

Adopted Levels, Gammas

$Q(\beta^-) = -2220.47$ 27; $S(n) = 4946.31$; $S(p) = 17533.4$ 13; $Q(\alpha) = -10648.36$ 8 2021Wa16

$S(n) = 4946.3087$ 5 2021Wa16

$S_{2n} = 23667.02$ 6; $S_{2p} = 31630.10$ 24 (2021Wa16).

1929Ki01, 1929Ki02: Discovered ${}^{13}\text{C}$ in the carbon spectrum from an electric furnace. See (2012Th01).

1984De53: Natural abundance: 1.10% 3.

1985De42: Deduced rms charge radius 2.4628 fm 39 from 2p-1s muonic transition. See also (1984Aa02).

Mass measurements: 1935Be02, 1969Wo03, 1993VaZY, 1995Di08, 1995Va38, 1997Br44, 2004Ra33, 2006Re19.

Nuclear moments:

Measurements: ${}^{13}\text{C}_{g.s.}$ 1954Ro34 $\mu = +0.7024118$ 14, 2005An15 $\mu = 0.7023694$ 35. ${}^{13}\text{C}^*$ (3.85 MeV) 1981Ru04 $\mu = 1.40$ 4.

Tabulations: 1964Li14, 1967Sh14, 1969Fu11, 1972Gl06, 1975Go12, 1989Ra17, 2011StZZ: $\mu(3.85 \text{ MeV}) = 1.40$ 4, 2019StZV: $\mu = 0.702369$ 4.

Calculations: 1937Ro01, 1963Be36, 1968Pe16, 1974Ha27, 1984Ka25, 1988Va03, 1990Iw02, 1991Bo02, 1996Ka14, 1999Ga57, 1999Ki27, 2003Su04, 2003Su09, 2003Su28, 2004Sa58, 2005Ko18, 2012Fu06, 2013Ma60, 2017Ya19, 2021Fr07, 2022St06, 2023Se01.

Theory:

Ground state and level properties: 1961Ku17, 1963Se19, 1966El08, 1967Ba12, 1970Pe18, 1971Gr02, 1971Ja13, 1973Ma48, 1975Er09, 1975Me24, 1975Yu03, 1978Sm02, 1981Av02, 1981Li19, 1983Sh38, 1984Fr13, 1987Sa15, 1990Mo17, 1992Zh01, 1993Ki01, 1993Pa19, 1993Sa20, 1995Vi06, 1996Ki24, 1996Ot01, 1996Re19, 1996Su24 1997Ba54, 1997Mo06, 1997Po12, 1998Ch38, 1998Sh16, 2000Ko23, 2001Ot04, 2003Sa50, 2003Su28, 2005Ni24, 2006Ko02, 2007Na16, 2007Sa50, 2014Ho08, 2015Sh21, 2019Bi03, 2020Su20, 2020So01, 2021Ga21, 2021Ma32, 2022Sa37, 2023Ch04.

Shell model: 1965Co25, 1970Hs02, 1971Ja14, 1971No02, 1973Ha49, 1973Sa30, 1978Bo31, 1983Va08, 1983Va08, 1983Va31, 1984Va06, 1987Nu02, 1988Wo04, 1990Bi16 1990Sk05, 1990Va01, 1992Kw01, 1993Go03, 1993Ki23, 1993Po11, 1993Zh17, 1996Ki27, 2003Na21, 2005Na41, 2006Le33, 2007Gu03, 2008Sh16, 2009Um05, 2010Ti04, 2012Yu07, 2013Ma60, 2015Fo06, 2016Ho14, 2018Fu14, 2018Ti08.

Cluster model and multi-body forces: 1974Si04, 1989Va06, 1995Ho13, 1996Du12, 1997De27, 1997Ho04, 1997Ka25, 1997Vo17, 2001Ka66, 2002Mi32, 2002Vo19, 2003Fr39, 2003Mi33, 2003Mi34, 2003Th06, 2003Vo24, 2004Bu25, 2004Mc02, 2004Na35, 2004Th11, 2004Th14, 2004Vo09, 2005Du03, 2005NeZZ, 2006It06, 2006Ka55, 2006Ta28, 2007Fr22, 2008Ya24, 2009Yo03, 2010VoZY, 2011Fu01, 2011Ya08, 2012Ya16, 2015Ya16, 2017De19, 2020Ca21, 2020Ro08.

Various topics:

Mirror and analog states: 1938Be05, 1963Fa03, 1971Ar03, 1971DiZT, 1971Ng01, 1972Ch16, 1974Ch46, 1975Gr03, 1975Ku21, 1973Sa25, 1975Me24, 1980Ba54, 1985An28 (IMME), 1986RoZQ, 1986Si22, 1995Fo18, 1998Ao02, 2005Ti14, 2006Sh10, 2011Ti09, 2012Am06 (IMME), 2015Fr04, 2018Fo04, 2019Mu05, 2022Va06.

Nuclear size: 1976Du04, 1982Sc11, 1992He21, 1992La13, 1996Sh13, 2001Oz03, 2001Oz04, 2002Me12, 2003Li31, 2004Ne16, 2005Ch02, 2006Pe01, 2008Ch34, 2011Gu03, 2016Og03 (radius of 3.09 MeV state), 2017Ah08, 2023De29.

Electromagnetic transitions: 1970Fo14, 1971DiZT, 1972Gu05, 1978Ki08, 1982MoZR, 1983Mi08, 1984Ku07, 1984Sc09, 1985Uc01, 2001Ra41, 2004Sa58, 2004Su23, 2005Sa63, 2021Sh20, 2011SuZU, 2015IzZZ.

Giant resonance: 1962Ea01, 1963Pe04, 1972Le06, 1974Mu13, 1989GoZQ, 1992Ba02, 2004El05, 2004Is09.

Others: 1981PI03, 1986Co21, 1990Mu10, 1994Fe06, 2009Ti11, 2013Ti05, 1978Le04, 1982We02, 2012Su15, 2013Su17, 2015Mo24, 2023Ga25, 2024Zh23.

Unplaced experimental results:

1966De09: ${}^{17}\text{O}(d, {}^6\text{Li})$. DWBA analysis of $L=3$ α transfer to ${}^{13}\text{C}_{g.s.}$.

1969Ba17: ${}^{14}\text{N}(\alpha, \alpha p)$. Analysis of sequential decay processes.

1973Va07, 1974Bu06, 1978Da17: ${}^{13}\text{C}(\text{pol. } d, d)$. Measured angular distributions and polarization observables to low-lying states.

1974Li15: ${}^{16}\text{O}(\pi^-, {}^{13}\text{C}\gamma)$. Discussed population of ${}^{13}\text{C}^*$ (3684, 3854).

1975Sc35, 1975Sc42: ${}^{14}\text{C}({}^{16}\text{O}, {}^{17}\text{O})$. DWBA analysis of the ground state reaction.

1976We21: Optical model analysis of (${}^{13}\text{C}, {}^{13}\text{C}_{g.s.}$) reactions on ${}^{12}\text{C}$, ${}^{16}\text{O}$, ${}^{28}\text{Si}$ and ${}^{32}\text{S}$.

1988Ya06, 1988Ya02: ${}^{28}\text{Si}({}^{13}\text{C}, {}^{13}\text{C}_{g.s.})$ $E=60$ MeV. Optical model analysis.

2020Li05: ${}^{28}\text{Si}({}^{13}\text{C}, {}^{13}\text{C})$ $E=30$ and 34 MeV. Coupled channels analysis.

1977Ar06: ${}^{232}\text{Th}({}^{22}\text{Ne}, {}^{13}\text{C})$ $E=172$ MeV. Analysis of secondary isotope production.

Adopted Levels, Gammas (continued)

- 1979Pr07: ¹²C(¹⁶O,¹⁵O) E=128 MeV. DWBA analysis of ground state reaction.
 1980Mi01: ²⁷Al(¹⁶O,¹³C) E=88 MeV. Analyzed reaction mechanism and Q-value dependence for production of various reaction products.
 1981Wh01: ¹⁴C(π^+ ,p). Analysis of (π^+ ,p) systematics for a variety of targets.
 1984Ho23: ¹⁹⁷Au(²⁰Ne,¹³C). Analysis of cluster-stripping reaction dynamics.
 1991Eu01: ⁷Li(⁶Li, γ) E_{c.m.}=1-8 MeV. Analyzed capture reactions to γ_0 , γ_1 , γ_{2+3} , γ_4 and γ_{5-7} .
 1999Az04, 2001Az01: ¹⁴N(⁷Be,⁸B). ANC approach to improve understanding of astrophysical ⁷Be+p→⁸B reaction.
 2021Ci02: ¹⁸¹Ta(¹⁸O,¹³C). ¹³C*(3853) benchmark of the AGATA+VAMOS+PARIS setup at GANIL. E γ =3852.170 keV 22 derived in (1980Wa24) is referenced.
 2021Su15: C(¹⁴C,¹³C) E≈240 MeV/nucleon. Glauber model analysis of single-neutron removal cross sections.
 2022Bo01: ¹²C(X,¹³C): X=¹⁵,¹⁶O, ¹⁴N E≈400 MeV/nucleon. Analyzed fragmentation products.
 2023Me12: natC(X,¹³C): X=¹⁴C, ¹⁴N, ¹⁶O, ¹⁶N E≈240 MeV/nucleon. Analyzed fragmentation products.
 2023Sp01: ¹²C(¹⁸O,¹⁷O) E=275 MeV. DWBA analysis of charge-exchange reactions.
 2022Ur01, 2024Ur02: ¹³C(d,d), (d,d₁₋₁₀) E=18 MeV. FRESKO analysis of angular distributions; deduced deformation lengths.
 2024Ra22: ²H(¹³N,²He) E=94 MeV/nucleon. Measured charge-exchange cross sections to high-lying states that could participate in high-energy electron capture reactions.

¹³C Levels

Cross Reference (XREF) Flags

A	¹³ B β^- decay	X	¹² C(n, γ):res	AT	¹³ C(α,α),(α,α'),($\alpha,\alpha'\gamma$)
B	¹³ N ϵ decay	Y	¹² C(n,n):res	AU	¹³ C(⁶ Li, ⁶ Li),(⁷ Li, ⁷ Li)
C	¹⁴ B β^- n decay	Z	¹² C(n,p):res	AV	¹³ C(⁹ Be, ⁹ Be),(⁹ Be, ⁹ Be')
D	¹⁷ N β^- α decay	Others:		AW	¹³ C(¹¹ B, ¹¹ B)
E	¹ H(¹² B,p):res	AA	¹² C(n,n'),(n,n' γ):res	AX	¹³ C(¹⁸ O, ¹⁸ O)
F	⁷ Li(⁹ Be, α ⁹ Be), ¹⁴ C(¹³ C, α ⁹ Be)	AB	¹² C(p, π^+)	AY	¹⁴ C(p,d)
G	⁹ Be(α,α):res	AC	¹² C(d,p),(d,p γ)	AZ	¹⁴ C(d,t)
H	⁹ Be($\alpha,n\gamma$):res	AD	¹² C(t,d), ¹³ C(t,t),(t,t')	BA	¹⁴ C(³ He, α)
I	⁹ Be(⁶ Li,d),(⁷ Li,t)	AE	¹² C(³ He,2p)	BB	¹⁴ N(γ ,p)
J	⁹ Be(⁹ Be, ¹³ C γ)	AF	¹² C(α , ³ He)	BC	¹⁴ N(μ^- , νn)
K	⁹ Be(¹⁶ O, ¹² C)	AG	¹² C(⁷ Li, ⁶ Li),(⁸ Li, ⁷ Li)	BD	¹⁴ N(n,d),(n,d γ)
L	¹⁰ B(t,p):res	AH	¹² C(⁹ Be, ⁸ Be)	BE	¹⁴ N(p,2p)
M	¹⁰ B(α ,p),(α ,p γ)	AI	¹² C(¹¹ B, ¹⁰ B),(¹² C, ¹¹ C)	BF	¹⁴ N(d, ³ He)
N	¹⁰ B(⁶ Li, ³ He)	AJ	¹² C(¹³ C, ¹³ C),(¹³ C,X)	BG	¹⁴ N(t, α)
O	¹⁰ B(⁷ Li, α)	AK	¹² C(¹⁴ N, ¹³ N)	BH	¹⁵ N(p, ³ He)
P	¹⁰ B(¹⁰ B, ¹³ C)	AL	¹³ C(γ,γ')	BI	¹⁵ N(d, α)
Q	¹⁰ B(¹⁴ N, ¹¹ C)	AM	¹³ C(γ ,n),(γ ,n γ),(γ ,p)	BJ	¹⁶ O(n, α),($n,\alpha\gamma$)
R	¹¹ B(d, γ):res	AN	¹³ C(γ ,p)	BK	¹⁶ O(p,p ³ He)
S	¹¹ B(d,p):res	AO	¹³ C(e,e),(e,e'),(e,e'p)	BL	¹⁶ O(α,α ³ He)
T	¹¹ B(d,n γ):res	AP	¹³ C(π,π),(π,π')	BM	²⁰ Ne(n,2 α)
U	¹¹ B(³ He,p),(³ He,p γ),(α ,d)	AQ	¹³ C(n,n),(n,n'),(n,n' γ)	BN	⁹³ Nb(¹² C, ¹³ C)
V	¹¹ B(⁶ Li, α)	AR	¹³ C(p,p),(p,p'),(p,pn)	BO	¹⁵⁹ Tb(¹⁹ F, ¹³ C), ¹⁵⁴ Sm(¹⁶ O, ¹³ C)
W	¹² C(n, γ):E=thermal	AS	¹³ C(³ He, ³ He),(³ He, ³ He')	BP	¹⁶⁵ Ho(¹⁴ N,n ¹² C)

E(level)	J ^π	T _{1/2} or Γ	XREF			Comments	
0	1/2 ⁻	stable	ABCD	IJK	MNOPQ	UVWX	XREF: Others: AB, AC, AD, AE, AF, AG, AH, AI, AJ, AK, AL, AO, AP, AQ, AR, AS, AT, AU, AV, AW, AX, AY, AZ, BA, BB, BC, BD, BE, BF, BG, BH, BI, BJ, BK, BL, BM, BN, BO $\mu=0.702369$ 4 (2019StZV,2005An15) J ^π : From mixed L=0+2 in ¹⁵ N(pol. p, ³ He) (1974Ma12) and trivial shell model consideration.

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Adopted Levels, Gammas (continued) ^{13}C Levels (continued)

E(level)	J^π	$T_{1/2}$ or Γ	XREF	Comments
3089.451 19	$1/2^+$	0.98 fs 9	A IJK MNOPQ UVW	XREF: Others: AB, AC, AD, AF, AG, AH, AI, AK, AL, AO, AP, AQ, AR, AS, AT, AU, AW, AX, AY, AZ, BA, BB, BC, BD, BE, BF, BG, BH, BI, BJ, BK, BO %IT=100 XREF: BE(3100) E(level): From least squares fit to $E_\gamma=169.300$ keV 4, 764.316 keV 10 and 3089.049 keV 20 (1980Wa24), and $E_\gamma=595.22$ keV 8 from (1982Mu14, 2008FiZZ) and $E_\gamma=3684.01$ keV 6 from (1967Pr10, 1982Mu14, 2008FiZZ). J^π : From E1 (no E2) from $1/2^-$ in $^{13}\text{C}(e,e')$ (1989Mi01). $T_{1/2}$: From $\tau=1.42$ fs 13 corresponding to $\Gamma=0.464$ eV 42 which is the weighted average of 0.463 eV 56 and 0.413 eV 50 (1968Ro02), 0.537 eV 42 (1993Mo23), and 0.39 eV 6 (1975Ra22).
3684.496 22	$3/2^-$	1.13 fs 6	A IJ MNOpQ UVW	XREF: Others: AB, AC, AD, AF, AG, AH, AI, AK, AL, AO, AP, AQ, AR, AS, AT, AU, AV, AW, AX, AY, AZ, BA, BB, BC, BD, BE, BF, BG, BH, BI, BJ, BK, BL, BN, BO %IT=100 XREF: p(3.78E3) E(level): From least squares fit to $E_\gamma=169.300$ keV 4, 764.316 keV 10 and 3089.049 keV 20 (1980Wa24), and $E_\gamma=595.22$ keV 8 from (1982Mu14, 2008FiZZ) and $E_\gamma=3684.01$ keV 6 from (1967Pr10, 1982Mu14, 2008FiZZ). J^π : From M1+E2 from $1/2^-$ in $^{13}\text{C}(e,e')$ (1989Mi01). $T_{1/2}$: From $\tau=1.63$ fs 9 obtained from the average of $\tau=1.59$ fs 13 (1991Li12: $\Gamma_{01}^2/\Gamma=0.408$ eV 26) and $\tau=1.63$ fs 12 (1993Mo23: $\Gamma=0.403$ eV 30) from $^{13}\text{C}(\gamma,\gamma')$ and $\tau=1.82$ fs 25 (1970Wi04: $\Gamma=0.36$ eV 5) from $^{13}\text{C}(e,e')$.
3853.796 21	$5/2^+$	8.6 ps 2	A IJK MNOp UV	XREF: Others: AB, AC, AD, AE, AF, AG, AH, AI, AJ, AK, AO, AP, AQ, AR, AS, AT, AW, AX, AY, AZ, BA, BB, BC, BD, BG, BI, BJ, BK %IT=100 $\mu=1.40$ 4 (1981Ru04,2011StZZ,2020StZV) XREF: p(3.78E3) E(level): From least squares fit to $E_\gamma=169.300$ keV 4, 764.316 keV 10 and 3089.049 keV 20 (1980Wa24), and $E_\gamma=595.22$ keV 8 from (1982Mu14, 2008FiZZ) and $E_\gamma=3684.01$ keV 6 from (1967Pr10, 1982Mu14, 2008FiZZ). J^π : From M2+E3 from $1/2^-$ in $^{13}\text{C}(e,e')$ (1989Mi01). $T_{1/2}$: from $\tau_m=12.4$ ps 3 which is the weighted average of $^{12}\text{C}(d,p)$ values: $\tau_m=12.4$ ps 8 (1974Be48), 13.0 ps 4 (1975Ra29), 12.6 ps 3 (1977He12) and 12.2 ps 4 (1981Ru04) and $^{10}\text{B}(\alpha,p)$ values: $\tau_m=10.7$ ps 10 (1969He22) and 9.9 ps 9 (1970Ga01). See also $\tau_m=9.0$ ps +25-15 (1968Ri16).
(4946.33 5)	$1/2^+$			E(level), J^π : From L=0 $^{12}\text{C}(n,\gamma)$:E=thermal capture state.
6860.04 ^b 46	$5/2^+$	6 keV	I MNOP UV Y	XREF: Others: AB, AC, AD, AG, AH, AI, AK, AO, AP, AQ, AR, AS, AT, AW, AY, BF, BG, BH, BI, BP $\Gamma_{n0}/\Gamma=0.99$ +I-9 (1973Ad02) XREF: P(6.75E3)

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Adopted Levels, Gammas (continued) ^{13}C Levels (continued)

E(level)	J^π	$T_{1/2}$ or Γ	XREF			Comments	
7492 10	(7/2 ⁺)	<5 keV	I	NOp	UV	Decay Mode: n. E(level): From (1990Pi05) $^{12}\text{C}(d,p)$. J^π : From L=2 and phase-shift analysis in $^{12}\text{C}(n,n)$ (1973Ab07). Γ : From (1977Ta08) $^{12}\text{C}(d,p)$. See other values around $\Gamma=7-9$ keV listed in $^{12}\text{C}(n,n)$:res. XREF: Others: AB, AC, AD, AI, AO, AP, AS, AT, AW, BG, BI $\Gamma_\gamma/\Gamma=0.003$ 1 (1971HiZF) XREF: V(7500) Decay Mode: γ . E(level): From the average of 7470 keV 20 (1955Mc75) and 7500 keV 12 (1959Yo25) $^{11}\text{B}(^3\text{He},p)$. J^π : From E3+M4 from 1/2 ⁻ in $^{13}\text{C}(e,e')$ (1989Mi01). Γ : From (1959Yo25) $^{11}\text{B}(^3\text{He},p)$.	
7547 3	5/2 ⁻	1.2 keV 3	A	I	MNOpQ	UV Y	XREF: Others: AB, AC, AD, AG, AI, AM, AO, AP, AQ, AR, AS, AT, AU, AV, AW, AY, BB, BE, BF, BG, BH, BI $\Gamma_{\gamma 0}=0.110$ eV 15 (1980Ho11) XREF: V(7550)ag(7600)AY(7560)BE(7500)BI(7530) Decay Modes: γ , n. E(level): From the average of 7546 keV 5 (1975He02) $^{12}\text{C}(n,n)$, 7554 keV 12 (1959Yo25) $^{11}\text{B}(^3\text{He},p)$ and 7547 keV 3 $^{13}\text{C}(e,e')$. J^π : From E2+M3 from 1/2 ⁻ in $^{13}\text{C}(e,e')$ (1989Mi01). The conference proceedings (1970CiZY) reports J=(5/2) and L=2 from $^{12}\text{C}(n,n)$: res. Γ : From (1975He02) $^{12}\text{C}(n,n)$. See also 6.5 keV (1970CiZY) $^{12}\text{C}(n,n)$ and 5 keV (1977Ta08) $^{12}\text{C}(d,p)$.
7688 5	3/2 ⁺	69 keV 4	I	NO	UV	Y	XREF: Others: AB, AC, AD, AG, AI, AM, AO, AR, AS, AT, AW, AY, BE, BG, BI $\Gamma_{\gamma 0}=0.6$ eV 1 (1980Ho11) XREF: Y(7658)AC(7641)ag(7600)BE(7800)BI(7640) Decay Modes: γ , n. E(level): From average of $E_x=7694$ keV 14 (1959Yo25) $^{11}\text{B}(^3\text{He},p)$, 7690 keV 10 (2013Ca25) $^{12}\text{C}(^{11}\text{B},^{10}\text{B})$ and 7686 keV 6 (1980Fu04) $^{13}\text{C}(\alpha,\alpha')$. See also 7641 keV 20 (1955Mc75) $^{12}\text{C}(d,p)$, and 7658 keV 9 (1973Fa06) $^{12}\text{C}(n,n)$. J^π : From L=2 and phase-shift analysis in $^{12}\text{C}(n,n)$ (1973Ab07). Γ : From the average of $\Gamma=60$ keV 13 (1955Mc75) $^{12}\text{C}(d,p)$, 75 keV 15 (1959Yo25) and 70 keV 10 (1970Me24) from $^{11}\text{B}(^3\text{He},p)$ and 70 keV 5 (1980Fu04) $^{13}\text{C}(\alpha,\alpha')$.
8220 40	3/2 ⁺	1026 keV 15				Y	$\Gamma_{\gamma 0}$: From (1980Ho11) $^{13}\text{C}(\gamma,n_0)$. XREF: Others: AB, AC, AD, AE, AH, AI, AM, AO, AR, AW, AY $\Gamma_{\gamma 0}=7.0$ eV 9 (1980Ho11) $\Gamma_{n0}/\Gamma\approx 1.0$ (1972Ga13) XREF: AB(8400)AC(8.4E3)AE(8000)AI(8250)AO(8200)AR(8200)

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Adopted Levels, Gammas (continued)

¹³C Levels (continued)

<u>E(level)</u>	<u>J^π</u>	<u>T_{1/2} or Γ</u>	<u>XREF</u>				<u>Comments</u>	
8866.9	1/2 ⁻	179 keV 17	A	I	N	UV	Y	<p>Decay Modes: γ, n. E(level): From the unweighted average of values in ¹²C(n,n): E_x=8149 keV 15 (1973Fa06), 8193 keV 50 (1960Ts02) and 8267 keV 50 (1966Li03). See also 8400 keV 300 (1955Mc75) ¹²C(d,p). J^π: From L=2 and phase-shift analysis in ¹²C(n,n) (1973Ab07). Γ: From average of Γ=1050 keV 100 (1966Li03) and 1025 keV 15 (1975Fa06) ¹²C(n,n). See also 375 keV (1977Wo04) ¹³C(γ,n). Γ_{γ0}: From (1980Ho11) ¹³C(γ,n₀). XREF: Others: AC, AM, AO, AP, AR, AS, AT, AY, BB, BF, BG, BH, BI, BJ Γ_{γ0}=5.4 eV 5 (1980Ho11) Γ_{n0}/Γ≈1.0 (1972Ga13) Decay Modes: γ, n. E(level): From the average of E_x=8869 keV 36 (1959Yo25) ¹¹B(³He,p), 8860 keV 30 (1970Me24) ¹¹B(³He,p), 8874 keV 14 (1973Fa06) ¹²C(n,n), 8860 keV 20 (1970Wi04) ¹³C(e,e'), 8860 keV 30 (1969Ba06) ¹³C(³He,³He') and 8860 keV 20 (1962Si04) ¹⁴N(t,α). See other values in ¹¹B(³He,p), ¹⁵N(p,³He) and ¹⁵N(d,α). J^π: From L=1 and phase-shift analysis in ¹²C(n,n) (1973Ab07). Γ: From the weighted average (external errors) of Γ=142 keV 30 from ¹¹B(³He,p), 205 keV 15 from ¹²C(n,n), 190 keV 35 (1970Wi04) ¹³C(e,e') and 145 keV 20 (1962Si04) ¹⁴N(t,α). XREF: Others: AA, AB, AC, AD, AE, AG, AI, AM, AO, AP, AR, AS, AT, AY, BF, BG, BH, BI, BP Γ_{n0}/Γ≈1.0 (1972Ga13) XREF: AA(9522) Decay Modes: γ, n. E(level),Γ: From (1980Ci03) ¹²C(n,n). See also E_x=9500 keV 7 (1989Mi01) ¹³C(e,e') and 9510 keV 12 from ¹¹B(³He,p). J^π: From M4(+E5) from 1/2⁻ in ¹³C(e,e') (1989Mi01); analysis of the σ(π⁺)/σ(π⁻) in (1979De34) ¹³C(π[±],π[±]) is consistent with a pure neutron transition and 9/2⁺; further support for an L=4 transfer is found in ¹³C(p,p') see references in (1981Aj01). See also J^π=(1/2⁻,3/2⁻) from phase-shift analysis of ¹²C(n,n) in (1972Ga13). Later, based on the (1972Ga13) result, J^π=3/2⁻ was deduced in comparisons of mirror pairs in (1968Hi01) ¹⁴N(d,³He) and (d,t) and (1968Fi03) ¹⁵N(p,³He) and (p,t), but note: in these studies J^π for ¹³C*(9.5 MeV) was still speculative because the 3/2⁻ partner in ¹³N was absent or unresolved.</p>
9499.71 ^C 6	9/2 ⁺	1.72 keV 8		I	MNOP	UV	Y	<p>XREF: Others: AA, AC, AM, AO, AR, AS, AT, AY, BF, BG, BH, BI, BP Γ_{n0}/Γ≈1.0 (1972Ga13) XREF: AA(9522) Decay Modes: γ, n. E(level),Γ: From (1980Ci03) ¹²C(n,n). See also E_x=9500 keV 7 (1989Mi01) ¹³C(e,e') and 9510 keV 12 from ¹¹B(³He,p). J^π: From M4(+E5) from 1/2⁻ in ¹³C(e,e') (1989Mi01); analysis of the σ(π⁺)/σ(π⁻) in (1979De34) ¹³C(π[±],π[±]) is consistent with a pure neutron transition and 9/2⁺; further support for an L=4 transfer is found in ¹³C(p,p') see references in (1981Aj01). See also J^π=(1/2⁻,3/2⁻) from phase-shift analysis of ¹²C(n,n) in (1972Ga13). Later, based on the (1972Ga13) result, J^π=3/2⁻ was deduced in comparisons of mirror pairs in (1968Hi01) ¹⁴N(d,³He) and (d,t) and (1968Fi03) ¹⁵N(p,³He) and (p,t), but note: in these studies J^π for ¹³C*(9.5 MeV) was still speculative because the 3/2⁻ partner in ¹³N was absent or unresolved.</p>
9894.50 ^C 17	3/2 ⁻	23.7 keV 4	A	I	NOP	UV	Y	<p>XREF: Others: AA, AC, AM, AO, AR, AS, AT, AY, BG, BI</p>

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Adopted Levels, Gammas (continued) ^{13}C Levels (continued)

<u>E(level)</u>	<u>J^π</u>	<u>T_{1/2} or Γ</u>	<u>XREF</u>				<u>Comments</u>
							<p>Γ_{n0}=20.6 keV 5 (1980Ci03) Γ_{n0}/Γ=0.869 (1980Ci03) XREF: AA(9946) Γ_{n1}/Γ_{n0}<0.15 (1973Ad02). Decay Modes: γ, n. E(level),Γ: From (1980Ci03) $^{12}\text{C}(n,n)$. See also E_x=9946 keV and Γ<80 keV (1959Ha13) $^{12}\text{C}(n,n')$ and 9898 keV 12 in $^{11}\text{B}(^3\text{He},p)$. J^π: From phase-shift analysis of $^{12}\text{C}(n,n)$ in (1972Ga13).</p>
10463 ^b		200 keV		0	U		<p>XREF: Others: AA, A0, AT Decay Mode: n. E(level),Γ: From (1959Ha13) $^{12}\text{C}(n,n')$. See also E_x=(10460) keV and J^π=5/2⁺ (1989Mi01) $^{13}\text{C}(e,e')$.</p>
10753.73 30	7/2 ⁻	50.9 keV 6	HI	N p	U	Y	<p>XREF: Others: AA, AC, AD, AR, AS, AT, BG, BH Γ_{n0}=43.4 keV 9 (1980Ci03) Γ_{n0}/Γ=0.853 (1980Ci03) XREF: BG(10736) Decay Mode: n. E(level): From (1980Ci03) $^{12}\text{C}(n,n)$. See also 10752 keV 5 (1969Da13) $^{12}\text{C}(n,n)$ and 10775 keV 5 (1973Go04) $^{12}\text{C}(d,p)$. J^π: From phase-shift analysis of $^{12}\text{C}(n,n)$ in (1972Ga13). Γ: From (1980Ci03) $^{12}\text{C}(n,n)$. See also 56 keV 2 (1973Go04).</p>
10812.8 6	(5/2) ⁻	18.7 keV 4	HI	MN p	U	Y	<p>XREF: Others: AA, AC, AR, AS, AT, BG Γ_{n0}=4.7 eV 3 (1980Ci03) Γ_{n0}/Γ=0.25 Decay Modes: n, α. E(level): From (1980Ci03) $^{12}\text{C}(n,n)$. See also 10815 keV 2 (1994Wr01) $^9\text{Be}(\alpha,\alpha)$ and 10818 keV 5 (1973Go04) $^{12}\text{C}(d,p)$. J^π: In (1974Ho06) the state is suggested as the analog of the $^{13}\text{N}^*(10.36\text{ MeV})$ J^π=5/2⁻ member of the J^π=5/2⁻ & 7/2⁻ doublet from comparison of the $^{10}\text{B}(^6\text{Li},^3\text{He})$ and $^{10}\text{B}(^6\text{Li},t)$ reactions. See also L=4 from J^π=1/2⁻ in $^9\text{Be}(^6\text{Li},d)$. Γ: From (1994Wr01). See also 18.1 keV 10 (1980Ci03) and 24 keV 3 (1973Go04).</p>
11001 ^c 2	1/2 ⁺	56.4 keV 1	HI	NO	U	Y	<p>XREF: Others: AA, AC, AM, AR, AT, AY, BG Γ_{n0}/Γ=0.4 1 (1972Ga13) XREF: I(10969)AA(10970) Decay Modes: γ, n, α. E(level): From the average of E_x=10994 keV 7 (1972Ga13) $^{12}\text{C}(n,n)$, 11002 keV 2 (1994Wr01) $^9\text{Be}(\alpha,n)$ and 10997 keV 8 (1973Go04) $^{12}\text{C}(d,p)$. J^π: From L=0 transfer in (1990Ya01) $^{14}\text{C}(p,d)$. See also the resonance phase analysis in (1956Ja28: E_x=11010 keV) $^9\text{Be}(\alpha,n)$ and phase-shift analysis in (1972Ga13) $^{12}\text{C}(n,n)$.</p>

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Adopted Levels, Gammas (continued) ^{13}C Levels (continued)

E(level)	J^π	$T_{1/2}$ or Γ	XREF				Comments
11076.01 ^b 18	1/2 ⁻	4.681 keV 19	HI	NO	U	Y	<p>Γ: From (1994Wr01) $^9\text{Be}(\alpha,n)$. See also $\Gamma=33$ keV 5 (1998Le17) $^9\text{Be}(^6\text{Li,d})$ and 82 keV 15 (1973Go04) $^{12}\text{C}(d,p)$.</p> <p>XREF: Others: AA, AC, AO, AR, AS, AT, AY, BG, BH</p> <p>$\Gamma_{n0}/\Gamma=0.63$ (1980Ci03)</p> <p>Decay Modes: n, α.</p> <p>E(level): From (1980Ci03) $^{12}\text{C}(n,n)$. See also $E_x=11076$ keV 2 (1994Wr01) $^9\text{Be}(\alpha,n)$, 11080 keV 5 (1973Go04) $^{12}\text{C}(d,p)$ and 11080 keV 5 (1989Mi01) $^{13}\text{C}(e,e')$.</p> <p>J^π: From E0+M1 from 1/2⁻ in $^{13}\text{C}(e,e')$ (1989Mi01).</p>
11727 2	3/2 ⁻	122.5 keV 8	HI		U	Y	<p>Γ: From (1994Wr01). See also $\Gamma=4.0$ keV 4 (1980Ci03).</p> <p>XREF: Others: AC, AO, AP, AR, AT, AY, BB, BE, BF, BG, BH</p> <p>$\%n\geq 80$; $\%\alpha>0$ (1983To19,1994Wr01)</p> <p>$\Gamma_{n0}/\Gamma=0.80$ 8 (1983To19)</p> <p>XREF: AO(11750)AR(11748)AT(11748)AY(11750)BB(11800)BE(11900)BH(11800)</p> <p>Decay Modes: n, α.</p> <p>E(level): From (1994Wr01) $^9\text{Be}(\alpha,n)$. See also $E_x=11733$ keV 15 (1996Ku07) $^9\text{Be}(\alpha,n)$ and 11748 keV 10 (1973Go03) $^{12}\text{C}(d,p)$.</p> <p>J^π: From phase-shift analysis of $^{12}\text{C}(n,n)$ in (1983To19).</p> <p>Γ: From (1994Wr01). See also $\Gamma=125$ keV 20 (1962Si04) $^{14}\text{N}(t,\alpha)$, 107 keV 14 (1973Go03) and 38 keV 10 (1998Le17) $^9\text{Be}(^7\text{Li,t})$.</p> <p>$\Gamma_n$: See also $\Gamma_{n0}/\Gamma=0.67$ 16 and $\Gamma_{n0}/\Gamma=0.33$ 8 (1973Ad02).</p>
11848 ^b 4	7/2 ⁺	68 keV 4	HI	M	PQ		<p>XREF: Others: AA, AC, AO, AP, AR, AS, AT</p> <p>$\%n>0$ (1959Ha13)</p> <p>XREF: H(11825)AP(11820)</p> <p>Decay Mode: n.</p> <p>E(level): From the average of $E_x=11851$ keV 5 (1973Go03) $^{12}\text{C}(d,p)$ and 11845 keV 5 (1989Mi01) $^{13}\text{C}(e,e')$.</p> <p>J^π: From E3+M4 from 1/2⁻ in $^{13}\text{C}(e,e')$ (1989Mi01).</p>
11947 3	5/2 ⁺	148.7 keV 4	FGHI	MNO		Y	<p>Γ: From (1973Go03) where the peak is well resolved. See also $\Gamma=144$ keV 5 (1989Mi01) and 46 keV 9 (1998Le17) $^9\text{Be}(^6\text{Li,d})$.</p> <p>XREF: Others: AA, AB, AC, AO, AR</p> <p>$\%n\approx 60$; $\%\alpha=40$ (1983To19,1974Sa16)</p> <p>$\Gamma_{n0}/\Gamma=0.51$ 6 (1983To19)</p> <p>$\Gamma_\alpha/\Gamma=0.4$ (1974Sa16)</p> <p>XREF: G(11990)M(11900)AR(11920)</p> <p>Decay Modes: n, α.</p> <p>E(level): From the average of $^9\text{Be}(\alpha,n)$ E_{res} values given in (1955Ta28, 1996Ku07, 1994Wr01).</p> <p>J^π: From phase-shift analysis of $^{12}\text{C}(n,n)$ in</p>

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Adopted Levels, Gammas (continued)

¹³C Levels (continued)

E(level)	J ^π	T _{1/2} or Γ	XREF	Comments
12055 ^a 3	1/2 ⁻	≈38 keV		(1983To19) and M2+E3 from 1/2 ⁻ in ¹³ C(e,e') (1989Mi01). See discrepant J ^π values (1/2 ⁻ ,7/2 ⁻) reported in ⁹ Be(α,n) (1956Ja28, 1970Va23, 1969K109). Γ: From (1994Wr01) ⁹ Be(α,n). See also Γ=150 keV 13 (1996Ku07) ⁹ Be(α,n) and see (1983To19) ¹² C(n,n) where E _x =11.97 MeV 8 and Γ=500 keV 80 are reported. Note: the broad E _x =11.84 and 11.95 MeV states are typically poorly resolved. XREF: Others: AT E(level),J ^π ,Γ: From (2021In04) ¹³ C(α,α'). DWBA analysis indicated a doublet at E _x =12055 keV 1 with Γ=38 keV 4. They find ΔL=0 and 2, which they assign L=0 and L=2 to the two states: one with J ^π =1/2 ⁻ and the other to (3/2,5/2) ⁻ . The ΔE=1 keV is statistical; the evaluator assumes 3 keV uncertainty from the Grand Raiden focal plane energy calibration.
12055 3	(3/2,5/2) ⁻	≈38 keV	Y	XREF: Others: AT %n≥84 Γ _{n0} /Γ=0.84 (1980Ci03) XREF: Y(12071.9) Decay Mode: n. E(level),J ^π ,Γ: From (2021In04) ¹³ C(α,α'). DWBA analysis indicated a doublet at E _x =12055 keV 1 with Γ=38 keV 4. They find ΔL=0 and 2, which they assign L=0 and L=2 to the two states: one with J ^π =1/2 ⁻ and the other to (3/2,5/2) ⁻ . The ΔE=1 keV is statistical; the evaluator assumes 3 keV uncertainty from the Grand Raiden focal plane energy calibration. See also a ¹² C(n,n) resonance reported with E _x =12072 keV 2 with Γ=82 keV 4 and J ^π =(3/2 ⁻).
12120 ^c 70	3/2 ⁺	540 keV 70	Y	XREF: Others: AM, AR Γ _{n0} /Γ=0.28 5 (1983To19) XREF: AM(12106)AR(12106) Decay Modes: γ, n. E(level),Γ: From (1983To19) ¹² C(n,n):res. See also E _x =12106 keV and Γ=150 keV (1977Wo04) ¹³ C(γ,n). In (1986Aj01) and later, the evaluations accepted E _x =12106 keV from (1977Wo04) and Γ=540 keV from the phase-shift analysis of (1983To19). The past and present evaluations accept much of the (1983To19) analysis; for this J ^π =3/2 ⁺ level, E _x and Γ from (1983To19) are accepted. J ^π : From phase-shift analysis of ¹² C(n,n) in (1983To19).
12130 46	5/2 ⁻	77 keV 30	I N Y	XREF: Others: AC, BG Γ _{n0} /Γ=0.43 6 (1983To19) XREF: N(12110)AC(12108) Decay Modes: n. E(level),Γ: From (1983To19) ¹² C(n,n):res.

