been measured at $E(^3\text{He}) = 15$ to 25.4 MeV [see (Aj 81)] and at 45.5 MeV (Ab 87; n_0, n_1). For ^{14}O*(5.17) [$J^\pi = 1^-$], $\Gamma_\gamma/\Gamma = (7.2 \pm 3.5) \times 10^{-5}$; using $\Gamma_{c.m.}$ from table 14.22, $\Gamma_\gamma = (2.7 \pm 1.3)$ eV (Fe 89d). (Ag 89; prelim.) report $\Gamma_\gamma = (7.6 \pm 3.8)$ eV.

TABLE 14.23

Levels of ^{14}O from $^{12}C(^{3}He, n)^{14}O$ [a])

E_x (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	L [b])	J^{π} [b])
0		0	0^+
5.173 ± 10		1	1^-
5.930 ± 15 [c])	≤47	0	0^+
6.272 ± 10	103 ± 6	3	3^-
6.596 ± 10 [d])	≤56	(2)	2^+ [e])
7.768 ± 10	76 ± 10	2	2^+
9.705 ± 25		(2)	(2^+)
9.915 ± 20 [b])	100 ± 50	4	4^+

[a]) For references see table 14.22 in (Aj 81).
[b]) See table 14.30 in (Aj 76).
[c]) $E_x = 5905 \pm 12$ keV has also been reported.
[d]) 6585 ± 5 keV has also been reported.
[e]) $J = 2$ follows from an np coincidence study. The J shown for $^{14}O^*$(5.92, 6.27, 7.77) are in accord with this work.

4. (a) $^{12}C(^{12}C, ^{10}Be)^{14}O$ $\quad Q_m = -20.6136$
(b) $^{12}C(^{14}N, ^{12}B)^{14}O$ $\quad Q_m = -18.513$

At $E(^{12}C) = 480$ MeV (reaction (a)) forward-angle differential cross sections have been studied for $^{14}O^*$(6.27, 9.9, 14.1, 15.7). $^{14}O^*$(0, 6.59) are also populated. The forward spectra are dominated by $^{14}O^*$(9.9) (Kr 88e). For the earlier work on both reactions see (Aj 76, Aj 81). See also (Me 88f).

5. $^{13}C(p, \pi^-)^{14}O$ $\quad Q_m = -137.161$

Differential cross sections have been measured at $E_p = 250$ MeV to $^{14}O^*$(0, 5.17, 6.27+6.59, 9.92) and at $E_p = 354$ and 489 MeV to $^{14}O^*$(0, 6.27+6.59) (Hu 88a). At $E_p = 489$ MeV a broad structure near 23 MeV is also observed (Hu 88b) but its origin is unknown (R.D. Bent and G.M. Huber, private communication) [*Note*: a $T = 2$ state in ^{14}O, corresponding to $^{14}C^*$(23.2) may be substantially broader and might be more difficult to detect].

At $E_{\vec{p}} = 200$ MeV angular distributions and A_y have been measured to $^{14}O^*$(0, 5.17, 6.1[u], 6.6[u], 7.8, 9.7+9.9, 10.9, (12.0), 14.2, (14.6, 17.4)). It is suggested that $^{14}O^*$(14.15) has $J^{\pi} = 5^-$: see $^{13}C(p, \pi^+)^{14}C$ (reaction 15) (Ko 89m, Ko 87). For the earlier work see (Aj 86). See also p. 104, (Ja 86i, Vi 87) and (Ku 86b; theor.).

6. $^{13}N(p, \gamma)^{14}O$ $\quad Q_m = 4.6280$

This reaction is important in the hot-CNO cycle if its rate is dominated by $l = 0$ capture through $^{14}O^*$(5.17). Calculations suggest Γ_γ for this state is 1.8 eV (Fu 87b), ≥4.1 eV (De 89q). See also (Aj 86) and references below. For measurements see reactions 3 and 8 and, in particular, (Fe 89d) [$\Gamma_\gamma = 7.6 \pm 3.8$ eV] for empirical

S-factors as $f(E)$. See also (Sm 90) and (Tr 82d, Ha 83u, Ba 85mm, Ca 85t, Fi 86f, Bu 87f, Ca 88m, Jo 88c, Ro 88c, Tr 88b, Ag 89, Ar 89, Ar 89a, Ba 89jj).

7. ^{14}C(π^+, π^-)^{14}O $\qquad Q_m = -4.9866$

Forward-angle cross sections have recently been measured for $E_{\pi^+} = 19$ to 79.5 MeV (Le 89c; 0°) and 300 to 500 MeV (Wi 89; 5°). For the earlier work see (Aj 86). See also (Al 85g, Gi 86a, Se 88, Le 89g) and (Ha 87r, Ch 89j, St 89e, Yu 89, Ch 90h; theor.).

8. ^{14}N(p, n)^{14}O $\qquad Q_m = -5.9255$
$E_{thresh.} = 6353.04 \pm 0.08$ keV (Wh 81c).

Angular distributions have been measured at $E_p = 35.2$ and 144 MeV [see (Aj 86) and (Mo 79cc)] as well as at 35 MeV (Or 87; to ^{14}O*(5.17)). A preliminary value for Γ_γ of ^{14}O*(5.17) is ~1 eV (Wa 88j) [see also the discussion in (Fe 89d)]. See also (Ba 84qq, Sm 90) and (Ca 88m, Le 88b; astrophys.).

9. ^{14}N(^{3}He, t)^{14}O $\qquad Q_m = -5.1617$

Triton groups have been observed at $E(^3\text{He}) = 44.6$ MeV to the first six states shown in table 14.22 and to levels with $E_x = 6.79 \pm 0.03$, 8.74 ± 0.06, 9.74 ± 0.03, 10.89 ± 0.05, 11.24 ± 0.05, 11.97 (unresolved), 12.84 ± 0.05, 13.01 ± 0.05, 14.15 ± 0.04, 14.64 ± 0.06 and 17.40 ± 0.06 MeV: see (Aj 81). [The states at 6.79 and 8.74 MeV reported in this reaction are relatively weakly excited and are not observed in reaction 3.] $\Gamma_{c.m.}$ of ^{14}O*(5.17) = 38.1 ± 1.8 keV (Ch 85c). See also (Ko 87s, De 89l).

10. ^{16}O(p, t)^{14}O $\qquad Q_m = -20.4045$

Angular distributions of ground-state tritons have been studied to $E_p = 54.1$ MeV: see (Aj 81). For comparison with the (p, ^{3}He) results see reaction 64 in ^{14}N.

Triton groups have been observed to states with $E_x = 5.21 \pm 0.04$, 5.92 ± 0.06, 6.28 ± 0.05, 6.59, 7.77, 8.69 ± 0.06 [weak, not observed in reaction 3], and 9.65 ± 0.06 MeV. Angular distributions have been studied with polarized protons at $E_p = 43.8$ MeV to ^{14}O*(0, 5.17, 6.27, 6.59, 7.77, 9.72): see (Aj 76).

^{14}F

(Not illustrated)

^{14}F has not been observed: its atomic mass excess is predicted to be 32.98 MeV which would make it unstable with respect to decay into ^{13}O + p by 2.58 MeV: see (Aj 81). See also (An 86u; theor.).

^{14}Ne, ^{14}Na, ^{14}Mg

(Not illustrated)

^{14}Ne, ^{14}Na and ^{14}Mg have not been observed. See (An 86u; theor.).

^{15}Li

(Not illustrated)

^{15}Li has not been observed. Its atomic mass excess is calculated to be 81.60 MeV: see (Aj 81). It is then unstable with respect to decay into ^{14}Li+n and ^{13}Li+2n by 1.2 and 5.1 MeV, respectively. (Po 85f) calculate [in a $(0+1)\hbar\omega$ model space] that the first four states of ^{15}Li at 0, 0.73, 2.39 and 2.77 MeV have, respectively, $J^\pi = \frac{3}{2}^-$, $\frac{1}{2}^-$, $\frac{7}{2}^-$ and $\frac{5}{2}^-$. See also (Po 88d; theor.).

^{15}Be

(Not illustrated)

^{15}Be has not been observed. The calculated mass excess is 51.18 MeV: see (Aj 81). ^{15}Be is then unstable with respect to ^{14}Be+n and ^{13}Be+2n by 3.4 and 0.04 MeV, respectively. (Po 85f) calculate [in a $(0+1)\hbar\omega$ model space] that the first four states of ^{15}Be at 0, 0.07, 2.32, 3.10 MeV have, respectively, $J^\pi = \frac{5}{2}^+$, $\frac{3}{2}^+$, $\frac{9}{2}^+$, $\frac{7}{2}^+$. See also (Sa 87g; theor.).

^{15}B

(Figs. 10 and 13)

Mass of ^{15}B: Wapstra adopts 28970 ± 22 keV (Wa 88b, and private communication) and so do we: see (Aj 86). ^{15}B is then stable with respect to ^{14}B+n by 2.77 MeV.

Decay of ^{15}B: ^{15}B decays by β^- emission to ^{15}C: Q_{β^-} (max) = 19.10 MeV. The character of the decay is not known but measurements of the half-life are 11 ± 1 ms (Du 84f), 8.8 ± 0.6 ms (Cu 86), 10.4 ± 0.3 ms (Mu 88a), 10.8 ± 0.5 ms (Sa 88a), $10.3^{+0.6}_{-0.5}$ ms (Le 89i). The weighted mean of these five values is 10.3 ± 0.2 ms. Omitting the low value from (Cu 86) gives 10.5 ± 0.3 ms, which we adopt.

Upper limits have been set on the P_{0n} and P_{2n}: 5% and 1.5%, respectively (Du 84f). See also (Le 89i).

General: (Po 85f) calculate [in a $(0+1)\hbar\omega$ model space] that the first four states of ^{15}B at 0, 1.53, 2.06, 2.71 MeV have, respectively, $J^\pi = \frac{3}{2}^-$, $\frac{5}{2}^-$, $\frac{1}{2}^-$ and $\frac{7}{2}^-$.

Interaction cross sections at 790 MeV/A of ^{15}B ions with Be, C and Al are reported by (Ta 88d). The interaction radius and the r.m.s. radius for the nucleon distributions in ^{15}B have also been derived (Ta 88d). See also (Sa 89g), (Du 86f, De 89v), (Gu 86h, Ba 88i, Mi 88f, Do 89g, Lo 90c) and (An 86u, Do 89i, Po 89g, Si 89g, Re 90a; theor.).

^{15}C

(Figs. 10 and 13)

GENERAL[†]

Model calculations: (Mi 88j, Po 89g, Wo 89c)

Electromagnetic transitions: (Va 84)

Astrophysical questions: (Ka 89b)

Complex reactions involving ^{15}C: (Po 85d, Av 86, Bi 86f, Du 86f, Ha 86f, Ha 86bb, Po 86d, Ri 87b, Sa 87m, Sn 87, Vi 87a, Ca 88, Jo 88a, Mi 88h, Ru 88, Sa 88h, As 89, Og 89a, Sa 89g, Si 89g, Yo 89)

Hypernuclei: (Ma 88f, Ta 89n)

Other topics: (An 85e, An 86u)

Ground state of ^{15}C: (An 85e, As 86a, Sa 87g, Va 87n, Va 88, Sa 89g, Wo 89c)

$$|g| = 2.63 \pm 0.14 \text{ (As 88; prelim.)}$$

$$\mu_{g.s.} = 1.315 \pm 0.07 \text{ n.m. (Ra 89g)}$$

$$\mu_{0.74} = -1.758 \pm 0.03 \text{ n.m. (Ra 89g)}$$

1. $^{15}C(\beta^-)^{15}N$ $\qquad Q_m = 9.7717$

The half-life of ^{15}C is 2.449 ± 0.005 s (Al 79m). Transitions have been observed to $^{15}N_{g.s.}$ and to the upper of the 5.3 MeV states in ^{15}N which has $J^\pi = \frac{1}{2}^+$. The $\log f t$ to ^{15}N*(5.30) indicates an allowed transition: therefore J^π ($^{15}C_{g.s.}$) $= \frac{1}{2}^+$ or $\frac{3}{2}^+$. Weak transitions are observed to ^{15}N*(7.30, 8.31, 8.57, 9.05) (Al 79m): see table 15.14. The shape of the $^{15}C_{g.s.} \to {}^{15}N_{g.s.}$ transition differs appreciably from an allowed shape (Wa 84). See also (As 86a, As 88), (Wa 88d) and (Ba 89cc, Po 89g; theor.).

2. $^9Be(^7Li, p)^{15}C$ $\qquad Q_m = 9.092$

Observed proton groups are displayed in table 15.2.

3. $^{13}C(t, p)^{15}C$ $\qquad Q_m = 0.9127$

Observed proton groups are displayed in table 15.3. See also (Aj 81).

4. $^{13}C(\alpha, 2p)^{15}C$ $\qquad Q_m = -18.9013$

See (Aj 81).

[†] See also (Aj 86).

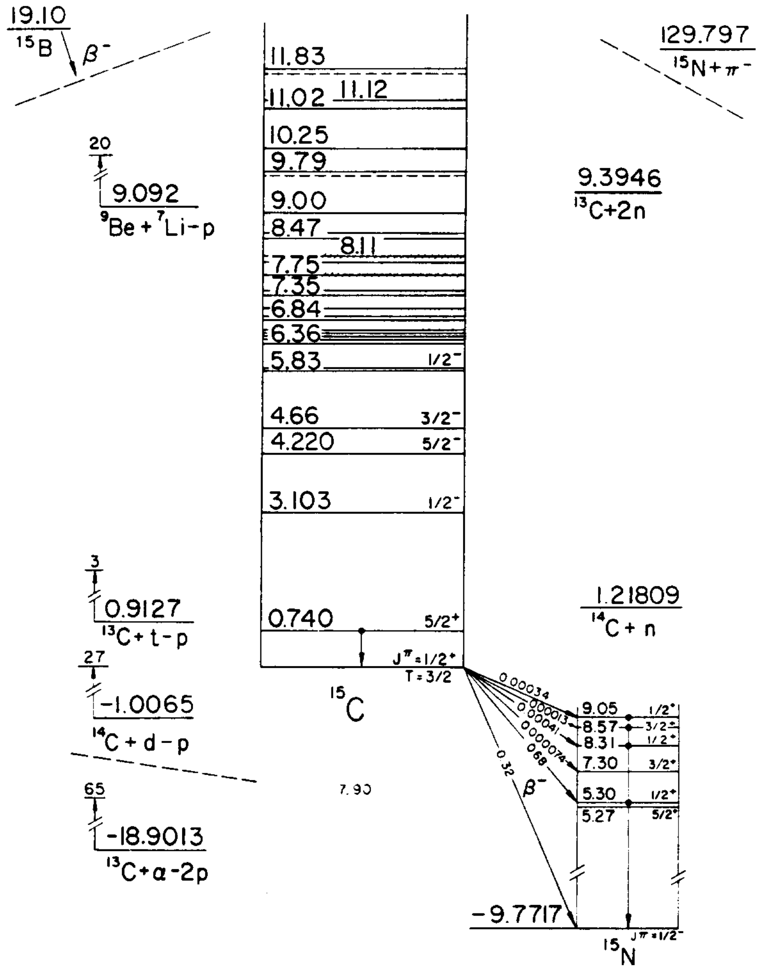


Fig. 10. Energy levels of ^{15}C. For notation see fig. 2.

5. ^{14}C(n, γ)^{15}C $\qquad Q_m = 1.2181$

$\sigma_\gamma < 1$ μb (Mu 81g).

6. ^{14}C(d, p)^{15}C $\qquad Q_m = -1.0065$

At $E_d = 16$ MeV angular distributions and A_y measurements are reported to a state at $E_x = 4.78 \pm 0.10$ MeV ($\Gamma_{c.m.} = 1.74 \pm 0.40$ MeV); $S = 0.5$. A narrow state at $E_x = 5.81 \pm 0.02$ MeV ($\Gamma_{c.m.} = 64.3 \pm 8.1$ keV), $S = 0.02$, is also observed. It is suggested that these are 1p2h and 3p4h $\frac{3}{2}^+$ states (Da 85d) [and S. E. Darden, private communication]. For the earlier work see table 15.2.

TABLE 15.1

Energy levels of ^{15}C [a])

E_x (MeV ± keV)	J^π; T	τ or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
g.s.	$\frac{1}{2}^+$; $\frac{3}{2}$	$\tau_{1/2} = 2.449 \pm 0.005$ s $\lvert g \rvert = 2.63 \pm 0.14$	β^-	1→4, 6, 7, 9
0.7400 ± 1.5	$\frac{5}{2}^+$	$\tau_m = 3.76 \pm 0.10$ ns $g = -0.703 \pm 0.012$	γ	2→4, 7, 8
3.103 ± 4	$\frac{1}{2}^-$	$\Gamma_{c.m.} \leq 40$		2, 3, 9
4.220 ± 3	$\frac{5}{2}^-$	<14		2, 3
4.657 ± 9	$\frac{3}{2}^-$			2, 3
4.78 ± 100	$\frac{3}{2}^+$	1740 ± 400		6
5.833 ± 20	$(\frac{3}{2}^+)$	64 ± 8		2, 6
5.866 ± 8	$\frac{1}{2}^-$			2, 3
6.358 ± 6	$(\frac{5}{2}, \frac{7}{2}^+, \frac{9}{2}^+)$	<20		2, 3
6.417 ± 6	$(\frac{3}{2} \to \frac{7}{2})$	~50		2, 3
6.449 ± 7	$(\frac{9}{2}^-, \frac{11}{2})$	<14		2, 3
6.536 ± 4	[a])	<14		2, 3
6.626 ± 8	$(\frac{3}{2})$	20 ± 10		2, 3
6.841 ± 4	[a])	<14		2, 3
6.881 ± 4	$(\frac{9}{2})$ [a])	<20		2, 3
7.095 ± 4	$(\frac{3}{2})$	<15		2, 3
7.352 ± 6	$(\frac{9}{2}, \frac{11}{2})$	20 ± 10		2, 4
7.414 ± 20				2
7.75 ± 30 [b])				2
8.01 ± 30				2
8.11 ± 10 [b])				2
8.47 ± 15	$(\frac{9}{2} \to \frac{13}{2})$	40 ± 15		2
8.559 ± 15	$(\frac{7}{2} \to \frac{13}{2})$	40 ± 15		2
9.00 ± 30				2
(9.73 ± 30)				2
9.789 ± 20	$(\frac{9}{2} \to \frac{15}{2})$	20 ± 15		2
10.248 ± 20	$(\frac{5}{2} \to \frac{9}{2})$	20 ± 15		2
11.015 ± 25				2
11.123 ± 20	$(\frac{11}{2} \to \frac{19}{2})$	30 ± 20		2
(11.68 ± 30)				2
11.825 ± 20	$\geq \frac{13}{2}$	70 ± 30		2

[a]) See also tables 15.2 and 15.3 and reaction 8.

[b]) Broad or unresolved states.

7. ^{14}C(^{13}C, ^{12}C)^{15}C $\qquad Q_m = -3.7283$

Angular distributions have been studied at $E(^{13}\text{C}) = 20.0$ to 27.5 MeV to ^{15}C*(0, 0.74) (Bi 88b). See also (Vo 90a).

8. ^{15}N(π^-, γ)^{15}C $\qquad Q_m = 129.797$

Radiative pion capture shows evidence for $J^\pi = \frac{5}{2}^+$, $T = \frac{3}{2}$ giant magnetic quadrupole states: transitions are reported to ^{15}C*(0.74) as well as to ^{15}C*(6.7, 8.6, 12.0) (St 83e).

9. ^{16}O(^{7}Li, ^{8}B)^{15}C $\qquad Q_m = -22.624$

At $E(^{7}\mathrm{Li}) = 82$ MeV ^{15}C*(0, 3.1) are populated (Al 85m).

TABLE 15.2

Proton groups from ^{9}Be(^{7}Li, p)^{15}C and ^{14}C(d, p)^{15}C [a]

^{9}Be(^{7}Li, p)^{15}C [b]			^{14}C(d, p)^{15}C [c]		
E_x (keV)	$\Gamma_{c.m.}$ (keV)	J^{π} [d]	E_x (keV)	$\Gamma_{c.m.}$ (keV)	J^{π} [e]
g.s.	bound		g.s.	bound	$\frac{1}{2}^{+}$ [o]
≈740 [f]	bound		744.1 ± 2 [j]	bound	$\frac{5}{2}^{+}$ [p]
3100 ± 30	<40	$(\frac{1}{2}^{-})$ [h]	3105.3 ± 5 [k]	~42	$(\frac{1}{2}^{-})$
4223 ± 15	<15	$(\frac{5}{2}^{-})$	4221.1 ± 3 [k]	<14	$(\frac{7}{2}^{+}, \frac{5}{2}^{-})$
(4550 ± 30)					
			4657 [k]		
			4780 ± 100 [l]	1740 ± 400	$\frac{3}{2}^{+}$
5833 ± 20		[i]	5810 ± 20 [l]	64 ± 8	$(\frac{3}{2}^{+})$ [q]
5858 ± 20		[i]			
6370 ± 15	<20	$(\frac{5}{2})$	[k,m]	<14	$(\frac{7}{2}, \frac{9}{2})^{+}$
6436 ± 20			6428.1 ± 7	~50	$(\frac{3}{2}, \frac{5}{2}, \frac{7}{2})$
6461 ± 20			[m]	<14	$(\frac{9}{2}^{-}, \frac{11}{2})$
6542 ± 15	<20	$(\frac{3}{2})$	6539.8 ± 5	<14	$(\frac{9}{2}^{-}, \frac{11}{2})$
6639 ± 15	20 ± 10	$(\frac{3}{2})$			
6847 ± 15	<20	$(\frac{11}{2}, \frac{13}{2})$	6844.9 ± 5	<14	$(\frac{13}{2}, \frac{11}{2})^{+}$
6894 ± 15	<20	$(\frac{7}{2}, \frac{9}{2})$	6882.4 ± 5		$((\frac{9}{2}^{-}, \frac{11}{2}^{+}, \frac{13}{2}^{+}))$
7100 ± 15	<15	$(\frac{3}{2})$	7097.2 ± 6		
7354 ± 15	20 ± 10	$(\frac{9}{2}, \frac{11}{2})$	7351.3 ± 6		
7414 ± 20					
7750 ± 30 [g]			7.81 ± 10 [n]		
8010 ± 30					
8130 ± 30 [g]			8.10 ± 10 [n]		
8491 ± 15	40 ± 15	$(\frac{9}{2}, \frac{11}{2}, \frac{13}{2})$	8.46 ± 10 [n]		
8559 ± 15	40 ± 15	$(\frac{7}{2} \rightarrow \frac{13}{2})$			
9000 ± 30					
(9730 ± 30)					
9789 ± 20	20 ± 15	$(\frac{9}{2} \rightarrow \frac{15}{2})$			
10248 ± 20	20 ± 15	$(\frac{5}{2}, \frac{7}{2}, \frac{9}{2})$			
11015 ± 25					
11123 ± 20	30 ± 20	$(\frac{11}{2} \rightarrow \frac{19}{2})$			
(11680 ± 30)					
11825 ± 20	70 ± 30	$(\frac{13}{2} \rightarrow \frac{31}{2})$			

[a] For references see table 15.2 in (Aj 81).