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Adopted Levels, Gammas (continued) ^{13}C Levels (continued)

<u>E(level)</u>	<u>J^π</u>	<u>$T_{1/2}$ or Γ</u>	<u>XREF</u>			<u>Comments</u>
12141 2	1/2 ⁺	370.2 keV 17	H		Y	See also $E_x=12131$ keV 30 and $\Gamma=125$ keV 30 (1962Si04) $^{14}\text{N}(t,\alpha)$ and 12108 keV 5 with $\Gamma=81$ keV 8 (1973Go03) $^{12}\text{C}(d,p)$. J^π : From phase-shift analysis of $^{12}\text{C}(n,n)$ in (1983To19). $\Gamma_{n0}/\Gamma=0.50$ 7 (1983To19) XREF: H(12141) Decay Modes: n, α . E(level): From (1994Wr01) $^9\text{Be}(\alpha,n)$. See also $E_x=12139$ keV 65 (1983To19) $^{12}\text{C}(n,n)$:res. J^π : From phase-shift analysis of $^{12}\text{C}(n,n)$ in (1983To19). See previously reported $J^\pi=5/2^-$ from $^9\text{Be}(\alpha,\text{pol. n})$ (1969Kl09). Γ : From (1994Wr01). See also $\Gamma=426$ keV 70 (1983To19).
12189 ^b 7	3/2 ⁻	130 keV 40	H	Op	Y	XREF: Others: AA, AO, AR $\Gamma_{n0}/\Gamma=0.73$ 8 (1983To19) XREF: H(12180)p(12.3E3)Y(12268) Decay Modes: n, α . E(level): From the average of $E_x=12187$ keV 10 (1989Mi01) $^{13}\text{C}(e,e')$ and 12190 keV 10 (1988Co05: priv. comm.) See also $E_x=12268$ keV 65, $\Gamma=186$ keV 50 and $J^\pi=3/2^-$ from (1983To19) $^{12}\text{C}(n,n)$, which had been adopted in (1985Aj01). J^π : From phase-shift analysis of $^{12}\text{C}(n,n)$:res in (1983To19). Γ : From $\Gamma=180$ keV (1959Ha13) $^{12}\text{C}(n,n)$, 120 keV (1969Kl09) $^9\text{Be}(\alpha,n)$, 109 keV 48 (1989Mi01) $^{13}\text{C}(e,e')$ and 110 keV 50 (1988Co05) $^{13}\text{C}(p,p')$. XREF: Others: AT, BE XREF: H(12229)p(12.3E3)BE(12300) Decay Modes: n, α . E(level), Γ : From (2021In04) $^{13}\text{C}(\alpha,\alpha')$. E(level): A statistical $\Delta E=5$ keV is given in the text; the evaluator assumes 3 keV uncertainty from the Grand Raiden focal plane energy calibration and added that in quadrature.
12282 6	1/2 ⁻	122 keV 22	HI	p		J^π : From L=0 in $^{13}\text{C}(\alpha,\alpha')$ (2021In04). XREF: Others: AA, AO, AR, BH $\Gamma_{n0}/\Gamma=0.42$ 6 (1983To19) XREF: p(12.3E3)AO(12438)AR(12438) Decay Modes: n, α . E(level), Γ : From (1994Wr01) $^9\text{Be}(\alpha,n)$. See also $E_x=12434$ keV 46 (1983To19) $^{12}\text{C}(n,n)$ and 12438 keV 12 (1989Mi01) $^{13}\text{C}(e,e')$. J^π : From phase-shift analysis of $^{12}\text{C}(n,n)$ in (1983To19). XREF: Others: AT
12420 ^b 2	7/2 ⁻	226 keV 3	H	NOp	Y	E(level), J^π,Γ : From (2021In04) $^{13}\text{C}(\alpha,\alpha')$. J^π : From L=0 in $^{13}\text{C}(\alpha,\alpha')$ (2021In04). E(level): A statistical $\Delta E=3$ keV is given in the text; the evaluator assumes 3 keV uncertainty from the
12450 ^a 4	1/2 ⁻	<70 keV				

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Adopted Levels, Gammas (continued) ^{13}C Levels (continued)

E(level)	J^π	$T_{1/2}$ or Γ	XREF			Comments
12601 ^a 4	1/2 ⁻	<70 keV				Grand Raiden focal plane energy calibration and added that in quadrature. XREF: Others: AT E(level), J^π , Γ : From (2021In04) $^{13}\text{C}(\alpha,\alpha')$. J^π : From L=0 in $^{13}\text{C}(\alpha,\alpha')$ (2021In04). E(level): A statistical $\Delta E=3$ keV is given in the text; the evaluator assumes 3 keV uncertainty from the Grand Raiden focal plane energy calibration and added that in quadrature.
12775 ^a 6	1/2 ⁻	<70 keV				XREF: Others: AT E(level), J^π , Γ : From (2021In04) $^{13}\text{C}(\alpha,\alpha')$. J^π : From L=0 in $^{13}\text{C}(\alpha,\alpha')$ (2021In04). E(level): A statistical $\Delta E=5$ keV is given in the text; the evaluator assumes 3 keV uncertainty from the Grand Raiden focal plane energy calibration and added that in quadrature.
$\approx 13000^c$			HI	M		XREF: Others: AM XREF: I(12830)M(13010) E(level): From (1996Ku07, 1968Le24) $^9\text{Be}(\alpha,n)$. Decay Modes: γ , n, α . Γ : broad.
13.20×10^3 10	3/2 ⁻	340 keV	G I			XREF: Others: AY $\Gamma_\alpha=294$ keV; $\Gamma_n=46$ keV (2011Fr12) XREF: AY(13280) Decay Modes: n, α . E(level): From (2006Pr01) $^7\text{Li}(^9\text{Be},\alpha)$. J^π , Γ : From R-matrix analysis of $^9\text{Be}(\alpha,\alpha)$ in (2011Fr12).
13420	(9/2 ⁻)	41 keV 6	FGHI	M		XREF: Others: AR $\%n>0$; $\%\alpha>0$ (2017Lo04) XREF: F(13.2E3) Decay Modes: n, α . E(level): From (1973Go15) $^9\text{Be}(\alpha,\alpha)$. J^π : From (1973Go15) $^9\text{Be}(\alpha,\alpha)$, where 9/2 ⁻ was deduced by comparison of the resonance shapes for other $J^\pi=9/2^-$ resonances, and from (2017Lo04) R-matrix analysis of $^9\text{Be}(\alpha,n)$ and $^9\text{Be}(\alpha,\alpha)$. Γ : From the average of values given in $^9\text{Be}(\alpha,n)$ and $^9\text{Be}(\alpha,\alpha)$.
13.6×10^3 2	7/2 ⁻	619 keV 50	FGH	O	Y	XREF: Others: AA, AM $\Gamma_\alpha/\Gamma=0.86$; $\Gamma_n/\Gamma=0.14$ (2011Fr12) Decay Modes: γ , n, α . E(level): From (2006Pr01) $^7\text{Li}(^9\text{Be},\alpha)$. Γ : From (1985To02) $^{12}\text{C}(n,n')$. J^π : From polarization data and phase-shift analysis of $^{12}\text{C}(n,n)$, (pol. n,n _{0,1}) in (1985To02).
13760 ^c	5/2 ⁺	77 keV 30	GHI			XREF: Others: AM, AO, AR $\Gamma_\alpha/\Gamma=0.306$; $\Gamma_n/\Gamma=0.694$ (2011Fr12) Decay Modes: γ , n, α . E(level): From (2011Fr12) $^9\text{Be}(\alpha,\alpha)$. J^π : From R-matrix analysis of $^9\text{Be}(\alpha,\alpha)$ in (2011Fr12).

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Adopted Levels, Gammas (continued)

^{13}C Levels (continued)				
E(level)	J^π	$T_{1/2}$ or Γ	XREF	Comments
13920 ^a 30		100 keV 30	I	Γ : From (1998Le17) $^9\text{Be}(^7\text{Li,t})$. See also $\Gamma=117$ keV (2012Wh01) $^9\text{Be}(^7\text{Li,t})$ and $\Gamma=335$ keV (2011Fr12). E(level), Γ : From (1998Le17) $^9\text{Be}(^7\text{Li,t})$.
14.13 $\times 10^3$	(3/2 ⁻ ,5/2 ⁻)	160 keV 20	FGHI M p Y	XREF: Others: AB, AR $\Gamma\alpha/\Gamma\approx 1$; $\Gamma_n/\Gamma>0$ (2011Fr12) XREF: F(14.2E3)M(14080)Y(14167) AB(14E3) Decay Modes: n, α . E(level): From (1988Co05) $^{13}\text{C}(p,p')$. Γ : From (1998Le17) $^9\text{Be}(^7\text{Li,t})$. J^π : Polarization data and phase-shift analysis of $^{12}\text{C}(n,n)$, (pol. n,n _{0,1}) in (1985To02) indicate $J^\pi=3/2^-$ while an R-matrix analysis of $^9\text{Be}(\alpha,\alpha)$ in (2011Fr12) indicates $J^\pi=5/2^-$. See extensive discussion and comparative fits in (2011Fr12). In (2002Mi32,2003Mi34) known levels were surveyed and, based on level spacings, they suggest this state is the $J^\pi=9/2^-$ member of a rotational band.
14390 ^b 15	7/2 ⁻	282 keV 65	GHI	XREF: Others: AO, AR $\Gamma\alpha/\Gamma=0.108$; $\Gamma_n/\Gamma=0.892$ (2011Fr12) XREF: I(14360) Decay Modes: n, α . E(level), Γ : From (1989Mi01) $^{13}\text{C}(e,e')$. J^π : From R-matrix analysis of $^9\text{Be}(\alpha,\alpha)$ in (2011Fr12,2018Lo07). See also $J^\pi=7/2^{(+)}$ from (1973Go15) $^9\text{Be}(\alpha,\alpha_0)$, and see $J^\pi=(1/2,5/2)^-$ from (1973De14) $^9\text{Be}(\alpha,\alpha_0)$.
14.5 $\times 10^3$ ^a 1	(1/2,3/2) ⁺			XREF: Others: AT Decay Modes: (n). E(level), J^π,Γ : From L=1 in (2021In04) $^{13}\text{C}(\alpha,\alpha')$. E(level): (1985To02) suggests two broad and overlapping $J^\pi=3/2^-$ states in this region. Γ : broad.
14582 ^b 10	9/2 ⁺	227 keV 41	FGHI	XREF: Others: AO, AR $\%n=14$; $\%\alpha=86$ (2011Fr12) $\Gamma\alpha/\Gamma=0.856$; $\Gamma_n/\Gamma=0.144$ (2011Fr12) Decay Modes: n, α . E(level), Γ : From (1989Mi01) $^{13}\text{C}(e,e')$. J^π : From R-matrix analyses of $^9\text{Be}(\alpha,\alpha)$ in (2011Fr12,2018Lo07).
14819 ^a			M	XREF: Others: AP E(level): From (1991Br26) $^{10}\text{B}(\alpha,p)$ and $^{10}\text{B}(^9\text{Be},^6\text{Li})$.
14983 ^c 10	7/2 ⁻	380 keV 53	FGH Y	XREF: Others: AM, AO, AR $\Gamma\alpha/\Gamma=0.586$; $\Gamma_n/\Gamma=0.414$ (2011Fr12) XREF: H(14941)Y(14997)

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Adopted Levels, Gammas (continued)

^{13}C Levels (continued)						
E(level)	J^π	$T_{1/2}$ or Γ	XREF			Comments
15108.7 9	$3/2^-$	5.49 keV 25	GHI	U	Y	<p>Decay Modes: γ, n, α. E(level),Γ: From (1989Mi01) $^{13}\text{C}(e,e')$. J^π: From polarization data and phase-shift analysis of $^{12}\text{C}(n,n)$, (pol. n,n_{0,1}) in (1985To02). XREF: Others: AM, AO, AR, AS, AT, AY, BA, BH T=3/2 (1966Ba13,1967Pe07,1969Ad01) $\Gamma_{\gamma 0}$=23.2 eV 15 $\Gamma_{\gamma 1}$=4.12 eV 74 (1977Ma16) $\Gamma_{\alpha 0}$=0.104 keV 28 (1978Hi06) $\Gamma_{n 0}$=0.38 eV 10 Γ_n: $\Gamma_{n 1}$=1.43 eV 18 and $\Gamma_{n 2}$=0.14 eV 10. Decay Modes: γ, n, α. E(level): From average of E_x=15109.3 keV 14 (1978Hi06) $^9\text{Be}(\alpha,\alpha)$ and 15108.2 keV 12 (1987Hi03) $^{12}\text{C}(n,n)$. J^π: From M1+E2 from $1/2^-$ in $^{13}\text{C}(e,e')$ (1989Mi01). Γ: From (1978Hi06) $^9\text{Be}(\alpha,\alpha)$. $\Gamma_{\gamma 0}$: Obtained using the average of $\Gamma_{\gamma 0}/\Gamma$=0.0053 6 (1968Co27) and $\Gamma_{\gamma 0}/\Gamma$=0.00396 30 (1977Ma16), which yields $\Gamma_{\gamma 0}/\Gamma$=0.00423 27; this value with Γ=5.49 keV 25 (1978Hi06) gives $\Gamma_{\gamma 0}$=23.2 eV 18; this value is then averaged with $\Gamma_{\gamma 0}(M1)$=22.7 eV 27 and $\Gamma_{\gamma 0}(E2)$=0.59 eV 11 from (1969Wi22,1970Wi04) to obtain $\Gamma_{\gamma 0}$=23.2 eV 15. The transition widths to other levels are determined in (1977Ma16). Γ_γ: $\Gamma_{\gamma(2+3)}$=18.2 eV 24 and $\Gamma_{\gamma \rightarrow 7.55 \text{ MeV}}$<0.9 eV (1977Ma16). Γ_n: See $\Gamma_{n 0}/\Gamma$=0.070 18, $\Gamma_{n 1}/\Gamma$=0.261 30 and $\Gamma_{n 2}/\Gamma$=0.026 18 (1973Ad02). Γ_α=154 keV; Γ_n=339 keV (2011Fr12) Decay Modes: n, α. E(level),Γ: From (2011Fr12) $^9\text{Be}(\alpha,\alpha)$. J^π: From (2011Fr12,1985To02). In (1991Aj01) the resonance is listed with J^π=9/2⁺, based on polarization data and phase-shift analysis of $^{12}\text{C}(n,n)$, (pol. n,n_{0,1}) in (1985To02), but the R-matrix analysis of (2011Fr12) $^9\text{Be}(\alpha,\alpha)$ find that interference from a J^π=9/2⁺ resonance is incompatible with their finding of a J^π=9/2⁺ resonance at E_x=14582; they assign J^π=5/2⁻. The issue is unresolved.</p>
15270	$(5/2^-, 9/2^+)$	493 keV	FGH	Y		<p>Γ_α=154 keV; Γ_n=339 keV (2011Fr12) Decay Modes: n, α. E(level),Γ: From (2011Fr12) $^9\text{Be}(\alpha,\alpha)$. J^π: From (2011Fr12,1985To02). In (1991Aj01) the resonance is listed with J^π=9/2⁺, based on polarization data and phase-shift analysis of $^{12}\text{C}(n,n)$, (pol. n,n_{0,1}) in (1985To02), but the R-matrix analysis of (2011Fr12) $^9\text{Be}(\alpha,\alpha)$ find that interference from a J^π=9/2⁺ resonance is incompatible with their finding of a J^π=9/2⁺ resonance at E_x=14582; they assign J^π=5/2⁻. The issue is unresolved.</p>
15526 ^b 11	$3/2^-$	147 keV 23	H	M	Y	<p>XREF: Others: AO, AR XREF: Y(15458) Decay Modes: n, α. E(level),Γ: From (1989Mi01) $^{13}\text{C}(e,e')$. J^π: From polarization data and phase-shift analysis of $^{12}\text{C}(n,n)$, (pol. n,n_{0,1}) in (1985To02).</p>

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Adopted Levels, Gammas (continued)

¹³C Levels (continued)

E(level)	J ^π	T _{1/2} or Γ	XREF			Comments
16080 ^b 7	7/2 ⁺	148 keV 13	FGH	M O	Y	XREF: Others: AO , AP , AR , AS , AT Γ _α /Γ=0.15; Γ _n /Γ=0.85 (2011Fr12) XREF: H(16023)Y(16103)AP(16050) Decay Modes: n, α. E(level),Γ: From (1986Hi06) ¹³ C(e,e'). J ^π : From R-matrix analysis in (2011Fr12) ⁹ Be(α,α), a comparison (1981Pe08) of the ¹³ C(³ He,t) with the ¹³ C(³ He, ³ He) ¹³ N* (16.0 MeV: 7/2 ⁺) angular distributions, and from E3+M4 from 1/2 ⁻ in ¹³ C(e,e') (1986Hi06).
16.1×10 ^{3ab} 1	(1/2,3/2) ⁺					XREF: Others: AO , AT XREF: AO(16183) E(level),J ^π : From L=1 in (2021In04) ¹³ C(α,α'). See also E _x =16183 keV and Γ=40 keV 20 (1989Mi01) ¹³ C(e,e').
16152 35	(5/2 ⁻)	240 keV	GH		Y	XREF: Others: AR Γ _α /Γ=0.091; Γ _n /Γ=0.909 (2011Fr12) XREF: Y(16103) Decay Modes: n, α. E(level),Γ: From (1966Mi12) ⁹ Be(α,n). J ^π : From R-matrix analysis in (2011Fr12) ⁹ Be(α,α). See other discussion on polarization data and phase-shift analysis in (1985To02) ¹² C(n,n).
16948 ^c 35		330 keV	F H			XREF: Others: AM , AO , AR XREF: F(16.8E3) Decay Modes: γ, n, α. E(level),Γ: From (1966Mi12) ⁹ Be(α,n).
17363 69		190 keV	H			XREF: Others: AR Decay Modes: n, α. E(level),Γ: From (1966Mi12) ⁹ Be(α,n).
17533 3		17 keV 6			Y	XREF: Others: AP T=(3/2) (1987Hi03) XREF: AP(17500) Decay Mode: n. E(level),Γ: From (1987Hi03) ¹² C(n,n).
17709 35	(3/2 ⁻ ,5/2)	225 keV	H			XREF: Others: AO , AR Decay Modes: n, α. E(level): From (1966Mi12) ⁹ Be(α,n). J ^π : From (1988Co05) ¹³ C(p,p'), L=2 or 3 were consistent, but 7/2 ⁺ was considered unlikely because of the shape at small angles. Γ: From average of Γ=170 (1965Gr22) and 280 (1966Mi12) from ⁹ Be(α,n). See also Γ=300 keV (1971Be51). E(level): In (1981Aj01) E _x =17699 keV 5 is listed; the origin of this value is untraceable.
17920 ^c 50	(9/2 ⁺ ,7/2 ⁺)			M		XREF: Others: AM , AP

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Adopted Levels, Gammas (continued)

^{13}C Levels (continued)					
E(level)	J^π	$T_{1/2}$ or Γ	XREF		Comments
					Decay Modes: γ , n. E(level), J^π : From (1982Se04) $^{13}\text{C}(\pi,\pi)$; angular distributions are consistent with $\Delta J=4$, $\Delta L=3$ and $\Delta S=1$ amplitudes indicating $(9/2^+, 7/2^+)$.
18081 3		12 keV 7		Y	T=(3/2) (1987Hi03) Decay Mode: n. E(level), Γ : From (1987Hi03) $^{12}\text{C}(\text{n,n})$.
18332 35		305 keV	H		XREF: Others: AO, AR Decay Modes: n, α . E(level): From (1965Gr22) $^9\text{Be}(\alpha,\text{n})$. Γ : From $\Gamma=210$ keV (1965Gr22) and $\Gamma=400$ keV (1966Mi12) in $^9\text{Be}(\alpha,\text{n})$.
18497? ^{ab} 10		91 keV 23			XREF: Others: AO E(level), Γ : From (1989Mi01) $^{13}\text{C}(\text{e,e}')$.
18699 ^c 5	(3/2 ⁺ , 5/2 ⁺)	98 keV 11	H		XREF: Others: AN, AO, AR XREF: H(18750)AN(18600) Decay Modes: γ , n, p, α . E(level), Γ : From (1989Mi01) $^{13}\text{C}(\text{e,e}')$.
					J^π : From (1988Co05) $^{13}\text{C}(\text{p,p})$ where the angular distribution suggests the state corresponds to $^{12}\text{C}(18.3 \text{ MeV}: 2^-; T=0) \otimes 1p_{1/2}$ and where the ^{12}C state is that reported in (1983Ba57).
19.0 $\times 10^3$ 1		≈ 600 keV	F	P	XREF: F(18.7E3) Decay Modes: α . E(level), Γ : From $^{10}\text{B}(^{10}\text{B}, ^7\text{Be})$ and $^{10}\text{B}(^{10}\text{B}, \alpha + ^9\text{Be})$ (2023Je05).
19512	5/2 ⁻	≥ 500 keV		T Y	XREF: Others: AO, AR XREF: T(19692)AO(19300) Decay Modes: n, d. E(level), Γ : From (1987To03) $^{12}\text{C}(\text{n,n})$.
					J^π : From polarization data and phase-shift analysis of $^{12}\text{C}(\text{n,n})$, (pol. n, n _{0,1}) in (1987To03). See also (1980Th07).
19.74 $\times 10^3$?	(3/2, 5/2, 7/2) ⁺	200 keV	E		T=3/2 Decay Mode: p. E(level), J^π , Γ : From (2008Sk06) $^1\text{H}(^{12}\text{B}, \text{p})$. J^π : From L=0,2 in $^1\text{H}(^{12}\text{B}, \text{p})$. J=3/2 ⁺ is preferred.
19.9 $\times 10^3$		≈ 600 keV	E	ST	XREF: Others: AA, AR XREF: E(19740)AA(19798) Decay Modes: p, n, d. E(level), Γ : From (1967Di01) $^{11}\text{B}(\text{d,n})$.
20021 ^b 12		232 keV 27		T	XREF: Others: AO, AR

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Adopted Levels, Gammas (continued)

^{13}C Levels (continued)				
E(level)	J^π	$T_{1/2}$ or Γ	XREF	Comments
20057 4		11 keV 8		Decay Modes: n, d. E(level), Γ : From (1989Mi01) $^{13}\text{C}(e,e')$. T=(3/2) (1987Hi03) Decay Mode: n.
20111	1/2 ⁻	1090 keV		E(level), Γ : From (1987Hi03) $^{12}\text{C}(n,n)$. XREF: Others: AO $\Gamma_{n0}/\Gamma=0.16$ (1987To03) XREF: AO(20100) Decay Mode: n.
20111	5/2 ⁺	440 keV		E(level), Γ : From (1987To03) $^{12}\text{C}(n,n)$. See also $E_x=20.1$ MeV and $\Gamma=0.7$ MeV from (1971Be51) $^{13}\text{C}(e,e')$. J^π : From polarization data and phase-shift analysis of $^{12}\text{C}(n,n)$, (pol. n,n _{0,1}) in (1987To03). $\Gamma_{n0}/\Gamma=0.05$ (1987To03) Decay Mode: n.
20.13×10 ³ ?	(5/2,1/2,3/2) ⁻	120 keV	E	E(level), Γ : From (1987To03) $^{12}\text{C}(n,n)$. J^π : From polarization data and phase-shift analysis of $^{12}\text{C}(n,n)$, (pol. n,n _{0,1}) in (1987To03). T=3/2 Decay Mode: p. E(level), J^π,Γ : From (2008Sk06) $^1\text{H}(^{12}\text{B},p)$. J^π : From L=1 in $^1\text{H}(^{12}\text{B},p)$. J=5/2 ⁻ is preferred.
20185	7/2 ⁺	630 keV		$\Gamma_{n0}/\Gamma=0.11$ (1987To03) Decay Modes: n. E(level), J^π,Γ : From polarization data and phase-shift analysis of $^{12}\text{C}(n,n)$, (pol. n,n _{0,1}) in (1987To03).
20296	7/2 ⁻	1.56 MeV		$\Gamma_{n0}/\Gamma=0.08$ (1987To03) Decay Mode: n. E(level), Γ : From (1987To03) $^{12}\text{C}(n,n)$. J^π : From polarization data and phase-shift analysis of $^{12}\text{C}(n,n)$, (pol. n,n _{0,1}) in (1987To03).
20.30×10 ³ ?	(5/2,3/2,7/2) ⁺	170 keV	E	%p≤100 (2008Sk06) T=3/2 Decay Mode: p. E(level), J^π,Γ : From (2008Sk06) $^1\text{H}(^{12}\text{B},p)$. J^π : From L=0,2 in $^1\text{H}(^{12}\text{B},p)$. J=5/2 ⁺ is preferred.
20342	9/2 ⁺	320 keV		$\Gamma_{n0}/\Gamma=0.06$ (1987To03) Decay Modes: n. E(level), Γ : From (1987To03) $^{12}\text{C}(n,n)$. J^π : From polarization data and phase-shift analysis of $^{12}\text{C}(n,n)$, (pol. n,n _{0,1}) in (1987To03).

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Adopted Levels, Gammas (continued)

^{13}C Levels (continued)					
E(level)	J^π	$T_{1/2}$ or Γ	XREF		Comments
20429 ^{ab} 8		112 keV 23			XREF: Others: AO , AR E(level), Γ : From (1989Mi01) $^{13}\text{C}(e,e')$.
20.52 $\times 10^3$ 7	(5/2 ⁻)	510 keV 70	RST	XYZ	XREF: Others: AO XREF: R(20200)Z(20500) Decay Modes: γ , p, n, d. E(level), Γ : From (1984Wo05) $^{12}\text{C}(n,\gamma)$. See (1984Wo05) for discussion on penetrability effects that impact the $^{11}\text{B}(d,n\gamma)$ results of (1958Ka31): $E_x=20521$ keV 8 and $\Gamma=115$ keV 10, and (1964Ku09): $E_x=20521$ keV 16 and $\Gamma=120$ keV. In (1984Wo05) primary and secondary doorway states at $E_x=20.52$ and 21.05 MeV with $\Gamma=0.51$ MeV 7 and 4.2 MeV 4, respectively, are discussed. E(level): In (1985Au10) $^{11}\text{B}(\text{pol. } d,\gamma)$ the two doorway states are found at $E_x=20.20$ MeV 7 and 20.57 MeV 84 with $\Gamma=0.56$ MeV 9 and 5.64 MeV 43, respectively, which suggests a lower energy for the these states. J^π : From polarization data and phase-shift analysis of $^{12}\text{C}(n,n)$, (pol. n,n _{0,1}) in (1987To03).
20.93 $\times 10^3$ ^a 10		0.24 MeV 10			XREF: Others: AR E(level), Γ : From (1988Co05) $^{13}\text{C}(p,p')$.
21050 60		4.2 MeV 4	R	X	XREF: Others: AM , AN XREF: R(20.57E3)X(21050)AM(20.8E3)AN(20700) Decay Modes: γ , p, n, d. E(level), Γ : From (1984Wo05) $^{12}\text{C}(n,\gamma)$. See comments on the $E_x=20.52$ MeV level.
21281 15		160 keV 15	ST		XREF: Others: AO , AR Decay Modes: p, n, d. E(level), Γ : From (1958Ka31) $^{11}\text{B}(d,p)$. See also $\Gamma=530$ keV in (2003So24) $^7\text{Li}(^9\text{Be},\alpha)$ and $\Gamma=400$ keV (1971Be51) $^{13}\text{C}(e,e')$.
21.3 $\times 10^3$		530 keV	F		Decay Mode: α . E(level), Γ : From (2003So24) $^7\text{Li}(^9\text{Be},\alpha+^9\text{Be})$.
21466 ^b 8	(9/2 ⁺ ,7/2 ⁺)	268 keV 14	M		XREF: Others: AB , AO , AP , AR %n=24; %p=76 (2022Ci07) T=(3/2) (1986Hi06) $\Gamma_n/\Gamma=0.24$ 5 $\Gamma_{p0}/\Gamma<0.23$; $\Gamma_{p1}/\Gamma=0.69$ 6 XREF: M(21400)AP(21370) Decay Modes: p, n. Γ : partial widths from (2022Ci07).

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Adopted Levels, Gammas (continued)

^{13}C Levels (continued)				
E(level)	J^π	$T_{1/2}$ or Γ	XREF	Comments
				Γ_p : $\Gamma_{p(2+3)}/\Gamma=0.07$ 2. Γ_n : Decay is to $^{12}\text{C}^*$ (15.11 MeV: $J^\pi=1^+$, $T=1$). T: $T=3/2$ is suggested by (2022Ci07) because of the strong neutron branch to $^{12}\text{C}^*$ (15.1 MeV: $T=1$) state. E(level), Γ : From (1986Hi06,1989Mi01) $^{13}\text{C}(e,e')$. J^π : From M4 from $1/2^-$ in $^{13}\text{C}(e,e')$ in (1986Hi06); $9/2^+$ is strongly preferred. See also (1982Se04) $^{13}\text{C}(\pi,\pi)$ where angular distributions are consistent with $\Delta J=4$, $\Delta L=3$ and $\Delta S=1$ amplitudes indicating $(9/2^+,7/2^+)$, and see discussion in (1988Co05).
21703 4		18 keV 9		Y XREF: Others: AP T=(3/2) (1987Hi03) XREF: AP(21600) Decay Mode: n. E(level), Γ : From (1987Hi03) $^{12}\text{C}(n,n)$. J^π : See $J^\pi=(9/2,7/2)^+$ in (1982Se04) $^{13}\text{C}(\pi^\pm,\pi^\pm)$.
21814 17	$\geq 5/2$	144 keV 21	P T	XREF: Others: AO, AR XREF: P(22.0E3) Decay Modes: n, d. E(level), Γ : From (1964Ku09) $^{11}\text{B}(d,n)$. J^π : From (1988Co05) $^{13}\text{C}(p,p)$ where a uniform magnitude in the angular distribution suggests a high spin.
22.2×10^3 1	$\leq 5/2$	1.1 MeV 5	R T Z	XREF: Others: AO, AR XREF: Z(22000) Decay Modes: γ , p, n, d. E(level), Γ : From (1988Co05) $^{13}\text{C}(p,p')$. J^π : From (1988Co05) $^{13}\text{C}(p,p')$ where forward peaking in the angular distribution suggests low spin.
23.0×10^3 ^c 2	$(5/2^+,3/2^+)$	≈ 1.5 MeV		Y XREF: Others: AA, AN, AO, AR XREF: AN(23500)AO(24700) Decay Modes: γ , n, p. E(level), J^π : From (1970De14) $^{12}\text{C}(n,n)$ where the resonance is best fit with a $d_{5/2}$ component, but where $d_{3/2}$ and $f_{7/2}$ could not be ruled out. See also (1988Co05) $^{13}\text{C}(p,p')$ where forward peaking in the angular distribution suggests low spin ($\leq 5/2$). Γ : See references in $^{12}\text{C}(n,n)$.
23.6×10^3 1		≈ 1.1 MeV	F P	XREF: F(23.9E3) Decay Mode: α . E(level): From $^{10}\text{B}(^{10}\text{B},\alpha+^9\text{Be})$ (2023Je05). Γ : From $^7\text{Li}(^9\text{Be},\alpha+^9\text{Be})$ (2003So24,2004So19,2004So35).
24×10^3 ^c 2		10 MeV 2		XREF: Others: AM, AN, AO XREF: AN(24500)AO(24700) Decay Modes: γ , p, n. E(level), Γ : From (1957Co57) $^{13}\text{C}(\gamma,n),(\gamma,p)$.

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Adopted Levels, Gammas (continued) ^{13}C Levels (continued)

E(level)	XREF		Comments
26000? ^c			XREF: Others: AN , AO XREF: AO(25500) Decay Modes: γ , p. E(level): From (1983Zu02) $^{13}\text{C}(\gamma,p)$.
26791		T	Decay Modes: n, d. E(level): From (1965Al17) $^{11}\text{B}(d,n\gamma)$.
27466	L	T	XREF: Others: AO XREF: L(28025)AO(27300) Decay Modes: p, n, d, t. E(level): From (1965Al17) $^{11}\text{B}(d,n\gamma)$.
$\approx 30 \times 10^3$ ^c			XREF: Others: AM , AO XREF: AO(28100) Decay Modes: γ , n. E(level): From (1979Ju01) $^{13}\text{C}(\gamma,n)$.

^a Decay mode not specified.

^b In ([1991Aj01](#)), γ is listed as a decay mode based on the level's population in $^{13}\text{C}(e,e')$. This interpretation is not followed here.

^c This level is populated in either photo-neutron or photo-proton production; therefore γ is listed as a decay mode, but no decay γ ray is listed since no decay transitions are observed.

Adopted Levels, Gammas (continued)

E _i (level)	J ^π _i	γ(¹³ C)					Mult.	δ	α ^d	Comments
		E _γ	I _γ	E _f	J ^π _f					
3089.451	1/2 ⁺	3089.049 20	100	0	1/2 ⁻	[E1]		1.28×10 ⁻³ 2	α(K)=1.959×10 ⁻⁷ 27; α(L)=8.98×10 ⁻⁹ 13 α(IPF)=0.001284 18 B(E1)(W.u.)=0.0427 39 E _γ : From (1980Wa24) ¹⁰ B(α,pγ). See also E _γ =3088.95 keV 19 from ¹² C(n,γ):E=th (1982Mu14,2008FiZZ). B(E1)(W.u.)=0.0382 25 E _γ : From E _γ =595.5 2 (1982Mu14) and 595.16 keV 9 (2008FiZZ). from ¹² C(n,γ):E=th. I _γ : From (1982Mu14). α(K)=1.996×10 ⁻⁷ 28; α(L)=9.15×10 ⁻⁹ 13 α(IPF)=0.000910 13 B(M1)(W.u.)=0.384 20; B(E2)(W.u.)=3.5 7 Mult.,δ: From (1980Wa24) who used B(E2) from (1970Wi04) ¹³ C(e,e') and τ _m to obtain δ=-0.094 9. See also δ=-0.096 +30-21 (1966Po11), δ=-0.154 54 (1973Go02) and δ=-0.100 8 (1969Wi22, 1970Wi04). E _γ : From E _γ =3684.0 2 (1982Mu14), 3683.94 keV 17 (1967Pr10), and 3684.02 keV 7 (2008FiZZ) from ¹² C(n,γ):E=th. See also E _γ =3685.041 keV 20 (1991Li12) ¹³ C(γ,γ). I _γ : From (1982Mu14). Mult.: From (1980Wa24). α(K)=0.0001402 20; α(L)=6.42×10 ⁻⁶ 9 B(E1)(W.u.)=0.01065 28 E _γ : From (1980Wa24) ¹⁰ B(α,pγ) and ¹² C(d,pγ). See also E _γ =169.356 keV 20 (1984Sc09). B(E2)(W.u.)=1.67 7 E _γ : From (1980Wa24) ¹⁰ B(α,pγ) and ¹² C(d,pγ). α(K)=2.406×10 ⁻⁷ 34; α(L)=1.102×10 ⁻⁸ 15 α(IPF)=0.000729 10 B(M2)(W.u.)=0.473 12; B(E3)(W.u.)=10.8 49 Mult.,δ: From (1966Po11) γγ angular correlations in ¹² C(d,pγ). E _γ : From (1969Li07). 3853.183 keV 21 is deduced from E _x and level-energy difference.	
3684.496	3/2 ⁻	595.22 8	0.75 3	3089.451	1/2 ⁺	[E1]				
		3684.01 6	100.00 3	0	1/2 ⁻	[M1+E2]	-0.094 9	9.10×10 ⁻⁴ 13		
3853.796	5/2 ⁺	169.300 4	58.1 ^c 10	3684.496	3/2 ⁻	[E1]		1.47×10 ⁻⁴ 2		
		764.316 10	1.92 ^c 6	3089.451	1/2 ⁺	[E2]				
		3854 1	100.0 ^c 10	0	1/2 ⁻	[E3+M2]	+0.12 3	7.29×10 ⁻⁴ 10		
(4946.33)	1/2 ⁺	1261.74 ^b 4	47.96 ^b 65	3684.496	3/2 ⁻					
		1856.89 ^b 19	0.24 ^b 2	3089.451	1/2 ⁺					
		4945.32 ^b 6	100.0 ^b 14	0	1/2 ⁻					
7492	(7/2 ⁺)	7490 ^a		0	1/2 ⁻	[E3]			Γ _γ : Γ _γ /Γ from (1971HiZF) ¹¹ B(³ He,pγ).	

Adopted Levels, Gammas (continued)

γ(¹³C) (continued)

<u>E_i(level)</u>	<u>J_i^π</u>	<u>E_γ</u>	<u>I_γ</u>	<u>E_f</u>	<u>J_f^π</u>	<u>Mult.</u>	<u>δ</u>	<u>Comments</u>
7547	5/2 ⁻	7545 ^a		0	1/2 ⁻	[E2+M3]	0.009 6	Γ _γ =0.110 eV 15 (1980Ho11) B(E2)(W.u.)=3.2 2; B(M3)(W.u.)=35 21 Γ _γ : From (1980Ho11) ¹³ C(γ,n ₀). The decay γ ray is reported in (1971HiZF) ¹¹ B(³ He,pγ). δ: Deduced from Γ _γ (E2)=0.115 eV 7 and Γ _γ (M3)=1.01E-5 eV 61, which are the electromagnetic partial widths determined in (1969Wi22, 1970Wi04) ¹³ C(e,e').
8866	1/2 ⁻	8863 ^a		0	1/2 ⁻	[M1]		Γ _γ =5.4 eV 5 (1980Ho11) B(M1)(W.u.)=0.374 35 Γ _{γ0} : From (1980Ho11) ¹³ C(γ,n ₀). The decay γ ray is observed in (2001Ne09) ¹⁶ O(n,αγ).
15108.7	3/2 ⁻	7559 ^a	<3.9	7547	5/2 ⁻	[M1]		Γ _γ <0.9 eV B(M1)(W.u.)<0.101 I _γ : From (1977Ma16). B(M1)(W.u.)≤0.589 I _γ : From (1977Ma16). Γ: Γ _{γ₂₊₃} =18.2 eV 24 unresolved.
		11419 ^a	78 10	3684.496	3/2 ⁻	[M1]		Γ _γ =4.12 eV 74 B(E1)(W.u.)=6.3×10 ⁻³ 12 I _γ : From (1977Ma16).
		12013 ^a	17.8 32	3089.451	1/2 ⁺	[E1]		Γ _γ =23.2 eV 15 B(M1)(W.u.)=0.317 21; B(E2)(W.u.)=0.51 11 I _γ : From Γ _{γ0} deduced from analysis of (1968Co27, 1977Ma16, 1978Hi06, 1969Wi22, 1970Wi04).
		15099 ^a	100.0 65	0	1/2 ⁻	[M1+E2]	0.161 17	Mult.,δ: From Γ _{γ0} (M1)=22.7 eV 27 and Γ _{γ0} (E2)=0.59 eV 11 (1969Wi22, 1970Wi04) ¹³ C(e,e'). See also δ ² =0.009 +18-8 and δ=0.095 7 (1968Di04) from ¹² C(p,γ), which is used in earlier studies of the analog transition since the ¹³ C and ¹³ N δs are expected to be similar.
20.52×10 ³	(5/2 ⁻)	20503 ^a		0	1/2 ⁻			Decay transition reported in (1984Wo05) ¹² C(n,γ) and (1985Au10) ¹¹ B(pol. d,γ).
21050		21037 ^a		0	1/2 ⁻			Decay transition reported in (1984Wo05) ¹² C(n,γ) and (1985Au10) ¹¹ B(d,γ).
22.2×10 ³	≤5/2	22180 ^a		0	1/2 ⁻			Decay transition reported in (1981Ka16) ¹¹ B(d,γ).

^a From level-energy difference.

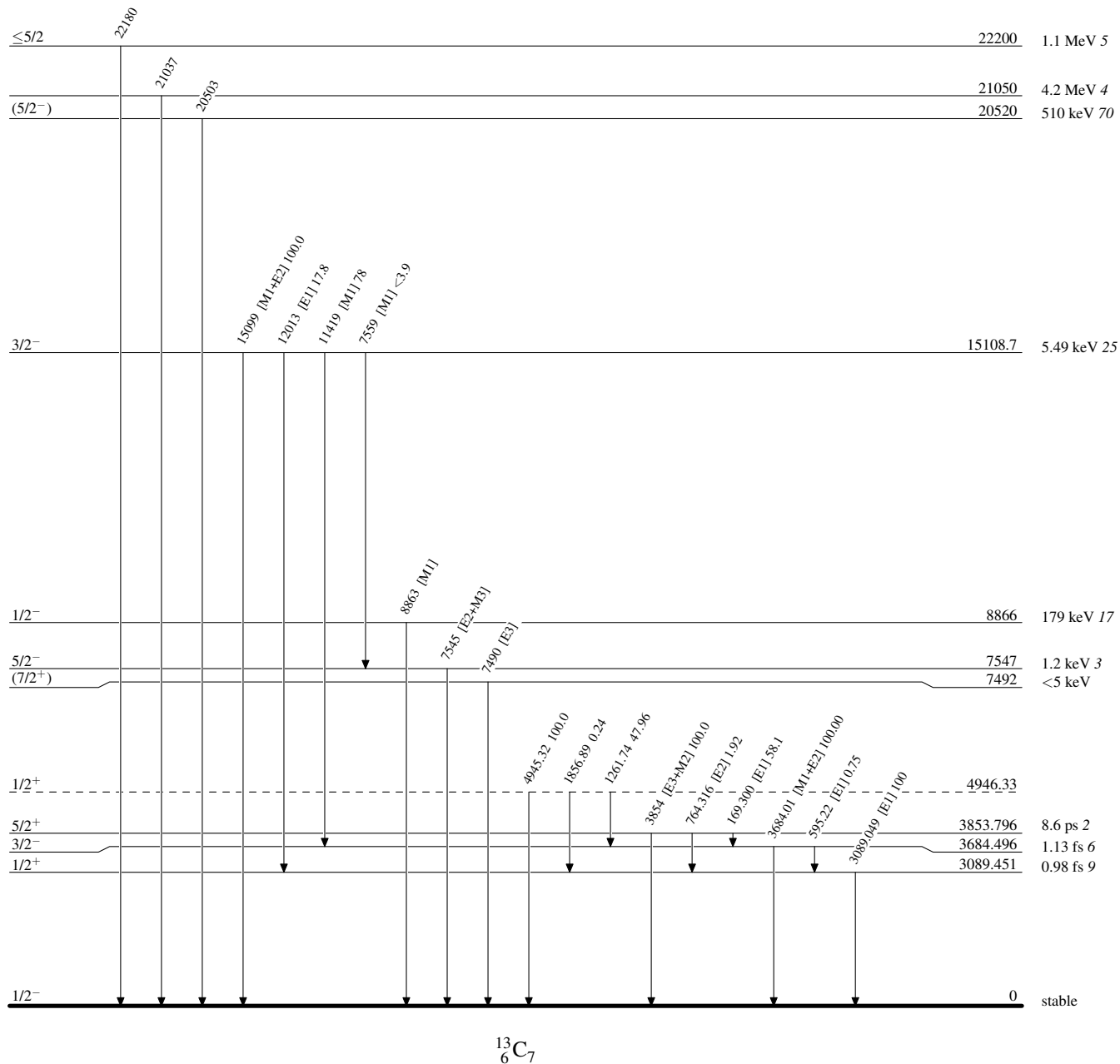
^b From ¹²C(n,γ):E=thermal.

^c From (1980Wa24).

^d Total theoretical internal conversion coefficients, calculated using the BrIcc code (2008Ki07) with "Frozen Orbitals" approximation based on γ-ray energies, assigned multipolarities, and mixing ratios, unless otherwise specified.

Adopted Levels, GammasLevel Scheme

Intensities: Relative photon branching from each level



^{13}B β^- decay

Parent: ^{13}B : $E=0$; $J^\pi=3/2^-$; $T_{1/2}=17.30$ ms 17; $Q(\beta^-)=13436.9$ 10; $\% \beta^-$ decay=100.0

^{13}B - $T_{1/2}$: From Adopted Levels.

^{13}B - $Q(\beta^-)$: From (2021Wa16).

1968Ma19: $^{13}\text{B}(\beta^-)$ from $^{11}\text{B}(t,p)$; measured β particles, and γ rays. Deduced ratio of $T_{1/2}(^{13}\text{B}/^{12}\text{B})=0.86$ 2. This presently implies $T_{1/2}=17.39$ ms 41. Deduced dominant decay branches to $^{13}\text{C}^*(0,3.68$ MeV) with $I\beta\approx 93\%$ and 7% , respectively; limits are set on other branches, including $<1.5\%$ from β -n events.

1968Ch28: Activated a natural boron target with tritons and measured β particles and delayed neutrons. Deduced $T_{1/2}=16$ ms 1 and $\% \beta$ -n=0.52 26. Compared with ^{13}O β -p.

1969Jo21: $^{13}\text{B}(\beta^-)$ from $^{11}\text{B}(t,p)$; measured $\beta\gamma$ -coin, E_β , β -n. Deduced branches to $^{13}\text{C}^*(0,3.68,7.58$ 6,8.79 10) with $I\beta(\%)=92.1$ 8, 7.6 8, 0.094 20 and 0.16 3, respectively.

1971Wi07: $^{13}\text{B}(\beta^-)$ from $^{11}\text{B}(t,p)$; measured $T_{1/2}=17.33$ ms 17.

1974Al12: $^{13}\text{B}(\beta^-)$ from $^{11}\text{B}(t,p)$; measured β -n-coin; deduced $\%I\beta(9.90)=0.022$ 7 by normalizing to $\%I\beta(8.86)=0.16$ 3 from (1969Jo21). Set upper limit on $\%I\beta(9.50)<0.01$. Discussed J^π values.

1988Sa04: $^{13}\text{B}(\beta^-)$ from $^{181}\text{Ta}(^{22}\text{Ne}, ^{13}\text{B})$; ^{13}B ; measured $T_{1/2}=17.6$ ms 12.

1991Re02,1994ReZZ, 1995ReZZ, 2008ReZZ: $^{13}\text{C}(\beta^-)$ using spallation products from $p+^{232}\text{Th}$. Ions were implanted in a Si detector and identification via standard techniques. $\% \beta$ -n from polyethylene moderated ^3He counter (zero-threshold). The β -delayed neutron probability ($P_n = P_{1n} + 2P_{2n} + 3P_{3n} + \dots$) and half-life were deduced. The evaluator favors the values from (1994ReZZ,2008ReZZ) $T_{1/2}=16.7$ ms 6 and $P_n=0.24$ 15, but other values based on this work are (1991Re02) $T_{1/2}=11$ ms 9 and $P_n=0.3$ 1.

1997So34: $^{13}\text{B}(\beta^-n)$; measured β -delayed neutrons, E_n , I_n ; deduced limit on $\%I\beta$ and $T_{1/2}=17.0$ ms 4. Results are generally excluded due to the limited description of the method.

2002GeZT,2005GeZY: $^{13}\text{B}(\beta^-)$ from $^{11}\text{B}(t,p)$; measured reaction excitation function from analysis of $E_\gamma=3681$ keV yield. Deduced $T_{1/2}\approx 17.36$ ms.

2004Na38: $^{13}\text{B}(\beta^-)$; measured $I_\beta(\theta,H,t)$, β -NMR and β -NQR spectra from polarized source. Deduced ^{13}B quadrupole moment and μ .

2006Ge21: $^{13}\text{B}(\beta^-)$ from $^{11}\text{B}(t,p)$; measured reaction excitation function from analysis of $E_\gamma=3681$ keV yield. Deduced $T_{1/2}\approx 16.59$ ms 2; discussed observed lifetime and suggested (t,d) contamination gives higher lifetime.

2010Ma44: $^{13}\text{B}(\beta^-)$; measured E_β , $I_\beta(\theta)$ from aligned ^{13}B ; deduced alignment correlation coefficient, G-parity tensor coupling constant.

Theory:

1977Ri08: Analysis of $\log ft$ values for $A=10-15$.

2003Fo11: ^{13}B ; analyzed β -delayed neutron decay data; deduced ground-state configuration features.

2003Sm02: $^{13}\text{B}(\beta^-)$; calculated Gamow-Teller decay rates. Comparison with data. ^{13}C calculated μ , quadrupole moments.

 ^{13}C Levels

E(level) ^a	J^π ^a	$T_{1/2}$ ^a	Comments
0	$1/2^-$	stable	
3089.451 19	$1/2^+$	0.98 fs 9	
3684.496 22	$3/2^-$	1.13 fs 6	
3853.796 21	$5/2^+$	8.6 ps 2	
7547 3	$5/2^-$	1.2 keV 3	$\%n\approx 100$
8866 9	$1/2^-$	179 keV 17	$\%n\approx 100$
9894.50 17	$3/2^-$	23.7 keV 4	$\%n\approx 100$

^a From Adopted Levels.

^{13}B β^- decay (continued) β^- radiations

E(decay)	E(level)	$I\beta^{-ac}$	Log ft	Comments
(3542.4 14)	9894.50	0.022 ^b 7	4.95 14	av $E\beta=1575.00$ 48
(4571 9)	8866	0.16 3	4.59 8	av $E\beta=2073.8$ 44
(5889.9 33)	7547	0.094 20	5.33 9	av $E\beta=2718.1$ 16
(9583.1 14)	3853.796	≤ 0.7	≥ 5.5	av $E\beta=4533.61$ 49
(9752.4 14)	3684.496	7.6 8	4.453 46	av $E\beta=4617.01$ 49
(10347.5 14)	3089.451	≤ 0.7	≥ 5.6	av $E\beta=4910.19$ 49
(13436.9 17)	0	92.1 8	4.037 6	av $E\beta=6433.44$ 49

$I\beta^-$: From 100%- Σ (decay to excited states).

^a From (1969Jo21), except where noted.

^b From (1974Al12) intensities are determined relative to $\%I\beta=0.16$ to $^{13}\text{C}^*$ (8.86) from (1969Jo21).

^c Absolute intensity per 100 decays.

 $\gamma(^{13}\text{C})$

E_γ ^b	I_γ ^{ac}	E_i (level)	J_i^π	E_f	J_f^π	Mult. ^b	δ ^b	Comments
169.300 4	≤ 0.009	3853.796	5/2 ⁺	3684.496	3/2 ⁻	[E1]		
595.22 8	0.057 7	3684.496	3/2 ⁻	3089.451	1/2 ⁺	[E1]		$\%I_\gamma=0.057$ 7
764.316 10	≤ 0.3	3853.796	5/2 ⁺	3089.451	1/2 ⁺	[E2]		
3089.049 20	≤ 0.7	3089.451	1/2 ⁺	0	1/2 ⁻	[E1]		
3684.01 6	7.6 8	3684.496	3/2 ⁻	0	1/2 ⁻	M1+E2	-0.094 9	$\%I_\gamma=7.6$ 8
3854 1	≤ 0.5	3853.796	5/2 ⁺	0	1/2 ⁻	[E3+M2]	+0.12 3	

^a Deduced from $I\beta$ and adopted γ branching ratios.

^b From Adopted Gammas.

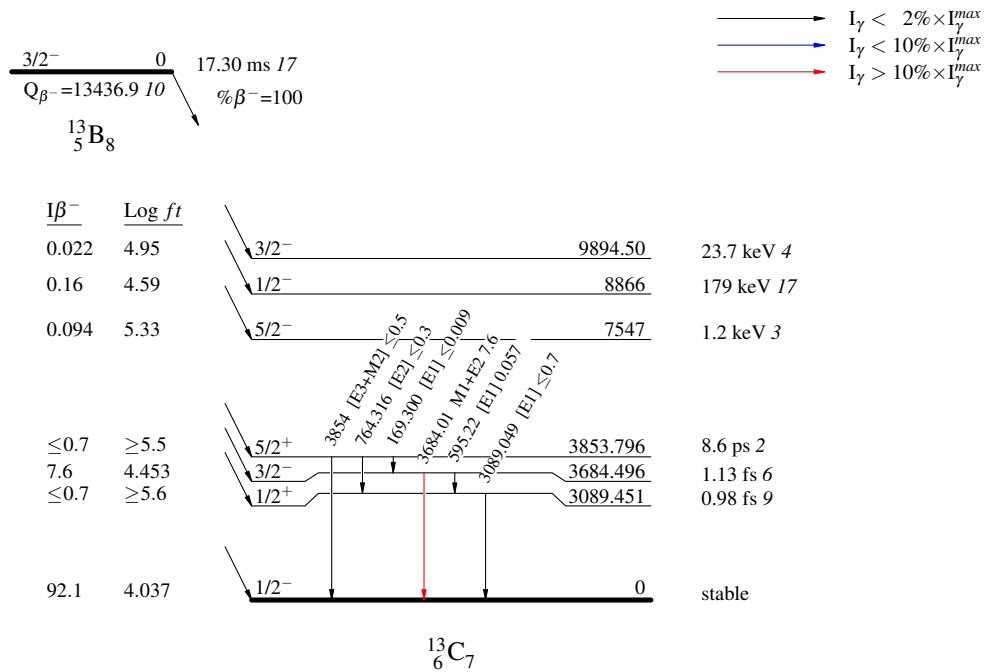
^c Absolute intensity per 100 decays.

$^{13}\text{B} \beta^-$ decay

Decay Scheme

Intensities: I_γ per 100 parent decays

Legend



${}^{13}\text{N}$ $\varepsilon+\beta^+$ decay

Parent: ${}^{13}\text{N}$; $E=0$; $J^\pi=1/2^-$; $T_{1/2}=9.9584$ min 36; $Q(\varepsilon)=2220.47$ 27; $\% \varepsilon + \% \beta^+$ decay=100.0

${}^{13}\text{N}$ - $T_{1/2}$: From Adopted Levels of ${}^{13}\text{N}$.

${}^{13}\text{N}$ - $Q(\varepsilon)$: From (2021Wa16).

1935Ru01: ${}^{13}\text{N}(\beta^+)$; ${}^{10}\text{B}(\alpha, n)$ was used to produce ${}^{13}\text{N}$, which was found to decay with $T_{1/2} \approx 14$ minutes.

1939Wa09: measured $T_{1/2}=9.93$ min 3.

1948Co24: ${}^{13}\text{N}(\beta^+)$; measured $T_{1/2}=10.2$ min 1.

1950Ho01: ${}^{13}\text{N}(\beta^+)$; measured end-point energy $E_\beta(\text{max})=1.202$ MeV 5 and $T_{1/2}=10.05$ min 10.

1953Ch34: ${}^{13}\text{N}(\beta^+)$; measured $T_{1/2}=602.9$ sec 19= 10.05 min 3.

1954Gr66: ${}^{13}\text{N}(\beta^+)$; measured $E_\beta(\text{max})=1.185$ MeV 25.

1955Wi43: ${}^{13}\text{N}$; measured $T_{1/2}=10.08$ min 4.

1957Da08: ${}^{13}\text{N}(\beta^+)$; measured $T_{1/2}=9.96$ min 3.

1957De22: ${}^{13}\text{N}(\beta^+)$; measured $T_{1/2}=10.02$ min 10.

1957No17: ${}^{13}\text{N}(\beta^+)$; measured $T_{1/2}=10.07$ min 6.

1958Ar15: ${}^{13}\text{N}(\beta^+)$; measured $T_{1/2}=9.96$ min 3.

1958Da09: ${}^{13}\text{N}(\beta^+)$; measured $E_\beta(\text{max})=1.190$ MeV 3 and $T_{1/2}$ as in (1957Da08).

1960Ja12: ${}^{13}\text{N}(\beta^+)$; measured $T_{1/2}=9.9965$ min 5.

1960Ki02: ${}^{13}\text{N}(\beta^+)$; measured $T_{1/2}=9.93$ min 5.

1961Ra06: ${}^{13}\text{N}(\beta^+)$; measured $T_{1/2}=12.3$ min 7 (excluded).

1965Bo42: ${}^{13}\text{N}(\beta^+)$; measured $T_{1/2}=10.05$ min 5.

1965Eb01: ${}^{13}\text{N}(\beta^+)$; measured $T_{1/2}=9.96$ min 2.

1968Ri15: ${}^{13}\text{N}(\beta^+)$; measured $T_{1/2}=9.963$ min 9.

1971Go40: ${}^{13}\text{N}(\beta^+)$; for decay to ${}^{13}\text{C}_{\text{g.s.}}$, $\log ft=3.667$ 1.

1973SiYS: ${}^{13}\text{N}(\beta^+)$; measured $T_{1/2}=10.0$ min 5.

1977Az01: ${}^{13}\text{N}(\beta^+)$; measured $T_{1/2}=9.965$ min 10.

1980An40: ${}^{13}\text{N}(\beta^+)$; measured $T_{1/2}=9.967$ min 10.

1989KaYR: ${}^{13}\text{N}(\beta^+)$; measured $T_{1/2}=9.962$ min 20.

2022Lo14: ${}^{13}\text{N}(\beta^+)$; measured $T_{1/2}=9.9508$ min 32; provided an analysis using only their value and (1968Ri15, 1977Az01) and recommended $T_{1/2}=9.9532$ min 37.

1995Va27: ${}^{13}\text{N}(\beta^+)$; measured β asymmetry following beam implantation in Pt; deduced beam polarization.

Theory:

1970Ko41: general model for β decay in even-odd nuclei.

1970Da21: generalized pairing-force model analysis of $\log ft$ values.

1972Ma72: calculated β shape spectra.

1973Wi04: analysis of the Axial-Vector coupling constant.

1973Su04: analysis of K-electron capture branching ratios.

1975Kr14: developed O(5) symmetry model to analyzed $\log ft$ values.

1977Ri08: Shell model analysis of $\log ft$ values.

1980An31: analysis of K-electron capture rates.

1984Ko40: analyzed isotensor component in isovectorial transition.

1991Na05: analyzed mirror nuclei decays in a search for evidence of right-handed currents.

1995Go34: analyzed β -decay polarization asymmetry data in a search for evidence of right-handed chirality.

2008Se10: analyzed half-lives, branching ratios, electron-capture probabilities; deduced ft values in mirror decays.

2008Pe13: analyzed correlations between β decays in mirror nuclei and their magnetic moments.

2012Sa50: analysis of isospin related corrections for superallowed β transitions.

2015Mo10, 2010MoZU: calculated improved beta spectra, shape factors, mean energies, experimental mean energies.

2015To02: developed parametrization of the statistical rate functions, f , for superallowed T=1/2 transitions.

2021Ir01: single-particle model analysis of the ${}^{13}\text{N}(\beta^+)$ reaction. Emphasized asymptotic normalization coefficients (ANCs) and spectroscopic factor data.

2021Da11: analyzed the role of tensor forces in β decay.

2024Fa01: analyzed decay between isobaric analog mirror states.

^{13}N $\varepsilon+\beta^+$ decay (continued) ^{13}C Levels

<u>E(level)</u>	<u>J^{π}</u>	<u>T_{1/2}</u>
0	1/2 ⁻	stable

 ε,β^+ radiations

<u>E(decay)</u>	<u>E(level)</u>	<u>Iβ^+^a</u>	<u>Iε^a</u>	<u>Log ft</u>	<u>I($\varepsilon+\beta^+$)^a</u>	<u>Comments</u>
(2220.5 15)	0	99.803 5	0.197 5	3.67174 44	100	av E β =492.21 12; ε K=0.00182 5; ε L=1.466 \times 10 ⁻⁴ 42 C1=0.001 24 (1958Da09). Cexp(W) = 1+C ₁ W.

^a Absolute intensity per 100 decays.

${}^{14}\text{B}$ β^- n decay 1994ReZZ

Parent: ${}^{14}\text{B}$: $E=0$; $J^\pi=2^-$; $T_{1/2}=12.6$ ms 6; $Q(\beta^-n)=12467$ 21; $\% \beta^-n$ decay=6.1 3

${}^{14}\text{B}$ - $T_{1/2}$: Weighted average (external errors) of $T_{1/2}=16.1$ ms 12: (1974Al11), 12.8 ms 8: (1986Cu01) and 12.4 ms 3: (1994ReZZ, see other results in 1991Re02, 1993ReZX, 1994KiZU, 1995ReZZ, 2008ReZZ). See also 13.7 ms 6 in (1987IsZZ).

${}^{14}\text{B}$ - $Q(\beta^-n)$: From (2021Wa16).

1991Re02: ${}^{14}\text{B}(\beta^-n)$; measured $T_{1/2}$, neutron emission probability, upper limits. TOF isochronous spectrometer, ion-neutron delayed coincidence.

1993ReZX: Spallation products from 800 MeV proton bombardment of a ${}^{232}\text{Th}$ target were captured by a transport line with a mass-to-charge filter and transferred to the TOFI spectrometer at LAMPF. The beamline was separately tuned to transport a number of different nuclides. The neutrons were detected in a polyethylene moderated ${}^3\text{He}$ counter, and standard techniques were implemented. The β -delayed neutron probabilities were deduced from analysis of the number of implanted ions (per beam pulse) and the rate of β -delayed neutrons detected in the zero-threshold counter.

An associated conference report (1994ReZZ) indicates the β -delayed neutron probability $P_n=6.1\%$ 3 and $T_{1/2} = 12.4$ ms 3.

Results presented in (1993ReZX) analyzed the data measured in the polyethylene moderated ${}^3\text{He}$ counter and deduced a general value for the energy of neutrons emitted from the decay; $E_n=1.38$ MeV +86-65. The value $E_n=1.3$ MeV 3 is published in (1994ReZZ).

1993Ok02: ${}^{14}\text{B}(\beta^-n)$; measured NMR spectra; deduced g factor.

1994KiZU: ${}^{14}\text{B}(\beta^-n)$; measured decay products, TOF, E_n , I_n , E_α , I_α ; deduced $T_{1/2}$, neutron emission probability. Comparison with available data.

1995ReZZ: ${}^{14}\text{B}(\beta^-n)$; measured neutron emission probabilities. TOF isochronous spectrometer.

1996OgZY: ${}^{14}\text{B}(\beta^-)$; measured E_β , β -delayed E_γ .

 ${}^{13}\text{C}$ Levels

<u>E(level)</u>	<u>J^π^a</u>
0.0	1/2 ⁻

^a From Adopted Levels for ${}^{13}\text{C}$.

Delayed Neutrons (${}^{13}\text{C}$)

<u>E(${}^{13}\text{C}$)</u>	<u>I(n)^a</u>
0.0	6.1 3

^a Absolute intensity per 100 decays.

${}^{17}\text{N}$ β^- α decay 1994Do08

Parent: ${}^{17}\text{N}$: $E=0$; $J^\pi=1/2^-$; $T_{1/2}=4.173\text{ s } 4$; $Q(\beta^- \alpha)=2320\text{ } 15$; $\% \beta^- \alpha\text{ decay}=0.0025\text{ } 4$

${}^{17}\text{N}$ - $T_{1/2}$: From weighted average of (1976Oh05,1972A142).

${}^{17}\text{N}$ - $Q(\beta^- \alpha)$: From (2021Wa16).

1993Bu21: ${}^{17}\text{N}(\beta^- \alpha)$; measured β -delayed E_α , I_α . The alphas ($E_\alpha=1.24$ and 1.40 MeV) result from decay of the 7.99 MeV and 8.20 MeV states in ${}^{17}\text{O}$. More details in (1994Do08).

1994Do08: A thick target was bombarded by 600 MeV protons to produce ${}^{17}\text{N}$ ions that were selected by the TISOL separator.

The ${}^{17}\text{N}$ beam was implanted into a thin carbon-foil collector. Thin surface barrier detector pairs counted the decay α particles in coincidence with ${}^{13}\text{C}$ recoils.

$T_{1/2}=3.92\text{ s } 44$ was reported which is in good agreement of $4.173\text{ s } 4$ (weighted average of 1976Oh05: $4174\text{ ms } 4$ and 1972A142:

$4169\text{ ms } 8$). The α spectrum was reasonably fitted with a K-matrix parametrization using the known resonances at ${}^{17}\text{O}^*(7.985$ and 8.204 MeV). Although two states are sufficient to fit the α -spectrum, the possibility of decay from the broad ${}^{17}\text{O}^*(7.56)$ state cannot be entirely discounted.

A small contamination of ${}^{18}\text{N}$ in the beam was used to make a relative normalization of the ${}^{17}\text{N}$ and ${}^{18}\text{N}$ activities; then using the lifetimes and ${}^{18}\text{N}$ decay results from (1989Zh04), the absolute $\beta\alpha$ branching of ${}^{17}\text{N}$ was determined to be $(2.5\text{ } 4)\times 10^{-5}$. The $\beta\alpha$ branching intensities to ${}^{17}\text{O}^*(7.985, 8.204)$ were found to be $(1.5\text{ } 3)\times 10^{-5}$ and $(9.8\text{ } 20)\times 10^{-6}$, respectively. An upper limit of delayed α decay intensity from ${}^{17}\text{O}^*(7.56)$, $<6.9\times 10^{-7}$, is deduced; though the small $\Gamma_\alpha/\Gamma=0.0002$ for this state corresponds to a rather large $I < 3.5\%$ beta-decay intensity to this state that could be observed in other decay channels. Another possible level at ${}^{17}\text{O}^*(8.18)$ could influence the $\beta\alpha$ decay, but the best fit in this experiment showed a minimal and excludable effect.

 ${}^{13}\text{C}$ Levels

<u>E(level)</u>	<u>J^π</u>
0.0	$1/2^-$

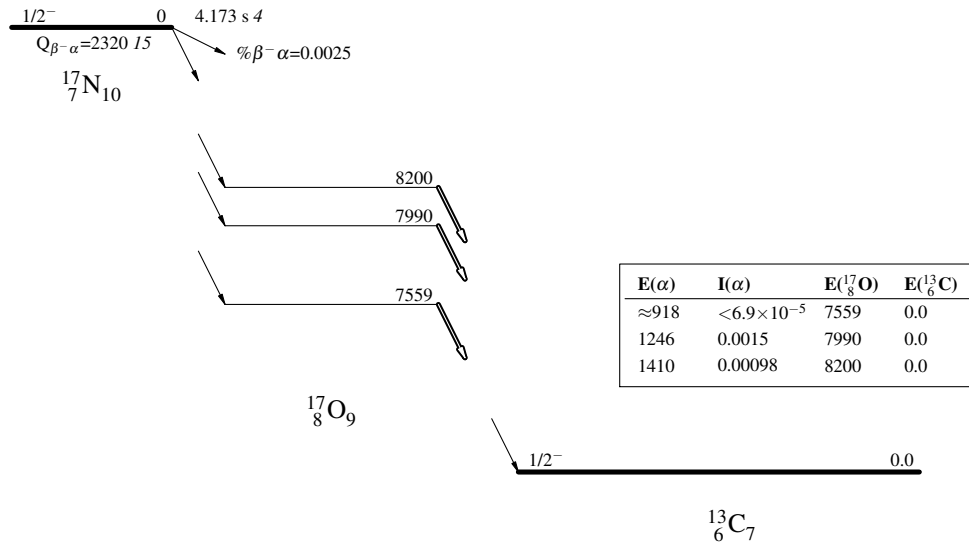
Delayed Alphas (${}^{13}\text{C}$)

<u>E(α)</u>	<u>E(${}^{13}\text{C}$)</u>	<u>I(α)^a</u>	<u>E(${}^{17}\text{O}$)</u>
≈ 918	0.0	$<6.9\times 10^{-5}$	7559
1246 12	0.0	$1.5\times 10^{-3}\text{ } 3$	7990
1410 5	0.0	$9.8\times 10^{-4}\text{ } 20$	8200

^a Absolute intensity per 100 decays.