[b] $E(^{7}\mathrm{Li}) = 20$ MeV. E_x based on 740 keV for first excited state.

[c] $E_d = 12$–14 MeV.

[d] Suggested J^{π} assignments based on angular distributions (and $2J_f + 1$ dependence) and l_{max} from Γ_n.

[e] Analysis of the two bound states is done using DWUCK. For the unbound states DOXY was used.

TABLE 15.3

Proton groups from ^{13}C(t, p)^{15}C [a])

E_x (MeV ± keV)	J^π	E_x (MeV ± keV)	J^π
0	$\frac{1}{2}^+$	6.440 ± 6	
0.743 ± 9 [b])	$\frac{5}{2}^+$	6.529 ± 6	
3.100 ± 6 [b])	$\frac{1}{2}^-$	6.622 ± 9	
4.215 ± 9 [b])	$\frac{5}{2}^-$	6.835 ± 6 [b])	$(\frac{7}{2}, \frac{9}{2})^-$
4.657 ± 9 [b])	$\frac{3}{2}^-$	6.876 ± 7	
5.867 ± 8	$\frac{1}{2}^-$	7.093 ± 6	
6.356 ± 6		7.387 ± 7 [b])	$(\frac{9}{2}, \frac{7}{2})^-$
6.404 ± 7			

[a]) (Tr 83h); $E_t = 18$ MeV; DWBA.
[b]) Strong group.

^{15}N

(Figs. 11 and 13)

GENERAL[†]

Nuclear models: (Kw 85, Ph 85, Ka 87a, Ki 87e, Me 87c, St 87b, Wo 88, Wo 89c, Va 90a)

Special states: (Ar 85i, Go 85v, Ph 85, Sh 85o, Ki 87e, St 87b, Kw 88, Zh 88a, Or 89a)

Electromagnetic transitions and giant resonances: (Bl 85h, Go 85v, Er 86, Ki 87e, St 87b, As 89b)

[†] See also (Aj 86).

Table 15.2 footnotes—continued

[f]) $E_x = 739 \pm 1$ keV [from E_γ]; $\tau_m = 3.77 \pm 0.11$ ns.
[g]) Broad or unresolved states.
[h]) $\theta_n^2 = 0.0075 \pm 0.0015$.
[i]) Sum of the J for these two states is 2 [based on $(2J_f + 1)$ dependence of cross section].
[j]) $\tau_m = 3.73 \pm 0.23$ ns.
[k]) See also (Da 85d).
[l]) See text, reaction 6 (Da 85d).
[m]) Observed but E_x not determined.
[n]) Observed at $E_d = 27$ MeV.
[o]) $S = 0.88$.
[p]) $S = 0.69$ or 0.55. $g = -0.77 \pm 0.06$.
[q]) May be unresolved.

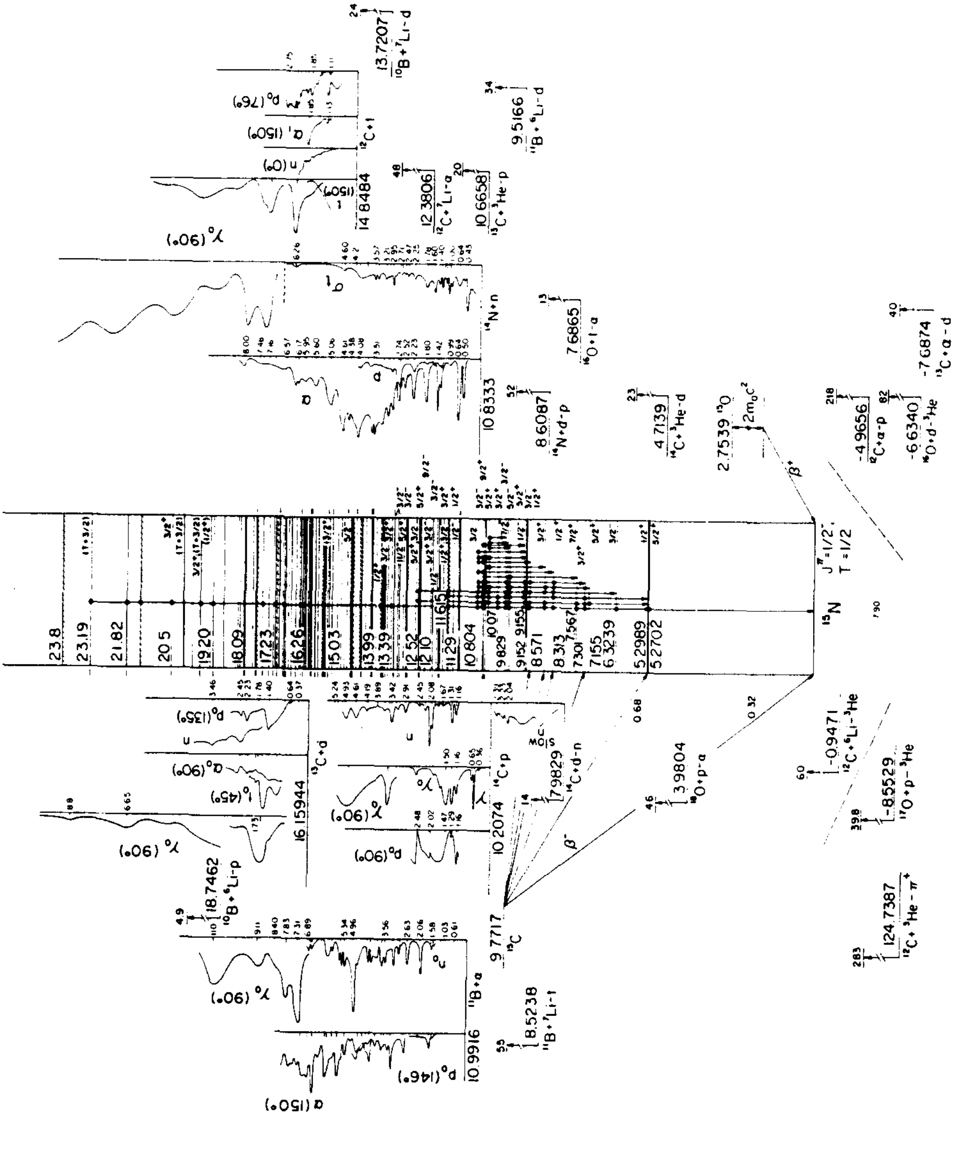


Fig. 11. Energy levels of ^{15}N. For notation see fig. 2.

Astrophysical questions: (Bu 82m, Ca 82h, Wo 82h, Pr 85e, Fr 86f, Ar 87i, Au 87d, Le 87i, Zi 87b, Fe 88, Kr 88f, Pi 88b, Wa 88h, Ch 89t, Gu 89b, Gu 89i, Gu 89k, Ji 89, Ka 89b, Ke 89c, Me 89, No 89, Wy 89, Yo 89g, Ha 90k, Ra 90g)

Complex reactions involving ^{15}N: (Ar 85i, Be 85o, Ha 85w, Po 85d, Si 85d, Ut 85a, Ai 86, Ch 86q, Co 86c, Gr 86m, Ha 86bb, Ma 86j, Ma 86k, Me 86d, Po 86d, Po 86k, Sa 86ee, Sc 86d, So 86d, To 86d, Ut 86, Va 86n, Ba 87w, Be 87o, Bu 87e, Fe 87, Mi 87s, Na 87, Ol 87, Ri 87b, St 87, Vi 87a, Ar 88c, Go 88k, Jo 88a, Sa 88h, Ut 88a, Ba 89cc, Ge 89, Gr 89e, Ki 89f, Pa 89a, Sa 89g, Te 89b, Yo 89, Da 90, Gl 90a, We 90a)

Applied work: (Am 86, Co 86c, En 86d, He 86c, Le 86g, No 86a, Sa 86m, St 86l, Si 87c, Gr 88, Pi 88c, Pr 88c, Vi 88a, Ku 89m, Ta 89y, Yo 89g, Am 90c)

Pion capture and reactions†: (Le 85j, Ma 85v, Ba 86kk, Si 86e, Ka 87a, Le 87m, Li 88h, Mi 88k, Ro 88l, Ta 88m, Ch 89w, Ge 89b, Jo 89a, Le 89g, Er 90c, Er 90d, Od 90, Ta 90d)

Reactions involving other mesons and hyperons: (Ia 85, Fe 86b, Do 89g, Do 89i)

Antiproton reactions: (Ba 85cc)

Hypernuclei: (Bo 84q, Ia 85, An 86s, Da 86a, Da 86b, Fe 86b, Ga 86m, Ko 86i, Ya 86e, Ma 87q, Mi 87b, Po 87e, Wu 87a, Mo 88k, Ba 89cc, Ba 89hh, Do 89i, Ko 89h, Mi 89a, Ta 89n)

Other topics: (An 85e, Ph 85, Sh 85o, An 86u, Wi 86a, Ch 87, Kw 88, Or 89a, Po 89g, Mu 90a)

Ground-state properties of ^{15}N: (An 85e, Ar 85a, Bl 85h, Go 85v, Ba 86b, Ba 86jj, Mc 86g, Wi 86a, Wu 86c, De 87b, Fu 87h, Ic 87, Ki 87e, Mi 87s, Ar 88a, Ar 88h, Ch 88t, De 88b, Fu 88a, Ke 88a, Ni 88a, Sh 88b, Va 88, Wa 88c, Wo 88, Ch 89i, Fu 89g, Go 89b, Ne 89, Sa 89g, Wo 89c, Va 90, Va 90a)

$$\langle r^2 \rangle^{1/2} = 2.612 \pm 0.009 \text{ fm (De 88b)}$$

$$\mu = -0.283188842\,(45) \text{ n.m. (see Ra 89g)}$$

Natural abundance: $(0.366 \pm 0.009)\%$ (De 84q)

$^{15}N^*(5.27)$: $\mu = +(2.35 \pm 0.18)$ n.m. (see Ra 89g)

1. (a) $^9Be(^6Li, n)^{14}N$	$Q_m = 14.4986$	$E_b = 25.3319$
(b) $^9Be(^6Li, p)^{14}C$	$Q_m = 15.1245$	
(c) $^9Be(^6Li, t)^{12}C$	$Q_m = 10.4835$	
(d) $^9Be(^6Li, \alpha)^{11}B$	$Q_m = 14.3403$	

† See also reactions 15, 43 and 46.

TABLE 15.4

Energy levels of ^{15}N [a])

E_x (MeV ± keV)	J^π; T	τ_m or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
0	$\frac{1}{2}^-$; $\frac{1}{2}$	-	stable	3→6, 13, 14, 16→20, 24→28, 31→35, 39→66
5.270155 ± 0.014 [b])	$\frac{5}{2}^+$	τ_m = 2.58 ± 0.14 ps g = +(0.94 ± 0.07)	γ	4, 5, 16, 17, 24, 25, 31, 32, 35, 40, 45, 46, 49, 50, 56, 59, 60, 64, 65
5.298822 ± 0.014 [b])	$\frac{1}{2}^+$	25 ± 7 fs	γ	4, 5, 10→12, 16, 18, 24→26, 31, 32, 35, 40, 42, 45, 49, 50, 56, 60, 64, 65
6.32378 ± 0.02 [b])	$\frac{3}{2}^-$	0.211 ± 0.012 fs	γ	4, 5, 10→13, 16, 18, 24, 26, 31, 32, 35, 39, 40, 42, 44→46, 49, 50, 56, 57, 59→61, 63→65
7.15505 ± 0.02 [b])	$\frac{5}{2}^+$	18 ± 8 fs	γ	4, 5, 12, 16→18, 24→26, 31, 32, 35, 40, 45, 49, 50, 60
7.30083 ± 0.02 [b])	$\frac{3}{2}^+$	0.61 ± 0.05 fs	γ	4, 5, 12, 16, 18, 24→26, 31, 32, 35, 40, 42, 45, 49, 50, 60
7.5671 ± 1.0 [c])	$\frac{7}{2}^+$	12^{+11}_{-6} fs	γ	4, 5, 10→12, 16→18, 24→26, 31, 40, 45, 46, 49, 50, 60, 64
8.31262 ± 0.027 [b])	$\frac{1}{2}^+$	1.7 ± 1.1 fs	γ	4, 5, 18, 24→26, 31, 35, 39, 40, 42, 45, 49, 50, 56
8.5714 ± 0.12	$\frac{3}{2}^+$	0.7 ± 0.7 fs	γ	4, 5, 10→12, 16→18, 24→26, 31, 40, 42, 45, 49, 50
9.04971 ± 0.07	$\frac{1}{2}^+$	0.50 ± 0.08 fs	γ	4, 5, 24, 25, 31, 35, 40, 42, 45, 56
9.15190 ± 0.12 [b])	$\frac{3}{2}^-$	1.40 ± 0.36 fs	γ	4, 5, 10, 11, 24, 25, 31, 35, 40, 45, 49, 50
9.15490 ± 0.03 [b])	$\frac{5}{2}^+$	7^{+6}_{-3} fs	γ	4, 5, 18, 24, 31, 35, 40, 49, 50
9.2221 ± 0.8	$\frac{1}{2}^-$	< 130 fs	γ	24, 26, 31, 35, 40, 56, 60
9.760 ± 1	$\frac{5}{2}^-$	2.6 ± 0.9 fs	γ	24, 40, 45
9.829 ± 3	$\frac{7}{2}^-$	17 ± 7 fs	γ	4, 5, 10, 11, 17, 18, 24, 26, 31, 40, 49, 50
9.9250 ± 0.2	$\frac{3}{2}^-$	0.31 ± 0.05 fs	γ	18, 24, 31, 35, 40, 45
10.0660 ± 0.2 [c])	$\frac{3}{2}^+$	0.100 ± 0.006 fs	γ	18, 35, 40, 44, 45, 49, 50
10.4497 ± 0.3	$\frac{5}{2}^-$	Γ < 0.5 keV	γ, p	5, 10, 11, 24, 28, 40
10.5333 ± 0.5	$\frac{5}{2}^+$		γ, p	5, 10, 11, 18, 24, 25, 28, 31, 40
10.6932 ± 0.3	$\frac{9}{2}^+$	τ_m = 18 ± 9 fs	γ, p	5, 11, 16, 28, 46
10.7019 ± 0.3	$\frac{3}{2}^-$	Γ = 0.2 keV	γ, p	10, 11, 17, 18, 24, 26, 28, 60
10.804 ± 2	$\frac{3}{2}^+$	$< 1 \times 10^{-3}$	γ, p	4, 5, 10, 11, 18, 24, 28, 40, 45
11.235 ± 5 [b])	$\geq \frac{3}{2}$	3.3	n	16, 31, 36, 40
11.2928 ± 0.7	$\frac{1}{2}^-$	8 ± 3	γ, n, p	16, 18, 28→31, 36, 38, 49

TABLE 15.4—continued

E_x (MeV ± keV)	$J^{\pi}; T$	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
11.4376 ± 0.7	$\frac{1}{2}^{+}$	41.4 ± 1.1	γ, n, p, α	6, 7, 10, 11, 18, 25, 28 → 31, 36, 38, 64
11.615 ± 4	$\frac{1}{2}^{+}; T = \frac{3}{2}$	405 ± 6	γ, n, p	28 → 30
11.763 ± 3	$\frac{3}{2}^{+}$	40	n, p, α	7, 29, 30, 36, 38
11.876 ± 3	$\frac{3}{2}^{-}$	25	γ, n, p, α	7, 29, 30, 36, 38, 48
11.942 ± 6	$\frac{9}{2}^{-}$	≤3.0	n, α	5, 16 → 18, 25, 26, 36
11.965 ± 3	$\frac{1}{2}^{-}$	17	n, p, α	5, 7, 10, 11, 29, 30, 36, 38
12.095 ± 3	$\frac{5}{2}^{+}$	14 ± 5	n, p, α	7, 25, 29, 30, 36, 38
12.145 ± 3	$\frac{3}{2}^{-}$	41 ± 5	n, p, α	7, 10, 11, 29, 30, 36, 38
12.327 ± 4	$\frac{5}{2}^{(+)}$	22	n, p	17, 18, 25, 29, 30, 36, 38
12.493 ± 4	$\frac{5}{2}^{+}; \frac{1}{2}$	40 ± 5	n, p, α	7, 18, 25, 29, 30, 36, 38
12.522 ± 8	$\frac{5}{2}^{+}; \frac{3}{2}$	58 ± 4	γ, p	28, 45
12.551 ± 10	$\frac{9}{2}^{+}$			5, 11, 16, 17, 25, 46
12.920 ± 4	$\frac{3}{2}^{-}$	56 ± 11	n, p, α	7, 9, 18, 29, 30, 36, 38
12.940 ± 10	$\frac{5}{2}^{+}$	81	p, α	7, 9, 29, 30
13.004 ± 10	$\frac{11}{2}^{-}$			5, 10, 11, 16, 18, 25, 26
13.149 ± 10		7 ± 3	n, p, α	7, 38
13.174 ± 7	$(\frac{9}{2})$	7 ± 3	n, p, α	5, 7, 11, 16 → 18, 29, 36, 38
13.362 ± 8	$\frac{3}{2}^{-}$	16 ± 8	n, p, α	7, 9, 29, 30, 38
13.390 ± 10	$\frac{3}{2}^{+}$	56	γ, n, p, α	7, 9, 28 → 30, 38
13.537 ± 10	$\frac{3}{2}^{-}$	85 ± 30	n, p, α	7, 9, 29, 30
13.608 ± 7	$\frac{5}{2}^{(+)}$	18 ± 4	n, p, α	7, 18, 36, 38
(13.612 ± 10)	$(\frac{1}{2}^{+})$	90	n, p, α	9, 29, 30
13.713 ± 10		26 ± 8	n, p, α	7, 29, 38
13.84 ± 30	$\frac{3}{2}^{+}$	75	n, p, α	5, 7, 9, 11, 25, 36, 38
13.9	$\frac{1}{2}^{+}$	930	γ, p	28, 29
13.99 ± 30	$\frac{5}{2}^{+}$	98 ± 10	n, p, α	7, 11, 29, 30
14.090 ± 7	$(\frac{9}{2}^{+}, \frac{7}{2}^{+})$	22 ± 6	n, p, α	5, 7, 10, 11, 18, 25, 36, 38, 46
14.10 ± 30	$\frac{3}{2}^{+}$	~100	n, α	5, 7, 9, 30
14.162 ± 10	$\frac{3}{2}^{(+)}$	27 ± 6	n, α	5, 7, 36, 38
14.24 ± 40	$\frac{5}{2}^{+}$	150	α	9, 10
14.38 ± 40	$\frac{7}{2}^{+}$	100	α	9
14.4		~1900	n, p, α	36, 38
14.55 ± 20		200 ± 50	n, (p), α	7
14.647 ± 10		33 ± 6	n, p, α	7, 36, 38
14.71		750	γ, p	28
14.720 ± 10	$\frac{5}{2}^{-}$	110 ± 50	γ, n, (p), α	7, 10, 11, 18, 36, 38, 45
14.86 ± 20		48 ± 11	n, α	7, 9, 18
14.920 ± 10		12 ± 3	n, α	7, 10, 38
15.025 ± 10		13 ± 3	n, α	7, 18
15.09 ± 20		80 ± 25	n, α	7, 9, 49
15.288 ± 10		26 ± 6	n, α	7, 9
15.373 ± 10	$\frac{13}{2}^{+}$			5, 10, 11, 16 → 18
15.38 ± 20		75 ± 25	n, t, α	7, 9, 14
15.43 ± 20		~100	n, (α)	7, 9
15.45		750	γ, p	28
15.53 ± 20		~35	n, α	7, 10, 11, 38
15.60 ± 20		95 ± 25	n, α	7

TABLE 15.4—continued

E_x (MeV ± keV)	$J^\pi; T$	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
15.782 ± 10			p, t, α	7, 14, 18
15.93 ± 20		35 ± 5	n, t, α	7, 14, 17
15.944 ± 15		21 ± 6	n, t, α	7, 14
16.026 ± 10		62 ± 12	n, p, t, α	7, 9, 14, 18, 38
16.190 ± 10	$\frac{3}{2}^+$	450 ± 100	γ, n, p, t, α	10, 14, 18
16.26 ± 20	$\frac{3}{2}^+$	150 ± 28	γ, n, t, α	6, 7, 9, 14, 17, 18
16.32 ± 20		~30	n, p, t, α	7, 14
16.39 ± 20	[illegible]	44 ± 11	n, p, t, α	7, 14, 17, 38
16.46		560	γ, p, d	21, 28
16.576 ± 15		27 ± 15	n, α	7, 38
16.59 ± 25	$\frac{3}{2}^-$	490	γ, n, p, t, α	14
16.677 ± 15	$\frac{1}{2}^+; \frac{1}{2}$	80 ± 20	γ, n, p, d, t, α	6, 7, 14, 17, 21, 23, 28, 30, 36, 38, 43
16.85 ± 30	$\frac{5}{2}$	110 ± 50	t, α	14
16.91		~350	n, p, d, t, α	14, 21, 36, 38
(17.05)			p, t	14
17.11		broad	d, α	23
17.15 ± 50	$(\frac{1}{2}^+, \frac{3}{2}^+)$	250 ± 60	γ, t, α	6, 14
17.23 ± 40		~175	d, t, (α)	23
17.37 ± 40		~250	p, d, t, α	14, 21, 23, 36, 38
17.58 ± 40	$\frac{3}{2}^+$	450 ± 120	γ, d, t, α	14, 23, 38
17.67 ± 40	$\frac{3}{2}^+; \frac{1}{2}$	600 ± 80	γ, n, d, α	6, 20, 21, 23
17.72 ± 10		48 ± 10	n, (p), d, t, α	18, 21, 23, 38
17.95 ± 20		167	n, α	18
18.06 ± 10		19 ± 4	(n), d, α	17, 21, 23
18.09 ± 20		~40	(n), p, d, t	21, 23
18.22		158	n, α	36, 38
18.27 ± 20		235 ± 60	n, p, d, α	18, 21, 23, 38
18.70 ± 20				11, 18
18.91 ± 150	$\frac{3}{2}^+ + \frac{1}{2}^+$	750 ± 70	γ, α	6
19.20 ± 35	$(\frac{1}{2}^+; \frac{1}{2})$	~130	n, d	18, 21
19.5	$\frac{3}{2}^+; (\frac{3}{2})$	~400	γ, p, t	14, 28, 29
19.72 ± 40		[d])		11, 17, 18
20.12 ± 50	$(T = \frac{3}{2})$			16, 46
20.5	$\frac{3}{2}^+$	~400	γ, n, p, d	21, 28
20.96 ± 65	$\frac{3}{2}^+ + \frac{1}{2}^+$	1740 ± 150	γ, α	6, 18
21.82		~600	γ, p, d	20, 28, 43
23.19 ± 60	$(T = \frac{3}{2})$		γ, p	28, 46
23.6		broad	γ, n, d	20, 43
24.75 ± 150		[d])		18
25.5	$\frac{3}{2}^-; (T = \frac{3}{2})$		γ, n, p	28, 43
(26.8)			t	14
~37			γ, p	28

[a]) See also tables 15.5 and 15.12 here, and table 15.6 in (Aj 86) [τ_m].