^{17}N β^- - α decay **1994Do08**

Decay Scheme

 $I(\alpha)$ Intensities: $I(\alpha)$ per 100 parent decays

$^1\text{H}(^{12}\text{B},\text{p})\text{:res}$ 2008Sk06

2008Sk06: XUNDL dataset compiled by McMaster, 2008.

A $E(^{12}\text{B})=44.6$ MeV beam from the Notre Dame TwinSol RIB facility impinged on a 16.97 mg/cm² CH₂ target that stopped the beam. Scattered protons were detected at $\theta=7.5^\circ$ and 15° using two Si ΔE -E telescopes. The excitation function for elastic proton scattering at $E_{\text{c.m.}}=1.25$ - 3.2 MeV was obtained using a thick-target inverse kinematics technique. Resonances were deduced and analyzed using an R-matrix analysis. Based on comparison with ^{13}O and ^{13}B , resonances at $E_{\text{c.m.}}=0.87$ ($l=0, (1/2^+), \Gamma=190$ keV) and 1.07 MeV ($l=0+2, (3/2^+), \Gamma=90$ keV) are assumed in the unmeasured low-energy region to account for the excess strength in this area.

Potential analog states in ^{13}N and ^{13}C are discussed.

					<u>^{13}C Levels</u>		
<u>$E(\text{level})^a$</u>	<u>J^π^b</u>	<u>Γ^b</u>	<u>L^b</u>	<u>$E(\text{c.m.}) (\text{MeV})^b$</u>		<u>Comments</u>	
19110?	$(3/2, 1/2, 5/2)^-$	<30 keV	1	1.58	T=3/2	J^π : $3/2^-$ is preferred.	
19740	$(3/2, 5/2, 7/2)^+$	200 keV	0,2	2.20	T=3/2	J^π : $3/2^+$ is preferred. E(level): If $J^\pi=5/2^+$ or $7/2^+$ then $E_{\text{c.m.}}=2350$ keV ($E_x=19900$ keV).	
20130	$(5/2, 1/2, 3/2)^-$	120 keV	1	2.60	T=3/2	J^π : $5/2^-$ is preferred.	
20300	$(5/2, 3/2, 7/2)^+$	170 keV	0,2	2.77	T=3/2	J^π : $5/2^+$ is preferred.	

^a S(p)+E(c.m.), where S(p) of $^{13}\text{C}=17533.4$ I3 (2021Wa16).

^b From R-matrix analysis.

$^7\text{Li}(^9\text{Be},\alpha^9\text{Be}), ^{14}\text{C}(^{13}\text{C},\alpha^9\text{Be})$

2003So24, 2004So19, 2004So35: $^7\text{Li}(^9\text{Be},\alpha^9\text{Be})$ E=70 MeV at the ANU accelerator facility in Canberra. Measured $E_{\text{rel}}(\alpha+^9\text{Be})$ spectrum using four strip detector telescopes. Deduced resonance energies, cluster structure.

2006Pr01: $^{14}\text{C}(^{13}\text{C},^{13}\text{C}'\rightarrow\alpha^9\text{Be})$ E=77.8,112.25,119.25 MeV at the Vivitron facility in Strasbourg. Measured $E_{\text{rel}}(\alpha+^9\text{Be})$ spectrum using two strip detector telescopes at $\theta=(+)21.2^\circ$ and $\theta=(-)17.4^\circ$. Deduced excited state energies, $\sigma(E_x,\theta)$ for $\theta\approx 5^\circ-25^\circ$, J, π , α -decay features, α -cluster structure. Compared with earlier results.

Theory:

2003Fr38: $^7\text{Li}(^9\text{Be},\alpha^9\text{Be})$ E=70 MeV; analyzed excitation energy spectra. Deduced level energies, cluster structure.

2007Pe26: ^{13}C ; calculated α -decay and cluster decay widths; deduced Γ . Self-consistent mean-field model, folding form cluster potential.

2008Yo10: ^{13}C ; calculated low-lying negative parity state energies, J, π , B(E0); deduced α -breaking effect. Microscopic cluster model.

 ^{13}C Levels

<u>E(level)^a</u>	<u>Jπ^d</u>	<u>Γ^c</u>	<u>Comments</u>
12.0×10 ³	5/2 ⁺		
13.2×10 ³ ^b 1	(9/2) ⁻		E(level): See also (2003So24,2004So19,2004So35: E _x =13400 keV).
13.6×10 ³ ? ^b 2	7/2 ⁻		
14.2×10 ³ ^b 1	3/2 ⁻		E(level): See also (2003So24,2004So19,2004So35: E _x =14100 keV). J ^π : Measurements of (2006Pr01) suggest 5/2 ⁺ .
14.6×10 ³	(7/2 ⁺ ,9/2 ⁺)		
15.0×10 ³ ^b 1	(7/2) ⁻		
15.2×10 ³ ?	9/2 ⁺		
16.0×10 ³ ^b 1	(7/2 ⁺ ,5/2 ⁻)		E(level): See also (2003So24,2004So19,2004So35: E _x =(16000) keV). J ^π : Measurements of (2006Pr01) suggest positive parity.
16.8×10 ³		310 keV	
17.9×10 ³ ?			
18.7×10 ³	(3/2 ⁺ ,5/2 ⁺)	570 keV	
21.3×10 ³		530 keV	
23.9×10 ³		1100 keV	
27.3×10 ³ ?			

^a From $^7\text{Li}(^9\text{Be},^9\text{Be}+\alpha)$ (2003So24,2004So19,2004So35) except where noted; ^{13}C states are α -decaying to $^9\text{Be}_{\text{g.s.}}$ (E_{thres.}=10.648 MeV).

^b From $^{14}\text{C}(^{13}\text{C},^9\text{Be}+\alpha)$ (2006Pr01).

^c From (2003So24).

^d From α -cluster configuration analysis in (2006Pr01); mainly from Adopted Levels (1991Aj01), except where noted.

⁹Be(α,α):res

- 1964Gr39: ⁹Be(α,α),(α,α') E=23.8 MeV; measured $\sigma(\theta)$ for $\theta=20^\circ$ to 175° .
 1965Ta04: ⁹Be(α,α) E=4-20 MeV; measured $\sigma(E;\theta)$ for $\theta=15^\circ$ to 165° . Multiple peaks are reported.
 1969Ha14: ⁹Be(α,α) E=104 MeV; measured $\sigma(\theta)$ for $\theta_{c.m.}=5^\circ$ to 80° ; deduced phase shifts, optical potentials.
 1973Go15: ⁹Be(α,α) E=1.7-6.2 MeV; measured $\sigma(E;E_\alpha,\theta)$ for $\theta\approx 50^\circ$ to 175° . ¹³C deduced levels, level-width, J, π . See also (1970GoZX).
 1974Sa16: ⁹Be(α,α) E=1.4-2.5 MeV; measured $\sigma(E,\theta)$ for $\theta=90^\circ-160^\circ$. ¹³C deduced resonance, J, π , α -width, level-width.
 1978Hi06: ⁹Be(α,α_0) E=6.4-6.5 MeV; measured $\sigma(E,\theta)$. for $\theta_{c.m.}=54.7^\circ, 90^\circ, 125.3^\circ$ and 175° . Deduced resonance parameters.
 2011Fr12: XUNDL dataset compiled by TUNL, 2011.
 The authors measured cross sections for ⁹Be+ α resonant scattering with the aims of characterizing the ¹³C excitation spectrum and evaluating the $3\alpha+n$ cluster structure of ¹³C.
 Beams of E(⁹Be)=12, 17, 20 and 21.4 MeV ions impinged on a helium gas cell having 460 to 1020 mb pressure (adequate to stop the ⁹Be beam). Scattered α particles escaped the gas cell and were detected in a 16-by-16 double-sided Si-strip detector that was positioned downstream at 0° . Resonant states in ¹³C are visible in the scattered α -particle energy spectra. Analysis of the spectra indicates that contributions by ⁹Be excited states to the reaction exit channel are minor.
 An R-matrix analysis is used to evaluate the resonance parameters and partial widths. Results are compared with ENSDF and a prior ⁹Be(α,α_0) measurement (1973Go15). Finally there is some commentary given on J^π assignments in ¹³C and associated molecular bands.
 2013Lo16: ⁹Be(α,α),(α,α') E=3.5-10 MeV; measured $\sigma(\theta,E)$ for $\theta=110^\circ-160^\circ$.
 2017Lo04: ⁹Be(α,α),(α,α'); combined data from (2013Lo16, 1973Go15) and performed R-matrix analysis; deduced $J^\pi=9/2^-$ for $E_x=13.42$ MeV in agreement with earlier result. See also (2020De05).
 2018Lo07: ⁹Be(α,α),(α,α') $E_{c.m.}=2.5-7$ MeV; AZURE R-matrix analysis of experimental energy spectra, and differential $\sigma(\theta,E)$. ⁹Be(α,n) reactions are also considered in the fit. Deduced ¹³C levels above the α threshold of $E_x=10.648$ MeV, J, π , Γ , Γ_{α_0} , Γ_{α_1} , Γ_n , and compared with literature data. The work merits consideration as an independent analysis; the narrow resonances deduced in the analysis are consistent with known literature values, but several new $\Gamma\geq 1$ MeV broad resonances have been added to give an improved fit to the rather structureless spectral shapes.
 1975Va19: See for ⁹Be(α,d) E=15-25 MeV.
 1973Ku03: See for α structure amplitudes in transfer reactions.

¹³C Levels

E(level) ^{ac}	J^π ^{ab}	Γ ^a	L ^a	E_α (res) (MeV) ^a	Comments
11990	5/2 ⁺	180 keV	1	1.93	E(level), J^π,Γ,E_α (res) (MeV): From (1974Sa16). $\Gamma: \Gamma_\alpha/\Gamma=0.4; \Gamma_\alpha=72$ keV. $\gamma^2=0.36$.
13280	3/2 ⁻	340 keV	(0,2)	3.80	E(level): See also (2011Fr12: from $E_{res}(c.m.)=2730$ keV). J^π : From (2011Fr12). See also (1973Go15: favored by the analysis but the assignment is not certain and more than one state may be involved). Γ : From (2011Fr12: $\Gamma_\alpha=294$ keV; $\Gamma_n=46$ keV); see also $\Gamma=343$ keV (1973Go15).
13420	(7/2 ⁺ ,9/2 ⁻)	58 keV	(4,6)	4.00	E(level): See also (2011Fr12: from $E_{res}(c.m.)=2780$ keV). J^π : $J^\pi=(9/2^-)$ is reported in (1973Go15); this is confirmed in (2017Lo04). This finding is in disagreement with (2002Mi32). In (2011Fr12), 7/2 ⁺ appears favored though 9/2 ⁻ is not excluded. Γ : From (1973Go15); (1991Aj01) indicates a resonance with (9/2 ⁻) and $\Gamma=35$ keV 3.
13560	7/2 ⁻	596 keV	(1,3)	4.20	E(level): See also (2011Fr12: from $E_{res}(c.m.)=2880$ keV). J^π : From (2011Fr12); see also $J^\pi=5/2^+$ (1973Go15), (1973De14: ⁹ Be(α,n)) suggest the opposite ordering

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$^9\text{Be}(\alpha,\alpha):\text{res}$ (continued) ^{13}C Levels (continued)

$E(\text{level})^{ac}$	J^π^{ab}	Γ^a	L^a	$E_\alpha(\text{res}) (\text{MeV})^a$	Comments
13760	$5/2^+$	337 keV	(1,3)	4.50	($3/2^+, 5/2^+$) for 13560 and 13760 states. Γ : From (2011Fr12: $\Gamma_\alpha=512$ keV; $\Gamma_n=84$ keV); see also $\Gamma=685$ keV (1973Go15). $E(\text{level})$: See also (2011Fr12: from $E_{\text{res}}(\text{c.m.})=3280$ keV). J^π : From (2011Fr12); see also $J^\pi=3/2^+$ (1973Go15), (1973De14: $^9\text{Be}(\alpha,n)$) suggest the opposite ordering ($3/2^+, 5/2^+$) for 13560 and 13760 states. Γ : From (2011Fr12: $\Gamma_\alpha=103$ keV; $\Gamma_n=334$ keV); see also $\Gamma=247$ keV (1973Go15). $E(\text{level})$: See also (2011Fr12: from $E_{\text{res}}(\text{c.m.})=3480$ keV). J^π : an equally good fit to the data is obtained with a $7/2^-$ state at $E_\alpha=5.0$ MeV and a ($3/2, 5/2, 7/2$) $^+$ state at $E_\alpha=5.075$ MeV (1973Go15). J^π : ($5/2^-$) is reported in (1973Go15); this is confirmed in (2017Lo04). See also $J^\pi=5/2^-$ (2011Fr12). This finding is in disagreement with an analysis of level spacings in (2002Mi32,2003Mi34); the analysis suggests this level is a $J^\pi=9/2^-$ member of a rotational band. (1991Aj01) indicates a resonance with $J^\pi=3/2^-$ and $\Gamma\approx 150$ keV. Γ : From (2011Fr12: $\Gamma_\alpha=124$ keV; $\Gamma_n=0$ keV); see also $\Gamma=75$ keV (1973Go15). J^π : In (1973Go15) an equally good fit to the data is obtained with a $7/2^-$ state at $E_\alpha=5.0$ MeV and a ($3/2, 5/2, 7/2$) $^+$ state at $E_\alpha=5.075$ MeV. In (2011Fr12), the state appears not to be required.
14110	$5/2^-$	124 keV	(2,4)	5.00	$\Gamma_\alpha=12$ keV; $\Gamma_n=999$ keV (2011Fr12) $E(\text{level})$: From (2011Fr12: $E_{\text{res}}(\text{c.m.})=3760$ keV). J^π, Γ : From (2011Fr12). J^π : See also $J^\pi=7/2^{(+)}$ (1973Go15) $^9\text{Be}(\alpha, \alpha_0)$.
14162?	$7/2^+$	73 keV	(3,5)	5.075	$E(\text{level})$: This level was introduced by (1973Go15) mainly to improve the fit near $E_\alpha=5$ MeV.
14390	$7/2^-$	111 keV			$\Gamma_\alpha=244$ keV; $\Gamma_n=41$ keV (2011Fr12) $E(\text{level})$: From (2011Fr12: $E_{\text{res}}(\text{c.m.})=4070$ keV). J^π, Γ : From (2011Fr12).
14460?	$(5/2^+)$	400 keV	(1,3)	(5.50)	$\Gamma_\alpha=238$ keV; $\Gamma_n=168$ keV (2011Fr12) $E(\text{level})$: From (2011Fr12: $E_{\text{res}}(\text{c.m.})=4310$ keV). J^π, Γ : From (2011Fr12).
14580	$9/2^+$	285 keV			$T=3/2$ $E(\text{level}), J^\pi, \Gamma, E_\alpha(\text{res}) (\text{MeV}), T$: From (1978Hi06). Γ : weak anomaly. $\Gamma_{\alpha_0}/\Gamma \geq 0.017$ with $\Gamma_{\alpha_0} \geq 0.093$ keV (1978Hi06). See also $\Gamma_{\alpha_0}=0.104$ keV 28 (1978Hi06, 1969Ne12).
14983	$7/2^-$	406 keV			$\Gamma_\alpha=154$ keV; $\Gamma_n=339$ keV (2011Fr12) $E(\text{level})$: From (2011Fr12: $E_{\text{res}}(\text{c.m.})=4500$ keV). J^π, Γ : From (2011Fr12), (1991Aj01) and (2003Mi34) indicate a resonance with $J^\pi=9/2^+$, but (2011Fr12) find interference from $J^\pi=9/2^+$ states at $E_x=14580$ and 15270 is incompatible with their data. In (2018Lo07) $J^\pi=3/2^+$ is suggested.
15109.3 14	$3/2^-$	5.49 keV 25		6.4435 20	$\Gamma_\alpha=21$ keV; $\Gamma_n=119$ keV (2011Fr12) $E(\text{level})$: From (2011Fr12: $E_{\text{res}}(\text{c.m.})=5510$ keV). J^π, Γ : From (2011Fr12).
15270	$(5/2^-)$	493 keV			$\Gamma_\alpha=23$ keV; $\Gamma_n=230$ keV (2011Fr12) $E(\text{level})$: From (2011Fr12: $E_{\text{res}}(\text{c.m.})=5490$ keV). J^π, Γ : From (2011Fr12).
16080	$7/2^+$	140 keV			
16150	$5/2^-$	253 keV			

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${}^9\text{Be}(\alpha,\alpha)$:res (continued)

${}^{13}\text{C}$ Levels (continued)

- ^a From single-level approximation analysis in (1973Go15) except where noted. Level energies are deduced using $E_{\alpha}(\text{res})$ and ${}^9\text{Be}$, ${}^4\text{He}$ and ${}^{13}\text{C}$ masses from (2021Wa16: AME-2020). $E_x = S(\alpha) + E_{c.m.}(\text{relativistic})$.
- ^b Values from (2011Fr12) are deduced from R-matrix analysis.
- ^c Several broad resonances from an R-matrix analysis are reported in (2018Lo07). These resonances are listed here, but are not adopted. $E_x = 15.04$ MeV 5 with $\Gamma = 965$ keV 37, 16.27 MeV 5 with $\Gamma = 1596$ keV 142, 16.64 MeV 5 with $\Gamma = 1502$ keV 156, 16.67 MeV 5 with $\Gamma = 904$ keV 100, 16.91 MeV 5 with $\Gamma = 1079$ keV 200, 17.23 MeV 5 with $\Gamma = 393$ keV 200, 17.52 MeV 5 with $\Gamma = 2153$ keV 290.

$^9\text{Be}(\alpha, n\gamma): \text{res}$

- 1932Ch02: $^9\text{Be}(\alpha, n)$, deduced existence of the neutron.
- 1953Ta06: $^9\text{Be}(\alpha, n\gamma)$ $E \leq 3.0$ MeV; measured γ -radiation yield, two resonances corresponding to $^{13}\text{C}^*(11.95, 12.46)$ MeV states were reported.
- 1954Be08: $^9\text{Be}(\alpha, n)$ $E < 1.5$ MeV; measured reaction products, En, In; deduced yields, resonances.
- 1955Ta28: $^9\text{Be}(\alpha, n)$ $E = 1.2-2.5$ MeV; measured $d\sigma/d\Omega(90^\circ)$ for 4.4 MeV γ -rays. In the region of 12 MeV excitation in ^{13}C , the states are not well defined and any attempt to assign such properties as spins and parities must be speculative.
- 1956Be98: $^9\text{Be}(\alpha, n)$ $E = 4.3-8.7$ MeV; measured products; deduced σ , $\sigma(E)$.
- 1956Bo61: $^9\text{Be}(\alpha, n)$ $E = 1.8-5.3$ MeV; studied excitation curves at $\theta = 0^\circ$ and 90° for neutrons and γ rays produced in this reaction. Resonances were reported at bombarding energies of 1.9, 2.3, 2.6, 3.98, 4.4, and 5.0 MeV.
- 1956Ja28: $^9\text{Be}(\alpha, n)$ $E = 0.4-1.3$ MeV; measured the angular distributions of the neutron groups. Tentative spin and parity to certain levels in ^{13}C were assigned.
- 1957Ri38: $^9\text{Be}(\alpha, n)$ $E = 1.7-5.0$ MeV; measured angular distribution and 0° excitation curves.
- 1958Ta05: $^9\text{Be}(\alpha, n)$ $E = 1.15-2.8$ MeV; stripping plays only a minor role.
- 1959Gi47: $^9\text{Be}(\alpha, n)$ $E = 2.5-8.2$ MeV; measured absolute neutron yields, several resonances were reported.
- 1963De27: $^9\text{Be}(\alpha, n_{0,1})$ $E = 14-23$ MeV; measured angular distributions for $\theta \approx 10^\circ$ to 170° . Discussed reaction mechanism.
- 1963Se04: $^9\text{Be}(\alpha, n)$ $E = 3.6-7.6$ MeV; measured angular distributions, the excitation function of the 4.43-MeV γ -ray from the $^9\text{Be}(\alpha, n_1 \gamma_{4.43})^{12}\text{C}$ reaction has been studied. Many broad resonances are found.
- 1965Gi02: $^9\text{Be}(\alpha, n)$ $E = 1.7-10.5$ MeV; measured the absolute total (4π) neutron yield. Resonance peaks were reported.
- 1965Gr22: $^9\text{Be}(\alpha, n)$ $E = 5-12$ MeV; measured the neutron cross sections for the ground state and first excited state of ^{12}C . Resonances were reported.
- 1965Li09: $^9\text{Be}(\alpha, n)$ $E = 1.9-4.5$ MeV; measured polarization (E, θ). Natural target.
- 1966Mi12: $^9\text{Be}(\alpha, n_0)$ $E = 5.0-12.0$ MeV; $^9\text{Be}(\alpha, n_1)$ $E = 4.3-12.0$; $^9\text{Be}(\alpha, n_2)$ $E = 6.0-10.1$; measured $\sigma(E, \theta = 0^\circ)$. ^{13}C deduced levels.
- 1968Da05: $^9\text{Be}(\alpha, n)$ $E = 0.34-0.68$ MeV; measured $\sigma(E, \text{En}, \theta)$.
- 1968Le24: $^9\text{Be}(\alpha, n)$ $E = 1-6$ MeV; measured $\sigma(E; \text{En})$. ^{13}C deduced resonance parameters.
- 1968Ve06: $^9\text{Be}(\alpha, n)$ $E = 6-10$ MeV; measured absolute differential cross sections.
- 1969Kl09: $^9\text{Be}(\alpha, n)$ $E = 1.75, 1.96$ MeV; measured $\sigma(\theta)$, Q, P(θ). ^{13}C deduced resonances, J, π , level-width.
- 1970St16: $^9\text{Be}(\alpha, n)$ $E = 2.4-2.9$ MeV; measured P(n)(E; θ), deduced J of $E_x = 11.95$ MeV.
- 1970Va23: $^9\text{Be}(\alpha, n)$ $E = 1.5-7.8$ MeV; measured $\sigma(E; \text{En}, \theta)$.
- 1971Kl04: $^9\text{Be}(\alpha, n)$ $E = 2.6$ MeV; measured $P_n(\theta)$.
- 1972Ob01: $^9\text{Be}(\alpha, n)$ $E = 1.69-6.44$ MeV; measured $\sigma(E; \theta)$.
- 1973De14: $^9\text{Be}(\alpha, n_0), (\alpha, n_1)$ $E = 4.5-5.85$ MeV; measured P(E; En, θ). ^{13}C deduced levels, J, π .
- 1973Ok06: $^9\text{Be}(\alpha, n)$ $E = 22.9$ MeV; measured $\sigma(\text{En}, \theta)$, P(En, θ).
- 1973We03: $^9\text{Be}(\alpha, n)$ $E = 5.01, 5.44, 6.37, 7.44$ MeV; measured $\sigma(E; \text{En}, \theta)$.
- 1975Ka26: $^9\text{Be}(\alpha, n)$ $E = 2.65$ MeV; measured polarization.
- 1977ScZG, 1978Hi06: $^9\text{Be}(\alpha, n_0), (\alpha, n_1)$ $E = 6.4-6.5$ MeV; measured $\sigma(E, \theta)$. ^{13}C deduced resonance parameters.
- 1978Le10: $^9\text{Be}(\alpha, n)$ $E = 100$ MeV; measured En, neutron polarization.
- 1982RaZP: $^9\text{Be}(\alpha, n)$ $E = 0.51-0.65$ MeV; measured $\sigma(E)$. Resonance observed corresponding to the $^{13}\text{C}^*(11.076)$ MeV level.
- 1990We10: $^9\text{Be}(\alpha, n)$ $E = 2.4-3.3$ MeV; measured $\sigma(\theta)$, polarization.
- 1994Ha32: $^9\text{Be}(\alpha, n)$ $E = 480-740$ keV; measured $\sigma(E)$; deduced resonance σ , width, tokamak materials study relevance. 4π neutron detector.
- 1994Wr01: $^9\text{Be}(\alpha, n)$ $E_{\text{c.m.}} = 0.16-1.87$ MeV; measured $\sigma(E)$, thick target yield. deduced (α, n) reaction rate vs temperature, astrophysical S-factor.
- 1996Ku07: $^9\text{Be}(\alpha, n)$ $E = 0.5-3.5$ MeV; measured yield, $\sigma(E)$; deduced astrophysical S-factor vs E, reaction rate. ^{13}C deduced resonances, Γ . Astrophysical implications.

Theory:

- 1975Fo19: $^9\text{Be}(\alpha, n)$; compiled, calculated thermonuclear reaction rates.
- 1989He04: $\text{Be}(\alpha, n)$ $E = 1-9.8$ MeV; analyzed thick target neutron yields data.
- 2003Sh22: $^9\text{Be}(\alpha, n)$ $E = 0.1-10$ MeV; calculated σ , neutron spectra. Comparison with data.
- 2017Lo04: $^9\text{Be}(\alpha, n)$ $E = 1.6-10$ MeV; calculated $\sigma(\theta)$ using R-matrix and comprehensive fit to published data. ^{13}C deduced 13.42 MeV resonance new J, π assignment.
- 2018Lo07: $^9\text{Be}(\alpha, n)$; $E_{\text{c.m.}} = 1-5$ MeV; analyzed experimental energy spectra, and differential $\sigma(\theta, E)$ data by R-matrix approach,

$^9\text{Be}(\alpha, n\gamma): \text{res}$ (continued)

^{13}C deduced levels above the α threshold of 10.648 MeV, J , π , Γ , $\Gamma_{\alpha 0}$, $\Gamma_{\alpha 1}$, Γ_n , and compared with literature data. Discussed possible existence of molecular bands associated to cluster structures.

E(level) ^a	J^π	Γ	$E_\alpha(\text{res})$ (keV)	<u>^{13}C Levels</u>
				Comments
10754		50.9 keV	153	E(level), Γ : From (1994Wr01).
10815 2		18.7 keV 4	240 2	E(level), Γ : From (1994Wr01).
11002 2	1/2 ⁺	56.43 keV 7	511 2	J^π : From the resonance phase analysis in (1956Ja28: $E_x=11010$ keV). $E_\alpha(\text{res})$ (keV): From (1994Wr01), see also 511 keV 7 (1996Ku07) and 530 keV (1954Be08,1956Ja28), 520 keV (1968Da05), 540 keV (1968Le24). Γ : From (1994Wr01); see also 56 keV 5 (1996Ku07), 70 keV (1969K109), ≈ 55 keV (1968Da05). $\omega\gamma(\text{cm})=2.86$ eV 100 determined from $S(\text{cm})=2.0\times 10^5$ MeV·b 3 (1996Ku07); see also $\omega\gamma(\text{cm})=3.97$ eV (1968Da05).
11076 2		4.681 keV 19	618 2	Γ : From (1994Wr01); see also ≈ 5.3 keV (1994Ha32), <4 keV (1968Da05) and <4.8 keV (1996Ku07). $E_\alpha(\text{res})$ (keV): From average of 618 keV 2 (1994Wr01) and 620 keV 4 (1996Ku07). See also 610 keV (1954Be08,1956Ja28), 600 keV (1968Da05), 618 keV (1982RaZP), 620 keV (1994Ha32). $\omega\gamma(\text{cm})=1.31$ eV 34 determined from $S(\text{cm})=1.4\times 10^5$ MeV·b 3 (1996Ku07); see also $\omega\gamma(\text{cm})=0.88$ eV (1968Da05).
11188?			(780)	$E_\alpha(\text{res})$ (keV): From (1968Le24).
11410?			(1100)	$E_\alpha(\text{res})$ (keV): From (1968Le24).
11618?			(1400)	$E_\alpha(\text{res})$ (keV): From (1968Le24).
11726 2		122.5 keV 8	1557 2	$E_\alpha(\text{res})$ (keV): From average of 1567 keV 22 (1996Ku07) and 1557 keV 2 (1994Wr01). Γ : From (1994Wr01); see also 122 keV 20 (1996Ku07). $\omega\gamma(\text{cm})=2.7$ keV 9 determined from $S(\text{cm})=6.5\times 10^3$ MeV·b 15 (1996Ku07).
≈ 11825			≈ 1700	$E_\alpha(\text{res})$ (keV): From (1996Ku07).
11947 3	(1/2 ⁻ , 7/2 ⁻)	148.7 keV 4	1876 4	J^π : See (1956Ja28,1970Va23: 7/2 ⁻ , 1969K109 (neutron polarization): 1/2 ⁻). Γ : From (1994Wr01); see also 150 keV 13 (1996Ku07), 200 keV (1956Bo61,1965Gi02) and 70 keV (1969K109). $\Gamma_n/\Gamma_\alpha \geq 12$ where Γ_n is width for neutron emission to both $^{12}\text{C}^*(0,4.44$ MeV) states and Γ_α is width for α -particle emission=0.09 MeV 1 (1955Ta28). $E_\alpha(\text{res})$ (keV): Weighted average of 1905 keV 10 (1955Ta28), 1879 keV 7 (1996Ku07) and 1874 keV 2 (1994Wr01). See also 1900 keV (1953Ta06,1954Be08,1956Bo61,1956Ja28), 1920 keV (1965Gi02), 1910 keV (1970Va23). $\omega\gamma(\text{cm})=50.3$ keV 80 determined from $S(\text{cm})=3.3\times 10^4$ MeV·b 4 (1996Ku07).
12141 2	5/2 ⁻	370.2 keV 17	2156 2	J^π : From (1969K109) (neutron polarization). Subsequent results show $J^\pi=1/2^+$. Γ : From (1994Wr01); see also 243 keV 40 (1996Ku07) and 280 keV (1969K109: $E_x=12070$ keV). $E_\alpha(\text{res})$ (keV): From (1994Wr01); see also 2157 keV 29 (1996Ku07). $\omega\gamma(\text{cm})=36.8$ keV 97 determined from $S(\text{cm})=6.9\times 10^3$ MeV·b 10 (1996Ku07).
12180	7/2 ⁺	120 keV		E(level), J^π , Γ : From (1969K109) (neutron polarization). J^π : Subsequent results show $J^\pi=3/2^-$.
12229		≈ 300 keV	2283	Γ : Average of 400 keV (1965Gi02) and ≈ 200 keV (1956Bo61).

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⁹Be(α,nγ):res (continued)

¹³C Levels (continued)

E(level) ^a	J ^π	Γ	E _α (res) (keV)	Comments
12420 2	(7/2 ⁻ ,1/2 ⁻)	226 keV 3	2559 2	E _α (res) (keV): Average of 2300 keV (1956Bo61,1968Le24) and 2250 keV (1965Gi02). J ^π : See (1956Ja28: (1/2 ⁻),1969K109 (neutron polarization): 7/2 ⁻ for E _x =12440 keV). Γ: From (1994Wr01); see also 336 keV 50 (1996Ku07), ≈200 keV (1956Bo61), 300 keV (1959Gi47, 1965Gi02), 90 keV (1965Gr22: n ₀), 400 keV (1969K109). E _α (res) (keV): From (1994Wr01); see also 2526 keV 29 (1996Ku07), 2650 keV (1953Ta06), 2600 keV (1955Ta28,1956Bo61,1956Ja28) and 2580 keV (1959Gi47, 1965Gi02, 1965Gr22). ωγ(cm)=58.5 keV 15 determined from S(cm)=3.5×10 ³ MeV·b 6 (1996Ku07).
≈13002			≈3400	E _α (res) (keV): From (1996Ku07); see also 3200 keV (1968Le24: E _x =12864 keV).
13418	9/2 ⁻	45 keV 7	4000	J ^π : From R-matrix analysis in (2017Lo04). Γ: (1972Ob01). See also 60 keV (1956Bo61,1965Gr22: n ₁), 80 keV (1959Gi47,1965Gi02). E(level),E _α (res) (keV): From (1959Gi47, 1965Gi02, 1965Gr22, 1968Le24). E _α (res) (keV): See also 3980 keV (1956Bo61, 1957Ri38, 1963Se04: n ₁ γ _{4,43} , 1972Ob01).
13542	(3/2 ⁺ ,5/2 ⁺)	570 keV	4180	E(level),E _α (res) (keV): From (1965Gr22: n ₀ , 1957Ri38, 1973De14). J ^π : From (1957Ri38); see also (1973De14: 3/2 ⁺ (neutron polarization)). Γ: From (1965Gr22: n ₀).
13764	5/2 ⁺	≈500 keV	4500	J ^π : From (1973De14) (neutron polarization). E(level),E _α (res) (keV): From (1959Gi47, 1965Gi02, 1973De14); see also E _α (res)=4400 keV (1956Bo61), 4450 keV (1963Se04), 4480 keV (1965Gr22: n ₁). Γ: From (1959Gi47,1965Gi02); see also ≈400 keV (1956Bo61), 90 keV (1965Gr22).
14110		≈300 keV	5000	E(level),E _α (res) (keV): From (1956Bo61, 1959Gi47, 1963Se04, 1965Gi02); see also E _α (res)=4800 keV (1968Le24), 5020 keV (1965Gr22: n ₁). Γ: From (1956Bo61,1959Gi47,1965Gi02); see also 90 keV (1965Gr22).
14387 69	(1/2 ⁻ ,5/2 ⁻)	260 keV	5.4×10 ³ 1	J ^π : From (1973De14) (neutron polarization). Γ: Average of 280 keV (1965Gr22: n ₀) and 240 keV (1966Mi12). E _α (res) (keV): From (1966Mi12); see also 5300 keV (1963Se04,1973De14), 5400 keV (1965Gr22).
14595		210 keV	5700	Γ: From (1965Gr22: n ₁). E _α (res) (keV): Average of 5750 keV (1959Gi47, 1965Gi02, 1965Gr22: n ₁), 5700 keV (1963Se04), 5600 keV (1968Le24).
14941 35	3/2 ⁺	375 keV	6200 50	J ^π : From (1973De14) (neutron polarization). Γ: Average of 350 keV (1965Gr22: n ₀) and 400 keV (1966Mi12). E _α (res) (keV): From (1966Mi12); see also 6250 keV (1965Gr22,1973De14).
15109.4 14	3/2 ⁻	5.49 keV 25	6443.5 20	T=3/2 (1978Hi06) J ^π ,E _α (res) (keV): From (1978Hi06). Γ: From (1978Hi06); also used (1973Ad02: ¹¹ B(³ He,np)) Γ _n /Γ values to obtain Γ _{n0} =0.38 keV 10, Γ _{n1} =1.43 keV 18,

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$^9\text{Be}(\alpha, n\gamma)$:res (continued) **^{13}C Levels (continued)**

<u>E(level)^a</u>	<u>Γ</u>	<u>E_α(res) (keV)</u>	<u>Comments</u>
			$\Gamma_{n2}=0.14$ keV <i>l0</i> . Other analysis in the text using $\Gamma_{\gamma0}/\Gamma$ can be used to obtain $\Gamma_{\gamma0}\approx 22.8$ keV.
			Other discussion in (1978Hi06) finds reduced transition strength, $\delta(M1)(\text{W.u.})=-0.15$ 7 and $\delta(E2)(\text{W.u.})=1.0$ 6 where $\delta\equiv B(^{13}\text{C})/B(^{13}\text{N})-1$.
15280		6690	E_α (res) (keV): From (1968Le24); see also (6700) keV; (broad) state (1965Gi02).
15564 35	215 keV	7100 50	Γ : Average of 220 keV (1965Gr22: $n_{0,1}$) and 210 keV (1966Mi12). E_α (res) (keV): From (1966Mi12); see also 7100 keV (1963Se04, 1965Gr22: n_0), 7000 keV (1965Gr22: n_1).
16023	210 keV	7763	Γ : From (1965Gr22: n_1). E_α (res) (keV): Average of 7800 keV (1959Gi47, 1965Gi02, 1968Le24), 7700 keV (1963Se04) and 7750 keV (1965Gr22).
16152 35	225 keV	7950 50	Γ : Average of 210 keV (1965Gr22: n_0) and 240 keV (1966Mi12). E_α (res) (keV): From (1966Mi12); see also 7940 keV (1965Gr22).
16948 35	330 keV	9100 50	Γ : Average of 280 keV (1965Gr22: n_0) and 380 keV (1966Mi12). E_α (res) (keV): From (1966Mi12); see also 9100 keV (1965Gi02), 9050 keV (1965Gr22).
17363 69	190 keV	9.7×10^3 <i>l</i>	Γ : Average of 240 keV (1965Gr22: $n_{0,1}$) and 140 keV (1966Mi12). E_α (res) (keV): From (1966Mi12); see also (9600) keV (1965Gr22: n_0), 9700 keV (1965Gr22: n_1), 9800 keV (1968Le24).
17709 35	225 keV	10200 50	Γ : Average of 170 keV (1965Gr22: n_0) and 280 keV (1966Mi12). E_α (res) (keV): From (1966Mi12); see also 10110 keV (1965Gr22).
17986?	40 keV	10600	Γ, E_α (res) (keV): From (1965Gr22: n_0).
18332 35	305 keV	11100 50	Γ : Average of 210 keV (1965Gr22: n_0) and 400 keV (1966Mi12). E_α (res) (keV): From (1966Mi12); see also 10950 keV (1965Gr22).
18750 21	70 keV	11700 30	Γ : Average of 60 keV (1965Gr22: $n_{0,1}$) and 80 keV (1966Mi12). E_α (res) (keV): From (1966Mi12); see also 11600 keV (1965Gr22).

^a Level energies are deduced using E_α (res) and ^9Be , ^4He and ^{13}C masses from (2021Wa16: AME-2020) where E_α (res) is listed.
 $E_x=S(\alpha)+E_{c.m.}(\text{relativistic})$.

⁹Be(⁶Li,d),(⁷Li,t)

1964Ca05: ⁹Be(⁷Li,t) E=3.2 MeV; populated the first eight states of ¹³C (not all resolved). No triton groups are observed to the previously reported ¹³C states at 5.51 and 6.10 MeV.

1969Sn02: ⁹Be(⁷Li,t) E=5.6,5.8,6.0,6.2 MeV; measured $\sigma(E;E_t,\theta)$. Absolute differential cross sections at $\theta=10^\circ-170^\circ$ have been measured; ¹³C levels observed.

1971Go24: ⁹Be(⁶Li,d),(⁷Li,t) E=24,30 MeV; measured $\sigma(E_d,\theta)$, $\sigma(E_t,\theta)$. ¹³C deduced levels, α -particle structure.

1989As01: ⁹Be(⁶Li,d) E=30 MeV; measured $\sigma(E_d)$, $\sigma(\theta)$; deduced optical model parameters. ¹³C deduced levels, L, J, π , spectroscopic strengths.

1998Le17: ⁷Li(⁹Be,t) E \approx 6.5-9.0 MeV/nucleon; measured E_α vs angle following compound nucleus decay. ¹³C deduced levels, widths, α -decay branching ratios.

2010RoZR, 2010RoZZ: ⁹Be(⁶Li,d) E=25.5 MeV; measured E_d , $I_d(\theta)$; deduced $\sigma(\theta)$; calculated $\sigma(\theta)$ using DWBA.

2011Bo17: ⁹Be(⁶Li,d) E=25.5 MeV; measured reaction products, deuteron spectra; deduced $\sigma(\theta)$, J, π . Comparison with DWBA calculations.

2012Wh01: XUNDL dataset compiled by TUNL, 2012.

The authors studied the decay modes of ¹³C states by measuring deuterons from the ⁹Be(⁶Li,d)¹³C reaction in coincidence with ¹²C or α particles from breakup of ¹³C into ¹²C+n or α +⁹Be, respectively.

A beam of 42 MeV ⁶Li ions impinged on a 240 $\mu\text{g}/\text{cm}^2$ ⁹Be target at the Munich MLL tandem laboratory. Recoiling deuterons were detected in the Q3D spectrometer, which was optimized for sensitivity to $E_x=11550$ keV (10.6 to 13.0 MeV) or 13280 keV (12.4 to 15.1 MeV). Charged particle ejectiles from breakup of correlated ¹³C* were detected in an array of four 50 mm \times 50 mm position sensitive Si strip detectors that covered 12 $^\circ$ to 91 $^\circ$ and -36 $^\circ$ to 39 $^\circ$ in the vertical and horizontal planes, respectively. The ¹²C+n_{0/n1} and ⁹Be+ α ₀ breakup paths were analyzed.

The absolute particle widths were determined for n₀, n₁ and α ₀ decay reactions by correlating deuterons in the Q3D focal plane with events in the strip detector array.

¹³C Levels

E(level) ^a	J ^{π} ^a	Γ ^{bc}	L ^a	Spectroscopic Strength ^a	Comments
0	1/2 ⁻		2	1.9	E(level): From (1964Ca05,1969Sn02,1971Go24,1989As01).
3089	1/2 ⁺		1	2.3	E(level): From (1964Ca05,1969Sn02,1971Go24,1989As01,2010RoZZ).
3685	3/2 ⁻		0+2	1.7	E(level): From (1964Ca05,1971Go24,2010RoZZ); see also (1969Sn02,1989As01: unresolved doublet). L: From (2010RoZZ, 2011Bo17), L=0 in (1989As01).
3854	5/2 ⁺		1	1.4	E(level): From (1964Ca05,2010RoZZ); see also (1969Sn02,1989As01: unresolved doublet).
6864	5/2 ⁺		1+3	0.19	E(level): See (1964Ca05,1969Sn02,1971Go24,1989As01,2010RoZZ). Spectroscopic Strength: for L=1 transfer; S=0.38 for L=3 transfer.
7492	(7/2 ⁺)				E(level): From (2010RoZZ); see also (1964Ca05,1969Sn02: unresolved doublet) and (1971Go24,1989As01: unresolved levels).
7547	5/2 ⁻				E(level): From (2010RoZZ); see also (1964Ca05,1969Sn02: unresolved doublet).
7686	3/2 ⁺				E(level): From (1964Ca05,1969Sn02).
8860	1/2 ⁻				E(level): From (⁷ Li,t) (1971Go24).
9500	9/2 ⁺		3	0.55	E(level): From (1969Sn02,1989As01,2010RoZZ); see also (1971Go24: unresolved levels).
9897	3/2 ⁻		0+2	7.2	E(level): From (1969Sn02,1989As01,2010RoZZ); see also (1971Go24: unresolved levels). Spectroscopic Strength: for L=0 transfer; S=1.45 for L=2 transfer.
10772	7/2 ⁻	61 keV	4	24.6	E(level): From (2010RoZR,2010RoZZ,2011Bo17,2012Wh01 (the experimental resolution is 82 keV)); see also (1971Go24: unresolved levels), (1989As01: the centroid of

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$^9\text{Be}(^6\text{Li,d}),(^7\text{Li,t})$ (continued) ^{13}C Levels (continued)

$E(\text{level})^a$	J^π^a	Γ^{bc}	L^a	Comments
				the peak is 10750 keV <i>18</i> with $\Gamma=130$ keV after removal of the 70 keV experimental resolution, more likely, the doublet $E_x=10.753$ and 10.818 MeV are populated) and (1998Le17: $E_x=10768$ keV with energy separation for fitting fixed at 70 keV). $\Gamma: \Gamma_{\alpha_0}/\Gamma < (0.05), \Gamma_{n_0}/\Gamma = 0.91$ <i>11</i> , $\Gamma_{n_1}/\Gamma \leq 0.13$ (2012Wh01). See also $\Gamma=55$ keV (1998Le17: Γ_{exp} was fixed at $\Gamma_{\text{exp}}=(\Gamma^2+50^2)^{1/2}$, using Γ values from (1991Aj01)). L: From (2011Bo17); $L=2$ in (1989As01).
10816	$(5/2^-)$	35 keV	4	E(level): From (2010RoZZ,2010RoZZ,2011Bo17,2012Wh01 (the experimental resolution is 82 keV)); see also (1989As01: unresolved doublet) and (1998Le17: $E_x=10838$ keV with energy separation for fitting fixed at 70 keV). $\Gamma: \Gamma_{\alpha_0}/\Gamma < (0.02), \Gamma_{n_0}/\Gamma = 0.51$ <i>4</i> , $\Gamma_{n_1}/\Gamma = 0.51$ <i>4</i> (2012Wh01). See also $\Gamma=25$ keV (1998Le17: Γ_{exp} was fixed at $\Gamma_{\text{exp}}=(\Gamma^2+50^2)^{1/2}$, using Γ values from (1991Aj01)). L: From (2011Bo17).
10969	$1/2^+$	33 keV <i>5</i>		E(level): From (1998Le17); see also $E_x=11010$ keV (2012Wh01). $\Gamma: \Gamma_{\alpha_0}/\Gamma < (0.08), \Gamma_{n_0}/\Gamma = 0.68$ <i>3</i> , $\Gamma_{n_1}/\Gamma = 0.42$ <i>2</i> (2012Wh01).
11080	$1/2^-$	<15 keV		E(level): From (2010RoZZ,2011Bo17); see also $E_x=11112$ keV (1998Le17). $\Gamma: \Gamma_{\alpha_0}/\Gamma < (0.02), \Gamma_{n_0}/\Gamma = 0.51$ <i>4</i> , $\Gamma_{n_1}/\Gamma = 0.51$ <i>4</i> (2012Wh01). See also $\Gamma=25$ keV (1998Le17: Γ_{exp} was fixed at $\Gamma_{\text{exp}}=(\Gamma^2+50^2)^{1/2}$, using Γ values from (1991Aj01)).
11711		38 keV <i>10</i>		E(level): From (1998Le17: see also $E_x=11700$ keV); the authors compared with (1991Aj01) Adopted Levels and suggested $E_x=11.74$ MeV <i>1</i> and $\Gamma=40$ keV <i>10</i> . $\Gamma: \Gamma_{\alpha_0}/\Gamma < (0.02), \Gamma_{n_0}/\Gamma = 0.51$ <i>4</i> , $\Gamma_{n_1}/\Gamma = 0.51$ <i>4</i> (2012Wh01). See also $\Gamma=25$ keV (1998Le17: Γ_{exp} was fixed at $\Gamma_{\text{exp}}=(\Gamma^2+50^2)^{1/2}$, using Γ values from (1991Aj01)).
11841	$7/2^+$	46 keV <i>9</i>		E(level): From (1998Le17,2012Wh01 (the experimental resolution is 82 keV)); see also (1989As01: unresolved doublet whose peaks have widths that are consistent with proposed $3/2^-$ strength at 11.85 MeV and a $5/2^-$ state at 12.13 MeV (1986Aj01)) and (1998Le17). $\Gamma: \Gamma_{\alpha_0}/\Gamma < (0.10), \Gamma_{n_0}/\Gamma = 0.49$ <i>8</i> , $\Gamma_{n_1}/\Gamma = 0.71$ <i>11</i> (2012Wh01).
11959		240 keV <i>30</i>		E(level): From (1998Le17: see also $E_x=11969$ keV); the authors compared with (1991Aj01) Adopted Levels and suggested $E_x=11.96$ MeV <i>3</i> . See also (1971Go24). $\Gamma: \Gamma_{\alpha_0}/\Gamma < (0.17), \Gamma_{n_0}/\Gamma = 0.49$ <i>8</i> , $\Gamma_{n_1}/\Gamma = 0.53$ <i>8</i> (2012Wh01).
12123	$5/2^-$	219 keV		E(level): From (2012Wh01: the experimental resolution is 82 keV); see also (1989As01: unresolved doublet). $\Gamma: \Gamma_{\alpha_0}/\Gamma < (0.17), \Gamma_{n_0}/\Gamma = 0.49$ <i>8</i> , $\Gamma_{n_1}/\Gamma = 0.53$ <i>8</i> (2012Wh01).
12300	$1/2^-$		2	E(level): From (2011Bo17,2010RoZZ). $J^\pi: \Gamma_{\alpha_0}/\Gamma < (0.17), \Gamma_{n_0}/\Gamma = 0.49$ <i>8</i> , $\Gamma_{n_1}/\Gamma = 0.53$ <i>8</i> (2012Wh01). $J^\pi: \Gamma_{\alpha_0}/\Gamma < (0.17), \Gamma_{n_0}/\Gamma = 0.49$ <i>8</i> , $\Gamma_{n_1}/\Gamma = 0.53$ <i>8</i> (2012Wh01). L: From (2011Bo17).
12830		1 MeV		E(level), $\Gamma: \Gamma_{\alpha_0}/\Gamma < (0.17), \Gamma_{n_0}/\Gamma = 0.49$ <i>8</i> , $\Gamma_{n_1}/\Gamma = 0.53$ <i>8</i> (2012Wh01). L: From (2011Bo17).
13270		315 keV <i>30</i>		E(level), $\Gamma: \Gamma_{\alpha_0}/\Gamma < (0.17), \Gamma_{n_0}/\Gamma = 0.49$ <i>8</i> , $\Gamma_{n_1}/\Gamma = 0.53$ <i>8</i> (2012Wh01). L: From (2011Bo17).
13410	$(9/2^-)$	33 keV <i>10</i>		E(level): From (1998Le17: see also $E_x=13360$ keV); the authors compared with (1991Aj01) Adopted Levels and suggested $E_x=13.28$ MeV <i>3</i> and $\Gamma=310$ keV <i>30</i> . See also $E_x=13300$ keV (1971Go24). $\Gamma: \Gamma_{\alpha_0}/\Gamma < (0.17), \Gamma_{n_0}/\Gamma = 0.49$ <i>8</i> , $\Gamma_{n_1}/\Gamma = 0.53$ <i>8</i> (2012Wh01).
13570?		≈ 75 keV		E(level): From (1998Le17: see also $E_x=13300$ keV (1971Go24)). $\Gamma: \Gamma_{\alpha_0}/\Gamma < (0.17), \Gamma_{n_0}/\Gamma = 0.49$ <i>8</i> , $\Gamma_{n_1}/\Gamma = 0.53$ <i>8</i> (2012Wh01).
13779?	$(5/2,3/2)^+$	77 keV <i>30</i>		E(level): From (1998Le17: see also $E_x=13530$ keV); see also $E_x=13500$ keV (2011Bo17). $\Gamma: \Gamma_{\alpha_0}/\Gamma < (0.17), \Gamma_{n_0}/\Gamma = 0.49$ <i>8</i> , $\Gamma_{n_1}/\Gamma = 0.53$ <i>8</i> (2012Wh01). L: From (2011Bo17).
13920		100 keV <i>25</i>		E(level): From (1998Le17: see also $E_x=13530$ keV); see also $E_x=13500$ keV (2011Bo17). $\Gamma: \Gamma_{\alpha_0}/\Gamma < (0.17), \Gamma_{n_0}/\Gamma = 0.49$ <i>8</i> , $\Gamma_{n_1}/\Gamma = 0.53$ <i>8</i> (2012Wh01). L: From (2011Bo17).

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$^9\text{Be}(^6\text{Li,d}),(^7\text{Li,t})$ (continued) ^{13}C Levels (continued)

<u>E(level)^a</u>	<u>J^{π}^a</u>	<u>Γ^{bc}</u>	<u>Comments</u>
			and suggested recommended values of $E_x=13.92$ MeV 3 and $\Gamma=100$ keV 30. Γ : From (1998Le17).
14120		160 keV 20	E(level): (1989As01: unresolved doublet; $E_x=14.11$ MeV ($5/2^-$) and 14.16 MeV($7/2^+$)), (2011Bo17: broad resonance) and $E_x=14080$ keV (1998Le17). Γ : From (1998Le17).
14360		115 keV 35	E(level), Γ : From (1998Le17).
14582?	($7/2^+,9/2^+$)	130 keV	E(level): From (1971Go24,2011Bo17,2012Wh01(the experimental resolution is 82 keV)). Γ : $\Gamma_{\alpha_0}/\Gamma=0.94$ 3, $\Gamma_{n_0}/\Gamma<(0.12)$, $\Gamma_{n_1}/\Gamma=0.13$ 2 (2012Wh01).
15100			E(level): From (2011Bo17).
15200 ^d			E(level): From (1971Go24).
16700 ^d			E(level): From (1971Go24).
18500 ^d			E(level): From (1971Go24).

^a Values mainly from DWBA analysis of spectroscopic strengths in (1989As01) $^9\text{Be}(^6\text{Li,d})$.

^b From (2012Wh01) except where noted; the experimental resolution of 82 keV has been removed from the quoted Γ_{total} value.

^c Widths shown in Fig. 6 in (1998Le17) are Γ_{exp} , while the width listed here are $\Gamma=(\Gamma_{\text{exp}}^2-(50 \text{ keV})^2)^{1/2}$, taking the experimental resolution as 50 keV from state 4 (1998Le17).

^d Some states are not associated with Adopted Levels because inadequate details for association are given in the literature.

$^9\text{Be}(^9\text{Be}, ^{13}\text{C}\gamma)$

1986Cu02: $^9\text{Be}(^9\text{Be}, ^{13}\text{C}\gamma)$ $E(\text{cm}) \approx 1.25-3$ MeV; measured E_γ , I_γ , γ , residual production $\sigma(E)$. α -transfer, statistical model analysis of ^{18}O excitation and decay, DWBA analyses. Enriched targets, Ge detectors.

1988La25: $^9\text{Be}(^9\text{Be}, ^{13}\text{C}\gamma)$ $E_{\text{c.m.}} = 1.4-3.4$ MeV; measured elastic $\sigma(\theta)$, total reaction $\sigma(E)$, $\sigma(E, E(\gamma))$ for transitions in ^{13}C . Optical model, statistical model and DWBA analysis. NaI and Ge detectors.

1993Da17: $^9\text{Be}(^9\text{Be}, ^{13}\text{C}\gamma)$ $E = 4.5-12.4$ MeV; measured $\sigma(E)$ for γ transitions in ^{13}C . Statistical model analysis of ^{18}O excitation and decay. Similar analyses for $^{14}\text{C} + \alpha$ and $^7\text{Li} + ^{11}\text{B}$.

1997Mu04: $^9\text{Be}(^9\text{Be}, ^{13}\text{C}\gamma)$ $E_{\text{c.m.}} = 1.3-7.6$ MeV; measured γ production σ vs E ; deduced partial, total fusion σ . Statistical model analysis, optical model calculations.

2011Gi03: $^9\text{Be}(^9\text{Be}, ^{13}\text{C}\gamma)$ $E = 30, 35, 40$ MeV; measured reaction products, E_γ , I_γ ; deduced production yields. Comparison with PACE, LisFus and GEMINI calculations.

 ^{13}C Levels

<u>$E(\text{level})^a$</u>	<u>J^π^a</u>	<u>$T_{1/2}$</u>	<u>L_α^b</u>	Comments
0	$1/2^-$			J^π : See (1997Mu04).
3090	$1/2^+$	0.69 fs	1	$E(\text{level})$: See (1986Cu02, 1988La25, 1993Da17, 1997Mu04). J^π : See (1986Cu02, 1988La25, 1997Mu04). $T_{1/2}$: From $\tau = 0.001$ ps (1988La25).
3680	$3/2^-$	0.69 fs	0	$E(\text{level})$: See (1986Cu02, 1988La25, 1993Da17, 1997Mu04). J^π : See (1986Cu02, 1988La25). $T_{1/2}$: From $\tau = 0.001$ ps (1988La25).
3850	$5/2^+$	8.32 ps	1,3	$E(\text{level})$: See (1986Cu02, 1988La25, 1993Da17, 1997Mu04). J^π : See (1986Cu02, 1988La25, 1997Mu04). $T_{1/2}$: From $\tau = 12$ ps (1988La25).

^a Values based on Adopted Levels.

^b From (1986Cu02).

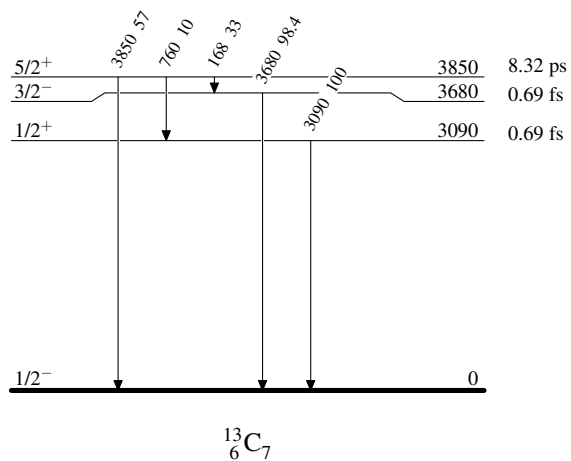
 $\gamma(^{13}\text{C})$

<u>$E_i(\text{level})$</u>	<u>J_i^π</u>	<u>E_γ</u>	<u>I_γ</u>	<u>E_f</u>	<u>J_f^π</u>	Comments
3090	$1/2^+$	3090	100	0	$1/2^-$	E_γ : See (1986Cu02, 1988La25, 1993Da17, 1997Mu04). I_γ : From (1988La25, 1997Mu04).
3680	$3/2^-$	3680	98.4	0	$1/2^-$	E_γ : See (1986Cu02, 1988La25, 1993Da17, 1997Mu04). I_γ : From (1988La25), see also 99% (1997Mu04).
3850	$5/2^+$	168	33	3680	$3/2^-$	E_γ : (2011Gi03). I_γ : (1997Mu04), see also 37% (1986Cu02).
		760	10	3090	$1/2^+$	E_γ, I_γ : (1997Mu04).
		3850	57	0	$1/2^-$	E_γ : See (1986Cu02, 1988La25, 1993Da17, 1997Mu04). I_γ : (1997Mu04), see also 63% (1986Cu02: 3850→3090 not observed), 63.4% (1988La25).

$^9\text{Be}(^9\text{Be}, ^{13}\text{C}\gamma)$

Level Scheme

Intensities: % photon branching from each level



${}^9\text{Be}({}^{16}\text{O}, {}^{12}\text{C})$ 1988We17

1987We08: ${}^9\text{Be}({}^{16}\text{O}, {}^{12}\text{C})$ $E \approx$ barrier; measured $\sigma(\theta)$; deduced ${}^9\text{Be}+\alpha$ molecular effects role.

1988We17: ${}^9\text{Be}({}^{16}\text{O}, {}^{12}\text{C})$ $E_{c.m.} = 7.2, 8.4, 9.6, 10.2$ MeV; measured $\sigma(\theta)$, low-lying states; deduced ${}^9\text{Be}+\alpha$ molecular effects existence. Second-order exact finite-range DWBA calculations.

Theory:

1994Os08: ${}^9\text{Be}({}^{16}\text{O}, {}^{12}\text{C})$ $E = 7.2-10.2$ MeV; analyzed $\sigma(\theta)$. ${}^{13}\text{C}$ levels deduced spectroscopic factors. Exact finite-range DWBA.

${}^{13}\text{C}$ Levels

<u>E(level)^a</u>	<u>J^{π}</u>
0	1/2 ⁻
3090	1/2 ⁺
3850	5/2 ⁺

^a From α -cluster configuration analysis in (1988We17).

$^{10}\text{B}(\text{t,p})\text{:res}$

1981Ci06: $^{10}\text{B}(\text{t,p})$ E=0.9,1.1 MeV; measured $\sigma(\theta)$; deduced evidence for different reaction mechanisms. DWBA.

1984GuZY: $^{10}\text{B}(\text{t,p})$ E=3-12 MeV; measured $\sigma(\text{E})$. ^{13}C deduced resonances, Γ .

1985Ab10: $^{10}\text{B}(\text{t,p})$ E=3-12 MeV; measured $\sigma(\text{E})$.

Theory:

1970Ma38: $^{10}\text{B}(\text{t,p})$ E=5-20 MeV; calculated $\sigma(\theta)$.

 ^{13}C Levels

<u>E(level)^a</u>	<u>Γ</u>	<u>$E_t(\text{res})$ (MeV)</u>	<u>Comments</u>
28025	≈ 1 MeV	5.4	E(level), Γ , $E_t(\text{res})$ (MeV): From (1984GuZY). A broad structure is reported in the activation cross section at $E_t(\text{res})\approx 5.5$ MeV, $\Gamma=2.7$ MeV and $\sigma_{\text{res}}(\text{max})=17$ mb (1985Ab10).

^a Deduced using $E_t(\text{res})$ and ^{10}B , ^3H and ^{13}C masses from (2021Wa16: AME-2020). $E_x=S(^3\text{H})+E_{\text{c.m.}}$ (relativistic).

${}^{10}\text{B}(\alpha, \text{p}), (\alpha, \text{p}\gamma)$

- 1953Sh64: ${}^{10}\text{B}(\alpha, \text{p})$ E=1-2 MeV; resonances for production of γ -rays and protons from the reaction were observed. Spins and parities of $3/2^-$ and $5/2^+$ were confirmed for the second and third excited levels of ${}^{13}\text{C}$.
- 1954St20: ${}^{10}\text{B}(\alpha, \text{p}\gamma)$; the angular distributions of the high energy γ -rays (a mixture of 3.7 and 3.9 MeV γ -rays) and of the low energy γ -rays (0.2 MeV) from the reaction, and the angular correlations of the high energy γ -rays with the emitted protons have been measured at five α -particle resonances $E_\alpha = 1.13, 1.51, 1.64, 1.68$ and 1.83 MeV.
- 1956Ma52: A scintillation spectrometer and a magnetic lens spectrometer have been used to study gamma rays from excited states of ${}^{13}\text{C}$ at 3.84 and 3.68 MeV, produced in the reactions ${}^{12}\text{C}(\text{d}, \text{p})$ and ${}^{10}\text{B}(\alpha, \text{p})$. Lines have been measured at 169.5 keV 4, 3.844 MeV 15, and 3.69 MeV 2.
- 1960Ka13: ${}^{10}\text{B}(\alpha, \text{p})$; estimated the strength of the corresponding but non-mirror M1 transition from the ${}^{13}\text{C}^*(3.68 \text{ MeV}; 3/2^-)$ state to the $1/2^-$ ground state and compared it with the same IPM calculation as accounts for the transition in ${}^{13}\text{N}$.
- 1960Pi09: ${}^{10}\text{B}(\alpha, \text{p})$ E=1.64 MeV; measured branching ratios of the ${}^{13}\text{C}^*(3854)$ level.
- 1961Ya02: ${}^{10}\text{B}(\alpha, \text{p})$ E=27.5, 33.1 MeV; measured angular distributions of ground state protons.
- 1962Ed01: ${}^{10}\text{B}(\alpha, \text{p})$, proton groups have been observed to the first four states of ${}^{13}\text{C}$.
- 1967Od01: The ground-state Q values of the reaction ${}^{10}\text{B}(\alpha, \text{p})$ was measured.
- 1968Ri16: ${}^{10}\text{B}(\alpha, \text{p})$ E=2.9 MeV; measured Doppler-shift attenuation. ${}^{13}\text{C}$, ${}^{13}\text{N}$ levels, deduced $T_{1/2}$.
- 1969Ga01: ${}^{10}\text{B}(\alpha, \text{p}\gamma)$ E=1.0-3.5 MeV; measured $\sigma(E; E_\gamma)$.
- 1969He22: ${}^{10}\text{B}(\alpha, \text{p})$ E=4.5 MeV; measured $\sigma(E_\gamma, E({}^{13}\text{C}))$. ${}^{13}\text{C}^*(3.85)$ level deduced $\tau=10.7$ ps 10. Recoil distance method.
- 1969Li07: ${}^{10}\text{B}(\alpha, \text{p}\gamma)$ E=5.15 MeV; measured E_γ, I_γ . ${}^{13}\text{C}$ levels deduced γ -branching. Ge(Li) detector.
- 1970Ga01: ${}^{10}\text{B}(\alpha, \text{p}\gamma)$ E=1.96 MeV; measured $E_\gamma(\theta(\gamma)=0^\circ)$, Doppler shift, recoil distance. For ${}^{13}\text{C}^*(3.85)$ they deduced $\tau=9.9$ ps 9.
- 1971HiZF: Studies of this reaction led to $J^\pi=3/2^-$ and $5/2^+$ for ${}^{13}\text{C}^*(3.68, 3.85)$ states respectively.
- 1974WiZL: ${}^{10}\text{B}(\alpha, \text{p})$ E=2.1-10.75 MeV; measured $\sigma(E, \text{p})$.
- 1975Wi04: ${}^{10}\text{B}(\alpha, \text{p})$ E=2-10 MeV; measured $\sigma(E, \text{Ep}, \theta)$. Proton groups have been observed to the first four states of ${}^{13}\text{C}$.
- 1980Wa24: ${}^{10}\text{B}(\alpha, \text{p})$ E=1.66 MeV; measured $E_\gamma, I_\gamma, \gamma\gamma$ -coin, $\gamma(\theta)$. ${}^{13}\text{C}$ level deduced $T_{1/2}$, levels, γ -branching, B(λ). Shell model.
- 1981Ki08: ${}^{10}\text{B}(\alpha, \text{p}_1\gamma)$ E=2.563-3.064 MeV; measured $\sigma(\theta_p)$. Legendre Polynomial analysis.
- 1983Cs03: ${}^{10}\text{B}(\alpha, \text{p}_1\gamma)$ E=2.56-3.06 MeV; measured $\sigma(E)$. See also (1983CsZY).
- 1983La17: ${}^{10}\text{B}(\alpha, \text{p}\gamma)$ E=2.4 MeV; measured E_γ, I_γ , thick target γ yields.
- 1986Ba58: ${}^{10}\text{B}(\alpha, \text{p})$ E=2.3 MeV; measured $\sigma(E_p), \sigma(E_\alpha)$. ${}^{13}\text{C}$ level deduced no neutral particle decay evidence, $\Gamma(\phi)/\Gamma_\gamma \leq 7 \times 10^{-5}$; upper limit of 10^{-6} . Fundamental symmetries.
- 1987MiZY: ${}^{10}\text{B}(\alpha, \text{p})$ E=48 MeV; measured $\sigma(E_p)$. ${}^{13}\text{C}$ deduced levels.
- 1988BrZY: ${}^{10}\text{B}(\alpha, \text{p})$ E=48 MeV; ${}^{13}\text{C}$ deduced levels, J, π .
- 1990JaZZ: ${}^{10}\text{B}(\alpha, \text{p})$ E=48 MeV; ${}^{13}\text{C}$ deduced level, possible T.
- 1991Br26: ${}^{10}\text{B}(\alpha, \text{p})$ E=48 MeV at 25° and 35° ; measured particle spectra. ${}^{13}\text{C}$ deduced levels, possible isospin. Also reported the analog reaction ${}^{10}\text{B}({}^9\text{Be}, {}^6\text{Li})$ at E=40 MeV and $\theta=22.5^\circ$ with low statistics. Compared with shell model predictions.
- 1995He40: ${}^{10}\text{B}(\alpha, \text{p})$ E=5.6-10 MeV; measured thick target γ yields; deduced γ production intensity distributions from materials related features.
- 1996Gi13: ${}^{10}\text{B}(\alpha, \text{p})$ E=4-5 MeV; measured $\sigma(E_p, \theta)$ for p_{0-3} at $\theta_{\text{lab}}=135^\circ$.
- 1997He11: ${}^{10}\text{B}(\alpha, \text{p})$ E=5.6-10 MeV; measured thick target residuals yields; deduced reaction mechanism related features.
- 1999Ki29: ${}^{10}\text{B}(\alpha, \text{p})$ E=1.2-4.0 MeV; measured Doppler broadened $E_\gamma, I_\gamma(\theta)$; deduced proton distributions; analyzed energy dependence of angular distribution parameters.
- 2003Ch44: ${}^{10}\text{B}(\alpha, \text{p})$ E=1.4-5.3 MeV; measured $E_p, \sigma(E, \theta)$. Application to boron depth profiling discussed.
- 2019Li42: ${}^{10}\text{B}(\alpha, \text{p})$ E=2.2-4.9 MeV; measured secondary E_γ, γ -ray yields, used for troubleshooting during the experiment.
- 2020Li08: ${}^{10}\text{B}(\alpha, \text{p}\gamma)$ E=835-1665 keV; measured E_γ and I_γ .
- 2023Gu04: ${}^{10}\text{B}(\alpha, p_{0,1,2,3}), (\alpha, \text{p}\gamma)$ $E_{\text{c.m.}}=0.19-1.43$ MeV; measured $\sigma(E_p, \theta)$ for $\theta=90^\circ$ and 135° at Notre Dame. R-matrix analysis of excitation function.

Theory:

- 2018Zh51: ${}^{10}\text{B}(\alpha, \text{p})$ E<10 MeV; analyzed available data; deduced σ , reaction rates. Comparison with TALYS calculations.

$^{10}\text{B}(\alpha,p),(\alpha,p\gamma)$ (continued)			
^{13}C Levels			
E(level) ^a	J^π ^e	$T_{1/2}$ or Γ	Comments
0	$1/2^-$		$Q_0=4130$ keV 20 (1953Sh64), 4063.4 keV 24 (1967Od01).
3089.443 ^b	20 $1/2^+$	<6.93 fs	$T_{1/2}$: From $\tau < 10$ fs (1968Ri16: Doppler shift method, $^{13}\text{C}(p,p')$ and $^{12}\text{C}(d,p)$). Total radiation width $\Gamma_\gamma > 0.066$ eV (1968Ri16).
3684.482 ^c	23 $3/2^-$	<18.02 fs	$T_{1/2}$: From $\tau < 26$ fs (1968Ri16: Doppler shift, $^{13}\text{C}(p,p')$ and $^{12}\text{C}(d,p)$); see also $\tau < 300$ fs (1956Ma52: Doppler shift). Total radiation width $\Gamma_\gamma > 0.025$ eV (1968Ri16). See also $\Gamma_\gamma = 0.40-0.75$ eV (1960Ka13: 3.68→g.s. M1 transition).
3853.783 ^d	22 $5/2^+$	7.02 ps +51–36	$T_{1/2}$: From $\tau = 10.13$ ps +73–52 which is the weighted value of $\tau = 9.0$ ps +25–15 (1968Ri16: Doppler shift), $\tau_m = 10.7$ ps 10 (1969He22: recoil-distance method), $\tau_m = 9.9$ ps 9 (1970Ga01: recoil-distance method). See also 10.8 ps 10 (1968Fo12; ref. within 1970Ga01). Total radiation width $\Gamma_\gamma = 7.3 \times 10^{-5}$ eV 16 (1968Ri16).
6860 ^g			
7570 ^g			
9500 ^{fg}			
10800 ^{fg}			E(level): Unresolved in (α,p).
11850 ^f			
11900 ^g			
13010 ^f			
13400 ^{fg}			E(level): Unresolved in (α,p).
14080 ^{fg}		132 ^f keV	J^π : Shell model predicts $J^\pi = 7/2^+$; However, the authors identified this strong state as the $^{13}\text{C}^*(14.13; J^\pi = 3/2^-)$ state seen in the $^{12}\text{C}(n,n)$ reaction (1985To02).
14819 ^{fg}			
15490 ^f			E(level): Unresolved in (α,p).
16080 ^f			E(level): Unresolved in (α,p).
17950 ^f			
19560 ^{fh}			
20100 ^{fh}			
21400 ^g			$T = (3/2, 1/2)$ T: 3/2 is favorable over T=1/2 (1991Br26). Not strongly populated.
22520 ^{fh}			

^a For each level in $^{13}\text{C}^*(0,3.09,3.68,3.85$ MeV) reported by references: 1953Sh64, 1954St20, 1956Ma52, 1960Ka13, 1960Pi09, 1967Od01, 1968Ri16, 1969He22, 1969Li07, 1970Ga01, 1975Wi04, 1980Wa24, 1983La17, 1995He40, 1996Gi13, 1997He11, 2007Ma58, 2020Li08.