[b]) Revisions in the values of the fundamental constants and of the binding energy of the deuteron, as well as a reevaluation of earlier work, lead (Wa 90b) to suggest values for E_x which differ from the ones shown by, typically, 40 eV [lower].

[c]) See also reaction 40.

[d]) Wide or unresolved.

Thick target neutron yields are reported at $E(^6Li) = 40$ MeV (Sc 87c). The yield of p_0 and p_1 (reaction (b)) for $E(^6Li) = 3.84$ to 6.40 MeV shows some broad structure: analysis in tems of Ericson fluctuation theory gives a value of ≈ 0.4 MeV for the average level width at $E_x = 28$ MeV in ^{15}N. The excitation functions for t_0 (reaction (c)), α_0, α_1 and α_2 (reaction (d)) show broad structures for $E(^6Li) = 4$ to 14 MeV. See (Aj 76) for the references.

2. $^9Be(^7Li, n)^{15}N$ $\qquad Q_m = 18.0818$

See (Mc 85c; applied).

TABLE 15.5

Radiative decays in ^{15}N [a])

E_i (MeV)	J_i^π	E_f (MeV)	J_f^π	Branch (%)	Mult. mixing ratio δ
5.27	$\frac{5}{2}^+$	0	$\frac{1}{2}^-$	100	-0.131 ± 0.013
5.30	$\frac{1}{2}^+$	0	$\frac{1}{2}^-$	100	
6.32 [b])	$\frac{3}{2}^-$	0	$\frac{1}{2}^-$	100	$+0.132 \pm 0.004$
7.16 [c])	$\frac{5}{2}^+$	5.27	$\frac{5}{2}^+$	100 ± 0.4	$-0.014^{+0.012}_{-0.015}$
7.30	$\frac{3}{2}^+$	0	$\frac{1}{2}^-$	99.3 ± 0.7	$-0.017^{+0.005}_{-0.008}$
		5.27	$\frac{5}{2}^+$	0.6 ± 0.1	$+0.18 \pm 0.15$, or $+2.5 \pm 1.0$
		5.30	$\frac{1}{2}^+$	0.2 ± 0.1	-0.31 ± 0.15, or $+4.6 \pm 3.4$
		6.32	$\frac{3}{2}^-$	<0.25	
7.57 [d])	$\frac{7}{2}^+$	0	$\frac{1}{2}^-$	1.3 ± 0.6	
		5.27	$\frac{5}{2}^+$	98.7 ± 1.0	-0.028 ± 0.012
8.31	$\frac{1}{2}^+$	0	$\frac{1}{2}^-$	79 ± 2	
		5.27	$\frac{5}{2}^+$	<3	
		5.30	$\frac{1}{2}^+$	10 ± 2	
		6.32	$\frac{3}{2}^-$	4.4 ± 1.0	
		7.16	$\frac{5}{2}^+$	1.2 ± 0.6	
		7.30	$\frac{3}{2}^+$	4.4 ± 0.7	
8.57 [e])	$\frac{3}{2}^+$	0	$\frac{1}{2}^-$	33 ± 2	$-0.085^{+0.005}_{-0.009}$
		5.27	$\frac{5}{2}^+$	65 ± 3	-0.091 ± 0.007
		6.32	$\frac{3}{2}^-$	1.4 ± 0.6	
		7.16	$\frac{5}{2}^+$	3.6 ± 0.5	
9.05 [f])	$\frac{1}{2}^+$	0	$\frac{1}{2}^-$	92 ± 3	
		5.27	$\frac{5}{2}^+$	3.5 ± 1	
		6.32	$\frac{3}{2}^-$	4.5 ± 1	
		7.30	$\frac{3}{2}^+$	1.2 ± 0.4	
9.152	$\frac{3}{2}^-$	0	$\frac{1}{2}^-$	100 ± 3	$+0.015^{+0.041}_{-0.034}$
9.155	$\frac{5}{2}^+$	0	$\frac{1}{2}^-$	<2	
		5.27	$\frac{5}{2}^+$	11 ± 1	
		5.30	$\frac{1}{2}^+$	10 ± 1	
		6.32	$\frac{3}{2}^-$	22 ± 2	
		7.16	$\frac{5}{2}^+$	57 ± 3	
9.22 [g])	$\frac{1}{2}^-$	0	$\frac{1}{2}^-$	22 ± 5	
		5.30	$\frac{1}{2}^+$	42 ± 8	
		6.32	$\frac{3}{2}^-$	35 ± 6	
		7.30	$\frac{3}{2}^+$	2.6 ± 0.7	

TABLE 15.5—continued

E_i (MeV)	J_i^π	E_f (MeV)	J_f^π	Branch (%)	Mult. mixing ratio δ
9.76 [h])	$\frac{5}{2}^-$	0	$\frac{1}{2}^-$	81.5 ± 2.8	
		5.27+5.30		7.5 ± 1.5	
		6.32	$\frac{3}{2}^-$	3.7 ± 0.8	
		7.16	$\frac{5}{2}^+$	2.3 ± 0.5	
		7.57	$\frac{7}{2}^+$	5.0 ± 0.6	
9.83 [i])	$\frac{7}{2}^-$	5.27	$\frac{5}{2}^+$	~85	
		6.32	$\frac{3}{2}^-$	2.2 ± 0.9	
		7.16	$\frac{5}{2}^+$	2.4 ± 1.1	
		7.30	$\frac{3}{2}^+$	3.7 ± 0.9	
		7.57	$\frac{7}{2}^+$	7.3 ± 1.0	
9.93 [j])	$\frac{3}{2}^-$	0	$\frac{1}{2}^-$	77.6 ± 1.9	
		5.27+5.30		15.4 ± 1.5	
		6.32	$\frac{3}{2}^-$	4.9 ± 1.2	
		7.30	$\frac{3}{2}^+$	2.1 ± 0.8	
10.07 [k])	$\frac{3}{2}^+$	0	$\frac{1}{2}^-$	96.0 ± 0.7	
		5.27+5.30		4.0 ± 0.7	
10.45 [l])	$\frac{5}{2}^-$	5.27	$\frac{5}{2}^+$	55.0 ± 0.8	$+0.021\pm0.033$
		6.32	$\frac{3}{2}^-$	31.3 ± 1.7	-0.59 ± 0.13
		7.16	$\frac{5}{2}^+$	5.2 ± 0.1	$+0.13^{+0.03}_{-0.04}$
		8.57	$\frac{3}{2}^+$	3.8 ± 0.6	-0.3 ± 0.4
		9.152	$\frac{3}{2}^-$	4.7 ± 0.1	$-0.32^{+0.09}_{-0.10}$
10.53 [m])	$\frac{5}{2}^+$	0	$\frac{1}{2}^-$	<0.1	
		5.27	$\frac{5}{2}^+$	38.7 ± 0.2	-0.27 ± 0.03
		6.32	$\frac{3}{2}^-$	7.7 ± 0.1	-0.028 ± 0.004
		7.16	$\frac{5}{2}^+$	19.4 ± 0.2	$+0.007^{+0.010}_{-0.008}$
		7.30	$\frac{3}{2}^+$	31.4 ± 0.5	$+0.066\pm0.005$
		8.57	$\frac{3}{2}^+$	2.4 ± 0.1	$+0.012^{+0.006}_{-0.005}$
		9.152	$\frac{3}{2}^-$	0.3 ± 0.1	$-0.20^{+0.03}_{-0.02}$
10.69 [m])	$\frac{9}{2}^+$	5.27	$\frac{5}{2}^+$	61.6 ± 0.3	
		7.16	$\frac{5}{2}^+$	2.1 ± 0.1	-0.03 ± 0.07
		7.57	$\frac{7}{2}^+$	36.3 ± 0.6	$+0.118\pm0.008$
10.70 [m])	$\frac{3}{2}^-$	0	$\frac{1}{2}^-$	52.6 ± 0.8	$+0.180^{+0.006}_{-0.002}$
		5.27	$\frac{5}{2}^+$	37.4 ± 0.6	$-0.24^{+0.004}_{-0.008}$
		5.30	$\frac{1}{2}^+$	0.8 ± 0.1	-0.13 ± 0.07
		6.32	$\frac{3}{2}^-$	3.8 ± 0.1	$+0.135\pm0.015$
		7.16	$\frac{5}{2}^+$	0.4 ± 0.1	0.3 ± 0.3
		7.30	$\frac{3}{2}^+$	2.3 ± 0.1	-0.027 ± 0.023
		8.31	$\frac{1}{2}^+$	0.8 ± 0.1	$-0.017^{+0.018}_{-0.016}$
		9.05	$\frac{1}{2}^+$	0.2 ± 0.1	-0.007 ± 0.12
		9.152	$\frac{3}{2}^-$	0.2 ± 0.1	-0.11 ± 0.03
		9.23	$\frac{1}{2}^-$	1.5 ± 0.1	$+0.049^{+0.006}_{-0.005}$
10.80 [n])	$\frac{3}{2}^+$	0	$\frac{1}{2}^-$	51.5 ± 0.4	-0.02 ± 0.01
		5.27	$\frac{5}{2}^+$	4.9 ± 0.1	-0.63 ± 0.04
		5.30	$\frac{1}{2}^+$	15.5 ± 0.2	-0.55 ± 0.02
		6.32	$\frac{3}{2}^-$	5.4 ± 0.2	-0.07 ± 0.05
		7.16	$\frac{5}{2}^+$	7.8 ± 0.1	$+0.14\pm0.03$
		7.30	$\frac{3}{2}^+$	5.8 ± 0.1	-0.12 ± 0.02
		8.31	$\frac{1}{2}^+$	3.6 ± 0.1	$+0.12\pm0.03$
		9.05	$\frac{1}{2}^+$	0.3 ± 0.1	

TABLE 15.5—continued

E_i (MeV)	J_i^π	E_f (MeV)	J_f^π	Branch (%)	Mult. mixing ratio δ
		9.152	$\frac{3}{2}^-$	0.9 ± 0.1	
		9.155	$\frac{5}{2}$	4.2 ± 0.1	
11.62 °)	$\frac{1}{2}^+$; $T = \frac{3}{2}$	0	$\frac{1}{2}^-$	90.7 ± 3.0	
		5.27	$\frac{5}{2}^+$	<1	
		5.30	$\frac{1}{2}^+$	7.4 ± 1.5	
		6.32	$\frac{3}{2}^-$	1.9 ± 1.5	
12.52	$\frac{5}{2}^+$; $T = \frac{3}{2}$	0	$\frac{1}{2}^-$	<1	
		5.27	$\frac{5}{2}^+$	94.2 ± 0.6	-0.02 ± 0.04
		5.30	$\frac{1}{2}^+$	<1	
		6.32	$\frac{3}{2}^-$	5.8 ± 0.6	-0.02 ± 0.04
13.39 ^{p})	$\frac{3}{2}^+$	0	$\frac{1}{2}^-$	100	

^{a}) See also tables 15.12 and 15.15, and 15.6 in (Aj 86). For references see table 15.4 in (Aj 81). Please note that (Be 76a) is an unpublished Ph.D. thesis.

^{b}) Transitions to $^{15}N^*(5.27, 5.30)$ are <0.1 and <0.05%, respectively (Mo 75m).

^{c}) Transitions to $^{15}N^*(0, 5.30, 6.32)$ are <0.1, <4 and <0.5%.

^{d}) Transitions to $^{15}N^*(5.30, 6.32)$ are <4 and <0.6%.

^{e}) Transitions to $^{15}N^*(5.30, 7.30, 7.57)$ are <12, <0.7 and <3%.

^{f}) Transitions to $^{15}N^*(7.16, 7.57, 8.31)$ are <10, <2 and <0.5%.

^{g}) Transitions to $^{15}N^*(7.16, 7.57, 8.31)$ are <1, <20 and <5%.

^{h}) Transitions to $^{15}N^*(7.30, 8.31, 8.57)$ are <2, <1 and <2%.

^{i}) Transitions to $^{15}N^*(0, 5.30)$ are <4 and <15%.

^{j}) Transitions to $^{15}N^*(7.16, 7.57, 8.31, 8.57)$ are each <1%.

^{k}) For upper limits for transitions to other states see table 15.4 in (Aj 81).

^{l}) Transitions to $^{15}N^*(0, 5.30, 9.83)$ are <12, <2 and <0.1%. See also (Go 90b).

^{m}) See also (Go 90b).

^{n}) π is + because if π were − the Γ_γ and δ of the 10.80→5.30 MeV transition would lead to an unacceptably high M2 value (33 W.u.) (P.M. Endt, private communication). See also (Go 90b).

^{o}) See footnote ^{g}) in table 15.4 (Aj 81).

^{p}) $\Gamma_{\gamma_0} = 3.0 \pm 0.9$ eV, $\Gamma_p \Gamma_{\gamma_0} / \Gamma = 1.70 \pm 0.5$ eV; $\delta = 0.00 \pm 0.04$ (M2/E1); $B(E1) = (1.2 \pm 0.4) 10^{-3}\ e^2 \cdot fm^2$. Transitions to $^{15}N^*(5.27, 5.30)$ are <8% and to $^{15}N^*(6.32, 7.16, 7.30)$ are <5%.

3. $^9Be(^{12}C, ^6Li)^{15}N$ $\qquad Q_m = -2.8395$

See (Go 88g; $E(^{12}C) = 65$ MeV; prelim.).

4. $^{10}B(^6Li, p)^{15}N$ $\qquad Q_m = 18.7462$

At $E(^6Li) = 4.9$ MeV, thirty proton groups are observed corresponding to ^{15}N states with $E_x < 16.8$ MeV. Angular distributions have been measured for the proton groups corresponding to $^{15}N^*(5.27+5.30, 6.32, 7.16+7.30, 7.57, 8.31, 8.57, 9.05+9.15)$: see (Aj 76).

5. $^{10}B(^7Li, d)^{15}N$ $\qquad Q_m = 13.7207$

At $E(^7Li) = 24$ MeV angular distributions have been studied to many of the ^{15}N states with $E_x < 15.5$ MeV: see (Aj 81).

6. $^{11}B(\alpha, \gamma)^{15}N$ $Q_m = 10.9916$

The 90° differential cross section for γ_0 production has been measured for $E_\alpha = 5.74$ to 18.0 MeV: see (Aj 81, Aj 86). For the observed resonances see table 15.6. See also (Wa 88i; prelim.).

7. (a) $^{11}B(\alpha, n)^{14}N$ $Q_m = 0.1583$ $E_b = 10.9916$
   (b) $^{11}B(\alpha, p)^{14}C$ $Q_m = 0.7842$

TABLE 15.6

Resonances in $^{11}B(\alpha, \gamma_0)^{15}N$ [a])

E_α (MeV)	E_x (MeV)	$\Gamma_{c.m.}$ (keV)	Γ_γ (eV)	J^π
7.20	16.27 ± 0.04	240 ± 30	≥ 11	$\frac{3}{2}^+$
7.70	16.64 ± 0.04	250 ± 30	≥ 11	$\frac{1}{2}^+$
8.40 [b])	17.15 ± 0.05	250 ± 60	≥ 2	$(\frac{1}{2}^+, \frac{3}{2}^+)$
9.11 [b])	17.67 ± 0.05	600 ± 80	≥ 7	$\frac{3}{2}^+$
10.80 [c])	18.91 ± 0.15	750 ± 70		$\frac{3}{2}^+ + \frac{1}{2}^+$
14.00 [c])	21.25 ± 0.15	1740 ± 150		$\frac{3}{2}^+ + \frac{1}{2}^+$

[a]) For references and other information see table 15.7 in (Aj 86).
[b]) These E_α may be 100 keV too high.
[c]) There is indication of M1/E2 transitions interfering with the predominant E1 transitions.

Reported resonances are displayed in table 15.7. Nine resonances have been observed in the total cross section for reaction (a) in the range $E_\alpha = 0.55$ to 2.40 MeV (Wa 88i; prelim.) [astrophysical reaction rates will be derived]. For thick target neutron yields for $E_\alpha = 1.0$ to 9.8 MeV, see the review in (He 89). See also (El 87a; applied).

TABLE 15.7

Resonances in $^{11}B + \alpha$ [a])

E_α (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Particle out	J^π	E_x (MeV)
0.606 [b])		γ, n	$\frac{7}{2}$	11.436
1.07 ± 20 [c])		n, p		11.78
1.20 ± 10 [c])		n, p		11.87
1.32 ± 10 [c])		n, p		11.96
1.50 ± 10 [c])		n, p	$(\frac{5}{2}^+)$	12.09
1.57 ± 10 [c])	41 ± 5	n, p	$(\frac{3}{2}^-)$	12.14
2.056 ± 10	34 ± 5	n_0, p_0	$\frac{5}{2}^+$	12.499
2.610 ± 13	56 ± 11	n_0, p_0, α	$\frac{3}{2}^-$	12.905
2.66 ± 30	81	p_0, α	$\frac{5}{2}^+$	12.94

TABLE 15.7—continued

E_α (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Particle out	J^π	E_x (MeV)
2.942 ± 10	7 ± 3	n_0, p_0		13.149
2.984 ± 10	7 ± 3	n_0, p_0		13.180
3.239 ± 15	16 ± 8	n_0, p, α	$\frac{3}{2}^-$	13.366
3.31 ± 30	61	p, α	$\frac{3}{2}^+$	13.42
3.46 ± 30	85 ± 30	n_0, α	$\frac{3}{2}^-$	13.53
3.560 ± 10	18 ± 4	n_0, p	$(\frac{5}{2}, \frac{7}{2})^-$	13.602
3.57 ± 30	94	α	$\frac{1}{2}^+$	13.61
3.712 ± 10	26 ± 8	n_0		13.713
(3.78 ± 30)	70	α	$(\frac{1}{2}^+)$	(13.76)
3.89 ± 30	~70	n_1, α	$(\frac{3}{2}^+)$	13.84
4.09 ± 30	~100	n_1		13.99
4.232 ± 10	22 ± 6	n_0		14.094
4.24 ± 30	~100	n_1, α	$\frac{3}{2}^+$	14.10
4.324 ± 10	27 ± 6	n_0		14.162
4.43 ± 40	150	α	$\frac{5}{2}^+$	14.24
4.62 ± 40	100	α	$\frac{7}{2}^+$	14.38
4.85 ± 20	200 ± 50	n_0		14.55
4.986 ± 10	33 ± 6	n_0		14.647
5.11 ± 30	110 ± 50	n_0		14.74
5.28 ± 20	48 ± 11	n_0, α		14.86
5.358 ± 10	12 ± 3	n_0		14.920
5.501 ± 10	13 ± 3	n_0		15.025
5.59 ± 20	80 ± 25	n_0, α		15.09
5.860 ± 10	22 ± 6	n_0, α		15.288
5.98 ± 20	75 ± 25	n_2, (α)		15.38
6.06 ± 20	~100	n_0, (α)		15.43
6.19 ± 20	~35	n_0		15.53
6.29 ± 20	95 ± 25	n_2		15.60
(6.65 ± 40)		(α)		(15.87)
6.73 ± 20	35 ± 10	n_0, n_2		15.93
6.755 ± 15	21 ± 6	n_1		15.944
6.83 ± 20	60 ± 20	n_2		16.00
6.884 ± 15	62 ± 12	n_0, α		16.039
(6.98 ± 40)		(α)		(16.11)
7.18 ± 20	~100	n_0, α		16.26
7.27 ± 20	~30	n_0		16.32
7.37 ± 20	44 ± 11	n_2		16.39
7.616 ± 15	27 ± 15	n_0, (n_2)		16.576
7.754 ± 15	60 ± 10	n_0, (n_2)		16.677

[a]) For references see table 15.7 in (Aj 81).

[b]) (Wa 88i; prelim.): $\Gamma < 0.2$ keV.

[c]) (Tu 87); $J^\pi = \frac{3}{2}^{(-)}, \frac{3}{2}^-, \frac{1}{2}^-, \frac{5}{2}^+, \frac{3}{2}^-$
[see also for partial widths].

The total cross section for reaction (b) has been measured for $E_\alpha = 0.9$ to 1.7 MeV: resonance information is deduced by (Tu 87). At higher energies (to 25 MeV) the p_0 excitation functions show broad features: see (Aj 81).

8. (a) $^{11}B(\alpha, d)^{13}C$ $Q_m = -5.1677$ $E_b = 10.9916$
   (b) $^{11}B(\alpha, t)^{12}C$ $Q_m = -3.8568$

The yield of d_0 has been measured for $E_\alpha = 13.5$ to 25 MeV. The excitation functions for t_0 and t_1 (to 25 MeV) show strong uncorrelated structures: see (Aj 76, Aj 81). See also (Va 89j).

9. $^{11}B(\alpha, \alpha)^{11}B$ $E_b = 10.9916$

Observed resonances are shown in table 15.7.

10. $^{11}B(^6Li, d)^{15}N$ $Q_m = 9.5166$

At $E(^6Li) = 34$ MeV angular distributions are reported to the states with $5.3 < E_x <$ 16.3 MeV: this reaction appears to be less selective than reaction 11. The most strongly populated states are $^{15}N^*$(9.2, 10.5, 10.7, 13.1, 14.8, 15.5). See (Aj 81). See also (Az 90).

11. $^{11}B(^7Li, t)^{15}N$ $Q_m = 8.5238$

At $E(^7Li) = 24$ and 34 MeV, angular distributions to states with $5.3 < E_x <$ 15.6 MeV have been measured: $^{15}N^*$(9.8, 10.5, 10.7, 15.4, 15.5) are particularly strongly populated at 34 MeV. $J^\pi = \frac{9}{2}^+, \frac{9}{2}, \frac{11}{2}, \frac{9}{2}, \frac{11}{2}, \frac{13}{2}, \frac{15}{2}$ are suggested for $^{15}N^*$(10.69, 12.56, 13.03, 13.19, 13.84, 14.11, 15.37). Only $^{15}N^*$(15.52) appears to have a large cluster component corresponding to $^{11}B + \alpha$. See (Aj 81). For a study of the γ-decay, see (Aj 81). At $E(^7Li) = 34$, 40, 45 and 55 MeV states at $E_x = 13.88$, 17.10, 18.67, 18.81, 19.70, 19.93 and 22.86 MeV are reported to be strongly populated (Az 90; prelim.). See also (Da 90).

12. $^{11}B(^9Be, \alpha n)^{15}N$ $Q_m = 9.4181$

Gamma-ray cross sections involving $^{15}N^*$(5.3, 6.32, 7.16, 7.30, 7.57, 8.57) are reported at $E_{c.m.} = 1.92$, 2.30 and 2.46 MeV (Cu 86a). See (Da 84j) for cross sections and S-factors.

13. $^{11}B(^{16}O, ^{12}C)^{15}N$ $Q_m = 3.8297$

Angular distributions have been measured at $E(^{16}O) = 27$ to 60 MeV involving the two proton-hole states of $^{15}N[^{15}N^*(0, 6.32); J^\pi = \frac{1}{2}^-, \frac{3}{2}^-]$ and $^{12}C^*$(0, 4.4, 9.6): see (Aj 76). See also (Ka 89e; theor.).

14. (a) $^{12}C(t, \gamma)^{15}N$ $Q_m = 14.8484$
    (b) $^{12}C(t, n)^{14}N$ $Q_m = 4.0151$ $E_b = 14.8484$
    (c) $^{12}C(t, p)^{14}C$ $Q_m = 4.6410$

(d) $^{12}C(t, t)^{12}C$

(e) $^{12}C(t, \alpha)^{11}B$ $Q_m = 3.8568$

The 90° excitation function for γ_0 in the range 1.0 to 6.5 MeV [see (Aj 81, Aj 86) shows one very strong resonance (at peak, 4.4 ± 0.5 μb/sr) corresponding to $^{15}N^*(16.7)$ as well as two other strong (unresolved and/or broad) resonances at $E_t \sim 3.3$ and 6 MeV: table 15.8 shows the derived parameters. Table 15.8 also displays the structures observed in reactions (b) → (e). At $E_t = 17$ MeV the polarization and analyzing power for the transition to $^{14}C_{g.s.}$ (reaction (c)) are shown to be the same, as required by the conservation of parity. The VAP for the elastic scattering (reaction (d)) has been measured at $E_t = 9$ and 11 MeV: see (Aj 84). See (Aj 81) for the earlier work. See also (Sa 85p, Ha 90f; theor.).

15. $^{12}C(^3He, \pi^+)^{15}N$ $Q_m = -124.7387$

Individual states have not been resolved in this reaction. The cross section over the bound states of ^{15}N is <0.03 nb at $E_{\pi^+} = 5$ MeV and 0.8 ± 0.2 nb at $E_{\pi^+} \sim 60$ MeV [$E(^3He) = 170.2$ and 236.3 MeV, respectively] (Ho 88i). For the earlier work see (Bi 84b, Sc 86c).

16. $^{12}C(\alpha, p)^{15}N$ $Q_m = -4.9656$

Angular distributions have been measured at many energies for $E_\alpha = 13.4$ to 96.8 MeV: see (Aj 76, Aj 81, Aj 86). See also (Mi 87q, Br 88b; $E_\alpha = 48$ MeV; prelim.), (Bi 87; $E_\alpha = 218$ MeV; prelim.) and (Br 89e).

17. $^{12}C(^6Li, ^3He)^{15}N$ $Q_m = -0.9471$

Observed ^{3}He groups are displayed in table 15.9 of (Aj 81). Comparisons of the angular distributions obtained in this reaction at $E(^6Li) = 60.1$ MeV and in the (^{6}Li, t) reaction shows analog correspondence for the following pairs of levels: 5.27-5.24, 7.16-6.86, 7.57-7.28, 8.57-8.28, 10.80-10.48, 13.15(u)-12.84, 15.49(u)-15.05 [first listed is E_x in ^{15}N-second in ^{15}O]. [E_x are nominal; u = unresolved.] For γ-decay measurements see table 15.5. See also (Az 90).

18. $^{12}C(^7Li, \alpha)^{15}N$ $Q_m = 12.3806$

Observed α-groups are shown in table 15.9. Angular distributions have been measured to $E(^7Li) = 48$ MeV. Comparison of spectra from this reaction ($E(^7Li) = 34.9$ MeV) with those from $^{13}C(^6Li, \alpha)$ (reaction 26) lead to configurations of $(d)^3$ for $^{15}N^*(10.7, 12.57, 13.20, 15.42)$ and suggest that $^{15}N^*(12.57, 13.20)$ have lower J than $^{15}N^*(10.7, 15.5)$, probably $J \leq \frac{7}{2}$. $^{15}N^*(13.02)$ is shown to be $p(d)^2$ in agreement with $J^\pi = \frac{11}{2}^-$: see (Aj 81).

$^{15}N^*(9.155)$ [$J = \frac{5}{2}$] decays to $^{15}N^*(5.30)$ [$J^\pi = \frac{1}{2}^+$] by an E2 transition; therefore its parity is positive. It has a large triton cluster parentage. This is not true of $^{15}N^*(9.152)$: see (Aj 81). For γ-decay measurements see table 15.5. See also (Sa 85p; theor.).

19. (a) $^{12}C(^{11}B, {}^{8}Be)^{15}N$ $Q_m = 3.6250$
(b) $^{12}C(^{13}C, {}^{10}B)^{15}N$ $Q_m = -9.0275$
(c) $^{12}C(^{18}O, {}^{11}B\alpha)^{15}N$ $Q_m = -11.9768$

For reaction (a) see (Aj 81) and (Ma 88b). For reaction (b) see (Vo 89). For reaction (c) see (Ra 84a).

20. $^{13}C(d, \gamma)^{15}N$ $Q_m = 16.1594$

The 90°-95° yields of γ_0 have been measured for $E_d = 1$ to 10 MeV: observed resonances are displayed in table 15.10. The γ-ray angular distributions are consistent with the emission of predominantly E1 radiation except for evidence of M1/E2 transitions in the region $E_x = 20$-21.5 MeV: see (Aj 81). See also (Ha 90f).

21. (a) $^{13}C(d, n)^{14}N$ $Q_m = 5.3260$ $E_b = 16.1594$
(b) $^{13}C(d, p)^{14}C$ $Q_m = 5.9519$
(c) $^{13}C(d, 2p)^{13}B$ $Q_m = -14.880$

TABLE 15.8

Resonances in $^{12}C + t$ [a])

E_t (MeV ± keV)	Particles out	J^π	Γ (keV)	E_x (MeV)
0.66	α_0			15.38
1.11	p_0, t_0, α_1			15.74
1.21	t_0			15.82
1.30 ± 20	n, α_0			15.89
1.39 ± 20	n, t_0, α_0			15.96
1.46	p_0			16.02
1.54	n, α_0, α_1			16.08
1.64 ± 40	γ_0, n, α_0	$\frac{3}{2}^+$	450 ± 100	16.16
1.78	α_0			16.27
1.85 ± 20	n, p_0, α_0, α_1			16.33
1.98 ± 20	n, p_0			16.43
2.05 ± 30	p_0, t_0, α_0			16.49
2.18 ± 25	γ_0, n, $p_0, t_0, \alpha_0, \alpha_1$	$\frac{3}{2}^-$	490	16.59
2.30	γ_0, n, p_0, α_0, α_1	$\frac{3}{2}^+$	130 ± 15	16.69 ± 0.01
2.39 ± 30	n, t_0, α_0, α_1			16.76
2.50 ± 30	α_0, α_1			16.85
2.60	α_0			16.93
2.75	p_0			17.05
2.82	$\gamma_0, t_0, \alpha_0, \alpha_1$	$\frac{3}{2}^-$		17.10
2.89 ± 50	α_0			17.16
3.14	α_1			17.36
3.30	γ_0	$\frac{3}{2}^+$	450 ± 120	17.49 ± 0.09
~6	γ_0			19.6
15.0	t_0			26.8

[a]) For references see tables 15.8 in (Aj 76, Aj 81) and 15.9 in (Aj 86).

TABLE 15.9

States of ^{15}N from ^{12}C(^{7}Li, α)

E_x (MeV ± keV)		E_x (MeV ± keV)		E_x (MeV ± keV)	
(Ts 73a) [a]	(Ze 80c) [b]	(Ts 73a) [a]	(Ze 80c) [b]	(Ts 73a) [a]	(Ze 80c) [b]
0		10.808		15.021	15.024
5.295	5.284		11.274	15.373	15.379
6.332	6.323	11.430	11.456	15.782	15.778
7.163	7.157	11.951	11.936	16.026	16.032
7.310	7.299	12.320 [a]	12.328	16.190	16.210
7.566	7.574	12.559 [a,c]	12.551		17.735
8.320		12.923			17.949 [b]
8.580 [a]	8.574	13.004 [a]	13.001		18.272
9.163 [a]	9.159	13.173 [a]	13.178		18.698 [b]
9.828 [a]	9.809	13.614			19.27 ± 40
9.932	9.921	14.087	14.097		19.68 ± 50 [b,d]
10.072	10.075	14.720	14.693		20.93 ± 50 [b,d]
10.524	10.518		14.874		24.75 ± 150 [b,d]
10.700 [a]	10.714				

[a]) $E(^7\text{Li}) = 35$ MeV; angular distributions have been measured for the states labelled by this footnote; $E_x \pm 10$ keV.

[b]) $E(^7\text{Li}) = 48$ MeV; angular distributions have been measured for the states labelled by this footnote; $E_x \pm 20$ keV unless otherwise shown.

[c]) (Ts 73a) suggest that this state is not the $T = \frac{3}{2}$ state at 12.52 MeV.

[d]) Wide or unresolved.

Observed resonances are displayed in table 15.10. Polarization measurements have been carried out at $E_d = 12.3$ MeV (reaction (a)) and 13 and 56 MeV (reaction (b)): see (Aj 86). See also (Ab 87). For VAP measurements (reaction (c)) at $E_d = 70$ MeV to ^{13}B$_{g.s.}$ see (Mo 86m).

22. ^{13}C(d, d)^{13}C $\qquad E_b = 16.1594$

Excitation functions for elastically scattered deuterons have been measured in the range $E_d = 0.4$ to 5.7 MeV: see (Aj 76). Polarization studies have been reported for $E_d = 12.5$ to 15 MeV and at $E_d = 56$ MeV: see (Aj 81, Aj 86).

23. (a) ^{13}C(d, t)^{12}C $\qquad Q_m = 1.3109 \qquad E_b = 16.1594$
(b) ^{13}C(d, ^{3}He)^{12}B $\qquad Q_m = -12.040$
(c) ^{13}C(d, α)^{11}B $\qquad Q_m = 5.1677$

Observed resonances are listed in table 15.10. For polarization measurements to $E_d = 29$ MeV [reactions (a), (b)] see (Aj 81).

24. ^{13}C(^{3}He, p)^{15}N $\qquad Q_m = 10.6658$

Observed proton groups and γ-rays are listed in table 15.11 of (Aj 81). Angular distributions have been reported for $E(^3\text{He}) = 4.37$ to 20 MeV: see (Aj 81).

TABLE 15.10

Resonances in ^{13}C + d [a])

E_d (MeV)	Particles out	Γ_{lab} (keV)	^{15}N* (MeV)
0.37	p		16.48
0.64	n, p_0, t_0	≈100	16.71
0.85	n, p_0	≈400	16.90
1.10	α_0	broad	17.11
1.24±0.04	t_0, (α_0)	≈200	17.23
1.40±0.04	p_0, t_0, α_0	≈400	17.37
1.64±0.04	t_0	≈200	17.58
1.74±0.04	γ_0, n, α_0	≈600	17.67 [b])
1.80±0.01	(p_0), t_0, α_1	55±10	17.72
2.20±0.01	(n), α_0, α_1	22±4	18.06
2.23±0.02	(n), p_0, t	≈50	18.09
2.45±0.03	n, p_0, α_0	270±70	18.28
3.46±0.03	n	≈150	19.16
5.1	n_1, p_0	≈50	20.6
6.65	γ_0	≈700	21.92
8.8	γ_0	broad	23.8

[a]) See references listed in tables 15.10 (Aj 76, Aj 81).
[b]) $J^\pi = \frac{1}{2}^-$ or $\frac{3}{2}^+$; $T = \frac{1}{2}$.

25. ^{13}C(α, d)^{15}N $\qquad Q_m = -7.6874$

At $E_\alpha = 34.9$ MeV a ZRDWBA analysis has been made of the angular distributions to ^{15}N*(5.27, 5.30, 7.16, 7.30, 7.56, 8.31, 8.57, 9.05, 9.15, 10.07, 10.53, 10.69, 11.43, 11.94, 12.10, 12.33, 12.49, 12.56, 13.00, 13.83, 14.08). $L = 0$ for the group(s) to ^{15}N*(9.15, 10.69); $L = 2$ for ^{15}N*(12.56); $L = 3$ for ^{15}N*(5.27, 7.16, 7.56); $L = 4$ for ^{15}N*(11.94, 13.00); $L = 1$ for the remaining transitions (Ya 84b). See also table 15.11 of (Aj 76).

26. ^{13}C(^{6}Li, α)^{15}N $\qquad Q_m = 14.6843$

Angular distributions have been measured at $E(^6\text{Li}) = 32$ MeV to ^{15}N*(0, 5.30, 6.32, 7.16, 7.30, 7.57, 8.31, 8.57, 9.15, 9.23, 9.83, 10.07, 10.70, 11.94, 13.00): the results are consistent with the previously known J^π, with (odd) parity for ^{15}N*(9.83) and with $J^\pi = \frac{9}{2}^-$ for ^{15}N*(11.94): see (Aj 81).

27. (a) ^{13}C(^{10}B, ^{8}Be)^{15}N $\qquad Q_m = 10.1328$
(b) ^{13}C(^{11}B, ^{9}Be)^{15}N $\qquad Q_m = 0.3440$

For reaction (a) see (Ma 88b). For reaction (b) see (Aj 81).

28. ^{14}C(p, γ)^{15}N $\qquad Q_m = 10.2074$

Observed resonances are displayed in table 15.11; the branching ratios are shown in table 15.5. Narrow anomalies (in the γ_0 yield for $E_p = 2.8$ to 30 MeV) are reported at $E_p = 10.0, 11.0, 12.35, 13.6, 16.4$ MeV. A good fit to the total cross section ($E_{\vec{p}} = 7.5$ to 19 MeV) is obtained with the GDR split into peaks at $E_x = 21.0$ and 25.5 MeV with $\Gamma = 6$ and 2 MeV, respectively. The integrated E2 cross section for $E_x = 19.5$ to 27.0 MeV is $(6.8 \pm 1.4)\%$ of the isoscalar sum rule. The reaction thus shows no sign of a collective E2 resonance in that E_x region. [Another study shows no appreciable E2 strength concentration for $E_x = 14.3$ to 23.3 MeV.] Above the GDR region the 90° γ_0 cross section decreases smoothly with energy except for a small peak which would correspond to ^{15}N*(37.). See (Aj 81, Aj 86) for the references. See also (Ca 85t, Ca 88m, Go 90b; astrophysics) and (Ha 90f; theor.).

29. ^{14}C(p, n)^{14}N $\quad Q_m = -0.6259 \quad E_b = 10.2074$

Observed resonances are displayed in table 15.11. Cross sections have recently been measured for $E_p = 0.67$ to 1.20 MeV (Ke 89a; prelim.). Polarization measurements are reported at $E_{\vec{p}} = 160$ MeV (Ta 84b, Ra 87d; A_y; $D_{NN}(0°)$; n to ^{14}N*(0, 2.31, 3.95, 13.72)). Forward-angle differential cross sections have been measured at $E_p = 200$, 300, (400), 450 MeV (Al 86o, Al 89; $n_1 + n_2$) and at 492 MeV (Ra 89b; n_1, n_2). See (Aj 86) for the earlier work. See also (Ta 85v), (Ta 86b, Ta 87f, Su 89c), (Ca 85t, Ca 88m; astrophysics) and (Be 87l, Lo 87b; theor.).

30. (a) ^{14}C(p, p)^{14}C $\quad E_b = 10.2074$
(b) ^{14}C(p, α)^{11}B $\quad Q_m = -0.7842$

Observed resonances and anomalies are displayed in table 15.11. For polarization measurements see (Aj 81, Aj 86). See also (Am 89; theor.).

31. ^{14}C(d, n)^{14}N $\quad Q_m = 7.9829$

Angular distributions have been measured for $E_d = 1.3$ to 6.5 MeV: see (Aj 76).

32. ^{14}C(^{3}He, d)^{15}N $\quad Q_m = 4.7139$

Angular distributions have been studied at $E(^3$He$) = 23$ MeV to ^{15}N*(0, 5.27 + 5.30, 6.32, 7.16, 7.30): see (Aj 81). See also (Aj 76).

33. ^{14}C(^{7}Li, ^{6}He)^{15}N $\quad Q_m = 0.2328$

See (Al 88f; $E(^7$Li$) = 27$ MeV; prelim.).

34. ^{14}C(^{16}O, ^{15}N)^{15}N $\quad Q_m = -1.9201$

See (Aj 76, Aj 86).

35. ^{14}N(n, γ)^{15}N $\quad Q_m = 10.8333$

The thermal cross section is 79.8 ± 1.4 mb (Is 90). See also (Mc 88e).

Observed γ-rays from thermal neutron capture are displayed in table 15.12. See also table 15.5. The 90° γ_0 yield and angular distributions have been measured for

TABLE 15.11

Resonances in $^{14}C+p$ [a])

E_p (MeV ± keV)	$\Gamma_{c.m.}$ (keV)	Γ_n (keV)	Γ_p (keV)	Γ_α (keV)	Γ_γ (eV)	J^π	E_x (MeV ± keV)
0.261 ± 0.6 [f])	<0.5		$(0.08 \pm 0.01) \times 10^{-6}$		(0.29 ± 0.05) meV [b])	$\frac{5}{2}^-$	10.4497 ± 0.3 [d])
0.352 ± 1 [f])					37 ± 6 meV [b])	$\frac{5}{2}^+$	10.5333 ± 0.5 [d])
0.519 ± 1 [f])			$(0.49 \pm 0.10) \times 10^{-6}$		3.1 ± 0.5 meV [b])	$\frac{9}{2}^+$	10.6932 ± 0.3 [d])
0.527 ± 1 [f])			0.2		0.37 ± 0.07 [g])	$\frac{3}{2}^-$	10.7019 ± 0.3 [d])
0.634 ± 1 [f])			$(0.22 \pm 0.10) \times 10^{-3}$		0.27 ± 0.14 [h])	$\frac{3}{2}^{(+)}$	10.804 ± 2 [d])
1.162 ± 2	7.9 ± 3	2.3	5.6	<0.3	0.29 [c])	$\frac{1}{2}^-$	11.291
1.3188 ± 0.5	41.4 ± 1.1	34.6 ± 0.9	6.8 ± 0.5	<0.3	4.2 ± 0.7 [c])	$\frac{1}{2}^+$	11.4376
1.509 ± 4	404.9 ± 6.3	4.0 ± 0.2	400.9 ± 6.3	<0.3	19.2 ± 0.4 [c])	$\frac{1}{2}^+$; $T=\frac{3}{2}$	11.615
1.668 ± 3	37	36.5	0.5	<0.3		$\frac{3}{2}^+$	11.763
1.788 ± 3	24.5	24.5	0.03	<0.3		$\frac{3}{2}^-$, $(\frac{5}{2}^-)$	11.875
1.884 ± 3	21.5	21.2	0.3	<0.3		$\frac{1}{2}^-$	11.965
2.025 ± 4	14 ± 5	12.0	1.7	0.6		$\frac{5}{2}^+$	12.096
2.077 ± 3	47 ± 7	30.2	16.6	2.2		$\frac{3}{2}^-$	12.145
2.272 ± 4	22	21.7	0.3	<0.3		$\frac{5}{2}^{(+)}$	12.327
2.450 ± 4	44 ± 3	28	0.3	5.5		$\frac{5}{2}^+$; $T=\frac{1}{2}$	12.493
2.482 ± 8	58 ± 4				4.6 ± 0.7	$\frac{5}{2}^+$; $T=\frac{3}{2}$	12.523
2.908 ± 4	70	25	9.0	15		$\frac{3}{2}^-$	12.920
2.93 ± 10	81	n.r.	0.5	80		$\frac{5}{2}^+$	12.940
3.19	5.5	r					13.18
3.38 ± 10	24	6	6.0	12		$\frac{3}{2}^-$	13.360
3.421 ± 10	57	20.6	35	5.5	3.0 ± 0.9	$\frac{3}{2}^+$	13.390
3.57 ± 10	124	~75	8.0	~40		$\frac{3}{2}^-$	13.537
3.65 ± 10	88	~16	12.0	~60		$\frac{1}{2}^+$	13.612
3.71		r					13.67
4.0	930		500		r	$\frac{1}{2}^+$	13.9

4.1 ± 100	98 ± 10		25	r		$\frac{5}{2}^+$	14.0
4.2 ± 100				r		$(\frac{3}{2})$	14.1
4.6 ± 150	74 ± 7		20	r	(r)	$\frac{3}{2}^-$	14.5
4.8	149 ± 18		39	r	(r)	$\frac{3}{2}^+$	14.7
4.83	750				r		14.71
5.08	158 ± 19		20		r	$\frac{3}{2}^+$	14.95
5.16 ± 130	28 ± 3		9.0	r		$\frac{3}{2}^+$	15.0
5.54 ± 130	39 ± 5		12	r	(r)	$\frac{3}{2}^-$	15.4
5.62	750				r		15.45
6.4 ± 150	130 ± 14		19	r		$\frac{3}{2}^+$	16.2
6.70	560				r		16.46
6.925	90 ± 10			r	r	$(\frac{3}{2}^+; \frac{1}{2})$	16.67
7.18 ± 180	110 ± 50			r		$\frac{5}{2}$	16.9
~9					r	$\frac{1}{2}^+; \frac{1}{2}$	19
10.0	sharp		(1000?)		r	$\frac{3}{2}^+; (T = \frac{3}{2})$	19.5 [e])
11.0	sharp				r	$\frac{3}{2}^+$	20.5
12.35					r		21.72
13.65					r		22.94
16.4					r	$(T = \frac{3}{2})$	25.5 [e])
~29					r		~37

r = resonant.

n.r. = non-resonant.

[a]) See tables 15.5 in (Aj 59), 15.11 in (Aj 70) and 15.12 in (Aj 81) for references and additional comments.

[b]) $\omega\gamma$.

[c]) Γ_{γ_0}. I am indebted to P.M. Endt for this correction.

[d]) E_x measured directly: see (Aj 81).

[e]) Analog not observed in $^{14}N(p, \gamma)^{15}O$.

[f]) Resonances are observed at $E_p = 262$, 351, 520, 528 and 635 keV [±1 keV] (Go 90b). See also table 15.5. I am indebted to Drs. J. Gorres and M. Wiescher for sending me these results prior to publication.

[g]) $\omega\gamma = 840 \pm 130$ meV (Go 90b).

[h]) $\omega\gamma = 270 \pm 40$ meV (Go 90b).