^b From measured $E_\gamma = 3089.049$ keV 20 with recoil energy $E_R = 394$ eV where $E_i - E_f = E_\gamma + E_R$ (1980Wa24).

^c From derived $E_\gamma = 3683.921$ keV 23 with $E_R = 561$ eV (1980Wa24).

^d From derived $E_\gamma = 3853.170$ keV 22 with $E_R = 613$ eV (1980Wa24).

^e From angular distributions and p- γ angular correlations in (1953Sh64, 1954St20, 1971HiZF).

^f Reported in $^{10}\text{B}(\alpha,p)$ (1991Br26).

^g Reported in $^{10}\text{B}(^9\text{Be}, ^6\text{Li})$ (1991Br26).

^h Some states are not associated with Adopted Levels because inadequate details for association are given in the literature.

$^{10}\text{B}(\alpha, \text{p}), (\alpha, \text{p}\gamma)$ (continued)								
$\gamma(^{13}\text{C})$								
$E_i(\text{level})$	J_i^π	E_γ	I_γ	E_f	J_f^π	Mult.	δ	Comments
3089.443	1/2 ⁺	3089.049 20		0	1/2 ⁻	E1		E_γ : Measured in (1980Wa24). E_γ also reported in (1960Pi09, 1968Ri16, 1983La17, 1997He11, 2020Li08). Mult.: (1960Pi09).
3684.482	3/2 ⁻	590 15	0.75 4	3089.443	1/2 ⁺	E1		E_γ : From (1960Ka13, 1960Pi09). 595.013 keV 11 is deduced from results in (1980Wa24). Mult.: (1960Ka13). I_γ : From (1980Wa24). See also $I_\gamma=6.5\times 10^{-3}$ 10 (1960Ka13) and 9.3×10^{-3} 20 (1960Pi09).
		(3690 20)	99.25 4	0	1/2 ⁻	E2+M1	-0.094 9	E_γ : From (1956Ma52). 3683.921 keV 23 is deduced in from results in (1980Wa24). See also $E_\gamma=3730$ keV 60 (1953Sh64: transitions from 3.68 or/and 3.85→g.s.). E_γ also reported in (1954St20: very weak except at the $E_\alpha(\text{res})=1.51$ MeV, where 16% of the total proton counts contributed to this decay, 1968Ri16, 1969Li07, 1983La17, 1997He11, 2007Ma58, 2020Li08). I_γ : From (1980Wa24). Mult.: (1980Wa24). See also (1960Ka13: M1). δ : From (1980Wa24: using $B(E2)=3.63$ 40 from (1970Wi04: $^{13}\text{C}(e, e')$) and $\tau_m=1.59$ fs 13 from (1991Aj01)). $\Gamma_\gamma=0.40-0.75$ eV (1960Ka13: M1).
3853.783	5/2 ⁺	169.300 4	36.3 6	3684.482	3/2 ⁻	E1		E_γ : Measured in (1980Wa24). See also $E_\gamma=210$ keV 30 (1953Sh64: about 30% decays to g.s. via 3.68 state), 169.5 keV 4 (1956Ma52), 180 keV (1960Pi09), 170 keV (1983La17). I_γ : From (1980Wa24). See other values: $I(3.85\rightarrow 3.68)/I(3.85\rightarrow \text{g.s.})=0.32$ 7 (1960Pi09), 0.55 3 (1969Li07). See also (1956Ma52: 3.85 MeV level decays through the 3.68 MeV level with a probability 0.24 5). Mult.: (1960Pi09; 1956Ma52: though M1 is not excluded).
		764.316 10	1.20 4	3089.443	1/2 ⁺	E2		E_γ : Measured in (1980Wa24). See also $E_\gamma=765$ keV 8 (1960Ka13, 1960Pi09). I_γ : From (1980Wa24). See other reported values: $I(3.85\rightarrow 3.09)/I(3.85\rightarrow \text{g.s.})=9.3\times 10^{-3}$ 20 (1960Pi09), 2.5×10^{-2} 5 (1969Li07). Transitions to the 3.09 MeV not observed in (1956Ma52) with the intensity <3% concluded. Mult.: (1960Pi09).
		3854 1	62.5 6	0	1/2 ⁻	M2		E_γ : From (1969Li07). 3853.170 keV 22 is deduced from results in (1980Wa24). See also $E_\gamma=3844$ keV 15 (1956Ma52). E_γ also reported in (1960Pi09, 1968Ri16, 1983La17, 1995He40, 1997He11,

Continued on next page (footnotes at end of table)

$^{10}\text{B}(\alpha, \text{p}), (\alpha, \text{p}\gamma)$ (continued) $\gamma(^{13}\text{C})$ (continued)

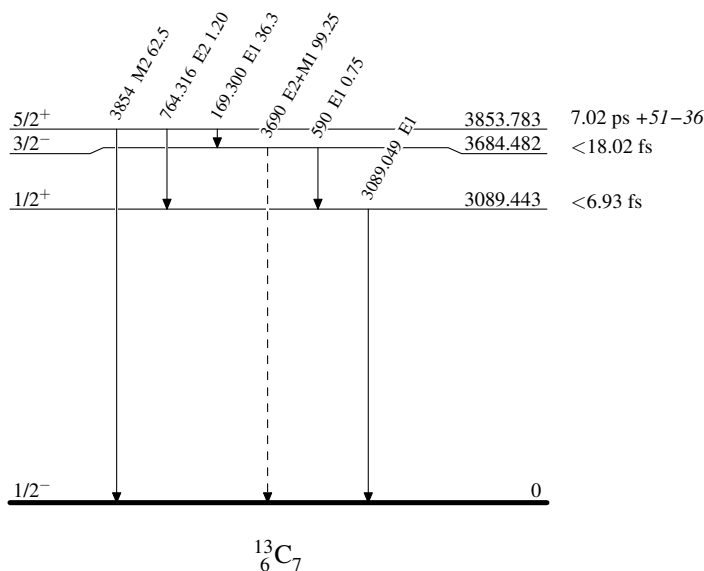
$E_i(\text{level})$	E_γ	Comments
		2007Ma58, 2020Li08).
		I_γ : From (1980Wa24). See other reported values in (1960Pi09, 1969Li07) above and $I(3.85 \rightarrow \text{g.s.})/I(3.85 \rightarrow 3.68 \rightarrow \text{g.s.})=7:3$ (1954St20).
		Mult.: (1960Pi09).
		$\Gamma_\gamma(\text{FWHM})=4.5 \text{ keV}$ (1969Li07).

 $^{10}\text{B}(\alpha, \text{p}), (\alpha, \text{p}\gamma)$

Legend

Level Scheme

Intensities: % photon branching from each level

-----▶ γ Decay (Uncertain) $^{13}\text{C}_7$

$^{10}\text{B}(^6\text{Li},^3\text{He})$

1965Ca05: $^{10}\text{B}(^6\text{Li},^3\text{He})$ $E \approx 5$ MeV; differential cross sections were measured at 15 angles, $\theta_{\text{lab}} = 0^\circ - \approx 150^\circ$. ^{13}C states were observed. Analyzed σ vs. $(2J+1)$ dependence.

1966Mc05: $^{10}\text{B}(^6\text{Li},^3\text{He})$ $E = 4.89$ MeV; measured cross section at five angles from 0-60 degrees. The first four states of ^{13}C have been observed. Analyzed σ vs. $(2J+1)$ dependence.

1974Ho06: $^{10}\text{B}(^6\text{Li},^3\text{He})$ $E = 18$ MeV; measured $\sigma(E(^3\text{He}), \theta)$. Identified J, π and analog pairs of states in ^{13}C and ^{13}N . An angular distribution is also reported for $^{13}\text{C}^*(9.50)$. See also (1972HoZN,1974HoZW).

 ^{13}C Levels

E(level)	J^π ^c	Γ ^b	^{13}C total cross sections (mb) ^d	Comments
0 ^a	1/2 ⁻		0.48	
3090 ^a	1/2 ⁺		0.42	
3680 ^a	3/2 ⁻			E(level): Unresolved with 3850 (1965Ca05,1966Mc05). ^{13}C total cross sections (mb): $\sigma = 22.2$ mb for $^{13}\text{C}^*(3680+3850)$.
3850 ^a	5/2 ⁺			E(level): Unresolved with 3680 (1965Ca05,1966Mc05). ^{13}C total cross sections (mb): $\sigma = 22.2$ mb for $^{13}\text{C}^*(3680+3850)$.
6860 ^b	5/2 ⁺			E(level): Reported in (1965Ca05).
7490 ^b	7/2 ⁺			J^π : identified as a mirror analog of $^{13}\text{N}^*(7.17; J^\pi = 7/2^+)$ from (1970Aj04).
7550 ^b	5/2 ⁻	<30 keV		
7690 ^b	3/2 ⁺	60 keV 30		
8860 ^b	1/2 ⁻			
9500 ^b	(3/2 ⁻)	<30 keV		
9900 ^b	3/2 ⁻			
10750 ^b	7/2 ⁻			
10820 ^b	5/2 ⁻			J^π : identified as a mirror analog of $^{13}\text{N}^*(10.35; J^\pi = 5/2^-)$ from (1970Aj04).
11000 ^b	(1/2 ⁺)			
11080 ^b	(1/2 ⁻)			
11950 ^b	(7/2 ⁻)			
12110 ^b				
12440 ^b				

^a Reported in (1965Ca05 and 1966Mc05): $\Delta E \approx 50$ keV).

^b Reported in (1974Ho06).

^c From (1970Aj04) and comparison of mirror state pairs populated in $^{10}\text{B}(^6\text{Li},^3\text{He})$ and $(^6\text{Li},t)$ in (1974Ho06).

^d From (1966Mc05) based on data at five angles from $0^\circ - 60^\circ$.

$^{10}\text{B}(^7\text{Li},\alpha)$

1963Mi02: $^{10}\text{B}(^7\text{Li},\alpha)$, deduced ^{13}C level properties.

1965Ca05: $^{10}\text{B}(^7\text{Li},\alpha)$ $E \approx 5$ MeV; differential cross sections were measured at 15 angles, $\theta_{\text{lab}}=0^\circ \sim 150^\circ$. ^{13}C states were observed. Analyzed σ vs. $(2J+1)$ dependence.

1966Mc05: $^{10}\text{B}(^7\text{Li},\alpha)$ $E=5.20$ MeV; measured cross section. ^{13}C states have been observed. Analyzed σ vs. $(2J+1)$ dependence.

1977Ko27: $^{10}\text{B}(^7\text{Li},\alpha)$ $E=24$ MeV; measured $\sigma(\theta)$; deduced total absolute σ , reaction mechanism. Unresolved high-energy ^{13}C states up to 30 MeV; a detailed analysis of the angular distributions is not performed.

 ^{13}C Levels

<u>E(level)^a</u>	<u>^{13}C total cross sections (mb)^a</u>	<u>Comments</u>
0 ^b	0.37	
3090 ^b	0.20	
3680 ^b		E(level): Unresolved with 3850. ^{13}C total cross sections (mb): $\sigma=1.42$ mb for $^{13}\text{C}^*(3680+3850)$.
3850 ^b		E(level): Unresolved with 3680. ^{13}C total cross sections (mb): $\sigma=1.42$ mb for $^{13}\text{C}^*(3680+3850)$.
6860 ^b	1.19	
7500		E(level): Unresolved with 7550, 7690. ^{13}C total cross sections (mb): $\sigma=2.86$ mb for $^{13}\text{C}^*(7500+7550+7690)$.
7550		E(level): Unresolved with 7500, 7690. ^{13}C total cross sections (mb): $\sigma=2.86$ mb for $^{13}\text{C}^*(7500+7550+7690)$.
7690		E(level): Reported (1966Mc05: $\Delta E \approx 50$ keV). E(level): Unresolved with 7500, 7550. ^{13}C total cross sections (mb): $\sigma=2.86$ mb for $^{13}\text{C}^*(7500+7550+7690)$.
9500		
9900		
10460		
11000		E(level): Unresolved with 11080.
11080		E(level): Unresolved with 11000.
11950		E(level): Unresolved with 12190, 12440.
12190		E(level): Unresolved with 11950, 12440.
12440		E(level): Unresolved with 11950, 12190.
13570		
16080		

^a Values listed in (1966Mc05: $\Delta E \approx 50$ keV), except where noted.

^b From (1965Ca05).

$^{10}\text{B}(^{10}\text{B},^{13}\text{C})$ 2023Je05

2023Je05: XUNDL dataset compiled by TUNL (2023).

Beams of 72.2 MeV ^{10}B ions from the Catania SMP Tandem accelerator impinged on 99.8% enriched ^{10}B targets. A set of four position-sensitive Si ΔE -E telescopes were positioned around the target to detect the reaction products. Three different configurations were utilized so that events with azimuthal angles in the range of 20° to 53° were measured.

Analysis of the $^{10}\text{B}(^{10}\text{B},^7\text{Be})$ singles events revealed well-resolved states up to $E_x \approx 12$ MeV. Above this energy a smooth and increasing background was subtracted, revealing many states up to $E_x \approx 22$ MeV. An energy resolution of $\text{FWHM} \approx 300$ keV for the peak widths suggests some observed peaks could represent unresolved doublets. A $\Gamma \approx 600$ keV state at $E_x \approx 19.15$ MeV appears to be a new state. The suggested members of a $K^\pi = 3/2^-$ rotational band (2002Mi32,2003Mi34) are all observed.

The relative energy spectrum of $^{10}\text{B}(^{10}\text{B},^{13}\text{C} \rightarrow \alpha + ^9\text{Be})$ events was analyzed by requiring detection of the $\alpha + ^9\text{Be}$ products. The $^7\text{Be}(0, 0.429$ MeV) levels populated with ^{13}C could not be separated, but the excited state component appears negligible. Participation of $^7\text{Be}(4.57$ MeV) is observed and analyzed separately from the lower-energy ground-state component. A prominent peak at $E_x \approx 19$ MeV is likely the new state mentioned above in the singles result. Near threshold ($S_\alpha = 10.65$ MeV) states at $E_x = 10.8$ and 12.1 MeV were observed along with other weaker groups at $E_x = 22$ and 24 MeV.

 ^{13}C Levels

E(level)	J^π ^a	$T_{1/2}$ ^b	Comments
0.0 ^b 3			
3.0×10 ^{3b} 1			
3.78×10 ^{3be} 1			E(level): Likely unresolved $^{13}\text{C}^*$ (3.68+3.85 MeV).
6.75×10 ^{3b} 4			
7.50×10 ^{3be} 1			E(level): Likely unresolved $^{13}\text{C}^*$ (7.49+7.55 MeV).
9.48×10 ^{3b} 2			
9.89×10 ^{3b} 4	3/2 ⁻		
10.78×10 ^{3bcd} 2	(5/2 ⁻)		E(level): Reported at $E_x = 10.8$ MeV <i>I</i> in $^{10}\text{Be}(^{10}\text{Be}, \alpha + ^9\text{Be})$. E(level): Likely unresolved $^{13}\text{C}^*$ (10.75+10.81 MeV).
11.84×10 ^{3b} 8			
12.3×10 ^{3bcde} 1	7/2 ⁻		E(level): Reported at $E_x = 12.1$ MeV <i>I</i> in $^{10}\text{Be}(^{10}\text{Be}, \alpha + ^9\text{Be})$. E(level): Likely unresolved $^{13}\text{C}^*$ (12.19+12.44 MeV).
14.20×10 ^{3b} 7	(9/2 ⁻)		J^π : Spin suggested by level spacings.
19.15×10 ^{3bcd} 4		≈ 600 keV	Suggested new level. E(level): Reported at $E_x = 19.0$ MeV <i>I</i> with $\Gamma \approx 660$ keV in $^{10}\text{Be}(^{10}\text{Be}, \alpha + ^9\text{Be})$.
22.0×10 ^{3bd} 3			E(level): Reported at $E_x = 21.9$ MeV <i>I</i> in $^{10}\text{Be}(^{10}\text{Be}, \alpha + ^9\text{Be})$.
23.6×10 ^{3c} 1			E(level): From $^{10}\text{Be}(^{10}\text{Be}, \alpha + ^9\text{Be})$.

^a Based on $K^\pi = 3/2^-$ rotational band suggested in (2002Mi32,2003Mi34) deduced from level spacings.

^b From the inclusive $^{10}\text{Be}(^{10}\text{Be}, ^7\text{Be})$ reaction, except where noted.

^c Observed in the exclusive $^{10}\text{Be}(^{10}\text{Be}, \alpha + ^9\text{Be})^7\text{Be}_{\text{g.s.}}$ reaction.

^d Observed in the exclusive $^{10}\text{Be}(^{10}\text{Be}, \alpha + ^9\text{Be})^7\text{Be}^*(4.57)$ reaction.

^e Possible doublet.

${}^{10}\text{B}({}^{14}\text{N}, {}^{11}\text{C})$

1966Co27: ${}^{10}\text{B}({}^{14}\text{N}, {}^{11}\text{C})$ E=16.3,19.8 MeV; the proton transfers to both the ground state and the first excited state of ${}^{13}\text{C}$ were observed. Total cross sections were measured.

1975Na15: ${}^{14}\text{N}({}^{10}\text{B}, {}^{11}\text{C})$ E=100 MeV; measured $\sigma(\theta)$. ${}^{13}\text{C}$ levels deduced S-factors. See also (1976Na09: theory).

1979Mo14: ${}^{10}\text{B}({}^{14}\text{N}, {}^{13}\text{C}){}^{11}\text{C}$, $S_1S_2=1.1$ for ${}^{11}\text{C}_{\text{g.s.}}$

 ${}^{13}\text{C}$ Levels

<u>E(level)^a</u>	<u>J^{π}^a</u>	<u>L transfer^a</u>	<u>C₂²S₂^a</u>	<u>Comments</u>
0	1/2 ⁻	1,2	0.62	E(level): also reported in (1966Co27). C ₂ ² S ₂ : deduced from C ₁ ² S ₁ C ₃ ² S ₂ =0.68 (1975Na15) and assuming C ₁ ² S ₁ given by (1967Co32).
3090	1/2 ⁺			E(level): Reported in (1966Co27).
3680	3/2 ⁻	0,1,2	0.22	C ₂ ² S ₂ : deduced from C ₁ ² S ₁ C ₃ ² S ₂ =0.24 (1975Na15) and assuming C ₁ ² S ₁ given by (1967Co32).
7550	5/2 ⁻			
11850	7/2 ⁺			

^a From DWBA analysis of spectroscopic factors in (1975Na15).

${}^{11}\text{B}(\text{d},\gamma):\text{res}$

1966Su05: ${}^{11}\text{B}(\text{d},\gamma_0)$, $0.5 < E < 5.5$ MeV; measured $\sigma(E)$.

1972BIZU: ${}^{11}\text{B}(\text{d},\gamma)$ $E=1.5-4.2$ MeV; measured $\sigma(E;E_\gamma)$. ${}^{13}\text{C}$ deduced giant dipole resonance, level-width, J , π .

1973We12: ${}^{11}\text{B}(\text{d},\gamma_0)$ $E=1-4$ MeV; measured $\sigma(E,\theta)$. ${}^{13}\text{C}$ deduced resonances. Enriched targets.

1981Ka16: ${}^{11}\text{B}(\text{d},\gamma)$ $E=1.95-12$ MeV; measured $\sigma(\theta,E_\gamma)$, $\sigma(\theta,E)$. ${}^{13}\text{C}$ deduced resonances, Γ , possible GDR excitation. NaI(Tl) crystal spectrometer, plastic scintillator anticoincidence shield.

1982AuZX: ${}^{11}\text{B}(\text{d},\gamma)$ $E=4-17$ MeV; measured $\gamma(\theta)$, E_γ , I_γ ; deduced reaction mechanism.

1985Au10: ${}^{11}\text{B}(\text{pol. d},\gamma)$ $E=1.6-4$ MeV; measured $\sigma(E,\theta)$, $A(E,\theta)$, $T_{20}(E,\theta)$. ${}^{13}\text{C}$ deduced doorway state parameters. Enriched targets. Secondary doorway state formalism. See also (1985AuZZ).

1991Co07: ${}^{11}\text{B}(\text{d},\gamma_{0,2+3})$ $E=12$ MeV; measured capture $\sigma(\theta)$; deduced reaction mechanism. Large anticoincidence NaI detectors.

See also (1969Fr03) ${}^{11}\text{B}(\text{d},\alpha)$ $E=0.7-2.2$ MeV.

 ${}^{13}\text{C}$ Levels

<u>E(level)^a</u>	<u>Γ</u>	<u>Comments</u>
20200 70	560 keV 90	E(level), Γ : From (1985Au10). E(level): The polarized d work of (1985Au10) identified two levels at $E_x=20.20$ and 20.57 MeV in the region previously identified as a single resonance at $E_d=2.0$ MeV. That resonance, now a doublet, was identified as a single resonance at $E_x=20369$ keV 85 with $\Gamma=508$ keV by (1973We12), and at $E_x=20400$ keV 100 with $\Gamma=600$ keV by (1981Ka16).
20.57×10^3 84	5.64 MeV 43	E(level), Γ : From (1985Au10).
22.0×10^3 2	≈ 1 MeV	E(level), Γ : From (1981Ka16). E(level): Reported at $E_d \approx 4000$ keV.

^a When not given in the manuscripts, E(level) are deduced using ${}^{13}\text{C}$, ${}^{11}\text{B}$ and d masses from (2021Wa16: AME-2020) and $E_d(\text{res})$. $E_x = S(^2\text{H}) + E_{\text{c.m.}}(\text{relativistic})$.

$^{11}\text{B}(\text{d,p})\text{:res}$

- 1949Hu41: $^{11}\text{B}(\text{d,p})$ E=0.3-1.85 MeV; no evidence of resonances.
 1957Ja37: $^{11}\text{B}(\text{d,p})$ E=0.2-1.8 MeV; cross sections were measured with no evidence of resonances.
 1958Ka31: $^{11}\text{B}(\text{d,p}\gamma(15.1 \text{ MeV}))$, the thin-target yield indicates $E_{\text{thresh.}}=1633 \text{ keV}$ with resonances at $E_d=2180$ and 3080 keV . At $E_d=1.5 \text{ MeV}$, $\sigma \approx 0.38 \text{ b}$.
 1967Pf02: $^{11}\text{B}(\text{d,p})$, the polarization of ^{12}B recoils has been studied for $E_d=0.9$ to 3.2 MeV : resonances in the recoil polarization are observed at $E_d=1.5, 2.1$ and 3.0 MeV .
 1970Fi07: $^{11}\text{B}(\text{pol. d,p})$ E=10, 12 MeV; measured analyzing power $A(\theta)$.
 1971HiZG: $^{11}\text{B}(\text{d,p})$ E=5.5 MeV; measured $\sigma(\theta)$, DSA. ^{13}C deduced levels, Γ , $T_{1/2}$, J, π .
 1976Ta07: $^{11}\text{B}(\text{d,p})$ E=1.3-3.0 MeV; measured polarization; deduced magnetic substate populations, J-mixing of transferred neutron, reaction mechanism.
 1977AnZO: $^{11}\text{B}(\text{d,p})$ E<1.4 MeV; measured absolute $\sigma(E,\theta)$.
 1985Ab10: $^{11}\text{B}(\text{d,p})$ E=3-10 MeV; measured $\sigma(E)$.
 1997Ya02: $^{11}\text{B}(\text{d,p}_0)$ $E_{\text{c.m.}}=76-144 \text{ MeV}$; measured energy spectra, $\sigma(\theta)$; deduced σ , astrophysical S-factor vs E.
 1997Ya08: $^{11}\text{B}(\text{d,p}_0)$ $E_{\text{c.m.}}=57-141 \text{ keV}$; measured astrophysical S-factors.
 2009Ko09: $^{11}\text{B}(\text{d,p}_0)$ E=900-1200 keV; measured $\sigma(\theta,E)$.

Theory:

- 1970Vo09: $^{11}\text{B}(\text{d,p})$ E=0.7-3.5 MeV; analyzed $\sigma(\theta)$. DWBA.
 1977Sa25: $^{11}\text{B}(\text{d,p})$ E=1.3-3.0 MeV; calculated magnetic substate populations, optical model parameters. DWBA calculations.
 1982Go05: $^{11}\text{B}(\text{d,p})$ E=12 MeV; analyzed data. ^{13}C level deduced S-factors. DWBA, nuclear vertex constants.
 2012Co01: $^{11}\text{B}(\text{d,p})$ E<10 MeV; calculated astrophysical reaction rates. TALYS code, comparison with NACRE compilations.

 ^{13}C Levels

<u>E(level)^c</u>	<u>Γ</u>	<u>$E_d(\text{res})$ (keV)</u>
19946 ^a		1500 ^a
20521 ^b 10	115 ^b keV 10	2180 ^b 10
21282 ^b 15	160 ^b keV 15	3080 ^b 15

^a From (1967Pf02); authors identified with $E_x=19.90$ and also reported $E_x=20.5$ and 21.28 MeV .

^b From (1958Ka31);

^c Level energies are deduced using $E_d(\text{res})$ and ^{11}B , d and ^{13}C masses from (2021Wa16: AME-2020).
 $E_x=S(^2\text{H})+E_{\text{c.m.}}(\text{relativistic})$.

¹¹B(d,n γ):res

- 1954Bu06: ¹¹B(d,n) E<2 MeV; angular distributions were measured. The authors suggest that the stripping process plays an important part in the reaction. No narrow resonances were observed in the excitation functions.
- 1955Ma76: ¹¹B(d,n) E=1.0-5.5 MeV; measured the absolute cross sections for the reaction.
- 1955Wa30: ¹¹B(d,n) E=600 keV; angular distributions of the neutron groups leading to the ground state and first excited state of ¹²C, have been determined. For the excited-state group ¹²C*(4.4), the interpretation is less clear; the observed distribution can be accounted for by p-wave formation of a J ^{π} =7/2⁺ level in ¹³C.
- 1957Am48: ¹¹B(d,n) E=0.5-1.15 MeV; measured angular distributions of the ground-state neutrons from the reaction.
- 1958Ka31: ¹¹B(d,n γ) E \leq 3.25 keV; measured σ . ¹³C deduced resonance parameters at 20.52 MeV (Γ =115 keV 10) and 21.28 MeV (Γ =160 keV 15) at 2.180 MeV 10 and 3.080 MeV 15, respectively.
- 1961Su17: ¹¹B(d,n γ) E γ =15.1 MeV, E_d=1.3-5.6 MeV; deduced σ (E).
- 1964Ku09: ¹¹B(d,n γ) E_d=1.5-5.5 MeV; measured σ . ¹³C deduced resonance parameters.
- 1965Al17: ¹¹B(d,n γ) E=1-11 MeV; measured σ (E;E_n, θ). Natural, enriched targets.
- 1965Cl02: ¹¹B(d,n₀),(d,n) E=1.5-3 MeV; measured σ (E, θ). Natural target.
- 1967Di01: ¹¹B(d,n) E=1.1-2.9 MeV; measured σ (E;E_n). Enriched targets.
- 1971Ri19: ¹¹B(pol. d,n) E=900 keV; measured analyzing power(θ). ¹³C deduced resonance, J, π . See also (1971RiZL).
- 1972Th14: ¹¹B(d,n γ) E=4-4.8 MeV, θ (n)=0 $^\circ$; measured σ (E,E_n,E γ , θ (n γ)); deduced stripping reduced width amplitudes. Natural, isotopic targets.
- 1981An16: ¹¹B(d,2n) E=7-16 MeV; measured σ (E), thick target yields. Activation technique. Statistical model, pre-equilibrium decay modes.
- 2001Ho23: ¹¹B(d,n) E=24-111 keV; measured σ , S-factor. Comparison with earlier data.
- 2006Pa27: ¹¹B(d,n) E=120-160 keV; measured E_n, yields, angular distributions; deduced astrophysical S-factors.
- 2013Co12: ¹¹B(d,n) E<5 MeV; measured reaction products, E γ , I γ ; deduced thin and thick target yields, σ (θ). Comparison with available data.
- See discussion on polarized neutron production in (1966Ma21, 1969Mi20, 1970Bu15, 1971Hi09, 1972Me06, 1974Th02, 1975Si22).

Theory:

- 1972Se09: ¹¹B(d,n) E=0.2-1.02 MeV; analyzed polarization effects, resonant matrix elements. Polarized beams.
- 1975Se07: ¹¹B(pol. d,n); analyzed data; deduced criteria for simplified polarization measurement analysis.
- 1977Se09: ¹¹B(pol. d,n); calculated A(θ).
- 2012Co01: ¹¹B(d,n) E<10 MeV; calculated astrophysical reaction rates. TALYS code, comparison with NACRE compilations.

¹³C Levels

E(level) ^a	J ^{π}	Γ	E _d (res) (keV)	Comments
19692	5/2 ⁻		1200	E(level): From E _d =1200 keV (1967Di01: n ₁); see also E _d \approx 1 MeV (1972Se09). J ^{π} : From polarization data in (1971Ri19); see also (1971Ri19, 1972Se09, 1975Se07, 1977Se09).
19904	(3/2 ⁺ ,5/2 ⁺)	\approx 600 keV	1450	E(level): From E _d =1450 keV (1967Di01: n ₀). J ^{π} : From polarization data in (1971Ri19); see also (1977Se09). Γ : From Γ_{lab} =700 keV (1967Di01).
20030		200 keV	1600	E(level): From E _d =1600 keV (1965Al17: n ₀); see also (1977Se09). Γ : From (1977Se09: proposed).
20521 8		116 keV 10	2180 10	E(level): From E _d =2180 keV 10 (1958Ka31: $\gamma_{15.1}$ MeV); see also E _d =2180 keV 20 (1964Ku09: $\gamma_{15.1}$ MeV), and 2200 keV (1967Di01: n ₁). See also E _x =20.2 MeV from E _d =1800 keV (1965Al17: n ₁). Γ : Weighted value from (1958Ka31: Γ_{cm} =115 keV 10) and (1964Ku09: Γ_{lab} =140 keV 20).
21281 13		159 keV 15	3080 15	E(level): From E _d =3080 keV 15 (1958Ka31: $\gamma_{15.1}$ MeV); see also 3080 keV 20 (1964Ku09: $\gamma_{15.1}$ MeV). Γ : Weighted value from (1958Ka31: Γ_{cm} =160 keV 15) and (1964Ku09: Γ_{lab} =185 keV 20).
21721?			3600	E(level): From E _d =3600 keV (1965Al17: n ₀).

Continued on next page (footnotes at end of table)

$^{11}\text{B}(\text{d},\text{n}\gamma):\text{res}$ (continued) ^{13}C Levels (continued)

<u>E(level)^a</u>	<u>Γ</u>	<u>E_d(res) (keV)</u>	<u>Comments</u>
21814 17	144 keV 21	3710 20	E(level): From E _d =3710 keV 20 (1964Ku09). Γ : From Γ_{lab} =170 keV 25 (1964Ku09).
22198		4165	E(level): From average of E _d =4100 keV (1965A117: n ₁ ,n ₂) and 4230 keV (1965A117: n ₀); see also 4400 keV (1964Ku09: $\gamma_{15.1}$ MeV). Γ : broad (1964Ku09).
23073?		5200	E(level): From E _d =(5200) keV (1965A117: n ₁).
26791		9600	E(level): From E _d =9600 keV (1965A117: n ₀ ,n ₁ ,n ₂ ,n ₃).
27466		10400	E(level): From E _d =10400 keV (1965A117: n ₀ ,n ₂ ,n ₃).

^a Deduced from E_d(res), using ^{13}C , ^{11}B and d masses from (2021Wa16: AME-2020). E_x=S(²H)+E_{c.m.}(relativistic).