TABLE 15.12

Gamma radiation from $^{14}N(n, \gamma)$ [a]

Transition in ^{15}N	E_{γ} [b] (keV)	E_x [b] (keV)	I_{γ} [c]
C → 0	10829.087 (46)	10833.302 (12)	13.65 (21)
C → 5.27	5562.062 (17)		10.65 (12)
C → 5.30	5533.379 (13)		19.75 (21)
C → 6.32	4508.783 (14)		16.54 (17)
C → 7.16	3677.772 (17)		14.89 (15)
C → 7.30	3532.013 (13)		9.24 (9)
C → 8.31	2520.418 (15)		5.79 (7)
C → 9.05			[a]
C → 9.152	1681.117 (171)		1.54 (15)
C → 9.155	1678.174 (55)		7.23 (18)
5.27 → 0	5269.169 (12)	5270.155 (10)	30.03 (20)
5.30 → 0	5297.817 (15)	5298.822 (11)	21.31 (18)
6.32 → 0	6322.337 (14)	6323.775 (15)	18.67 (14)
7.16 → 0		7155.051 (16)	
7.16 → 5.27	1884.879 (21)		18.66 (25)
7.16 → 5.30			0.8 (2)
7.30 → 0	7298.914 (33)	7300.832 (16)	9.73 (9)
7.30 → 5.30			[a]
8.31 → 0	8310.143 (29)	8312.620 (25)	4.22 (5)
8.31 → 5.30	3013.494 (73)		0.69 (2)
8.31 → 6.32	1988.507 (239)		0.37 (9)
8.57 → 0	8568.920 (230)	8571.412 (120)	0.073 (4)
8.57 → 5.27	3300.728 (113)		0.16 (2)
9.05 → 0	9046.802 (69)	9049.713 (69)	0.186 (5)
9.152 → 0		9151.895 (120)	
	9149.222 (47)		1.62 (2)
9.155 → 0		9154.895 (23)	
9.155 → 5.27	3884.184 (39)		0.57 (2)
9.155 → 5.30	3855.579 (45)		0.70 (1)
9.155 → 6.32	2830.809 (70)		1.75 (3)
9.155 → 7.16	1999.708 (86)		3.99 (9)
9.212 → 0	9219.022 (763)	9222.06 (76)	0.024 (5)
9.925 → 0	9921.511 (166)	9925.033 (166)	0.127 (4)
10.066 → 0	10062.345 (197)	10065.969 (197)	0.062 (4)

C = capturing state.

[a]) See also tables 15.13 in (Aj 81, Aj 86) for earlier references, comments and reports. The previously reported transition to $^{15}N^*(9.76)$ has not been confirmed: $I_{\gamma} < 0.01\%$ (T. J. Kennett, private communication). (Wa 90b) [see footnote [b]) in table 15.4] recommends different values for E_{γ} and E_x.

[b]) Error in Q_m not included. Adjustments due to it require the addition in quadrature of the Q_m error: see (Ke 86j).

[c]) In units of photons/100 captures (Ke 86j): errors are statistical only but these are predominant.

$E_n = 5.6$ to 15.3 MeV. The cross section shows two prominent dips at $E_x = 16.7$ and 18.1 MeV [compare with $^{14}N(p, \gamma)$; reaction 9 in ^{15}O] and broad structures at $E_x \sim 17$ and 19 MeV. The angular distribution data are consistent with essentially pure E1 radiation in the region $E_x = 17$ to 24 MeV (We 82). See also (Wo 89a) and (Gu 89i; astrophys.).

36. $^{14}N(n, n)^{14}N$ $E_b = 10.8333$

The scattering amplitude (bound) $a = 9.37 \pm 0.03$ fm, $\sigma_{free} = 10.05 \pm 0.12$ b, σ_{inc}^{spin} (bound nucleus) $= 0.49 \pm 0.11$ b (Ko 79w). Observed resonances are displayed in table 15.13: for a discussion of the evidence leading to J^{π} assignments see (Aj 59). Cross section curves and a listing of references can be found in (Mc 88e). Recent measurements are reported at $E_n = 0.14$, 1.3 and 2.1 MeV (Ko 88k; σ_t), 7.67 to 13.50 MeV (Ch 86cc; el and inel; prelim.). 10.96, 13.96 and 16.95 MeV (Te 85a; elastic). The (n, n′γ) cross section has been measured for $E_n = 2.5$ to 3.5 MeV (St 89f; prelim.; applied). Analyzing powers for the n_0 group have been measured for $E_{\vec{n}} = 10$ to 17 MeV (Li 89l). See also ^{14}N, (Ba 86gg, Li 86a) and (Ma 88g).

37. $^{14}N(n, 2n)^{13}N$ $Q_m = -10.5535$ $E_b = 10.8333$

Cross sections have been measured for $E_n = 10$ to 37 MeV [see (Mc 88e)] and at $E_n = 13.40$ to 14.87 MeV (Ka 89k). See also (Ka 89w).

38. (a) $^{14}N(n, p)^{14}C$ $Q_m = 0.6259$ $E_b = 10.8333$
(b) $^{14}N(n, d)^{13}C$ $Q_m = -5.3260$
(c) $^{14}N(n, t)^{12}C$ $Q_m = -4.0151$
(d) $^{14}N(n, ^3He)^{12}B$ $Q_m = -12.7436$
(e) $^{14}N(n, \alpha)^{11}B$ $Q_m = -0.1583$

(Ko 89a), using the "white" neutron source LANSCE, have measured the (n, p) cross section from 61 meV to 34.6 keV. Their results support the role of this reaction as a "poison" during s-process nucleosynthesis. [See (Ko 89a) for a discussion of other measurements.] See also (Br 88f, Ke 89a). For a display of the measured cross sections for (a) and (c), see (Mc 88e). See also (Su 88f; $E_n = 5.0$ to 10.6 MeV; $\sigma = 11$ to 30 mb; prelim.) for reaction (c) and (Ma 88g). For resonances in reactions (a) and (e), see table 15.13. (Su 86h) report double-differential cross sections at $E_n = 27.4$, 39.7 and 60.7 MeV for all five reactions. See also (Ch 89bb).

39. $^{14}N(p, \pi^+)^{15}N$ $Q_m = -129.518$

At $E_{\vec{p}} = 200$ MeV, angular distributions and A_y have been measured for the transitions to $^{15}N^*(0, 6.32, 8.31)$ as well as for a number of unresolved transitions. A sharp group at $E_x = 21.5$ MeV is suggested to correspond to a $\frac{15}{2}^-$ state (Az 88c, Az 87; Ph.D. thesis and abstract).

40. $^{14}N(d, p)^{15}N$ $Q_m = 8.6087$

TABLE 15.13

Resonances in $^{14}N+n$ [a]

E_{res} (MeV ± keV)	Γ_{lab} (keV)	Γ_n (keV)	Γ_p (keV)	Γ_α (keV)	J^π	$^{15}N^*$ (MeV)
0.430 ± 5	3.5	<3	<0.01		$\geq\frac{3}{2}$	11.235
0.4926 ± 0.65	7.5	<3	<10		$\frac{1}{2}^-$	11.2928
0.639 ± 5	43	34	9		$\frac{1}{2}^+$	11.429
0.998 ± 5	46	45	0.8		$\frac{3}{2}^+$	11.764
1.120 ± 6	19	19	0.20		$\frac{3}{2}^-$	11.878
1.188 ± 6	≤3.2	<2	<0.1		$\geq\frac{3}{2}$	11.942
1.211 ± 7	13	12	0.4		$\frac{1}{2}^-$	11.963
1.350 ± 7	21	20	0.9	0.4	$\frac{5}{2}^{(+)}$	12.093
1.401 ± 8	54	41	11	1.8	$\frac{5}{2}^{(+)}$	12.140
1.595 ± 8	22	21	0.2	<0.1	$\frac{5}{2}^{(-)}$	12.321
1.779 ± 10	47	37	0.5	9.0	$(\frac{5}{2}^+)$	12.493
2.23	65	39	7.8	18	$\frac{3}{2}^-$	12.91
2.47	<3			r		13.14
2.52	~7	r		r		13.18
2.71	40			r	$\frac{3}{2}^-$	13.36
2.74	95		r		$\frac{5}{2}^+$	13.39
2.95	20	16	1.1	3.2	$\frac{5}{2}^+$	13.59
3.09	60		r	r		13.72
3.21	85	r	r	r	$\frac{3}{2}^+$	13.83
3.51	~20	r	r	r		14.11
3.57	30	r	r	r	$\frac{3}{2}^{(+)}$	14.16
~3.8	~2000	~1000	200	~1000		14.4
4.09	50	r	r	r		14.65
~4.2	~300	r	r	r		14.8
4.38	40			r		14.92
4.60		r		r		15.12
5.03				r		15.52
5.60	100			r		16.06
5.94				r		16.37
6.16	75			r		16.58
6.26	100	r		r		16.67
6.55	170	r		r		16.94
6.94	200	r		r		17.31
7.16				r		17.51
7.34	120			r		17.68
7.48	180	r		r		17.81
7.92	170	r		r		18.22
8.00	120			r		18.29

r = resonant.

[a]) See references in tables 15.14 in (Aj 70, Aj 76).

Proton groups (and γ-rays) from this reaction are displayed in table 15.15 of (Aj 81). The results include $E_x = 7567.1 \pm 1.0$ keV for $^{15}N^*(7.57)$. Newer values, derived from measurements of proton groups in a spectrograph, are 5270.2 ± 1.3, 6324.0 ± 1.0, 7154.85 ± 0.17, 7300.80 ± 0.09, 7563.25 ± 0.19, 8312.79 ± 0.12, $8571.53 \pm$

0.25, 9050.24 ± 0.33, 10064.34 ± 0.31 and 11235.5 ± 0.5 keV (Pi 90b). Angular distributions have been measured for $E_d = 0.32$ to 52 MeV and lead to l_n, J^π and spectroscopic factors: see table 15.15 in (Aj 81). Branching ratios and multipolarities are shown in table 15.5. See also (Li 85e, Me 85d, Si 87c, Li 88d, Vi 88a, Vi 89a; applications).

41. $^{14}N(^{14}N, ^{13}N)^{15}N$ $\quad Q_m = 0.2799$

See (Aj 81) and (Da 88f; theor.).

42. $^{15}C(\beta^-)^{15}N$ $\quad Q_m = 9.7717$

See reaction 1 in ^{15}C and table 15.14.

43. (a) $^{15}N(\gamma, n)^{14}N$ $\quad Q_m = -10.8333$
(b) $^{15}N(\gamma, 2n)^{13}N$ $\quad Q_m = -21.3868$
(c) $^{15}N(\gamma, p)^{14}C$ $\quad Q_m = -10.2074$
(d) $^{15}N(e, ep_0)^{14}C$ $\quad Q_m = -10.2074$
(e) $^{15}N(\gamma, d)^{13}C$ $\quad Q_m = -16.1594$
(f) $^{15}N(\gamma, t)^{12}C$ $\quad Q_m = -14.8484$
(g) $^{15}N(\gamma, \pi^-)^{15}O$ $\quad Q_m = -142.322$

The total photoneutron cross section from threshold to 38 MeV shows a very broad GDR which extends from ~16 to 30 MeV. Maxima are observed at $E_\gamma \sim 23.5$ and 25.5 MeV ($\sigma \simeq 11$ mb): see (Di 88) [based on (Ju 82a; monoenergetic photons)]. However, (Ba 89r) report a sharper single peak at $E_\gamma = 25.5$ MeV in the (γ, Sn) reaction with a cross section of ≃16 mb. See (Ba 89r) for a discussion of the $T_<$ and $T_>$ components of the GDR.

The (γ, n_0) cross section for $E_x = 13$ to 24 MeV shows a broad structure centered at $E_x \sim 14.5$ MeV and a resonance at $E_x = 17.3 \pm 0.1$ MeV. A large fraction of the

TABLE 15.14

Beta decay of ^{15}C [a])

Decay to $^{15}N^*$ (keV)	J^π	Branch (%)	log ft
g.s.	$\frac{1}{2}^-$	36.8 ± 0.8 [c])	5.99 ± 0.03 [c])
5298.87 ± 0.15 [b])	$\frac{1}{2}^+$	63.2 ± 0.8 [c])	4.11 ± 0.01
6323.3 ± 0.6	$\frac{3}{2}^-$	$\leq 0.4 \times 10^{-2}$	≥7.8
7301.1 ± 0.5	$\frac{3}{2}^+$	$(0.74 \pm 0.08) \times 10^{-2}$	6.89 ± 0.05
8312.9 ± 0.5	$\frac{1}{2}^+$	$(4.1 \pm 0.5) \times 10^{-2}$	5.18 ± 0.05
8571.4 ± 1.0	$\frac{3}{2}^+$	$(1.3 \pm 0.2) \times 10^{-2}$	5.34 ± 0.07
9050.0 ± 0.7	$\frac{1}{2}^+$	$(3.4 \pm 0.3) \times 10^{-2}$	4.05 ± 0.04

[a]) (Al 79m).
[b]) (Al 76d). 5297.794 ± 0.035 keV: see (Wa 811).
[c]) (Wa 84).

photoabsorption strength leading to $^{14}N_{g.s.}$ is due to the formation of $\frac{3}{2}^+$, $T=\frac{1}{2}$ states in ^{15}N which decay by d-wave emission. The absorption is essentially pure E1 (Wa 83). See also (Aj 81).

The (γ, 2n) reaction has been studied from threshold to 38 MeV [see (Di 88)] and more recently from 20 to 28 MeV by (Mc 88a). The cross section remains near zero for 3 MeV above threshold and then rises sharply at about 24 MeV to a maximum value of 1.7 mb (Mc 88a) [see, however, (Ju 82a)]. For discussions of the results in terms of the density of $T_>$ states in ^{14}N, see (Mc 88a, Ba 89r (p. 511)).

For discussions of the (γ, p) reaction see (Aj 81) and (Ba 89r). The latter show a curve for the total absorption cross section [(γ, n)+(γ, p)] from 10 to 27 MeV dominated by a peak (see above) at $E_\gamma \simeq 25$ MeV with $\sigma \sim 23$ mb.

A study at $E_e = 18.8$, 20.8, 25.7 and 29.7 MeV (reaction (d)) shows a "pigmy" resonance at $E_x = 14.8$ MeV, a shoulder at 15.6 MeV, a peak at 16.7 MeV [probably $\frac{1}{2}^+$ but $\frac{3}{2}^+$ is not ruled out], and the giant dipole resonance, which exhibits a great deal of structure, centered at 22 MeV. The data on the pigmy resonance are consistent with an admixture of ~1% $\frac{3}{2}^-$ (E2) or $\frac{1}{2}^-$ (M1) to a predominantly $\frac{1}{2}^+$ (E1) state. The experiment shows that for $14 < E_x < 28$ MeV the reaction goes predominantly via $\frac{1}{2}^+$ or $\frac{3}{2}^+$ (E1) states in ^{15}N; the $T=\frac{3}{2}$ strength is concentrated above 18 MeV: see (Aj 81).

The cross section for d_0 [reaction (e)] is reported at 90° for $E_\gamma \simeq 20.5$ to 28.5 MeV: a resonance is observed at $E_x \simeq 21.9$ MeV. The (γ, t_0) cross section (reaction (f)) at 90° decreases from a value of 30 μb/sr at 20 MeV to 5 μb/sr at 22 MeV and remains flat out to 25 MeV. Comparison of this cross section, and those of the other photonuclear reactions, suggests an isospin splitting of ~6 MeV with the $T=\frac{1}{2}$ strength concentrated between 16 and 21 MeV and the $T=\frac{3}{2}$ strength between 21 and 28 MeV. $^{15}N^*(21.9)$ is not observed. See (Aj 81) for references. For reaction (g) [to $^{15}O_{g.s.}$] see (Li 88h, Ko 89l). See also (Go 85v, Ki 87e; theor.).

44. $^{15}N(\gamma, \gamma)^{15}N$

See table 15.15 and (Aj 81). See also (Mo 87b).

45. $^{15}N(e, e)^{15}N$

The charge r.m.s. radius of ^{15}N is 2.612 ± 0.009 fm. The C0 elastic scattering form factor of ^{15}N has been measured over $q = 0.4$–$3.2\ \text{fm}^{-1}$ (De 88b). Inelastic groups are displayed in table 15.15.

The giant resonance is split into two main peaks at $E_x = 22$ and 25.5 MeV with some structure around 20 MeV. $\Gamma_{\gamma_0}(C1) = (1.1 \pm 0.3) \times 10^3$ eV (14–18.5 MeV), $\Gamma_{\gamma_0}(C2) = 12.5 \pm 2.0$ eV assuming the states responsible are $\frac{3}{2}^+$ and $\frac{3}{2}^-$, respectively. For $E_x = 18.5$ to 30 MeV, $\Gamma_{\gamma_0}(C1) = (1.96 \pm 0.04) \times 10^4$ eV while $\Gamma_{\gamma_0} < 0.1$ eV for any C2 strength. See (Aj 81, Aj 86) for references. See also (Mu 88e; (e, e'γ); prelim.), (Pa 86m, De 87c, Li 88h, Pa 88r, Ko 89l, Pa 90a) and (Je 86, Do 87i, Fu 88a, Go 88a, Sh 88b, Fu 89g, Wo 89c, Bl 90a, Fu 90c; theor.).

TABLE 15.15

Radiative widths [a]) from ^{15}N(γ, γ') and ^{15}N(e, e')

E_x (MeV ± keV)	J^π	Mult.	Γ_{γ_0} (eV)
5.27	$\frac{5}{2}^+$	C3	$(4.2 \pm 0.3) \times 10^{-6}$
		M2	$(1.2 \pm 0.7) \times 10^{-4}$
5.30	$\frac{1}{2}^+$	C1	2.2 ± 2.3
6.323 ± 1 [b])	$\frac{3}{2}^-$	C2	0.050 ± 0.004
		M1	1.9 ± 0.4 [c])
		M1 + E2	3.12 ± 0.18 [b,d,e])
7.16	$\frac{5}{2}^+$	C3	$(0.86 \pm 0.10) \times 10^{-5}$
7.301 ± 1 [b])	$\frac{3}{2}^+$	C1	2.6 ± 1.0
		M2	$(0.3 \pm 0.2) \times 10^{-5}$
		E1 + M2	1.08 ± 0.08 [b])
7.57	$\frac{7}{2}^+$	C3	$(1.84 \pm 0.16) \times 10^{-5}$
8.310 ± 4 [b])	$\frac{1}{2}^+$	E1	0.3 ± 0.2 [b])
8.575 ± 4 [b])	$\frac{3}{2}^+$	E1 + M2	0.3 ± 0.3 [b])
9.048 ± 1 [b])	$\frac{1}{2}^+$	E1	1.2 ± 0.2 [b])
9.150 ± 1 [b])	$\frac{3}{2}^-$	C2	0.095 ± 0.005 [f])
		M1	0.2 ± 0.8
		M1 + E2	0.47 ± 0.12 [b,g])
9.760 ± 1 [b])	$\frac{5}{2}^-$	C2	0.20 ± 0.05
		E2	0.21 ± 0.07 [b])
9.924 ± 1 [b])	$\frac{3}{2}^-$	M1	1.6 ± 0.2 [b])
10.064 ± 1 [b])	$\frac{3}{2}^+$	E1	6.3 ± 0.4 [b])
10.8	$\frac{3}{2}^+$	M2	$(1.8 \pm 0.8) \times 10^{-2}$
11.88	$\frac{3}{2}^-$	C2	0.44 ± 0.10
		M1	4.4 ± 3.8
12.5	$\frac{5}{2}^+$	M2	$(5.2 \pm 2.0) \times 10^{-2}$
(13.98)			
14.7	$\frac{5}{2}^-$	C2	1.8 ± 0.2
20.10			
23.25			

[a]) For references and $B(\lambda)\uparrow$ see table 15.17 in (Aj 81). See also tables 15.5 and 15.6 here. Form factors have also been measured to ^{15}N*(9.23, 11.29 [both $\frac{1}{2}^-$], 10.45 [$\frac{5}{2}^-$], 12.1[u], 12.9[u]) (De 87o) [unpublished Ph.D. thesis].

[b]) (Mo 81a): (γ, γ).

[c]) See note added in proof in (Mo 75m).

[d]) δ(E2/M1) = 0.137 ± 0.005. See, however, table 15.5.

[e]) Using δ(E2/M1) = 0.132 ± 0.004 [see table 15.5] $\Gamma_{\gamma_0} = 3.07 \pm 0.18$ eV (M1) and $(5.34 \pm 0.44) \times 10^{-2}$ eV (E2) (D.J. Millener, private communication).

[f]) δ(E2/M1) > 0.3.

[g]) Mixing ratio is very small [see table 15.5] and the transition is almost purely M1 (D.J. Millener, private communication).

46. $^{15}N(\pi^{\pm}, \pi^{\pm})^{15}N$

At $E_{\pi^{\pm}} = 164$ MeV angular distributions have been studied to states at $E_x = 10.68 \pm 0.03$, 12.52 ± 0.02, 14.04 ± 0.03 and 17.19 ± 0.03 MeV: $J^{\pi} = \frac{9}{2}^+, \frac{9}{2}^+, (\frac{9}{2}^+, \frac{7}{2}^+)$ and $(\frac{9}{2}^+, \frac{7}{2}^+)$, respectively, as well as to the $^{15}N_{g.s.}$. Additional π^+ cross sections were measured at 120 and 260 MeV: peaks were observed at $E_x = 20.11 \pm 0.06$ and 23.19 ± 0.06 MeV [both are probably $T = \frac{3}{2}$ states]. $^{15}N^*(5.27, 6.32, 7.57)$ were also populated (Se 85). At $E_{\pi^+} = 164$ MeV, elastic scattering has been studied from $^{15}\vec{N}$: A_y for $\theta = 60°–100°$ is consistent with zero (Ta 89w, Ta 90e). See also (Ta 90) and (Go 88a; theor.).

47. $^{15}N(n, n)^{15}N$

See ^{16}N in (Aj 86a). See also (Fu 89f).

48. $^{15}N(p, p)^{15}N$

Angular distributions of elastically scattered protons have been measured at E_p to 44.2 MeV: see (Aj 81, Aj 86). For measurements of $K_y^{y'}$ at $E_{\vec{p}} = 65$ MeV see (Na 90a). See also ^{16}O in (Aj 86a) and (Du 90; theor.).

49. (a) $^{15}N(d, d)^{15}N$
    (b) $^{15}N(^3He, ^3He)^{15}N$

Angular distributions of elastically scattered deuterons have been measured at $E_d = 5–6$ MeV. Elastic and inelastic ^{3}He distributions have been studied for $E(^3He) = 11$ to 39.8 MeV: see (Aj 76). Elastic distributions and A_y have also been measured at $E(^3\overrightarrow{He}) = 33$ MeV (Dr 86).

50. $^{15}N(\alpha, \alpha)^{15}N$

At $E_{\alpha} = 40.5$ MeV, a number of particle groups have been observed and angular distributions have been measured: see table 15.17 of (Aj 76). At $E_{\alpha} = 48.7$ and 54.1 MeV elastic angular distributions have been reported by (Ab 87a). See also (Aj 81) for additional information and (Sh 85g; theor.).

51. $^{15}N(^7Li, ^7Li)^{15}N$

The elastic scattering has been studied at $E(^7Li) = 28.8$ MeV: see (Aj 86).

52. (a) $^{15}N(^{12}C, ^{12}C)^{15}N$
    (b) $^{15}N(^{13}C, ^{13}C)^{15}N$
    (c) $^{15}N(^{14}C, ^{14}C)^{15}N$

Angular distributions of elastic scattering have been measured at $E(^{15}N) = 31.5$ to 47 MeV [reaction (a)] and $E(^{13}C) = 105$ MeV [reaction (b)]: see (Aj 81, Aj 86) [also for yield measurements]. See also (Ha 86s, Be 89z) and (Hu 85, Ba 86uu, Ha 86i; theor.).