¹¹B(³He,p),(³He,pγ),(α,d)

- 1955Bi26: ¹¹B(³He,p) E=900 keV; measured particle spectra. ¹³C deduced level energies.
- 1957Ga01: ¹¹B(³He,p) E=1.25 MeV; spectra of charged particles were observed at θ=45°, 90° and 135° in a NaI-crystal spectrometer. With the well known states ¹³C*(0,3.097,3.684,3.844,6.864) calibrations, ten ¹³C states were determined.
- 1957Ho61: ¹¹B(³He,p) E=4.5 MeV; angular distributions have been measured for the p₀, p₁ and p₂₊₃ groups at 14 angles θ=5°–130°. The p₀ group appears to be peaked in both the forward and the backward direction. The other groups do not exhibit a strong angular variation.
- 1958Mo99: ¹¹B(³He,p) E≤1.25 MeV. With the well-known ¹³C levels up to 6.87 MeV being used as calibrations, other levels of ¹³C*(5.51,6.10,7.55,8.87,9.52,9.91 MeV) were reported. The levels at 5.51 and 6.10 MeV have not previously been detected.
- 1958Sw63: ¹¹B(³He,p) E=6.05 MeV; the angular distributions of proton groups were investigated using 6 MeV Van de Graaff generator at AWRE, Aldermaston. The p₀ group is strongly peaked forward.
- 1959Yo25: ¹¹B(³He,p) E=5.5 MeV; Q values corresponding to excitations of ¹³C from 3.7 to 9.90 MeV were observed. Level widths were determined.
- 1963Ga03: ¹¹B(³He,p) E=3.50 MeV; the proton spectrum was observed at θ=132.5°. Peaks corresponding to the ground state and to the well-established levels in ¹³C at 3.09, 3.68, 3.85, 6.86, 7.47, 7.53, and 7.64 MeV are present.
- 1963Ma24: ¹¹B(³He,p) E=8.6,9.6,10.3 MeV; angular distributions have been measured for p₀.
- 1964Ma57: ¹¹B(³He,p) E=1.51 MeV; measured nuclear reaction Q₀ value at the National University of Mexico (UNAM).
- 1966Ch18: ¹¹B(³He,p) E=1.23,1.50,2.00 MeV; previously reported levels of ¹³C*(5.51,6.10) have been found to come from the proton decay of the states of ¹³N*(9.48,10.37) rather than from states in ¹³C. ¹³C states at E_x=3.09, 3.68, 3.85, 6.86 MeV were reported.
- 1967Od01: The ground state Q₀ value of the reaction ¹¹B(³He,p) was measured as 13185.4 keV 40.
- 1968Co27: ¹¹B(³He,p) E=7.3 MeV; measured E_γ, pγ-coin. ¹³C deduced levels, level-width, isobaric analog, γ-decay.
- 1969Ad01: ¹¹B(³He,p)¹³C*(15.11)→n+¹²C, E=7 MeV; measured σ(E_n). ¹³C levels deduced n-decay branching, form of isospin impurity.
- 1970Me24: ¹¹B(³He,p) E=3 MeV; measured σ, σ(E), σ(θ), E_γ, I_γ, Q, σ(E_p,θ). ¹³C deduced levels and widths.
- 1971HiZF: Experimental studies of some excited levels of nuclei ¹²B, ¹³C, and ¹⁹O: considerations on the mixtures of configurations and on the residual interaction. Values of Γ_γ/Γ=(0.3±0.1)%, <0.1% were given for ¹³C*(7.49,7.55) states, respectively.
- 1971Me01: ¹¹B(³He,p) E=2.8,3 MeV; measured σ(E_p,θ); deduced reaction mechanism. ¹³C deduced levels, J, π. Natural, enriched target.
- 1971WuZY: ¹¹B(³He,p) E=4-12 MeV; measured σ(E;θ).
- 1971WuZZ: ¹¹B(³He,p) E=4,6,8,10,12 MeV; measured σ(E_p,θ). Zero-range DWBA analysis.
- 1973Ad02: ¹¹B(³He,np) E=7.5,6.6 MeV; measured σ(E_n,E_p,θ(n),θ(p)), np-coin. ¹³C deduced level-width(γ), level-width(n).
- 1973Wu01: ¹¹B(³He,p) E=4,6,8,10,12 MeV; measured σ(θ). Enriched target.
- 1975Ma21: ¹¹B(³He,pγ); measured pγ-coin.
- 1975Va19: ¹¹B(α,d) E=15-25 MeV.
- 1977Ma16: ¹¹B(³He,pγ) E=5.3 MeV; measured particle γ-coin. ¹³C levels deduced partial, total Γ, B(λ).
- 1975MaXS: ¹¹B(³He,pγ), measured γ-spectra, proton decays. ¹³C deduced levels.
- 1983Va28: ¹¹B(α,d) E=25-30 MeV; measured σ(θ); deduced reaction mechanism, optical model parameters, residual level production σ. ¹³C levels deduced L. DWBA analysis.
- 1996Mc09: ¹¹B(³He,p) E=2-4 MeV; measured σ(E_p,θ).

Theory:

- 1970Ma38: ¹¹B(³He,p); calculated σ(θ).
- 1984Be23: ¹¹B(α,d) E=30.1 MeV; analyzed σ(θ); deduced optical model parameters, exchange process role.

¹³C Levels

E(level) ^{abe}	Γ ^c	L ^d	Comments
0		0+2	
3090		1	
3685	<5 keV	0+2	E(level): Unresolved (1958Mo99: E _x =3.74 MeV, 1977Ma16).
3854	<5 keV	1+3	E(level): Unresolved (1958Mo99: E _x =3.74 MeV, 1977Ma16).

Continued on next page (footnotes at end of table)

$^{11}\text{B}(^3\text{He,p}),(^3\text{He,p}\gamma),(\alpha,\text{d})$ (continued) ^{13}C Levels (continued)

E(level) ^{abe}	Γ^c	L ^d	Comments
6871 12	<10 keV	1+3	E(level): From (1959Yo25). Branching ratio of the decay $^{13}\text{C}^*(6.87\text{ MeV}) \rightarrow ^{12}\text{C}_{\text{g.s.}} + n = 0.99$ 9 (1973Ad02). See also $\Gamma_n/\Gamma = 1.05$ 11 (1969Ad01).
7500 12	<5 keV		E(level): From (1959Yo25). E(level): Unresolved (1958Mo99: $E_x = 7.55\text{ MeV}$; 1973Wu01). Γ : $\Gamma_\gamma/\Gamma = 0.3\%$ 1 (1971HiZF).
7554 12	<5 keV		E(level): From (1959Yo25). E(level): See also $E_x = 7580$ 60 (1957Ga01) and 7550 40 (1958Mo99). E(level): Unresolved (1973Wu01). Γ : $\Gamma_\gamma/\Gamma < 0.1\%$ (1971HiZF).
7694 14	72 keV 10	1+3	E(level): From (1959Yo25). Γ : Weighted value of 75 keV 15 (1959Yo25) and 70 keV 10 (1970Me24).
8863 30	142 keV 30		E(level): Weighted value of 8850 keV 60 (1957Ga01), 8870 keV 50 (1958Mo99), 8869 keV 36 (1959Yo25) and 8860 keV 30 (1970Me24). Γ : Weighted value of 175 keV 50 (1959Yo25) and 130 keV 30 (1970Me24).
9510 12	<10 keV		E(level): Weighted value of 9540 keV 80 (1957Ga01), 9520 keV 60 (1958Mo99) and 9509 keV 12 (1959Yo25).
9898 12	<10 keV	0+2	E(level): Weighted value of 9920 keV 60 (1957Ga01), 9910 keV 50 (1958Mo99), 9896 keV 12 (1959Yo25). Branching ratio of the decay $^{13}\text{C}^*(9.989) \rightarrow ^{12}\text{C}_{\text{g.s.}} + n = 1.0$ 2 vs $\rightarrow ^{12}\text{C}^*(4.4) + n < 0.15$ (1973Ad02).
10460			E(level): From (1970Me24).
10760 10			E(level): From (1970Me24).
10820 10			E(level): From (1970Me24).
11006 30			E(level): Weighted value of 10900 keV 150 (1957Ga01) and 11010 keV 30 (1970Me24).
11.10×10 ³ 15			E(level): From (1957Ga01).
11720			E(level): From (1973Ad02); see also $E_x = 11670\text{ keV}$ (1955Bi26). Branching ratio of the decay $^{13}\text{C}^*(11.72) \rightarrow ^{12}\text{C}_{\text{g.s.}} + n = 0.67$ 16; $\rightarrow ^{12}\text{C}^*(4.4) + n = 0.33$ 8 (1973Ad02).
12.08×10 ³ f 10			E(level): From (1957Ga01).
12.81×10 ³ f 10			E(level): From (1957Ga01).
15110	≈5.31 keV		$T = 3/2$ (1969Ad01) Γ : (1968Co27) measured $\Gamma_{\gamma 0}/\Gamma = 0.53\%$ 6. Using this and $\Gamma_{\gamma 0}(M1) = 25\text{ eV}$ 7 from (1967Pe07: $^{13}\text{C}(e,e')$) and $\delta^2 = E2/M1 = 0.009 + I8 - 8$ (1968Di04: $^{12}\text{C}(p,\gamma)$) they deduced $\Gamma = 4.7\text{ keV}$. Γ : (1969Ad01) measured $\Gamma_{n0}/\Gamma = 0.065$ 14 and $\Gamma_{n1}/\Gamma = 0.250$ 36. Γ : (1973Ad02) measured $\Gamma_{n0}/\Gamma = 0.070$ 18, $\Gamma_{n1}/\Gamma = 0.261$ 30 and $\Gamma_{n2}/\Gamma = 0.026$ 18. Γ : (1975Ma21, 1977Ma16) measured $\Gamma_{\gamma 0}/\Gamma = 0.396\%$ 30 and the relative γ_0 , γ_1 and γ_{2+3} intensities. They combined with $\Gamma_{\gamma 0}(M1) = 22.7\text{ eV}$ 27 from (1969Wi22, 1970Wi04: $^{13}\text{C}(e,e')$) and $\delta^2 = E2/M1 = 0.009 + I8 - 8$ (1968Di04: $^{12}\text{C}(p,\gamma)$) to obtain $\Gamma_{\gamma 0}(M1) = 22.7\text{ eV}$ 26, $\Gamma_{\gamma 0}(E2) = 0.59\text{ eV}$ 11, $\Gamma_{\gamma 1} = 4.12\text{ eV}$ 74, $\Gamma_{\gamma_{2+3}} = 18.2\text{ eV}$ 24 and $\Gamma_{\gamma(7.55\text{ MeV})} < 0.9\text{ eV}$. They deduced $\Gamma = 5.88\text{ keV}$.

^a Values listed in, for example, (1977Ma16) except where noted.

^b For levels reported, see (1955Bi26, 1957Ga01, 1958Mo99, 1959Yo25, 1963Ga03, 1964Ma57, 1966Ch18, 1967Od01, 1968Co27, 1969Ad01, 1970Me24, 1971HiZF, 1971Me01, 1973Ad02, 1973Wu01, 1975Ma21, 1977Ma16).

^c From (1959Yo25) except where noted.

^d From (1973Wu01).

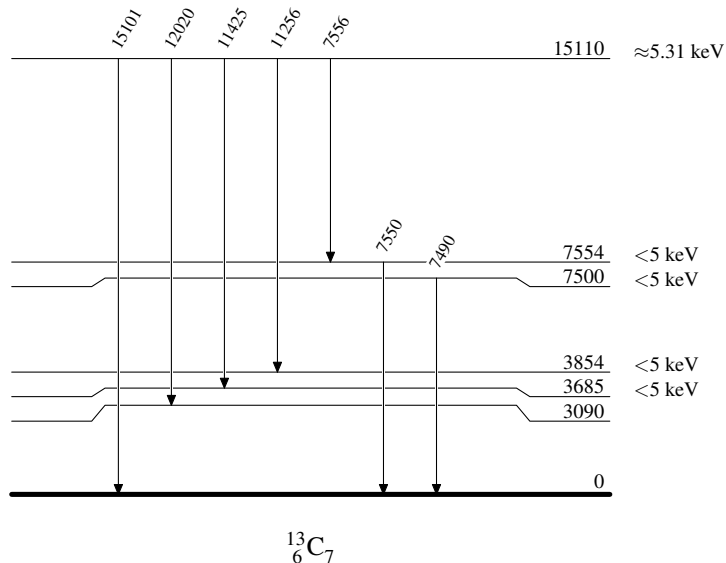
^e Levels at $E_x = 5.50\text{ MeV}$ and 6.10 MeV were reported by (1957Ga01, 1958Mo99) based on the observed proton energy; however, these levels were misidentified. They result from the decay of proton unbound levels populated in $^{11}\text{B}(^3\text{He,n})^{13}\text{N}^*$; see (1966Ch18).

^f Some states are not associated with Adopted Levels because inadequate details for association are given in the literature.

$^{11}\text{B}({}^3\text{He,p}),({}^3\text{He,p}\gamma),(\alpha,\text{d})$ (continued) $\gamma({}^{13}\text{C})$

E_γ^a	$E_i(\text{level})$	E_f	Comments
7490	7500	0	E_γ : $\Gamma_\gamma/\Gamma=0.3\%$ 1 (1971HiZF).
7550	7554	0	E_γ : $\Gamma_\gamma/\Gamma<0.1\%$ (1971HiZF).
7556	15110	7554	
11256	15110	3854	Unresolved.
11425	15110	3685	Unresolved.
12020	15110	3090	
15101	15110	0	$\Gamma_{\gamma 0}/\Gamma=0.53\%$ 6 (1968Co27); $\Gamma_{\gamma 0}/\Gamma=0.396\%$ 30 (1975Ma21,1977Ma16).

^a See (1968Co27,1969Ad01,1973Ad02,1975Ma21,1977Ma16) except where noted.

 $^{11}\text{B}({}^3\text{He,p}),({}^3\text{He,p}\gamma),(\alpha,\text{d})$ Level Scheme

$^{11}\text{B}(^6\text{Li},\alpha)$

1965Ca05: $^{11}\text{B}(^6\text{Li},\alpha)$ $E \approx 5$ MeV; measured differential cross sections were measured at 15 angles in the laboratory. ^{13}C states were observed. Analyzed σ dependence on J.

1966Mc05: $^{11}\text{B}(^6\text{Li},\alpha)$ $E=4.72$ MeV; measured cross section. ^{13}C states have been observed.

 ^{13}C Levels

<u>E(level)^a</u>	<u>$\sigma(\text{mb})^a$</u>	<u>Comments</u>
0 ^b	0.36	
3090 ^b	0.23	
3680 ^b		E(level): Unresolved with 3850. $\sigma(\text{mb})$: $\sigma=1.91$ mb for $^{13}\text{C}^*(3680+3850)$.
3850 ^b		E(level): Unresolved with 3680. $\sigma(\text{mb})$: $\sigma=1.91$ mb for $^{13}\text{C}^*(3680+3850)$.
6860 ^b	1.16	
7500		E(level): Unresolved with 7550, 7690. $\sigma(\text{mb})$: $\sigma=2.27$ mb for $^{13}\text{C}^*(7500+7550+7690)$.
7550		E(level): Unresolved with 7500, 7690. $\sigma(\text{mb})$: $\sigma=2.27$ mb for $^{13}\text{C}^*(7500+7550+7690)$.
7690		E(level): Unresolved with 7500, 7550. $\sigma(\text{mb})$: $\sigma=2.27$ mb for $^{13}\text{C}^*(7500+7550+7690)$.
8860		
9500		
9900		

^a From (1966Mc05).

^b Reported in (1965Ca05).

$^{12}\text{C}(\text{n},\gamma):\text{E=thermal}$

- 1953Ba18:** $^{12}\text{C}(\text{n},\gamma)$; measured thermal neutron capture radiation from carbon, in addition to the 4948 keV 8 ground state γ ray previously reported, $E_\gamma=3.68$ MeV 5 was also found.
- 1958Gr01:** $^{12}\text{C}(\text{n},\gamma)$; measured thermal neutron capture radiation $E_\gamma=4950$ keV 15, 3680 keV 20 and 1260 keV 15; deduced I_γ .
- 1958Hu18:** $^{12}\text{C}(\text{n},\gamma)$; measured thermal capture cross sections as 3.3 mb 2.
- 1961Ja19:** $^{12}\text{C}(\text{n},\gamma)$; measured thermal neutron capture radiation E_γ ; deduced I_γ .
- 1964St25:** $^{12}\text{C}(\text{n},\gamma)$; measured thermal capture cross sections as 3.4 mb 3.
- 1965Ja09:** $^{12}\text{C}(\text{n},\gamma)$; the neutron separation energy for the reaction was determined by measuring the γ -ray transitions: $E_\gamma=4946$ keV 1 implies $S_n=4947.0$ keV 10.
- 1967Pr10:** $^{12}\text{C}(\text{n},\gamma)$; deduced $S_n=4946.28$ keV 17 from analysis of $E_{\gamma 0}=4945.46$ keV 17, $E_{\gamma 1}=1261.92$ keV 6 and $E_\gamma(3864\rightarrow 0)=3683.94$ keV 17. Ge(Li) detector.
- 1967Ra24:** $^{12}\text{C}(\text{n},\gamma)$ E=thermal; measured E_γ ; deduced Q. Natural targets.
- 1967Th05:** $^{12}\text{C}(\text{n},\gamma)$; measured thermal neutron capture radiation E_γ ; deduced $I_\gamma(4945)=66$ 3 per 100 decays; $I_\gamma(3685)=34$ 2 and $I_\gamma(1262)=34$ 2.
- 1968Sp01:** $^{12}\text{C}(\text{n},\gamma)$ E=thermal; measured $E_\gamma=1261.76$ keV 7, $I_\gamma=32$ 1 per 100 decays; $E_\gamma=3684.28$ keV 14, $I_\gamma=32$ 1; $E_\gamma=4945.8$ keV 6, $I_\gamma=68$ 1; Q=4946.03. keV 15.
- 1972Op01:** $^{12}\text{C}(\text{n},\gamma)$ E=thermal; measured E_γ , I_γ , used as calibration line. Ge(Li), NaI detectors.
- 1973Mu14:** $^{12}\text{C}(\text{n},\gamma)$; measured thermal capture cross section as 3.4 mb 3.
- 1974Sp04:** $^{12}\text{C}(\text{n},\gamma)$; measured E_γ ; deduced Q=4946.2 keV 4.
- 1975Sm02:** $^{12}\text{C}(\text{n},\gamma)$; deduced Q from rf spectrometer mass measurement.
- 1978Ha14:** $^{12}\text{C}(\text{n},\gamma)$; deduced Q from double focusing mass spectrometer measurement; result implies $S_n=4946.320$ keV 50.
- 1981MuZQ:** $^{12}\text{C}(\text{n},\gamma)$ E=thermal; measured $\sigma(\text{capture})$, ratio.
- 1981Pr04:** $^{12}\text{C}(\text{n},\gamma)$ E=thermal; measured thermal capture cross section on $^{\text{nat}}\text{C}$ as $\sigma=3.50$ mb 16.
- 1982Ju01:** $^{12}\text{C}(\text{n},\gamma)$ E=thermal; measured E_γ , I_γ , at LANL Omega West reactor. Reported the thermal capture cross section as $\sigma=3.53$ mb 7. Deduced $I_\gamma(4946)=68.6$ 9 per 100 decays and $I_\gamma(3684)=31.0$ 4; implies $I_\gamma(1261)\approx 31.4$ 9. Additionally, they observed a ground state decay from $^{13}\text{C}^*(3089)$ with $I_\gamma(3089)/I_\gamma(4946)\approx 0.006$.
- 1982Mu14:** $^{12}\text{C}(\text{n},\gamma)$ E=thermal; measured E_γ , I_γ using a 55 cm³ Ge-Li detector at Chalk River. For six transitions they deduced $I_\gamma(4945.32)=67.47$ 92 per 100 decays; $I_\gamma(1856.6$ keV 4)=0.16 1; $I_\gamma(1261.6$ keV 1)=32.36 44; $I_\gamma(3684.0$ keV 2)=32.14 64; $I_\gamma(595.5$ keV 2)=0.24 1 and $I_\gamma(3089.5$ keV 4)=0.43 2. Notably, $I_\gamma(3089)/I_\gamma(4946)\approx 0.00597$ in agreement with (1982Ju01). Analyzed capture mechanism.
- 1982Va13:** $^{12}\text{C}(\text{n},\gamma)$; measured γ rays from $^1\text{H}(\text{n},\gamma):\text{E=thermal}$. Using this value, the Q-values for various reactions, such as $^{12}\text{C}(\text{n},\gamma)$ were evaluated and associated γ -ray energies were calculated.
- 1983Co09:** $^{12}\text{C}(\text{n},\gamma)$; deduced Q from analysis of atomic mass data.
- In (1986Aj01) the E_γ values 4946.397 keV 31, 1261.854 keV 6 and 3684.516 keV 30 are credited to van der Leun, et al., Neutron-Capture Gamma-Ray Spectroscopy and Related Topics 1981, London, No. 62 (1981) 548.
- 2008FiZZ** and unpublished EGAF (Evaluated Gamma-ray Activation File) data: $^{12}\text{C}(\text{n}_{\text{th}},\gamma)$ E=thermal; measured $\sigma(E_\gamma)$, deduced I_γ .
- The authors measured thermal neutron capture reactions on several natural and enriched isotopic targets at the 10-MW Budapest Reactor. Yields were normalized to a limited set of standard targets, with the aim of improving absolute capture cross sections and transition probabilities. The capture γ rays from a graphite powder target were measured using a single Compton suppressed 27% HPGe detector. The relative γ intensities were normalized primarily to the $^1\text{H}(\text{n},\gamma)$ ($\sigma_\gamma=332.5\pm 0.7$ mb) cross section. The transition probabilities and cross sections were deduced by balancing the intensity feeding and deexciting each state. The neutron separation energy $S_n=4946.32$ keV 6 is deduced along with $\sigma=3.87$ mb 3.
- For six transitions the unpublished Budapest data used for EGAF gives: $I_\gamma(4945.30$ keV 7)=68.6 20 per 100 decays; $I_\gamma(1856.98$ keV 22)=0.193 40; $I_\gamma(1261.71$ keV 6)=31.2 8; $I_\gamma(3684.02$ keV 7)=29.7 10; $I_\gamma(595.16$ keV 9)=0.274 25 and $I_\gamma(3088.80$ keV 21)=0.373 56.
- 2016Fi06:** XUNDL dataset compiled by TUNL, 2016.
- The authors combined their EGAF data with other literature results to obtain a set of recommended values. Because the (2016Fi06) data are folded with other results, they are a resource for comparison. The present evaluation develops a different set of recommended reaction parameters based solely on reported $^{12}\text{C}(\text{n}_{\text{th}},\gamma)$ data.
- For six transitions they deduced $I_\gamma(4945.30$ keV 7)=67.8 4 per 100 decays; $I_\gamma(1856.98$ keV 22)=0.0162 9; $I_\gamma(1261.71$ keV 6)=32.1 4; $I_\gamma(3684.02$ keV 7)=32.0 4; $I_\gamma(595.16$ keV 9)=0.0248 9 and $I_\gamma(3088.80$ keV 21)=0.041 12. Notably, $I_\gamma(3089)/I_\gamma(4946)\approx 0.00060$ is in disagreement with (1982Ju01) and (1982Mu14); the three weak transitions are reported with

intensities that are 10 times lower than (1982Mu14). Comparison with (2008FiZZ) suggests the discrepancy is a typo, but the

¹²C(n,γ):E=thermal (continued)

collection of associated works contains many inconsistencies.

Theory:

- 1980Gr02: Analyzed S_n.
- 1981MuZQ: ¹²C(n,γ) E=thermal; Z=1-60; compiled, evaluated thermal neutron induced σ, resonance parameter data.
- 1983Ho17: ¹²C(n,γ) E=thermal; calculated radiative capture σ; deduced potential, resonance scattering interference effects.
- 1987Ly01: ¹²C(n,γ) E=thermal; calculated capture σ. Optical model, Lane-Lynn-Raman method.
- 1999ZhZM: ¹²C(n,γ) E=thermal; compiled, evaluated prompt γ-ray data.
- 2000ZhZP: ¹²C(n,γ) E=thermal; compiled, analyzed prompt E_γ, I_γ.
- 2002Re13: ¹²C(n,γ) E=thermal; compiled, analyzed prompt E_γ, I_γ.
- 2003MoZU: ¹²C(n,γ) E=thermal; compiled, analyzed k₀ factors and capture σ, neutron binding energies.
- 2003MuZZ: compiled, analyzed thermal neutron capture σ.
- 2004Ma76: ¹²C(n,γ) E=thermal; analyzed data; deduced k₀ factors, γ-emission probabilities.
- 2011SI01: ¹²C(n,γ) E=thermal; compiled, evaluated σ, σ(E_γ), γ decay schemes, levels, J, π using ENDF, DICEBOX.
- 2021Si17: ¹²C(n,γ) E=thermal-0.86 MeV; calculated σ, reaction rates using TALYS nuclear model code.

¹³C Levels

E(level) ^a	J ^π	Comments
0	1/2 ⁻	J ^π : See (1953Ba18,1967Pr10,1967Th05,1968Sp01,1982Mu14,2016Fi06). Q ₀ =4946.32 keV 6 (2016Fi06), 4946.336 keV 14 (1983Co09), 4946.337 keV 20 (1982Va13); for earlier values see (1965Ja09, 1967Th05, 1968Sp01, 1974Sp04, 1975Sm02, 1978Ha14, 1980Wa24).
3089.30 8	1/2 ⁺	J ^π : See (1982Mu14,2016Fi06).
3684.52 5	3/2 ⁻	J ^π : See (1967Pr10, 1967Th05, 1968Sp01, 1982Mu14, 2016Fi06); see also (1953Ba18: (1/2 ⁻ ,3/2 ⁻)).
4946.33 5	1/2 ⁺	E(level): see (1953Ba18, 1958Gr01, 1961Ja19, 1965Ja09, 1967Pr10, 1967Th05, 1968Sp01, 1972Op01, 1980Wa24, 1982Ju01, 1982Mu14, 1982Va13, 1986Ke14). J ^π : See (1967Th05,1968Sp01,1982Mu14,2016Fi06).

^a From least squares fit to E_γ.

γ(¹³C)

E _γ ^b	I _γ ^{ac}	E _i (level)	J _i ^π	E _f	J _f ^π	Comments
595.22 8	0.24 1	3684.52	3/2 ⁻	3089.30	1/2 ⁺	E _γ ,I _γ : See I _γ (*595.5 keV 2)=0.24 1 (1982Mu14) and I _γ (*595.16 keV 9)=0.274 25 (2008FiZZ); I _γ <0.6 (1967Th05).
1261.74 4	32.36 44	4946.33	1/2 ⁺	3684.52	3/2 ⁻	E _γ ,I _γ : See I _γ (*1261.6 keV 1)=32.36 44 (1982Mu14), E _γ =*1261.92 6 (1967Pr10), E _γ =*1261.7 4 (1972Op01: from 1261.9 4, the E _γ recoil corrected value given in the text), E _γ =1261.847 33 (1980Wa24: deduced), E _γ =1261.765 28 (1983Ra04: listed as a calibration line) I _γ (*1261.71 6)=31.2 8 (2008FiZZ), I _γ (1260 15)=25 (1958Gr01), I _γ (1270)=30 (1961Ja19), I _γ (1262)=34 2 (1967Th05), I _γ (*1261.61 7)=32 1 (1968Sp01: from 1261.76 7, the E _γ recoil corrected value given in the text), σ(γ)=1.14 mb 2, S-factor(dp)=0.1 with R=2.91 fm (1982Mu14).
1856.89 19	0.16 1	4946.33	1/2 ⁺	3089.30	1/2 ⁺	E _γ ,I _γ : See I _γ (*1856.6 keV 4)=0.16 1 (1982Mu14) and I _γ (*1856.98 keV 22)=0.193 40 (2008FiZZ).
3088.95 19	0.43 2	3089.30	1/2 ⁺	0	1/2 ⁻	E _γ ,I _γ : See I _γ (*3089.5 keV 4)=0.43 2 (1982Mu14) and I _γ (*3088.80 keV 21)=0.373 56 (2008FiZZ). If 3.1 MeV γ-ray occurs, its intensity is ≤0.10 γ/capture (1953Ba18).
3683.96 6	32.14 64	3684.52	3/2 ⁻	0	1/2 ⁻	E _γ ,I _γ : See I _γ (*3684.0 2)=32.14 64 (1982Mu14), E _γ (*3683.94 17) (1967Pr10), E _γ =3683.915 15 (1990Wa22: deduced value). I _γ (*3684.02 7)=29.7 10 (2008FiZZ), I _γ (3680 50)=30 (1953Ba18), I _γ (3680 20)=25 (1958Gr01), I _γ (3680)=31

Continued on next page (footnotes at end of table)

¹²C(n,γ):E=thermal (continued)

γ(¹³C) (continued)

<u>E_γ^b</u>	<u>I_γ^{ac}</u>	<u>E_i(level)</u>	<u>J_i^π</u>	<u>E_f</u>	<u>J_f^π</u>	<u>Comments</u>
4945.32 6	67.47 92	4946.33	1/2 ⁺	0	1/2 ⁻	(1961Ja19), I _γ (3684)=34 2 (1967Th05), I _γ (3684)=31.0 4 (1982Ju01), I _γ (*3683.72 14)=32 1 (1968Sp01: from 3684.28 14, the E _γ recoil corrected value given in the text). If 3.9 MeV γ-ray occurs (transition 3850→0), its intensity is <0.06 γ/capture (1953Ba18). E _γ , I _γ : See I _γ (4945.32)=67.47 92 (1982Mu14), E _γ =4946 1 (1965Ja09), E _γ =*4945.46 17 (1967Pr10), E _γ =4945.328 20 (1982Va13: deduced from Q ₀), I _γ (*4945.30 7)=68.6 20 (2008FiZZ), I _γ (4948 8)=70 (1953Ba18), I _γ (4950 15)=75 (1958Gr01), I _γ (4946)=69 (1961Ja19), I _γ (4945)=66 3 (1967Th05: I _γ <0.2 for capture state→3848 transition), I _γ (*4944.8 6)=68 1 (1968Sp01: from 4945.8 6, the E _γ recoil corrected value given in the text), I _γ (4946)=68.6 9 (1982Ju01), I _γ (4945)=68.4 5 (1986Ke14). σ(γ)=2.38 mb 5, S-factor(dp)=1.1 with R=2.91 fm (1982Mu14).

^a From (1982Mu14).

^b From average of values listed with *.

^c Intensity per 100 neutron captures.

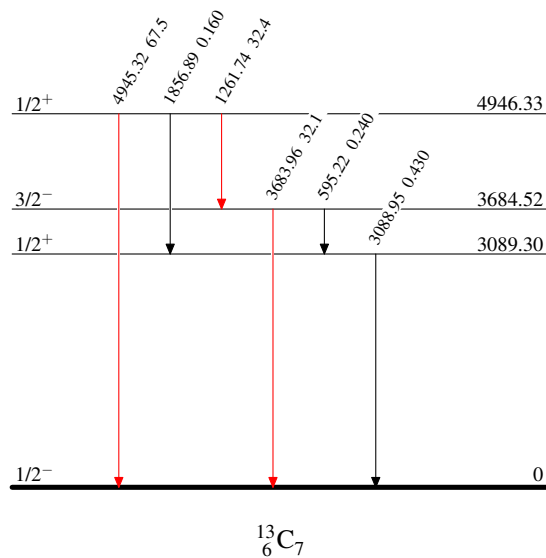
¹²C(n,γ):E=thermal

Level Scheme

Intensities: I_γ per 100 neutron captures

Legend

- I_γ < 2% × I_γ^{max}
- I_γ < 10% × I_γ^{max}
- I_γ > 10% × I_γ^{max}



$^{12}\text{C}(\text{n},\gamma):\text{res}$

- 1950Ki68: $^{12}\text{C}(\text{n},\gamma)$ E=slow; measured E_γ , I_γ .
- 1963Ma60: $^{12}\text{C}(\text{n},\gamma)$ E \approx 30,65 keV; measured neutron radiative capture cross sections for $Z\leq 92$.
- 1975Ar19: $^{12}\text{C}(\text{n},\gamma_0)$ E=14 MeV; measured γ -yields, $I_\gamma(\theta)$. There is an indication γ_0 peaks at backward angles.
- 1984Wo05: $^{12}\text{C}(\text{n},\gamma_0)$, (pol. n, γ_0) E=12-18.8 MeV; measured $\sigma(\theta)$, analyzing power for $\theta\approx 50^\circ-140^\circ$. Deduced states at $E_x=16-21.75$ MeV. Combined analysis with other data indicates a secondary doorway state. Deduce a_1 , a_2 , b_1 , b_2 from Legendre fit.
- 1985AuZZ: $^{12}\text{C}(\text{n},\gamma)$ E=6.5-18.5 MeV; measured $\sigma(\theta)$. $^{12}\text{C}(\text{pol. n},\gamma)$ E=12-18.8 MeV; measured analyzing, vector analyzing power vs θ . ^{13}C deduced resonances, doorway characteristics.
- 1986Be17: $^{12}\text{C}(\text{n},\gamma)$ E=7-19.5 MeV; measured $\sigma(E,\theta=90^\circ)$. Deduced $T_{\leq 1/2}$ giant resonance at $E_x=20.8$ MeV with $\Gamma\approx 2.5$ MeV along with lower unresolved strength near $E_n\approx 10$ MeV identified as the *pygmy* resonance. DSD model.
- 1987Au02: $^{12}\text{C}(\text{n},\gamma)$ E=6.5-18.5 MeV; measured $\sigma(E,\theta)$, $\theta=90^\circ$. Pygmy and giant resonance region. Direct-semidirect calculations.
- 1988McZT: $^{12}\text{C}(\text{n},\gamma)$; analyzed $\sigma(E_n)$.
- 1989Hu15: $^{12}\text{C}(\text{n},\gamma)$ E=14.2 MeV; measured $\gamma(\theta)$; deduced γ -multipolarity. Direct-semidirect model.
- 1990Ha19: $^{12}\text{C}(\text{n},\gamma)$ E=8-11 MeV; measured $\sigma(\theta=90^\circ)$ in the Pygmy and giant resonance region.
- 1990Ma52: $^{12}\text{C}(\text{n},\gamma)$ E<46 keV; measured effective capture $\sigma(E)$; deduced Maxwellian averaged σ .
- 1991Hu05: $^{12}\text{C}(\text{n},\gamma)$ E=7-14 MeV; measured $\sigma(\theta)$ vs E, E_γ , I_γ , $\gamma(\theta)$. Analyzed pygmy resonance.
- 1991Na06, 1991Na19: $^{12}\text{C}(\text{n},\gamma)$ E=30 keV, stellar energy; measured capture σ , E_γ , I_γ ; deduced nucleosynthesis implications.
- 1992Wi08: $^{12}\text{C}(\text{pol. n},\gamma)$ E=20-35 MeV; measured $\gamma(\theta)$, A_γ vs E, $\gamma(\text{recoil})$ -coin; deduced E2, E1 capture interference. Direct semidirect model. Deduce a_1 , a_2 , b_1 , b_2 from Legendre fit.
- 1994Oh02, 1996Na27: $^{12}\text{C}(\text{n},\gamma)$ E=10-250 keV; measured E_γ , I_γ , $\sigma(E)$; deduced Maxwellian averaged σ and astrophysical implications.
- 1998Ki09: $^{12}\text{C}(\text{n},\gamma)$ E=550 keV; measured E_γ , I_γ ; deduced partial capture σ . Deduced spectroscopic factor of $^{13}\text{C}^*(3.09\text{ MeV})$.
- 1999Oh04: $^{12}\text{C}(\text{n},\gamma)$ E \approx 42 keV; measured capture $\sigma(E)$, E_γ , I_γ .
- 2008Oh05: XUNDL dataset compiled by McMaster, 2008.
- E(n)=10-80 keV neutrons produced in the $^7\text{Li}(\text{p},\text{n})$ reaction using the 3.2 MV Pelletron accelerator at the Tokyo Institute of Technology. Measured E_γ , I_γ , $\gamma\gamma$ coin using anti-Compton NaI(Tl) spectrometer, time-of-flight method. Non-resonant study.