53. $^{15}N(^{16}O, ^{16}O)^{15}N$

Elastic angular distributions have been measured at $E(^{16}O) = 35.1$ and 42.6 MeV: see (Aj 86). For fusion cross sections and yields see (Aj 76, Aj 86) and (No 85i, Ha 86s). See also (Hu 85; theor.).

54. (a) $^{15}N(^{27}Al, ^{27}Al)^{15}N$
(b) $^{15}N(^{28}Si, ^{28}Si)^{15}N$

Elastic distributions have been measured in the range $E(^{15}N) = 32.8$ to 69.8 MeV [reaction (a)] and at 44 MeV [reaction (b)]: see (Aj 81, Aj 86). See also (Sn 88).

55. $^{15}O(\beta^+)^{15}N$ $Q_m = 2.7539$

See ^{15}O.

56. (a) $^{16}O(\gamma, p)^{15}N$ $Q_m = -12.1276$
(b) $^{16}O(e, ep)^{15}N$ $Q_m = -12.1276$

Over the giant resonance region in ^{16}O, the decay takes place to the odd-parity states $^{15}N^*(0, 6.32)$ and less strongly to the even-parity states $^{15}N^*(5.27, 5.30, 8.31, 9.05)$ and to $^{15}N^*(9.22)$: see (Aj 70, Aj 76). At $E_e = 500$ MeV most of the 1p hole strength is concentrated in the groups to $^{15}N^*(0, 6.32)$. The 1s state shows up as a very wide asymmetric structure centered at $E_x \sim 41$ MeV: see (Aj 81). See also (Le 90g). In the range $E_\gamma = 101.5$ to 382 MeV differential cross sections are reported for the p_0, (p_{1+2}) and p_3 groups at $\theta = 45°$, 90° and 135° (Le 85b). Differential cross sections have also been measured at $E_\gamma = 196$, 257, 312, 316 MeV for the p_0 and $p_{1\text{-}3}$ groups [the latter not at 316 MeV] (Ad 88c, Tu 85a). $^{15}N^*(0, 6.3, 10.8)$ have been populated at $E_e = 500$ MeV (Be 82a). See also (Aj 86), (Vo 87c, Le 88, Le 89; prelim.), (Ma 87r) and (Ca 85j, Go 85w, Ch 86, Lu 86, Po 86i, Ry 87, Ca 88c, Du 88c, Ho 88b, Ji 88b, Lo 88c, Mc 88b, Ry 88, Ry 89, Br 90b, Fl 90, Ow 90; theor.).

57. $^{16}O(\mu^-, \nu n)^{15}N$ $Q_m = 92.7492$

Gamma rays from the decay of one of the states at 5.3 MeV and from $^{15}N^*(6.3)$ are reported by (Va 83j).

58. $^{16}O(n, d)^{15}N$ $Q_m = -9.9030$

Angular distributions of the d_0 group have been reported at $E_n = 14$ and 14.4 MeV: see (Aj 76). See also (Yo 88c; $E_n = 60$ MeV; prelim.) and (Mc 90b; applied).

59. (a) $^{16}O(\pi^\pm, \pi^\pm p)^{15}N$ $Q_m = -12.1276$
(b) $^{16}O(p, 2p)^{15}N$ $Q_m = -12.1276$

At $E_{\pi^\pm} = 240$ MeV, the spectra are dominated by $^{15}N^*(0, \sim 6.5)$. The π^+/π^- ratio has been measured for the ground-state transitions (Ky 84). At $E_{\pi^+} = 2.0$ GeV/c differential cross sections have been determined for the transition to $^{15}N^*(6.3)$ (Ki 83).

At $E_p = 505$ MeV the summed proton spectrum shows two peaks corresponding to the knockout of $p_{1/2}$ and $p_{3/2}$ protons with binding energies of 12.12 and 18.44 MeV [^{15}N*(0, 6.32)]. Differential cross sections and (p, 2p)/(p, pn) ratios are also reported (Mc 86e). For work at 1 GeV involving the knockout of $s_{1/2}$ protons see (Be 85v). For γ-ray production (^{15}N*(5.27)) at $E_p = 30$–40 MeV see (Le 88b). See also (Ki 85k, Ch 86z, Vd 87c), (La 87e, Le 88b; astrophys.) and (Bo 86k; theor.). For the earlier work see (Aj 76).

60. ^{16}O(d, ^{3}He)^{15}N $Q_m = -6.6340$

Angular distributions of ^{3}He groups have been measured for $E_d = 20$ to 82 MeV: see (Aj 76, Aj 81). The spectra are dominated by the transitions to ^{15}N*(0, 6.32). A ZRDWBA analysis leads to $C^2S = 2.25$ and 3.25 for these two states [and to 2.37 and 3.31 for the analog states in ^{15}O studied with the (d, t) reaction]. $J^\pi = \frac{3}{2}^-$ for both ^{15}N*(9.93, 10.70): see (Aj 81). See also (Mo 87b) for a re-analysis of C^2S.

61. ^{16}O(α, αp)^{15}N $Q_m = -12.1276$

At $E_\alpha = 139.2$ MeV the absolute spectroscopic factors $S = 5.4$ and 6.9 for ^{15}N*(0, 6.32) (Sa 87).

62. (a) ^{16}O(^{6}Li, ^{7}Be)^{15}N $Q_m = -6.522$
(b) ^{16}O(^{7}Li, ^{8}Be)^{15}N $Q_m = 5.1268$
(c) ^{16}O(^{16}O, ^{17}F)^{15}N $Q_m = -11.5274$

For reaction (a) see (Gl 86e). For reaction (b) see (Ma 88b) and for (c) see (Au 88a). For other heavy-ion reactions see (Aj 81, Aj 86).

63. ^{17}O(p, ^{3}He)^{15}N $Q_m = -8.5529$

At $E_p = 39.8$ MeV angular distributions of the groups to ^{15}N*(0, 6.32) have been compared with those to the analog states in ^{15}O reached in the (p, t) reaction: see (Aj 76).

64. ^{18}O(p, α)^{15}N $Q_m = 3.9804$

Angular distributions of α_0 have been measured for $E_p = 0.125$ to 42.2 MeV: see (Aj 76, Aj 81) and ^{19}F in (Aj 87). At $E_p = 40.9$ MeV angular distributions have also been studied to ^{15}N*(0, 5.27+5.30, 6.32, 7.57, 9.15[u], 9.83[u], 10.7[u], 11.24[u], 11.44, 12.52[u] (Ca 87f; see for C^2S).

For ^{15}N*(5.27), $\tau_m = 2.49 \pm 0.24$ ps, $|g| = 0.94 \pm 0.07$ (Bi 83g). See also (Co 86q), (Fi 88b, Nw 89, Mi 90b; applied) and (Ba 86qq, Ca 88m; astrophys.).

65. ^{19}F(d, ^{6}Li)^{15}N $Q_m = -2.5388$

Angular distributions involving ^{15}N*(0, 5.3, 6.3) have been measured in the range $E_d = 9.0$ to 28 MeV [see (Aj 76, Aj 81)].

66. $^{19}F(^{3}He, ^{7}Be)^{15}N$ $\qquad Q_m = -2.4265$

See (Aj 76) and (Ha 86k; theor.).

^{15}O

(Figs. 12 and 13)

GENERAL[†]

Nuclear models: (St 87b)

Special states: (Sh 85o, Li 86n, St 87b, An 88e, Wu 89b)

Electromagnetic transitions: (Va 84, Ho 87g, St 87b)

Astrophysical questions: (Ta 85y, Ra 87m, Ji 89, St 89g, Ra 90g)

Complex reactions involving ^{15}O: (Fi 85d, Hu 85a, Po 85d, Si 85d, Gr 86m, Me 86d, Po 86d, To 86d, Ut 86, Ba 87w, Be 87o, Bu 87e, Na 87, Ri 87b, St 87, Be 88b, Be 88ii, Mi 88h, Ba 89cc, Ca 89c, Dr 89a, Ki 89f, Po 89d, Sa 89g, Ta 89l, Yo 89)

Applied work: (Bo 85k, Ha 85r, Hi 87, Hi 88f, Vo 88c, Ar 89c, Wo 89)

Pion and other mesons capture and reactions[‡]: (Li 86n, Le 87m, Ch 88g, Mi 88k, Le 89g, Od 90)

Hypernuclei: (Zh 84b, Da 86a, Ba 89hh, Ko 89h, Ta 89n)

Other topics: (An 85e, Sh 85o, An 86u, Wi 86a, Ch 87, Wu 89b, Mu 90a)

Ground-state properties of ^{15}O: (An 85e, Ar 85a, Mc 86g, Wi 86a, Wu 86c, Fu 87h, Sa 87g, Ar 88a, Ch 88t, Fu 88a, Ni 88a, Sh 88b, Va 88, Wa 88c, Ch 89i, Fu 89g, Ne 89, Sa 89g)

$$\mu = 0.7189\ (8)\ \text{n.m.}$$ (Le 78n). See also (Ra 89g).

$^{15}O^*(5.24)$: $\mu = +(0.65 \pm 0.07)$ n.m.: see (Ra 89g).

1. $^{15}O(\beta^+)^{15}N$ $\qquad Q_m = 2.7539$

The half-life of ^{15}O is 122.24 ± 0.16 s: see (Aj 81); $\log f_0 t = 3.637$. The K/β^+ ratio is $(10.7 \pm 0.6) \times 10^{-4}$: see (Aj 76). The β-anisotropy has been measured by (Se 89g, Se 88g). See also (Aj 86), (St 90), (Ba 85q, Ba 85oo, Gr 86c, Ba 87j, Fr 87, Ri 87d, We 87a, Ba 88g, Ba 88z, Ba 89ee, Da 89f; astrophysics) and (Ta 88l, To 88b, Wo 89c; theor.).

[†] See also (Aj 86)

[‡] See also reactions 8, 16, 17 and 21.

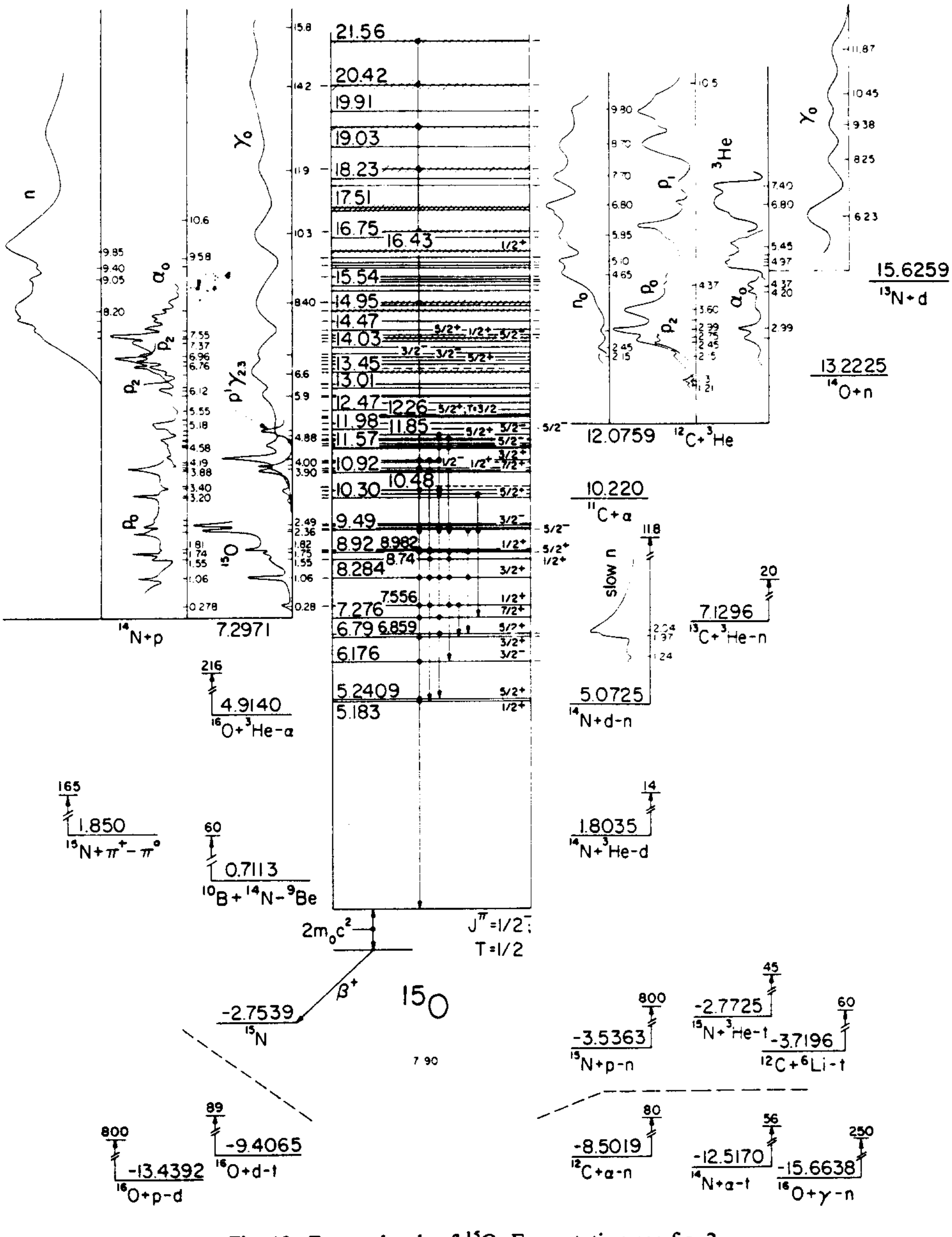


Fig. 12. Energy levels of ¹⁵O. For notation see fig. 2.

Table 15.16

Energy levels of ^{15}O a)

E_x in ^{15}O (MeV ± keV)	$J^\pi; T$	τ or $\Gamma_{c.m.}$ (keV)	Decay	Reactions
0	$\frac{1}{2}^-; \frac{1}{2}$	$\tau_{1/2} = 122.24 \pm 0.16$ s	β^+	1, 3→9, 14→25, 27, 28
5.183 ± 1	$\frac{1}{2}^+$	$\tau_m = 8.2 \pm 1.0$ fs	γ	5, 7, 9, 14, 15, 19, 20, 23→25
5.2409 ± 0.3	$\frac{5}{2}^+$	3.25 ± 0.30 ps $g = +0.248 \pm 0.026$	γ	4→7, 9, 14, 15, 18→20, 23→25, 27
6.1763 ± 1.7	$\frac{3}{2}^-$	<2.5 fs	γ	5, 7, 9, 14, 15, 18→25, 27
6.7931 ± 1.7	$\frac{3}{2}^+$	<28 fs	γ	5, 7, 9, 14, 15, 19, 25
6.8594 ± 0.9	$\frac{5}{2}^+$	16.0 ± 2.5 fs	γ	4, 5, 7, 9, 14, 15, 19, 20, 25, 27
7.2759 ± 0.6	$\frac{7}{2}^+$	0.70 ± 0.15 ps	γ	4→8, 14, 15, 18, 19, 23, 25, 27
7.5565 ± 0.4	$\frac{1}{2}^+$	$\Gamma = 0.99 \pm 0.10$ keV	γ, p	7, 9, 14, 15, 18, 19, 23, 25
8.2840 ± 0.5	$\frac{3}{2}^+$	3.6 ± 0.7	γ, p	5, 7, 9, 14, 15, 25
8.743 ± 6	$\frac{1}{2}^+$	32	γ, p	7, 9, 25
8.922 ± 2	$\frac{5}{2}^+$	3.3 ± 0.3	γ, p	4, 5, 7, 9, 23, 25
8.922 ± 2	$\frac{1}{2}^+$	7.5	γ, p	4, 7, 9, 23, 25
8.9821 ± 1.7	$(\frac{1}{2})^-$	3.9 ± 0.4	γ, p	5, 7, 9, 25
9.484 ± 8	$(\frac{3}{2})^+$	~200	γ, p	9, 25
9.488 ± 3	$\frac{5}{2}^-$	10.1 ± 0.5	γ, p	5, 7, 9, 25
9.609 ± 2	$\frac{3}{2}^-$	8.8 ± 0.5	γ, p	4, 5, 7, 9, 25
9.662 ± 3	$(\frac{7}{2}, \frac{9}{2})^-$	2 ± 1	p	4, 5, 7, 11, 25
10.29 b)	$(\frac{5}{2}^-)$	3 ± 1	p	5, 7, 11, 25
10.30 b)	$\frac{5}{2}^+$	11 ± 2	p	5, 7, 11, 25
10.461 ± 5	$(\frac{9}{2}^+)$	<2	γ, p	4→7, 9, 25
10.48	$(\frac{3}{2}^-)$	25 ± 5	γ, p	4, 7, 9, 11, 24
(10.506)	$(\frac{3}{2})^+$	140 ± 40	γ, p	9, 11
10.917 ± 12	$\frac{7}{2}^+$	90	p	11, 25
10.938 ± 3	$\frac{1}{2}^+$	99 ± 5	γ, p	9, 11, 25
11.025 ± 3	$\frac{1}{2}^-$	25 ± 2	γ, p	9, 11, 25
11.151 ± 7		<10	p	5, 11, 25
11.218 ± 3	$\frac{3}{2}^+$	40 ± 4	γ, p	9, 11, 25
11.565 ± 15		<10	p	5, 11, 25
11.569 ± 15	$\frac{5}{2}^-$	20 ± 15	γ, p	5, 9, 11
11.616 ± 15	$(\frac{3}{2}, \frac{1}{2})^-$	80 ± 50	γ, p	9, 11
11.719 ± 8		<10	p	4, 5, 11, 25
11.748 ± 3	$\frac{5}{2}^+$	99 ± 5	γ, p	9, 11
11.846 ± 3	$\frac{5}{2}^-$	65 ± 3	γ, p	9, 11
11.980 ± 10	$\frac{5}{2}^-$	20 ± 5	p	5, 11, 25
12.129 ± 15	$\frac{5}{2}^+$	200 ± 50	p	11
12.222 ± 20		100 ± 50	p	11
12.255 ± 13	$\frac{5}{2}^+; \frac{3}{2}$	135 ± 15	p	27
12.295 ± 10				5
12.471 ± 3	$\frac{5}{2}^-, (\frac{3}{2}^-)$	77 ± 4	p	11
12.60 ± 10				5
12.80		~250	γ, p	9
12.835 ± 3		16 ± 1	p	4→6, 11

TABLE 15.16—continued

E_x in ^{15}O (MeV ± keV)	J^π; T	$\Gamma_{c.m.}$ (keV)	Decay	Reactions
13.008 ± 3		215 ± 3	p	11
13.025 ± 3		40 ± 30	p, (^{3}He)	3, 11
13.45	$(\frac{1}{2}, \frac{3}{2})^+$	~1000	γ, p, (α)	9, 11, 13
(13.49)	$(\frac{3}{2}^+)$		(p)	11
13.60	$\frac{5}{2}^+$		p, α	13
13.70	$\frac{3}{2}^-$		p	11
13.79	$\frac{3}{2}^-$		n, p, ^{3}He, α	3, 11, 13
13.87		~150	γ, p	9
14.03 ± 40	$(\frac{1}{2}^-, \frac{3}{2}^-)$	160 ± 20	n, p, ^{3}He	3
14.17	$\frac{5}{2}^-$		p, α	13
14.27 ± 10	$\frac{1}{2}^+$	340 ± 30	n, p, ^{3}He, α	3 → 5, 10 → 13
14.34	$\frac{5}{2}^+$	(240)	p, (^{3}He), α	3, 13
14.465 ± 10	$\frac{3}{2}^+, \frac{5}{2}^+$	100 ± 10	n, p, ^{3}He, α	3, 10, 11, 13
14.70 ± 40		170 ± 35	n, p, ^{3}He	3, 10
14.95 ± 40		400 ± 25	n, p, ^{3}He, α	3, 10 → 13
15.05 ± 10	$((\frac{13}{2}^+))$			4 → 6
15.1	$(\frac{1}{2}, \frac{3}{2})^+$	~1000	γ, p	9
15.45 ± 30		70 ± 20	p, ^{3}He, α	3
15.54 ± 10			(p, ^{3}He, α)	3, 5
15.60 ± 10			(p, ^{3}He, α)	3, 5
15.65 ± 10				4, 5
15.80 ± 10			n, ^{3}He	3, 5
15.90 ± 15	$\frac{1}{2}^-, \frac{3}{2}^-$	350	^{3}He, α	3
16.05 ± 20		~185	n, p, ^{3}He, α	3, 10, 11, 13
16.10 ± 20			(n), ^{3}He, α	3
16.21 ± 20		~140	(n), p, ^{3}He, α	3, 11 → 13
16.43 ± 75	$\frac{1}{2}^+$	560 ± 100	n, ^{3}He, α	3, 10, 12
16.75 ± 50			n, ^{3}He	3, 25
17.05 ± 60	$(\frac{1}{2}, \frac{3}{2})^+; \frac{1}{2}$	700 ± 70	γ, p, ^{3}He	3, 9, 11, 13
17.46 ± 20				5
17.51 ± 20	$\frac{1}{2}^-, \frac{3}{2}^-$	640 ± 120	γ, n, ^{3}He, α	3, 5
17.99 ± 50	$\frac{1}{2}^-, \frac{3}{2}^-$	200	^{3}He	3
18.23 ± 50			n, p, ^{3}He	3
18.67 ± 60	$(\frac{1}{2}, \frac{3}{2})^+; \frac{1}{2}$	520 ± 110	γ, ^{3}He	3, 9
19.03 ± 50		1120 ± 300	γ, n, ^{3}He	3, 23
19.57 ± 80	$(\frac{1}{2}, \frac{3}{2})^+; \frac{1}{2}$	780 ± 270	γ, ^{3}He	3
19.91 ± 50			n, ^{3}He	3
20.42 ± 70	$(\frac{3}{2}, \frac{1}{2})^+; \frac{1}{2}$	970 ± 240	γ, p, ^{3}He	3, 9
21.56 ± 70	$(\frac{3}{2}, \frac{1}{2})^+; \frac{1}{2}$	730 ± 120	γ, p, ^{3}He	3, 9, 23
23.8 ± 0.1		≤500	γ, ^{3}He	3
(26.0)	$(\frac{13}{2}^-)$	~600	^{3}He	3
(28.0)	$(\frac{9}{2}^-, \frac{11}{2}^-)$	~2500	^{3}He	3
(29.0)		~2500	^{3}He	3

[a]) See also table 15.17.

[b]) It is possible that these two are in fact a single state: see (Aj 76).

2. (a) ^{11}B(^{7}Li, 3n)^{15}O	$Q_m = -3.494$	
(b) ^{11}B(^{9}Be, t2n)^{15}O	$Q_m = -13.932$	

For reaction (a) see (Be 86gg); for reaction (b) see (Be 86aa). For other heavy-ion reactions see (Aj 86).

3. (a) ^{12}C(^{3}He, γ)^{15}O	$Q_m = 12.0759$	
(b) ^{12}C(^{3}He, n)^{14}O	$Q_m = -1.1466$	$E_b = 12.0759$
(c) ^{12}C(^{3}He, p)^{14}N	$Q_m = 4.7789$	
(d) ^{12}C(^{3}He, d)^{13}N	$Q_m = -3.5500$	
(e) ^{12}C(^{3}He, t)^{12}N	$Q_m = -17.357$	
(f) ^{12}C(^{3}He, ^{3}He)^{12}C		
(g) ^{12}C(^{3}He, α)^{11}C	$Q_m = 1.8560$	

Excitation functions and polarization measurements for these reactions have been measured over a wide range of energies: see tables 15.20 in (Aj 70, Aj 76), (Aj 81) and the text below. Observed resonances are displayed in table 15.18 here.

The 90° yield and angular distributions of γ_0, measured from $E(^3\text{He}) = 5.24$ to 13.95 MeV show five resonances attributed to E1 transitions from $J^\pi = \frac{1}{2}^+$ or $\frac{3}{2}^+$, $T = \frac{1}{2}$ states in the GDR characterized by a considerable 3p4h admixture (De 78j [also for ω_γ], De 84f). Yields of γ_{1+2} at 90° have also been reported at $E(^3\text{He}) = 5.3$ to 16.7 MeV: the cross section is some eight times greater than that for (^{3}He, γ_0) and is similar to that for the ^{14}N(p, γ_0)^{15}O reaction over the same excitation range. Three resonances are reported [see table 15.18 (Ki 89b)]: it is suggested that they are due to cluster states with a large 3p4h component. See also (Bl 88c; prelim.; $E(^3\text{He}) = 12.0$ to 24.6 MeV; γ to many states of ^{15}O).

The yield of n_0 (reaction (b)) shows resonances for $E(^3\text{He}) < 10$ MeV and little structure above, to 30.6 MeV: see (Aj 81) [n_1 and n_{2+3+4} yields are also reported].

The yield of protons (reaction (c)) shows some clear resonances below $E(^3\text{He}) =$ 4.5 MeV and some uncorrelated structures at higher energies (to $E(^3\text{He}) = 12$ MeV) with the possible exception of states at $E_{\text{res}} = 7.8$, 9.2-9.6 and (10.5) MeV. For $E(^3\text{He}) = 16$ to 30.6 MeV no appreciable structure is observed in the p_0, p_1 and p_2 yields: see (Aj 76). At $E(^3\overrightarrow{\text{He}}) = 33$ MeV A_y has been measured for ^{14}N*(0, 2.31, 3.95): see (Aj 86). For polarization effects in the (^{3}He, 2p) reaction at $E(^3\overrightarrow{\text{He}}) =$ 33 MeV see (Ka 86aa). For reactions (d) and (e) see (Aj 76, Aj 81, Aj 86).

The elastic scattering (reaction (f)) shows some resonant structure near 3, 5 and 6 MeV and some largely uncorrelated structures in the range $E(^3\text{He}) = 16.5$ to 24 MeV. There is some suggestion, however, of two resonances at $E(^3\text{He}) = 17$ and 20 MeV: see (Aj 76). Resonance-like behavior is also reported at $E(^3\overrightarrow{\text{He}}) = 29$ MeV. Polarization measurements are reported for $E(^3\overrightarrow{\text{He}}) = 20.5$ to 32.6 MeV: see (Aj 81). See also (Aj 86). The yield of α-particles displays resonance structure below 8 MeV, and broad fluctuations for $E(^3\text{He}) = 12$ to 18.6 MeV: see (Aj 76). Polarization measurements are reported for $E(^3\overrightarrow{\text{He}}) = 33.3$ MeV for the α_0 and α_1 groups: see

TABLE 15.17

Radiative decays in ^{15}O [a])

E_i (MeV)	J_i^π	E_f (MeV)	J_f^π	Branch (%)	δ [b])
5.24	$\frac{5}{2}^+$	0	$\frac{1}{2}^-$	100	+0.10±0.04 (E3/M2)
6.18 [c])	$\frac{3}{2}^-$	0	$\frac{1}{2}^-$	100	−0.125±0.007 (E2/M1) [k])
6.79 [d])	$\frac{3}{2}^+$	0	$\frac{1}{2}^-$	100	−0.02±0.02 (M2/E1)
6.86 [e])	$\frac{5}{2}^+$	5.24	$\frac{5}{2}^+$	100	+0.04±0.03 (E2/M1)
7.28 [f])	$\frac{7}{2}^+$	0	$\frac{1}{2}^-$	3.8±1.2	
		5.24	$\frac{5}{2}^+$	96.2±1.2	
7.56 [g])	$\frac{1}{2}^+$	0	$\frac{1}{2}^-$	3.5±0.5	
		5.18	$\frac{1}{2}^+$	15.8±0.6	
		6.18	$\frac{3}{2}^-$	57.5±0.4	
		6.79	$\frac{3}{2}^+$	23.2±0.6	
		6.86	$\frac{5}{2}^+$	[l])	Γ_γ (eV)
8.28 [h])	$\frac{3}{2}^+$	0	$\frac{1}{2}^-$	53.2±0.25 [m])	0.24
		5.18	$\frac{1}{2}^+$	1.2±0.1	0.006
		5.24	$\frac{5}{2}^+$	42.2±0.5 [m])	0.20
		6.18	$\frac{3}{2}^-$	2.2±0.6 [m])	0.01
		6.86	$\frac{5}{2}^+$	1.2±0.3 [m])	0.006
8.74 [h])	$\frac{1}{2}^+$	5.18	$\frac{1}{2}^+$	64±3	0.18
		6.18	$\frac{3}{2}^-$	36±3	0.10
8.922 [i])	$\frac{5}{2}^+$	0	$\frac{1}{2}^-$	9±4	
		5.18	$\frac{1}{2}^+$	39±3	
		6.18	$\frac{3}{2}^-$	24±3	
		6.86	$\frac{5}{2}^+$	28±3	
8.922 [i])	$\frac{1}{2}^-$	0	$\frac{1}{2}^-$	50±25	
		5.18	$\frac{1}{2}^+$	20±10	
		6.18	$\frac{3}{2}^-$	20±10	
		6.86	$\frac{5}{2}^+$	(10±10)	
8.982 [j])	$(\frac{3}{2})^-$	0	$\frac{1}{2}^-$	94±1	
		5.18	$\frac{1}{2}^+$	6±1	
9.48 [h])	$(\frac{3}{2}^+)$	0	$\frac{1}{2}^-$	100	9.1±2.0 [n])
9.49	$\frac{5}{2}^-$	0	$\frac{1}{2}^-$	86	2.1
		5.24	$\frac{5}{2}^+$	6.5	0.15
		6.18	$\frac{3}{2}^-$	0.7	0.22
		6.86	$\frac{5}{2}^+$	3.4	0.08
		7.28	$\frac{7}{2}^+$	5.1	0.11
9.61	$\frac{3}{2}^-$	0	$\frac{1}{2}^-$	79	4.0
		5.24	$\frac{5}{2}^+$	19	1.0
		6.18	$\frac{3}{2}^-$	2	0.1
10.46	$(\frac{9}{2}^+)$	5.24	$\frac{5}{2}^+$	62±6	18±6 [n])
		6.86	$\frac{5}{2}^+$	<4	<1.5
		7.28	$\frac{7}{2}^+$	38±6	11±4 [n])
10.48	$(\frac{3}{2})^-$	0	$\frac{1}{2}^-$	60±8	0.21±0.07 [n])
		5.24	$\frac{5}{2}^+$	40±6	0.14±0.01 [n])
		6.18	$\frac{3}{2}^-$	<4	<0.02
		9.79	$\frac{3}{2}^+$	<4	<0.02
10.94	$\frac{1}{2}^+$	0	$\frac{1}{2}^-$	44±8	14±4
		5.18	$\frac{1}{2}^+$	34±3	11±2
		6.18	$\frac{3}{2}^-$	22±8	7±2
		6.79	$\frac{3}{2}^+$	<8	<3

TABLE 15.17—continued

E_i (MeV)	J_i^π	E_f (MeV)	J_f^π	Branch (%)	Γ_γ (eV)
11.03 [a])	$\frac{1}{2}^-$	0	$\frac{1}{2}^-$	100	1.4 ± 0.4
11.22	$\frac{3}{2}^+$	0	$\frac{1}{2}^-$	74 ± 5	5.5 ± 0.5
		5.18	$\frac{1}{2}^+$	14 ± 5	1.0 ± 0.2
		5.24	$\frac{5}{2}^+$	12 ± 5	0.9 ± 0.2
		6.79	$\frac{3}{2}^+$	<4	<0.4
11.57	$\frac{5}{2}^-$	0	$\frac{1}{2}^-$	18 ± 9	0.3 ± 0.2
		5.24	$\frac{5}{2}^+$	63 ± 9	1.2 ± 0.1
		6.18	$\frac{3}{2}^-$	20 ± 9	0.4 ± 0.2
		6.79	$\frac{3}{2}^+$	<3	<0.1
11.75 [a])	$\frac{5}{2}^+$	5.24	$\frac{5}{2}^+$	47 ± 7	5 ± 1
		6.18	$\frac{3}{2}^-$	53 ± 7	5 ± 1
11.85 [a])	$\frac{5}{2}^-$	5.24	$\frac{5}{2}^+$	100	1.4 ± 0.6

[a]) For references and other comments see table 15.19 in (Aj 81).
[b]) δ = multipole mixing ratio.
[c]) Branches to $^{15}O^*(5.18, 5.24)$ are $<2.5\%$ each.
[d]) Branches to $^{15}O^*(5.18, 5.24, 6.18)$ are <3, <3 and $<7\%$, respectively.
[e]) Branches to $^{15}O^*(0, 5.18, 6.18)$ are <10, <4 and $<0.4\%$, respectively.
[f]) Branches to $^{15}O^*(5.18, 6.18)$ are <4 and $<2\%$, respectively.
[g]) Branchings shown to $^{15}O^*(5.18, 6.18, 6.79)$ are weighted means of values shown in table 15.19 of (Aj 81), recalculated to sum to 100% for all the transitions.
[h]) (Sc 87b).
[i]) See, however, the comments in reaction 14 of (Aj 81).
[j]) Branchings to $^{15}O^*(6.18, 6.86)$ are $<1\%$ each.
[k]) Weighted mean of values shown in table 15.19 of (Aj 81).
[l]) Intensity $<25\%$ of transition to $^{15}O^*(6.79)$.
[m]) Recalculated because of new transition to $^{15}O^*(\frac{1}{2}^+)$ (Sc 87b).
[n]) Γ_γ values assume J-values in column 2.

(Aj 81). For A_y measurements of the (^3He, ^7Be) and (^3He, ^6Li) reactions see (Si 89, Cl 86). For $\pi^\pm$ production see (Mi 86p). For a search for subthreshold K^+ production see (Ia 85). For work at very high energies see (Ab 85i, Ad 85c). See also (Aj 86), (Na 84s), (To 90a; applied) and (Ev 86, Si 86d; theor.).

4. $^{12}C(\alpha, n)^{15}O$ $\qquad Q_m = -8.5019$

Angular distributions of the n_0 group have been measured for $E_\alpha = 18.4$ to 23.1 MeV: see (Aj 76). At $E_\alpha = 41$ MeV angular distributions are reported to $^{15}O^*(5.24, 6.86+7.28, 9.63$ [u], 10.48 [u], 11.72 [u], 12.85 [u], 15.05 [u]). $^{15}O^*(8.92, 11.1, 12.3, 13.45, 13.72, 14.27, 15.65)$ are also populated (Ov 81a [uncertainties in E_x are not shown; unresolved states are a problem]). At $E_\alpha = 47.4$ MeV groups are populated at $\theta = 0°$ corresponding to $^{15}O_{g.s.}$ and to unresolved states at 5.2, 7.3, 10.0, 12.5 and 15.3 MeV (Lu 88a). See also (Ca 88m; astrophys.).

TABLE 15.18

Resonances in $^{12}C+^{3}He$ [a])

$E(^3He)$ (MeV ± keV)	Resonant for	$\Gamma_{c.m.}$ (keV)	J^π	E_x (MeV)
1.21	p_0, p_2		$(\frac{5}{2})^-$	13.04
1.3	$p_0 \rightarrow p_3$			13.1
2.15	n, p_0		$(>\frac{5}{2})$	13.79
2.45 ± 40	$n_0, p_0 \rightarrow p_3$	160 ± 20	$(\frac{1}{2}^-, \frac{3}{2}^-)$	14.03
2.75 ± 40	$n_0, p_1, p_2, ^3He, \alpha_0$	340 ± 30	$\frac{1}{2}^+$	14.27
(2.87)	p_0, p_2	240		(14.37)
2.990 ± 10	$n_0, p_0, p_1, p_2, p_4, p_5, p_8, ^3He, \alpha_0$	100 ± 10	$\frac{3}{2}^+, \frac{5}{2}^+$	14.465
3.28 ± 40	$p_0, (p_1, p_2)$	180 ± 40		14.70
3.60 ± 40	p_0, p_1, p_2	400 ± 25		14.95
4.20 ± 10	p_5, p_6, α_0	65 ± 15		15.43
4.37 ± 40	$p_0, p_1, p_2, p_4, p_7, p_8, \alpha_0$	80 ± 25		15.57
4.65 ± 50	n_0			15.79
4.78 ± 50	$^3He, \alpha_0$	350	$\frac{1}{2}^-, \frac{3}{2}^-$	15.90
4.97 ± 20	α_0			16.05
5.03 ± 20	$n_0, ^3He, \alpha_0$			16.10
5.15 ± 20	$n_0, ^3He, \alpha_0$			16.19
5.45 ± 50	$^3He, \alpha_0$	170	$\frac{1}{2}^+$	16.43
5.85 ± 50	$n_0, ^3He$			16.75
6.23 ± 70	γ_0	700 ± 70	$(\frac{1}{2}, \frac{3}{2})^+$	17.05 ± 0.06 [b])
6.83 ± 40	$\gamma_{1+2}, n_0, ^3He, \alpha_0$	640 ± 120	$\frac{1}{2}^-, \frac{3}{2}^-$	17.53 [c])
7.40 ± 50	^3He	200	$\frac{1}{2}^-, \frac{3}{2}^-$	17.99
7.70 ± 50	n_0, p_0			18.23
8.25 ± 70	γ_0	520 ± 110	$(\frac{1}{2}, \frac{3}{2})^+$	18.67 ± 0.06 [b])
8.70 ± 50	γ_{1+2}, n_0	1120 ± 300		19.03 [c])
9.38 ± 100	γ_0	780 ± 270	$(\frac{1}{2}, \frac{3}{2})^+$	19.57 ± 0.08
9.80 ± 50	n_0			19.91
10.45 ± 90	$\gamma_0, (p_0)$	970 ± 240	$(\frac{3}{2}, \frac{1}{2})^+$	20.42 ± 0.07 [b])
11.87 ± 80	γ_0	730 ± 120	$(\frac{3}{2}, \frac{1}{2})^+$	21.56 ± 0.07 [b])
14.7	γ_{1+2}	≤0.5 MeV [e])		23.8 ± 0.1 [c])
(17.0) [d])	^3He	~600	$(\frac{13}{2}^-)$	(26.0)
(20.0) [d])	^3He	~2500	$(\frac{9}{2}^-, \frac{11}{2}^-)$	(28.0)
(21.5)	^3He to $^{12}C^*(15.1)$	~2500		(29.0)

[a]) For references see table 15.21 in (Aj 76).

[b]) (De 78j, De 84f [see p. 290]); $T=\frac{1}{2}$; $\Gamma_{^3He}/\Gamma_p = 0.17 \pm 0.07$ and 0.09 ± 0.04 for $^{15}O^*(17.05, 18.67)$.

[c]) (Ki 89b). See also for ω_γ. See also table 15.19 in (Aj 86); $T=\frac{1}{2}$ if they are 3p4h cluster states.

[d]) $\Gamma_p = 0.06$ and ≥ 0.1 MeV for $^{15}O^*(26, 28)$.

[e]) Estimated by reviewer.

5. $^{12}C(^6Li, t)^{15}O$ $Q_m = -3.7196$

States observed in this reaction are displayed in table 15.19 (Bi 75c: $E(^6Li) =$ 59.8 MeV). Comparisons of angular distributions of the triton groups in this reaction and of the ^3He groups to analog states in ^{15}N have been made: analog correspondence is established for (10.48-10.70), (12.84-13.15 (u)) and (15.05-15.49 (u)) [E_x in ^{15}O, E_x in ^{15}N; u = unresolved] (Bi 75c). See also (Aj 76) for the earlier work.

6. $^{12}C(^{12}C, ^9Be)^{15}O$ $Q_m = -14.2031$

At $E(^{12}C) = 187$ MeV, $\theta_{lab} = 8°$, the spectrum is dominated by $^{15}O^*$ (12.84, 15.05) [assumed $J^\pi = \frac{1}{2}^-, \frac{13}{2}^+$, respectively]. $^{15}O^*(7.28)$ [$J^\pi = \frac{7}{2}^+$] is populated but $^{15}O^*(0, 6.79)$ are not observed. The situation is similar at $E(^{12}C) = 114$ MeV but at $E(^{12}C) =$ 72 MeV ($\theta_{lab} = 11°$) $^{15}O^*(0, 5.2, 7.28)$ are populated with comparable intensities: see (Aj 76).

At $E(^{12}C) = 480$ MeV the three most strongly excited states in the forward direction are $^{15}O^*(10.46, 12.83$ [u], 15.05 [u]) [$J^\pi = \frac{9}{2}^+, \frac{11}{2}^-, \frac{13}{2}^+$] and forward angle $\sigma(\theta)$ have been measured. $^{15}O^*(0, 5.24, 7.3, 8.9$ [u], 16.7 [u], 18.2 [u], 21.1 [u], 22.1 [u]) are also populated (Kr 88e).

TABLE 15.19

Levels of ^{15}O from $^{12}C(^6Li, t)^{15}O$ [a])

E_x (MeV ± keV)	L	E_x (MeV ± keV)	L
5.180 ± 5		11.72 ± 10	[c])
5.242 ± 5	[b])	11.98 ± 10	
6.179 ± 5		12.295 ± 10	[c])
6.790 ± 5		12.60 ± 10	
6.865 ± 5	[b])	12.835 ± 10 [e])	3
7.275 ± 5	[b])	13.55 ± 10	[c,d])
8.285 ± 5	[b])	13.75 ± 10	[c,d])
8.918 ± 5	[c])	14.27 ± 10	[c])
8.978 ± 5		15.05 ± 10 [e])	3
9.485 ± 5		15.48 ± 10	
9.610 ± 5	[c,d])	15.54 ± 10	
9.658 ± 5	[c,d])	15.60 ± 10	[c,d])
9.76 ± 5		15.65 ± 10	
10.27 ± 5		15.80 ± 10	
10.45 ± 5 [e])	3	17.46 ± 20	
11.145 ± 10		17.51 ± 20	
11.56 ± 10			

[a]) (Bi 75c): $E(^6Li) = 59.8$ MeV.

[b]) Angular distributions measured and compared with those of the $(^6Li, ^3He)$ reaction to analog states in ^{15}N.

[c]) Angular distribution measured: analog states in ^{15}N not known.

[d]) Unresolved in angular distribution.

[e]) $\Gamma_\gamma/\Gamma < 0.13$.

7. $^{13}C(^{3}He, n)^{15}O$ $Q_m = 7.1296$

Observed groups are displayed in table 15.22 of (Aj 81).

8. $^{14}C(p, \pi^-)^{15}O$ $Q_m = -132.115$

At $E_{\vec{p}} = 183$ MeV differential cross sections and A_y are reported for the transitions to $^{15}O^*(0, 7.3)$, the two states strongly populated in the reaction (Ja 82a, Vi 82a). See also (Ja 86i) and (Ku 86b, Ku 90a; theor.).

9. $^{14}N(p, \gamma)^{15}O$ $Q_m = 7.2971$

Observed resonances in the yield of γ-rays are listed in table 15.20. Branching ratios are displayed in table 15.17. Measurements of E_γ lead to $E_x = 5183 \pm 1$, 5240.9 ± 0.4, 6175 ± 2, 6794 ± 2, 6858 ± 2, 8284.1 ± 0.8, 8922 ± 2 and 8978 ± 2 keV: see (Aj 81). For τ_m see (Aj 81).

(Sc 87b) have studied absolute cross sections, γ-ray angular distributions and excitation functions for $E_p = 0.2$ to 3.6 MeV: $S(0)$ is determined to be 3.20 ± 0.54 keV · b. C^2S are derived for the first eight states of ^{15}O (Sc 87b).

The 90° γ_0 yield has been measured for $E_p = 2.2$ to 19 MeV: resonances are observed over most of the range. The $(\gamma_1 + \gamma_2)$ yield is relatively weak. For $E_p = 18$ to 28 MeV the excitation function for γ_0 decreases smoothly with energy: there is

TABLE 15.20

Resonances in $^{14}N + p$ [a])

E_p (keV)	Γ_{lab} (keV)	$\omega\Gamma_\gamma$ (eV)	Particles out	J^π	E_x (MeV)
278.1 ± 0.4	1.06 ± 0.11 [b])	$(14 \pm 1) \times 10^{-3}$ [a,b])	γ	$\frac{1}{2}^+$	7.5565
1058.0 ± 0.5	3.9 ± 0.7	0.31 ± 0.04 [a,b])	γ	$\frac{3}{2}^+$	8.2840
1550 ± 6	34	$(93 \pm 20) \times 10^{-3}$ [a,b])	γ	$\frac{1}{2}^+$	8.743
1742 ± 2 [c])	3.5 ± 0.3	0.16	γ, p_0	$\frac{5}{2}^+$	8.922
1742 ± 2 [c])	8	0.06	γ, p_0	$\frac{1}{2}^+$	8.922
1806.4 ± 1.5	4.2 ± 0.4	0.52	γ	$(\frac{3}{2})^-$	8.9821
2344 ± 8 [b])	205 [b])	6.1 ± 1.3 [b])	γ, p_0	$(\frac{3}{2}^+)$	9.484
2348 ± 3	10.8 ± 0.5	2.4	γ	$\frac{5}{2}^-$	9.488
2479 ± 1.7	9.4 ± 0.5	3.3	γ	$\frac{3}{2}^-$	9.609
2537 ± 4	2 ± 1		p_0	$(\frac{7}{2}, \frac{9}{2})^-$	9.664
3209	3 ± 1		p_0	$(\frac{5}{2}^-)$	10.291
3215	12 ± 2		p_0	$\frac{5}{2}^+$	10.296
3392 ± 5	<2	0.029 ± 0.010	γ_2, γ_6	$(\frac{9}{2}^+)$	10.461
3410	27 ± 5		γ_0, γ_2, p_0	$(\frac{3}{2})^-$	10.478
3440	150 ± 45		γ, p_0	$(\frac{3}{2})^+$	10.506
3880 ± 15	97		p_0	$\frac{7}{2}^+$	10.916
		Γ_{γ_0} (eV)			
3903 ± 3	106 ± 5	14 ± 3	γ, p_0, p_1	$\frac{1}{2}^+$	10.938
3996 ± 3	27 ± 2	1.4 ± 0.4	γ, p_0, p_1	$\frac{1}{2}^-$	11.025
4130 ± 15	<10		p_0		11.150

TABLE 15.20—continued

E_p (keV)	Γ_{lab} (keV)	Γ_{γ_0} (eV)	Particles out	J^π	E_x (MeV)
4203 ± 3	43 ± 4	5.2 ± 0.4	γ, p_0	$\frac{3}{2}^+$	11.218
4575 ± 15	<10		p_0		11.565
4580 ± 15	21 ± 15	0.7 ± 0.2	γ, p_0	$\frac{5}{2}^-$	11.569
4580	150		γ		11.57
4630 ± 15	86 ± 50		γ, p_0	$(\frac{3}{2}, \frac{1}{2})^-$	11.616
4740 ± 15	<10		p_0		11.718
4772 ± 3	106 ± 5		γ, p_0, p_1	$\frac{5}{2}^+$	11.748
4877 ± 3	70 ± 3		γ, p_0, p_1	$\frac{5}{2}^-$	11.846
5025 ± 15	21 ± 5		p_0, p_1	$\frac{5}{2}^-$	11.984
5180 ± 15	214 ± 50		p_0, p_1	$\frac{5}{2}^+$	12.129
5280 ± 20	106 ± 50		p_1 [d]		12.222
5547 ± 3	82 ± 4		p_1, p_2	$\frac{5}{2}^-(\frac{3}{2}^-)$	12.471
5900	~250		γ		12.80
5937 ± 3	17 ± 1		p_2 [e]		12.835
(6100)	30		$p_0 \rightarrow p_2$, α_0	$\frac{5}{2}^+$	(12.99)
6123 ± 3	230 ± 30		p_2 [e]		13.008
6141 ± 3	43 ± 30		p_2 [e]		13.025
6600	~1000		γ, (p_2, α_0)	$(\frac{1}{2}, \frac{3}{2})^+$	13.45
6640			(p_0), (p_2)	$(\frac{3}{2}^+)$	13.49
6760			α_0	$\frac{5}{2}^+$	13.60
6870			p_2	$\frac{3}{2}^-$	13.70
6960			p_1, p_2, p_4, α_0	$\frac{3}{2}^-$	13.79
7050	~150		γ		13.87
7370			α_0	$\frac{5}{2}^-$	14.17
7500	~500		n, $p_0 \rightarrow p_2$, ^3He, α		14.29
7550			α_0	$\frac{5}{2}^+$	14.34
7700			n, p_0, α_0		14.48
7950	170 ± 50		n		14.71
8200			n, $p_2 \rightarrow p_6$, ^3He, α_0, α_1		14.94
8400	~1000		γ	$(\frac{1}{2}, \frac{3}{2})^+$	15.1
9050			n		15.74
[f]					
9370 ± 20	~200		n, p_2, p_8, α_1		16.04
9580 ± 20	~150		p_0, p_1, $p_3 \rightarrow p_7$, p_9, ^3He, α_1		16.23
9850 ± 50	600 ± 100		n, ^3He		16.48
10300	~1000		γ	$(\frac{1}{2}, \frac{3}{2})^+$	16.9
10600			$p_4 \rightarrow p_9$, α_0, α_1		17.2
11900	~1000		γ	$(\frac{1}{2}, \frac{3}{2})^+$	18.4
14200	~2000		γ	$(\frac{1}{2}, \frac{3}{2})^+$	20.5
15800	~2000		γ	$(\frac{1}{2}, \frac{3}{2})^+$	22.0

[a]) For references see (Aj 70, Aj 76, Aj 81). See also table 15.17 here.
[b]) (Sc 87b). See also (Kr 87e; theor).
[c]) Separated by 0.5 ± 0.5 keV: see, however, reaction 14 in (Aj 81).
[d]) Weak.
[e]) Strong.
[f]) See footnote [e]) in table 15.23 of (Aj 81).

no evidence for structures [see (Aj 81)]. See also (Ca 85t, Kr 87e, We 87a, Ca 88i, Ca 88m, Ba 89ee, Th 89b, Ma 90f; astrophysics) and (Ha 90f; theor.).

10. $^{14}N(p, n)^{14}O$ $Q_m = -5.9255$ $E_b = 7.2971$

The excitation function has been measured for $E_p = 6.3$ to 12 MeV: see (Aj 70). Observed resonances are displayed in table 15.20. The cross section [obtained by measuring the 2.31 MeV γ-rays from the ^{14}O (β^+) decay] is reported at 12 energies in the range $E_p = 7$ to 22 MeV (Dy 81). Production cross sections for the 2.31 MeV γ-rays have been measured at $E_p = 8.9$, 20, 30, 33 and 40 MeV by (Le 88b). The ratio of the cross section to $^{14}O_{g.s.}$ to that for the analog state $^{14}N^*(2.31)$ [from the (p, p′) reaction] has been determined at $E_p = 35$ MeV (Ta 84a). Forward-angle differential cross sections (n_0) are reported by (Mo 79cc) at $E_p = 144$ MeV. See also (Ca 85t; astrophys.) and ^{14}O.

11. $^{14}N(p, p)^{14}N$ $E_b = 7.2971$

The yields of elastic and inelastic protons, and of 2.31 MeV γ-rays, have been studied at many energies: see (Aj 59, Aj 70, Aj 76). Observed resonances are displayed in table 15.20. At higher energies excitation functions have been measured for the p_0, p_1 and p_2 groups for $E_p = 17$ to 26.5 MeV: there is no evidence for resonant behavior but the p_1 yield shows a large increase between $E_p = 20$ and 23 MeV. Total cross sections for the $p_0 \rightarrow p_9$ groups have been measured at $E_p = 8.6$, 10.6, 12.6 and 14.6 MeV [see (Aj 81)]. Total reaction cross sections have also been measured in the range $E_p = 22.9$ to 49.0 MeV by (Ca 85q). (Le 88b) report 2.31-MeV γ-ray production cross sections at $E_p = 8.9$, 20, 30, 33 and 40 MeV. For measurements at $E(^{14}N) = 516$ MeV/A see (We 90a).

Polarization measurements have been carried out at $E_p = 3.0$ to 159.4 MeV [see (Aj 70, Aj 76, Aj 86)] and at $E_{\vec{p}} = 35$ MeV (Ie 90; p_1) and 0.8 GeV (Bl 85g; A_y; elastic). See also ^{14}N, (Ba 86aa), (Ba 86nn, Hu 87) and (Am 89; theor.).

12. $^{14}N(p, ^3He)^{12}C$ $Q_m = -4.7789$ $E_b = 7.2971$

Excitation functions for the ground-state group have been measured at $E_p = 7$ to 11 MeV: some resonant structure is indicated [see table 15.20]. See also (Aj 76).

13. $^{14}N(p, \alpha)^{11}C$ $Q_m = -2.9228$ $E_b = 7.2971$

Excitation functions and total cross-section measurements have been measured for the α_0 group for $E_p = 3.8$ to 45 MeV: see (Aj 76). Fairly sharp structures persist until $E_p = 15$ MeV: see table 15.20 here and footnote [e]) in table 15.23 of (Aj 81). See also (Ha 86hh; applied) and (Ca 85t; astrophys.).

14. $^{14}N(d, n)^{15}O$ $Q_m = 5.0725$

Angular distributions have been studied at many energies in the range $E_d = 0.9$ to 11.8 MeV: see tables 15.27 and 15.28 in (Aj 70) and table 15.26 in (Aj 76). For

τ_m measurements see (Aj 70). See also table 15.21 here, ^{16}O in (Aj 86a), (Hi 87; applied) and (Bl 84h; theor.).

15. ^{14}N(^{3}He, d)^{15}O $Q_m = 1.8035$

See table 15.28 in (Aj 70). See also table 15.21 here.

16. ^{15}N(γ, π^-)^{15}O $Q_m = -142.322$

At $E_\gamma = 170$ MeV four-point angular distributions of the π^- to $^{15}O_{g.s.}$ have been measured by (Li 88h) and (Ko 89l): the two studies are not in good agreement. See also (Er 90c; theor.).

17. ^{15}N(π^+, π^0)^{15}O $Q_m = 1.850$

Angular distributions of the π^0 to $^{15}O_{g.s.}$ have been studied at $E_{\pi^+} = 32.4$ and 55.5 MeV (Ir 85b), at 48 MeV (Co 84f, Le 86) and at 165 MeV (Do 82h). Forward-angle differential cross sections of the π^0 to $^{15}O_{g.s.}$ have also been measured at $E_{\pi^+} = 20$ MeV (Ir 87) and at 40.7 and 63.6 MeV (Ir 85b). See also (Le 89g).

18. ^{15}N(p, n)^{15}O $Q_m = -3.5363$

Angular distributions have been measured for $E_p = 3.95$ to 18.5 MeV [see (Aj 81, Aj 86)], at 35 MeV (Or 87; ^{15}O*(7.56) [$J^\pi = \frac{1}{2}^+$]), at 135 MeV (Wa 85k; ^{15}O*(0, 6.2)) and at 200 and 494 MeV (Ci 88; prelim.; also A_y). Forward-angle differential cross sections at $E_p = 200$, 300 and 400 MeV to ^{15}O*(0, 6.2) are reported by (Al 87f; prelim.). The ratio of the population of $^{15}O_{g.s.}$ to that of ^{15}O*(6.2) has been determined at $E_p = 800$ MeV (Ki 86c). ^{15}O*(6.2) contains only about $\frac{1}{3}$ of the expected GT strength (Go 85a). [I am indebted to Prof. C.D. Goodman for his comments.] For a discussion of GT strengths, see (Ta 87c). ^{15}O* (5.2 [u], 6.8 [u], 7.28) have also been populated (Or 87). For the earlier work see (Aj 86). See also ^{16}O in (Aj 86a), (Go 85m, Vo 86j, Be 87p, Ro 88n, Wa 88p), (Ma 86n, Hi 87, Hi 88f; applied) and (Ra 89d; theor.).

19. ^{15}N(^{3}He, t)^{15}O $Q_m = -2.7725$

Angular distributions for the t_0, t_{1+2}, t_3, t_{4+5}, t_6 and t_7 groups have been studied for $E(^3\mathrm{He}) = 16.5$ to 44.6 MeV: see (Aj 76).

20. ^{16}O(γ, n)^{15}O $Q_m = -15.6638$

The spectrum of photoneutrons has been investigated at many energies. Measurements over the giant dipole resonance region show the predominant strength is to the $J^\pi = \frac{1}{2}^-$ and $\frac{3}{2}^-$ states $E_x = 0$ and 6.18 MeV, consistent with the basic validity of the single-particle, single-hole theory of photoexcitation in ^{16}O. However, the positive-parity states at $E_x = 5.18$, 5.24, 6.86 MeV are also populated suggesting some more complicated excitations in ^{16}O: see (Aj 70, Aj 76). Differential cross sections for the n_0 group have been measured from threshold to $E_\gamma = 28$ MeV [see (Aj 76)], at $E_\gamma = 60$ to 160 MeV (also ^{15}O*(6.18); no appreciable strength in the 5.2 MeV doublet) [see (Aj 86)] and at 150, 200 and 250 MeV (Be 89g). See also ^{16}O in (Aj 86a) and (Ry 87, Ca 88c, Du 88c, Ry 88, Br 90b, Fl 90; theor.).

21. (a) $^{16}O(\pi^+, p)^{15}O$ $Q_m = 124.687$
    (b) $^{16}O(\pi^+, \pi^+ n)^{15}O$ $Q_m = -15.6638$
    (c) $^{16}O(\pi^+, \pi^0 p)^{15}O$ $Q_m = -10.277$

For reaction (a) see (Do 82). At $E_{\pi^+} = 2.0$ GeV/c differential cross sections have been determined for the transition to ^{15}N*(6.2) (Ki 83) in reaction (b). For reaction (c), see (Gi 86b).

22. $^{16}O(p, pn)^{15}O$ $Q_m = -15.6638$

At $E_p = 505$ MeV the summed spectra show two peaks corresponding to the $p_{1/2}$ and $p_{3/2}$ knockouts [^{15}O*(0, 6.18)] (binding energies of 15.64 and 21.82 MeV). Differential cross sections are also reported (Mc 86e) [see also reaction 59 in ^{15}N]. For work at 1 GeV, see (Be 85v). See also (Wa 83m) and (Hi 87; applied).

23. $^{16}O(p, d)^{15}O$ $Q_m = -13.4392$

Angular distributions have been reported at many energies for $E_p = 18.5$ to 155.6 MeV [see table 15.30 in (Aj 70), (Aj 76), (Aj 86)]: at those energies ^{15}O*(0, 6.18) are preferentially populated. At $E_p = 200$ MeV angular distributions have been studied for ^{15}O*(0, 6.18) (Ab 89) [also A_y and C^2S]. At $E_p = 800$ MeV ^{15}O*(0, 5.2 [u], 6.18, 7.4 [u], 9.0 [u], 10.42 ± 0.15, 10.87 ± 0.15, 12.21 ± 0.15, 13.59 ± 0.15, 19.0 ± 0.2, 21.1 ± 0.2) [the last two states have $\Gamma \geq 0.8$ MeV] have been populated (Sm 84).

For γ-ray production [^{15}O*(5.24)] see (Le 88b). See also ^{17}F in (Aj 86a), (Ki 89c) and (La 87e, Le 88b, Gu 89h; astrophysics).

24. $^{16}O(d, t)^{15}O$ $Q_m = -9.4065$

Angular distributions have been reported at a number of energies in the range $E_d = 20$ to 52 MeV [see (Aj 81) and reaction 60 in ^{15}N here] and at $E_d = 89$ MeV (Sa 90h; ^{15}O*(0, 6.18)). See also ^{18}F in (Aj 83).

25. $^{16}O(^3He, \alpha)^{15}O$ $Q_m = 4.9140$

The $p_{1/2}$ and $p_{3/2}$ hole states ^{15}O*(0, 6.18) are strongly populated. Information on these and other states are displayed in table 15.25 of (Aj 81). Angular distributions have been measured at energies up to $E(^3He) = 217$ MeV: see (Aj 81). Branching ratios and multipole mixing ratios are displayed in table 15.17. (Be 78e) report τ_m of ^{15}O*(5.24) = 3.25 ± 0.30 ps, $|g| = 0.260 \pm 0.028$. (Bi 83g) determine $g = +0.17 \pm 0.07$. See also (Aj 86), ^{19}Ne in (Aj 83) and (Ab 90; applied).

26. $^{16}O(^6Li, ^7Li)^{15}O$ $Q_m = -8.414$

See (Gl 86e; prelim.).

27. ^{17}O(p, t)^{15}O $Q_m = -11.3254$

At $E_p = 39.8$ MeV angular distributions of t_0 and t_3 groups have been compared to those of the ^{3}He groups to the analog states in ^{15}N. At $E_p = 45$ MeV a state, assumed to be the $J^\pi = \frac{5}{2}^+$, $T = \frac{3}{2}$ analog of ^{15}C*(0.74), is observed at $E_x = 12.255 \pm 0.013$ MeV, $\Gamma_{c.m.} = 135 \pm 15$ keV. The state decays by proton emission to the $T = 1$, 0^+ state ^{14}N*(2.31) [the population of some $T = \frac{1}{2}$ states is also reported]: see (Aj 81).

At $E_{\bar{p}} = 89.7$ MeV angular distributions and A_y measurements have been reported to ^{15}O*(0, 5.24 [u], 6.18, 6.86, 7.28) (Vo 85e).

28. ^{19}F(^{3}He, ^{7}Li)^{15}O $Q_m = -4.3185$

See (Aj 76). See also (Ha 86k; theor.).

TABLE 15.21

Levels of ^{15}O from ^{14}N(d, n) and ^{14}N(^{3}He, d) [a])

E_x in ^{15}O [b]) (MeV ± keV)	l_p	S	J^π
0	1 [d])	0.87	$\frac{1}{2}^-$
5.18	(0) [e])	0	$\frac{1}{2}^+$
5.2410 ± 0.5 [c])	2 [d])	(0.03)	$\frac{5}{2}^+$
6.180 ± 4 [c])	1 [d])	0.04	$\frac{3}{2}^-$
6.79	0 [d])	≤0.3	$\frac{3}{2}^+$
6.8598 ± 1.0 [c])	2 [d])	0.4	$\frac{5}{2}^+$
7.2762 ± 0.6 [c])	2 [d])	0.42	$\frac{7}{2}^+$
7.56	0 [d])	≤0.4	$\frac{1}{2}^+$
8.28	0 [e])		$\frac{3}{2}^+$

[a]) See tables 15.28 in (Aj 70) and 15.26 in (Aj 76) for references and additional information.

[b]) Nominal energies if uncertainty is not indicated.

[c]) From γ-ray measurements.

[d]) From both (d, n) and (^{3}He, d) work: see (Aj 76).

[e]) From (^{3}He, d).

^{15}F

(Fig. 13)

GENERAL†

See (Ay 89a, Og 89a) and (An 85e, An 86u, Co 88e; theor.). See (An 86u) for comments on ^{15}Ne.

† See also (Aj 86).

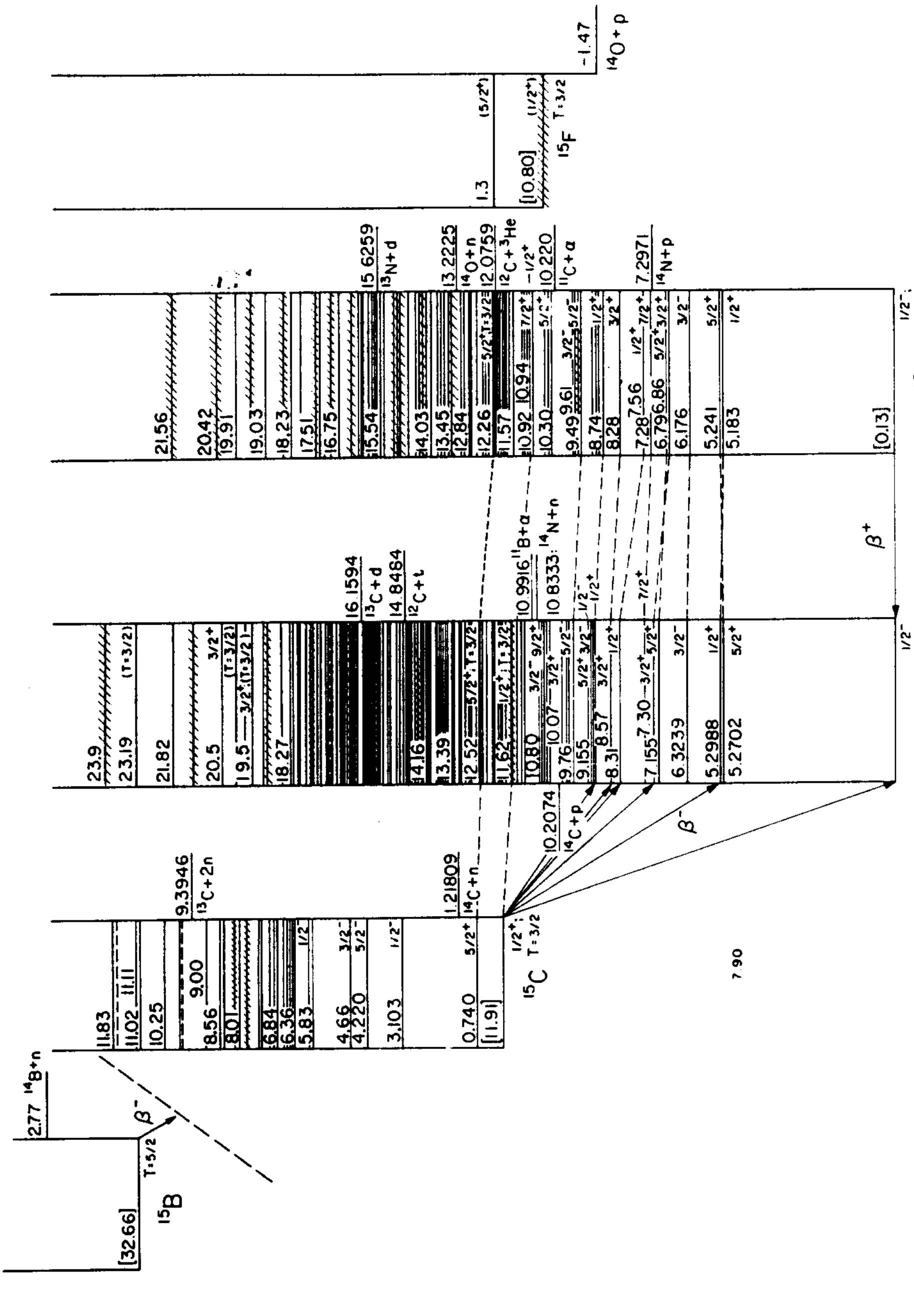


Fig. 13. Isobar diagram, A = 15. For notation see fig. 4.

TABLE 15.22

Energy levels of ^{15}F

E_x in ^{15}F (MeV)	$J^\pi; T$	$\Gamma_{c.m}$ (MeV)	Decay	Reaction
g.s.	$(\frac{1}{2}^+); \frac{3}{2}$	1.0 ± 0.2	p	2
1.3 ± 0.1	$(\frac{5}{2}^+); \frac{3}{2}$	0.24 ± 0.03	p	2

Mass of ^{15}F: The atomic mass excess of ^{15}F is 16.77 ± 0.13 MeV. ^{15}F is unstable with respect to breakup into $^{14}O + p$ by 1.47 MeV: see (Aj 81).

1. $^{12}C(^3He, \pi^-)^{15}F$ $\qquad Q_m = -141.41$

This reaction is not observed at $E(^3He) = 235$ MeV, $\theta_{lab} = 20°$: the differential cross section (c.m.) is $\leq 4 \times 10^{-11}$ b (Bi 84b).

2. $^{20}Ne(^3He, ^8Li)^{15}F$ $\qquad Q_m = -29.83$

This reaction has been studied at $E(^3He) = 74.5$ MeV (Be 78o) and 75.4 and 87.8 MeV (Ke 78c). Two groups are observed: the ground state [$\Gamma_{c.m.} = 0.8 \pm 0.3$ MeV (Ke 78c), 1.2 ± 0.3 MeV (Be 78o)] and a relatively strongly populated state, presumed to be the mirror of $^{15}C^*(0.74)$ [$J^\pi = \frac{5}{2}^+$], with $E_x = 1.3 \pm 0.1$ MeV (Ke 78c), 1.2 ± 0.2 MeV (Be 78o) and $\Gamma_{c.m.} = 0.5 \pm 0.2$ MeV (Ke 78c), 0.24 ± 0.03 MeV (Be 78o). The differential cross section for populating $^{15}F^*(1.3)$ is 250 ± 20 nb/sr at 10° and $E(^3He) = 74.5$ MeV (Be 78o) and 80 ± 25 nb/sr at 9°, 87.8 MeV (Ke 78c). At $E(^3He) = 75.4$ MeV, $\theta = 9°$, the ground state is populated with a differential cross section of 8 ± 4 nb/sr (Ke 78c).

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(Closed ~July 1, 1990)[†]

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(iv) "Nuclear Data for Basic and Applied Science", Editors: P.G. Young *et al.*, published by Gordon and Breach (1986), referred to herein as "SANTA FE 1985".

[†] Date at which journals reached our library.

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