Theory:

- 1971AI33, 1971AIYV: $^{12}\text{C}(\text{n},\gamma)$ E \approx 30 keV; compiled experimental Maxwellian averaged σ ; deduced empirical correlation between σ and nucleosynthesis abundances.
- 1974Ma10: $^{12}\text{C}(\text{n}_0,\gamma)$; analyzed isospin splitting in the giant dipole resonance.
- 1986Li16: $^{12}\text{C}(\text{pol. n},\gamma)$ E \leq 9 MeV; calculated polarization effects.
- 1987LyZY: $^{12}\text{C}(\text{n},\gamma)$ E=slow; analyzed data; deduced model parameters, capture mechanism.
- 1990Wa22: $^{12}\text{C}(\text{n},\gamma)$; analyzed data; deduced calibration γ -energies. Proposed $E_\gamma=3683.915$ keV 15 for transition 3.684 \rightarrow 0.
- 1991Ho18: $^{12}\text{C}(\text{n},\gamma)$ E=threshold-30 keV; calculated σ ; deduced reaction mechanism.
- 1993Ho06: $^{12}\text{C}(\text{n},\gamma)$ E \approx 8-20 MeV; analyzed $\sigma(\theta)$ vs E; deduced GDR, resonance parameters. Unified formalism.
- 1994Ot04: $^{12}\text{C}(\text{n},\gamma)$ E<0.5 MeV; calculated $\sigma(E)$; deduced S-factor. Kinematically complete approach.
- 1995Li31: $^{12}\text{C}(\text{n},\gamma)$ E \approx 6-20 MeV; calculated capture $\sigma(\theta)$ vs E. Direct-semidirect model.
- 1995Me14: $^{12}\text{C}(\text{n},\gamma)$ E \leq 500 keV; calculated capture $\sigma(E)$. Direct capture model.
- 1996Re16: $^{12}\text{C}(\text{n},\gamma)$; analyzed inverse Coulomb dissociation reaction and relevance for astrophysical input.
- 1997Du09: $^{12}\text{C}(\text{n},\gamma)$ $E_{\text{c.m.}}\leq 0.5$ MeV; calculated capture $\sigma(E)$. Calculated levels, $B(\lambda)$, rms radius vs $R(\text{c})$. Multicenter approach.
- 1997Li10: $^{12}\text{C}(\text{n},\gamma)$ E<600 keV; calculated $\sigma(E_n)$; deduced influence of scattering potential depth. Consistent direct-semidirect model.
- 1997Ti03: Analyzed vertex constants for capture reactions.
- 1998Ki01: $^{12}\text{C}(\text{n},\gamma)$ E<1 MeV; calculated σ ; deduced optical potential features.
- 1999MeZW: $^{12}\text{C}(\text{n},\gamma)$ E<0.8 MeV; analyzed capture σ ; deduced parameters.
- 2003Wu01: $^{12}\text{C}(\text{n},\gamma)$ E=0-1 MeV; calculated σ . Asymptotic normalization coefficient method, comparison with data.
- 2004Ba62: $^{12}\text{C}(\text{n},\gamma)$ E=0-0.6 MeV; calculated S-factors, $\sigma(E)$ for radiative capture. Taylor expansion.
- 2004Hu10: $^{12}\text{C}(\text{n},\gamma)$ E=low; calculated astrophysical reaction rate, resonance effects.
- 2009Wa17: $^{12}\text{C}(\text{n},\gamma)$ $E_{\text{c.m.}}< 1$ MeV; analyzed σ , spectroscopic factors and other parameters for nonresonant neutron capture using simple polynomials obtained from Taylor expansions. Comparison with experimental data.
- 2010Hu11: $^{12}\text{C}(\text{n},\gamma)$ $E_{\text{c.m.}}< 2$ MeV; calculated binding energies, σ , S-factors, spectroscopic factors. Single-particle potential model.
- 2012Pr13, 2020Pr08: $^{12}\text{C}(\text{n},\gamma)$ E<20 MeV; calculated Maxwellian-averaged σ , astrophysical reaction rates, neutron thermal σ ,

$^{12}\text{C}(n,\gamma)$:res (continued)

Westcott factors, resonance integrals.

2013Di12: $^{12}\text{C}(n,\gamma)$ $E < 20$ MeV; analyzed available data; deduced recommended σ , k_{eff} .

2013Du08: $^{12}\text{C}(n,\gamma)$ $E < 1$ MeV; calculated σ , low-energy phase shifts. Potential cluster model, comparison with available data.

2013Du16: $^{12}\text{C}(n,\gamma)$ $E < 1$ MeV; calculated σ , phase shifts. Young diagrams, potential cluster model.

2017HaZY: $^{12}\text{C}(n,\gamma)$ $E = 0-0.2$ MeV; calculated σ .

2018Br05: $^{12}\text{C}(n,\gamma)$ $E = 30$ keV; calculated Maxwellian-averaged σ .

2024Sa13: $^{12}\text{C}(n,\gamma)$; R-matrix analysis of the astrophysically relevant region of the reaction.

 ^{13}C Levels

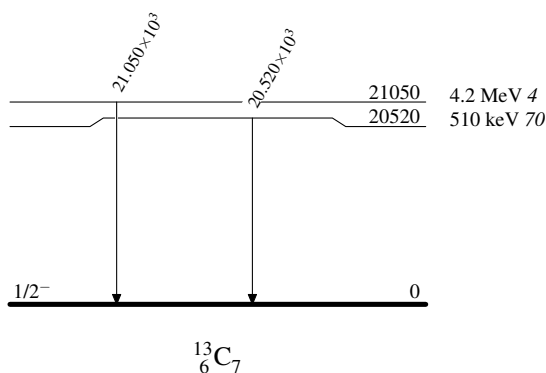
<u>E(level)^a</u>	<u>J^{π}</u>	<u>Γ</u>	<u>Comments</u>
0	1/2 ⁻		
20520 70		510 keV 70	E(level), Γ : From the analyzing power data in (1984Wo05): secondary doorway state.
21050 60		4.2 MeV 4	E(level), Γ : From the analyzing power data in(1984Wo05): primary doorway state. See also $E_x \approx 20.81$ MeV and $\Gamma \approx 2.5$ MeV in (1986Be17).

^a (1986Be17) also observed an unresolved broad peak at $E_n(\text{res}) \approx 10$ MeV ($E_x \approx 14180$ keV).

 $\gamma(^{13}\text{C})$

<u>E_γ^a</u>	<u>$E_i(\text{level})$</u>	<u>E_f</u>	<u>J_f^π</u>
20.520×10^3	20520	0	1/2 ⁻
21.050×10^3	21050	0	1/2 ⁻

^a From level energy difference.

 $^{12}\text{C}(n,\gamma)$:resLevel Scheme

$^{12}\text{C}(\text{n,n}):res$

- 1950Fr61: C(n,x) E=530 keV-4.8 MeV; measured total σ via transmission study.
- 1951Bo45: $^{12}\text{C}(\text{n,n})$ E=1-3.3 MeV; measured the total σ ; resonances were observed around $E_n=2.08$ and 2.95 MeV.
- 1953Ne01: C(n,x) E=2.6-13.9 MeV; measured $\sigma(E)$; several broad resonances are observed.
- 1956Be98: C(n,x) E=4.3-8.7 MeV; measured $\sigma(E)$. Peaks are observed around $E_n=4.95, 5.4, 7.8$ MeV.
- 1957Bo13: C(n,n) E=3.8-8.1 MeV; measured the total σ of C. Several peaks are observed. Table of $\sigma(E)$ is given.
- 1958Wi36: $^{12}\text{C}(\text{n,n})$ E=1.45-4.10 MeV; measured angular distributions, deduced resonances, J, Γ .
- 1960Br13: $^{12}\text{C}(\text{n,n})$ E=5.6 MeV; the differential elastic scattering cross sections for carbon have been obtained for $\theta=30^\circ$ to 150° .
- 1960Hu02: $^{12}\text{C}(\text{n,n})$ $E_n=500$ to 1350 keV; measured the total σ in search of resonances. No resonances were observed within the 5% accuracy.
- 1960Ts02: $^{12}\text{C}(\text{n,n})$ E=3.3-5.0 MeV; several resonances in the cross sections were analyzed to give spin assignments.
- 1961Bo06: $^{12}\text{C}(\text{n,n})$ E=15-120 MeV; measure rather structureless neutron total cross section at high energies.
- 1961Fo07: $^{12}\text{C}(\text{n,n})$ E=3.4-16 MeV; observed several sharp peaks in the total σ ; deduced E_x, Γ, J .
- 1963Pi03: $^{12}\text{C}(\text{n,n})$, the elastic scattering of neutrons by ^{12}C has been investigated at low energies.
- 1963Se13: $^{12}\text{C}(\text{n,n})$ E=3-660 keV; measured total σ via transmission method. No structures were observed.
- 1964Ma46: C(n,X) E=7.0-14.3 MeV; measured total σ ; Presented table of $\sigma(E)$.
- 1965Ha21: $^{12}\text{C}(\text{n,n})$ E=17-21 MeV; measured total $\sigma(E)$ and $\sigma(E,\theta)$ for $\theta=36^\circ, 51^\circ, 60^\circ, 86^\circ, 123.5^\circ$ and 139° . Report peak at 19.5 MeV ($\Gamma \approx 1.1$ MeV) in $\sigma(E,\theta)$ data and at 19.6 MeV ($\Gamma \approx 1.2$ MeV) in $\sigma(E)$.
- 1966Li03: $^{12}\text{C}(\text{n,n})$ E=3.0-4.7 MeV; measured differential cross sections, level parameters were determined for $^{13}\text{C}^*$ (8.2,8.9 MeV).
- 1968Bo34: $^{12}\text{C}(\text{n},\gamma)$ E=14-25 MeV; measured $\sigma(E,\theta)$ for $\theta=30^\circ, 39.2^\circ, 54.7^\circ$ and 90° . Deduced high-lying resonances.
- 1969Da13: $^{12}\text{C}(\text{n,X})$ E=3-8 MeV; measured $\sigma(E)$. ^{13}C deduced resonances at $^{13}\text{C}^*$ (9.5, 9.9, 10.75, 12.1 MeV).
- 1970CiZY: C(n,X) E=0.5-30 MeV; measured total $\sigma(E)$. Deduced resonance parameters.
- 1970De14: $^{12}\text{C}(\text{n,n})$ E=17-20.5 MeV; measured $\sigma(E;E_n',\theta)$ for $\theta \approx 10^\circ$ to 150° . Deduced optical model parameters, $E_x=23$ MeV resonance energy, J, π .
- 1970UtZZ: C(n,X) E=70 eV-1.5 MeV; measured $\sigma(E)$; analyzed levels.
- 1972Ga13: C(n,n) E=3-7 MeV; measured $\sigma(E;\theta)$ for $\theta=16.3^\circ$ to 157° ; $\sigma(E)$ tables provided; deduced phase shifts. Deduced J, π, Γ for levels between $E_x=8.3$ to 11 MeV.
- 1973Ab07: $^{12}\text{C}(\text{n,n})$ E=1.98-4.64 MeV; measured $\sigma(E;\theta)$ for $\theta=30^\circ$ to 150° . Deduced resonances, L, J, π, Γ .
- 1973Fa06: $^{12}\text{C}(\text{n,n})$ E=2.1-4.7 MeV; measured $\sigma(E), \sigma(E,\theta)$; calculated phase shifts, polarization P(E, θ). Deduced E_x, Γ .
- 1973Ho39: $^{12}\text{C}(\text{n,n})$ E=2-5 MeV; $\theta(\text{lab})=20^\circ-150^\circ$; measured P(E, θ); R-function, phase-shift analyses.
- 1973Kn06: $^{12}\text{C}(\text{n,n})$ E=2.63 MeV; measured total $\sigma, \sigma(\theta)$ for $\theta_{c.m.} \approx 20^\circ$ to 130° , n-polarization. Deduced phase shifts. The influence of narrow states at $E_x=7.50$ and 7.55 MeV is discussed.
- 1975He02: $^{12}\text{C}(\text{n,X})$ E=1 keV-15 MeV; measured total σ . Deduced resonance energies.
- 1979Sm08: $^{12}\text{C}(\text{n,n})$ E=1.5-4.0 MeV; measured total s(E), $\sigma(\theta)$ for $\theta \approx 15^\circ$ to 175° . Deduced R-function parameters. Multilevel R-matrix analysis.
- 1980Th07: $^{12}\text{C}(\text{n,n}), (\text{pol. n}, n')$ E=15-18.25 MeV; measured $\sigma(E,\theta), A_y(\theta)$. Mainly focused on ^{13}C , but includes OM analysis finding a dominant $f_{5/2}$ resonance at $E_n=15.7$ MeV 2 with $\Gamma=0.6$ MeV ($E_x \approx 19.4$ MeV); the fit was improved by including a $d_{3/2}$ resonance at $E_n=15.4$ MeV 2 with $\Gamma \approx 2.2$ MeV ($E_x \approx 19$ MeV).
- 1980Ci03: C(n,X) E=3-30 MeV; measured total σ . Deduced resonances, Γ, T . Tof. Breit-Wigner analysis.
- 1983Wo02: $^{12}\text{C}(\text{pol. n,n}), (\text{pol. n}, n')$ E=8.9-14.9 MeV; measured $A_y(\theta)$ for $\theta=30^\circ$ to 150° .
- 1985To02: $^{12}\text{C}(\text{pol. n,n})$ E=8.91-12 MeV; measured $\sigma(\theta)$ for $\theta \approx 30^\circ$ to 170° , analyzed $A_y(\theta)$ from (1983Wo02) and other literature data to carry out a phase-shift analysis. Deduced $\sigma(E), J, \pi$.
- 1987Hi03: $^{12}\text{C}(\text{n,X}), (\text{n,n})$ E ≤ 22 MeV; measured total $\sigma(E)$, transmission. Deduced resonance energies, Γ, Γ_{n0} . Discussed isospin and likely ^{13}C T=3/2 states at $^{13}\text{C}^*$ (15.1, 17.5, 18.1, 20.1 and 21.7 MeV) along with suggested analog states in ^{13}B .
- 1987To03: $^{12}\text{C}(\text{pol. n,n})$ E=15.55-17.35 MeV; measured analyzing power vs θ . ^{13}C deduced levels, J, π . Phase-shift analysis. Authors indicate more data are needed to further support their results.

Theory:

- 1968Da31: $^{12}\text{C}(\text{n,n})$ E < 5 MeV; analyzed available data; deduced σ , single effective ranges.
- 1971CiZV: $^{12}\text{C}(\text{n,n})$ E below inelastic threshold; calculated $\sigma(E)$. ^{13}C levels calculated 2p-1h contributions.
- 1971Gr48: $^{12}\text{C}(\text{n,n})$ E=4.4 MeV; analyzed P(n). ^{13}C resonance deduced parity.
- 1971LeZG: $^{12}\text{C}(\text{n,n})$ E not given; calculated $\sigma(\theta), P(\theta)$, phase shifts. ^{13}C calculated resonances, level-width, J, π .
- 1971We08: $^{12}\text{C}(\text{n,n})$ E=0.5-4 MeV; calculated $\sigma(E)$. ^{13}C resonances deduced S.
- 1971WeZQ: $^{12}\text{C}(\text{n,n})$ E not given; analyzed $\sigma(E)$. ^{13}C deduced resonance parameters. R-matrix, potential-resonance method.

¹²C(n,n):res (continued)

- 1972Mo45: ¹²C(n,n) E<4.4 MeV; calculated $\sigma(E)$. ¹³C calculated binding energy. Coupled-channel method.
 1972Ro07,1972Ro08: ¹²C(n,n) E<5 MeV; calculated $\sigma(E)$. ¹³C calculated levels. Feshbach, R-matrix theories; shell model, particle-rotator model.
 1973Co27: ¹²C(n,n); calculated $\sigma(E)$. ¹³C calculated levels.
 1973Le02: ¹²C(n,n) E<5 MeV; calculated $\sigma(E;\theta)$. ¹³C calculated levels, level-width.
 1981Az01: ¹²C(n,n) E=1.9-5.2 MeV; calculated P(θ). ¹³C resonances deduced Γ_n . Reaction matrix method.
 1981KnZY: ¹²C(n,n), E not given; analyzed data. ¹³C levels deduced J, π . R-matrix.
 1981KnZZ: ¹²C(n,n) E not given; analyzed data. ¹³C level deduced tentative J, π , configuration. R-matrix.
 1982Kn02: ¹²C(n,n) E=0.0-9 MeV; analyzed data. ¹³C deduced levels, J, π , reduced widths. R-matrix analysis, comparison to model predictions.
 1983To19: ¹²C(n,n) E=7.03-8.56 MeV; analyzed phase-shift data. ¹³C levels deduced J, π , Γ .
 1986ToZY: ¹²C(pol. n,n) E=12-17 MeV; analyzed data. ¹³C deduced resonances. Phase-shift analysis.
 1991Io01: ¹²C(n,n) E=0.9-10 GeV/c; calculated σ vs beam momentum; deduced collective dual diffractive resonances role.
 2003Am08: ¹²C(n,n) E=0-5 MeV; calculated elastic σ , polarization, resonance effects. Sturmian expansions of multichannel interactions. Comparison with data.
 2004Ke08: ¹²C(n,n) E=7.5 MeV; calculated $\sigma(\theta)$. Comparisons with data.
 2005Ch58: ¹²C(n,n) E=7-26 MeV; compiled, analyzed $\sigma(\theta)$, analyzing power, total σ . ¹³C deduced level and resonance parameters. Phase-shift analysis, comparison with previous results.
 2005Pi16: ¹²C(n,n) E \approx 0-5 MeV; analyzed elastic σ . ¹³C deduced sub-threshold bound state and resonance features. Multichannel algebraic scattering theory.
 2005WaZV: ¹²C(n,n) E<3 GeV; analyzed σ .
 2006Oh02: Analyzed E_x/S_n systematics.
 2009We04: ¹²C(n,n); analyzed σ , $\sigma(\theta)$.
 2010Na18: ¹²C(n,n); calculated σ , $\sigma(\theta)$, analyzing powers, phase shifts. No-core shell model, resonating-group method (NCSM/RGM). Comparison with experimental data.
 2012Pr13: ¹²C(n,n) E<20 MeV; calculated Westcott factors, resonance integrals and their uncertainties.
 2016Fr09: ¹²C(n,n) E<6.5 MeV; calculated elastic and reaction $\sigma(E)$, deduced effect of particle-emitting resonances on the scattering cross section.
 2017HaZY: ¹²C(n,n) E=0-6.45 MeV; calculated σ , $\sigma(\theta)$, analyzing power.
 2017Lo02: ¹²C(n,n) E=17.29 MeV; analyzed differential $\sigma(\theta)$ data.
 2018We08: ¹²C(n,n) E=75 MeV; calculated $\sigma(\theta)$, σ ; deduced optical model parameters.
 2019BI07: ¹²C(n,n) E=0.050-1.040 MeV; calculated asymptotic normalization coefficients (ANC) for excited s-states in ¹³C.

¹³C Levels

<u>E(level)^a</u>	<u>J^{π}^b</u>	<u>Γ</u>	<u>L</u>	<u>E_n(res) (keV)</u>	<u>Comments</u>
3090					E(level): See (1963Se13) who determined the relative reduced width for this bound 2s _{1/2} state; $\theta^2=0.20$. They also set upper limits on widths for a proposed state at E _x =(5510) keV with $\Gamma_n \leq 0.01$ keV.
6864 3	5/2 ⁺	6.9 keV	2	2079 3	E(level): From E _{res} =2079 keV 3 (1975He02); see also E _{res} (keV)=2076 8 (1958Wi36), 2077 3 (revised value from 1968Da31) and (1951Bo45,1963Pi03,1970CiZY,1973Ab07,1973Ho39). J ^{π} : From (1958Wi36,1963Pi03,1973Ab07); see also J ^{π} \geq 3/2 (1951Bo45), 5/2 (1970CiZY). Γ : Average of Γ_{lab} (keV)=7 (1958Wi36), 7.9 (1963Pi03), $\Gamma_{c.m.}$ =7 keV (1973Ab07); see also $\Gamma_{c.m.} \leq 11$ keV (1951Bo45), Γ_{lab} =9 keV (1970CiZY). L: From (1963Pi03,1970CiZY,1973Ab07); see also L>0 (1951Bo45). The dimensionless single particle reduced width, $\theta^2=0.006$ (1958Wi36).
7546 5	(5/2)	1.2 keV 3	2	2819 5	E(level): From E _{res} =2819 keV 5 (1975He02); see also (1950Fr61,1970CiZY). J ^{π} ,L: From (1970CiZY). Γ : From (1975He02). See also Γ_{lab} =7 keV (1970CiZY).
7658 9	3/2 ⁺	124 keV 7	2	2940 10	E(level): From E _{res} =2940 keV 10 (1973Fa06); see also (1951Bo45,

Continued on next page (footnotes at end of table)

$^{12}\text{C}(\text{n,n})\text{:res}$ (continued) ^{13}C Levels (continued)

$E(\text{level})^a$	$J^\pi{}^b$	Γ	L	$E_n(\text{res})$ (keV)	Comments
8220 40	$3/2^+$	1026 keV 15	2	3530 40	<p>1958Wi36, 1970CiZY, 1973Ab07, 1973Ho39). J^π: From (1958Wi36,1973Ab07); see also $J^\pi=3/2$ (1951Bo45,1970CiZY). Γ: From (1973Fa06); see also $\Gamma(\text{keV})=120$ (1951Bo45), 100 (1973Ab07), $\Gamma_{\text{lab}}=90$ keV (1958Wi36). L: From (1973Ab07,1970CiZY); see also L=1,2 (1951Bo45). $\theta^2=0.038$ (1958Wi36). E(level): From the unweighted average of $E_{\text{res}}=3472$ keV 15 (1973Fa06) 3520 keV 50 (1960Ts02), 3600 keV 50 (1966Li03). See other results in (1950Fr61, 1958Wi36, 1961Fo07, 1970CiZY, 1972Ga13, 1973Ab07, 1973Ho39). J^π: From (1958Wi36, 1966Li03, 1972Ga13, 1973Ab07); see also $J^\pi=3/2$ (1961Fo07,1970CiZY). Γ: Weighted average of 1050 keV 100 (1966Li03) and 1025 keV 15 (1973Fa06); see also $\Gamma_{\text{lab}}=1690$ keV (1958Wi36), $\Gamma_{\text{c.m.}}(\text{keV})=700$ (1961Fo07), 900 (1973Ab07). $\Gamma_n/\Gamma>0.99$ (1966Li03), $\Gamma_{n0}/\Gamma=1.00$ (1972Ga13). L: From (1970CiZY,1973Ab07). $\theta^2=0.51$ (1958Wi36), 0.35 (1966Li03).</p>
8874 14	$1/2^-$	205 keV 15	1	4259 15	<p>E(level): From $E_{\text{res}}=4259$ keV 15 (1973Fa06); see also $E_{\text{res}}(\text{keV})=4320$ 50 (1960Ts02), 4250 20 (1966Li03), 4260 20 (1972Ga13) and (1950Fr61, 1961Fo07, 1970CiZY, 1973Ab07, 1973Ho39). J^π: From (1966Li03,1972Ga13,1973Ab07); see also $J^\pi=1/2^+$ (1960Ts02), $1/2$ (1961Fo07,1970CiZY). Γ: Weighted average of 180 keV 50 (1966Li03), 200 keV 40 (1972Ga13: lab value), 210 keV 15 (1973Fa06); see also $\Gamma(\text{keV})\approx 300$ (1960Ts02), 220 (1961Fo07), 180 (1973Ab07). $\Gamma_n/\Gamma>0.99$ (1966Li03), $\Gamma_{n0}/\Gamma=1.00$ (1972Ga13). L: From (1970CiZY,1973Ab07). $\theta^2=0.03$ (1966Li03).</p>
9499.71 6	$(9/2^+)$	1.72 keV 8	1	4937.07 7	<p>E(level): From $E_{\text{res}}=4937.07$ keV 7 (1980Ci03: Table 2); see also $E_{\text{res}}(\text{keV})=4940$ 10 (1960Ts02), 4935 4 (1969Da13), 4940 11 (1975He02) and (1956Be98, 1961Fo07, 1970CiZY, 1972Ga13). J^π: From (1982Kn02); see also $J^\pi\geq 1/2$ (1961Fo07,1970CiZY), $(1/2^-,3/2^-)$ (1972Ga13), $(5/2^-)$ (1980Ci03). Γ: From (1980Ci03); see also $\Gamma(\text{keV})\approx 20$ (1960Ts02), ≤ 10 (1961Fo07), $\Gamma_{\text{lab}}=14$ keV (1970CiZY). $\Gamma_{n0}=1.60$ keV 4 (1980Ci03), $\Gamma_{n0}/\Gamma=1.00$ (1972Ga13). L: From (1972Ga13), but this result is inconsistent with later results.</p>
9894.50 17	$3/2^-$	23.7 keV 4	1	5365.21 18	<p>E(level): From $E_{\text{res}}=5365.21$ keV 18 (1980Ci03: Table 5b); see also $E_{\text{res}}(\text{keV})=5368$ 5 (1969Da13), 5378 13 (1975He02) and (1956Be98, 1961Fo07, 1970CiZY, 1972Ga13). J^π: From (1972Ga13); see also $J^\pi>1/2$ (1956Be98), $\geq 3/2$ (1961Fo07), $3/2$ (1970CiZY). Γ: Derived from (1980Ci03); see also $\Gamma=30$ keV (1961Fo07), $\Gamma_{\text{lab}}=30$ keV (1970CiZY). $\Gamma_{n0}=20.6$ keV 5 (1980Ci03), $\Gamma_{n0}/\Gamma=0.70$ 10 (1972Ga13). L: From (1970CiZY,1972Ga13).</p>
10753.73 30	$7/2^-$	50.9 keV 6	3	6297.07 32	<p>E(level): From $E_{\text{res}}=6297.07$ keV 32 (1980Ci03: Table 5b); see also $E_{\text{res}}(\text{keV})=6294$ 5 (1969Da13), 6295 keV 16 (1975He02) and (1953Ne01, 1957Bo13, 1961Fo07, 1970CiZY, 1972Ga13).</p>

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$^{12}\text{C}(\text{n,n})\text{:res}$ (continued) ^{13}C Levels (continued)

E(level) ^a	J ^{π} ^b	Γ	L	E _n (res) (keV)	Comments
10812.8 6		18.1 keV 10		6361.1 6	J ^{π} : From (1972Ga13); see also J ^{π} >1/2 (1953Ne01), $\geq 7/2$ (1961Fo07, 1970CiZY). Γ : From (1980Ci03); see also $\Gamma=65$ keV (1961Fo07), $\Gamma_{\text{lab}}=55$ keV (1970CiZY). $\Gamma_{\text{n0}}=43.4$ keV 9 (1980Ci03), $\Gamma_{\text{n0}}/\Gamma=0.70$ 10 (1972Ga13). L: From (1972Ga13). E(level): From E _{res} =6361.1 keV 6 (1980Ci03: Table 5b). Γ : From (1980Ci03). $\Gamma_{\text{n0}}=4.7$ keV 3 (1980Ci03).
10941?				6500	E(level): From E _{res} =6500 keV (1961Fo07).
10994 7	(1/2 ⁺)		0	6558 8	E(level): From E _{res} =6558 keV 8 (1972Ga13); see also E _{res} =6570 keV (1961Fo07). J ^{π} ,L: From (1972Ga13). $\Gamma_{\text{n0}}/\Gamma=0.40$ 10 (1972Ga13).
11076.01 18		4.0 keV 4		6646.71 20	E(level): From E _{res} =6646.71 keV 20 (1980Ci03: Table 5b); see also E _{res} =6700 keV (1961Fo07). J ^{π} : (1980Ci03) identified with the E _x =11080 keV; J ^{π} =(1/2 ⁻) state in (1976Aj04). Γ : From (1980Ci03). $\Gamma_{\text{n0}}=2.52$ keV 16 (1980Ci03).
11725 46	3/2 ⁻	129 keV 40		7350 50	E(level): From E _{res} =7350 keV 50 (1983To19). J ^{π} , Γ : From (1983To19). $\Gamma_{\text{n0}}/\Gamma=0.80$ 8 and $\gamma^2=29$ keV 7 (1983To19).
11973 90	5/2 ⁺	494 keV 80		7620 90	E(level): From E _{res} =7620 keV 90 (1983To19). J ^{π} , Γ : From (1983To19). E _n (res) (keV): See also E _{res} =(7400) keV (1961Fo07: identified with the E _x =11870 keV; J ^{π} =(7/2 ⁻) state). J ^{π} : See also J ^{π} =($\geq 5/2$) (1961Fo07). Γ : See also $\Gamma=(250)$ keV (1961Fo07). $\Gamma_{\text{n0}}/\Gamma=0.51$ 6 and $\gamma^2=100$ keV 12 (1983To19).
12071.9 19	(3/2 ⁻)	81.5 keV 33		7726.8 21	E(level): From E _{res} =7726.8 keV 21 (1980Ci03: Table 5b). J ^{π} , Γ : From (1980Ci03). $\Gamma_{\text{n0}}=69.0$ keV 30 (1980Ci03).
12120 70	3/2 ⁺	538 keV 65		7759 8	E(level): From E _{res} =7780 keV 80 (1983To19); see also E _{res} =7759 keV 8 (1969Da13); 7730 (1961Fo07). J ^{π} : From (1983To19); see also J ^{π} =($\geq 7/2$) (1961Fo07). Γ : From (1983To19); see also $\Gamma=(200)$ keV (1961Fo07). $\Gamma_{\text{n0}}/\Gamma=0.28$ 5 and $\gamma^2=58$ keV 12 (1983To19).
12130 46	5/2 ⁻	77 keV 30		7790 50	E(level): From E _{res} =7790 keV 50 (1983To19). J ^{π} , Γ : From (1983To19). $\Gamma_{\text{n0}}/\Gamma=0.43$ 6 and $\gamma^2=29$ keV 7 (1983To19).
12139 65	1/2 ⁺	426 keV 70		7800 70	E(level): From E _{res} =7800 keV 70 (1983To19). J ^{π} , Γ : From (1983To19). $\Gamma_{\text{n0}}/\Gamma=0.50$ 7 and $\gamma^2=49$ keV 10 (1983To19).
12268 65	3/2 ⁻	186 keV 50		7940 70	E(level): From E _{res} =7940 keV 70 (1983To19). J ^{π} , Γ : From (1983To19). $\Gamma_{\text{n0}}/\Gamma=0.73$ 8 and $\gamma^2=36$ keV 9 (1983To19).
12434 46	7/2 ⁻	114 keV 40		8120 50	E(level): From E _{res} =8120 keV 50 (1983To19). J ^{π} , Γ : From (1983To19). $\Gamma_{\text{n0}}/\Gamma=0.42$ 6 and $\gamma^2=39$ keV 9 (1983To19). See also E _{res} =(8100) keV; J ^{π} =($\geq 1/2$); $\Gamma=(150)$ keV (1961Fo07).
13568	7/2 ⁻	619 keV 50		9350	E(level): From E _{res} =9350 keV (1985To02); see also E _{res} =9300 keV (1961Fo07). J ^{π} : From (1985To02); see also J ^{π} =($\geq 1/2$) (1961Fo07). Γ : From (1985To02); see also $\Gamma=370$ keV (1961Fo07). $\Gamma_{\text{n0}}/\Gamma=0.18$ 3 (1985To02).
14167	3/2 ⁻			10000	E(level): From E _{res} =10000 keV (1985To02). J ^{π} : From (1985To02).
14997	7/2 ⁻			10900	E(level): From E _{res} =10900 keV (1985To02).

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$^{12}\text{C}(\text{n,n})\text{:res}$ (continued) ^{13}C Levels (continued)

$E(\text{level})^a$	$J^\pi{}^b$	Γ	L	$E_n(\text{res})$ (keV)	Comments
15108.2 12	$3/2^-$				J^π : From (1985To02). T= $3/2$ (1987Hi03). E(level): From $E_{\text{res}}(\text{c.m.})=10161.9$ keV 12(1987Hi03). J^π : From (1987Hi03).
15273	$9/2^+$			11200	$\Gamma_{n0}=0.34$ keV 9 (1987Hi03: weak resonance anomaly). E(level): From $E_{\text{res}}=11200$ (1985To02). J^π : From (1985To02). See also $E_x=15181$ keV from $E_{\text{res}}=11100$ keV, $\Gamma=450$ keV and $J \geq 3/2$ in (1961Fo07).
15458	$3/2^-$			11400	E(level): From $E_{\text{res}}=11400$ (1985To02). J^π : From (1985To02).
16103	($\geq 1/2$)	230 keV		12100	E(level): From $E_{\text{res}}=12100$ keV (1961Fo07). J^π, Γ : From (1961Fo07). See discussion in (1985To02) where an unresolved pair of states with $J^\pi=7/2^+$ and $5/2^-$ are suggested near $E_x=16$ MeV.
17533 3		17 keV 6			T=($3/2$) (1987Hi03) E(level): From $E_{\text{res}}(\text{c.m.})=12587$ keV 3 (1987Hi03). Γ : From (1987Hi03); (J+ $1/2$) $\Gamma_{n0}/\Gamma=14\%$ 3 (1987Hi03).
18081 3		12 keV 7			T=($3/2$) (1987Hi03) E(level): From $E_{\text{res}}(\text{c.m.})=13135$ keV 3 (1987Hi03). Γ : From (1987Hi03); (J+ $1/2$) $\Gamma_{n0}/\Gamma=11\%$ 4 (1987Hi03).
19512	$5/2^-$	≥ 500 keV	0,1	15800	E(level): From $E_{\text{res}}=15800$ keV (1968Bo34,1987To03). J^π : From (1987To03); see also $J^\pi=1/2$ (1968Bo34). Γ : From (1987To03); see also $\Gamma=500$ keV (1968Bo34). L: From (1968Bo34).
20057 4		11 keV 8			T=($3/2$) (1987Hi03) E(level): From $E_{\text{res}}(\text{c.m.})=15111$ keV 4 (1987Hi03). Γ : From (1987Hi03); (J+ $1/2$) $\Gamma_{n0}/\Gamma=15\%$ 8 (1987Hi03).
20111	$1/2^-$	1090 keV		16450	E(level): From $E_{\text{res}}=16450$ keV (1987To03). J^π, Γ : From (1987To03). $\Gamma_{n0}/\Gamma=0.16$ (1987To03).
20111	$5/2^+$	440 keV		16450	E(level): From $E_{\text{res}}=16450$ keV (1987To03). J^π, Γ : From (1987To03). $\Gamma_{n0}/\Gamma=0.05$ (1987To03).
20185	$7/2^+$	630 keV		16530	E(level): From $E_{\text{res}}=16530$ keV (1987To03). J^π, Γ : From (1987To03). $\Gamma_{n0}/\Gamma=0.11$ (1987To03).
20296	$7/2^-$	1560 keV		16650	E(level): From $E_{\text{res}}=16650$ keV (1987To03). J^π, Γ : From (1987To03). $\Gamma_{n0}/\Gamma=0.08$ (1987To03).
20342	$9/2^+$	320 keV		16700	E(level): From $E_{\text{res}}=16700$ keV (1987To03). J^π, Γ : From (1987To03). $\Gamma_{n0}/\Gamma=0.06$ (1987To03).
20526	$5/2^-$	≈ 500 keV		16900	E(level): From $E_{\text{res}}=16900$ keV (1987To03). J^π, Γ : From (1987To03).
21703 4		18 keV 9			T=($3/2$) (1987Hi03) E(level): From $E_{\text{res}}(\text{c.m.})=16757$ keV 4 (1987Hi03). Γ : From (1987Hi03); (J+ $1/2$) $\Gamma_{n0}/\Gamma=21\%$ 6 (1987Hi03).

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$^{12}\text{C}(\text{n},\text{n})\text{:res (continued)}$ ^{13}C Levels (continued)

<u>E(level)^a</u>	<u>J^π^b</u>	<u>Γ</u>	<u>L</u>	<u>Comments</u>
23.00×10 ³ 19	5/2 ⁺ , 1/2 ⁻ , 3/2 ⁻ , 7/2 ⁻	≈1.5 MeV	0,1	E(level): Weighted average of 23.0 MeV 2 (1970De14) and 22.99 MeV 19 (1964Ha36, 1965Ha21: using E _{res} =19.55 MeV 20 which is the average of 19.5 MeV 2 and 19.6 MeV 2); see also E _{res} =19500 keV (1968Bo34). J ^π : 5/2 ⁻ is concluded in (1970De14); yet they are unable to eliminate (1/2 ⁻ , 3/2 ⁺ , 7/2 ⁻); see also J ^π =1/2 (1968Bo34). Γ: Average of Γ(MeV)=2.0 (1968Bo34), 1.1 (1965Ha21), 1.2 (1965Ha21), 1.6 (1970De14). L: From (1968Bo34).

^a Level energies are deduced using ^{12}C , ^{13}C and n masses from (2021Wa16: AME-2020) and the resonance energy E_n(res) except where noted. E_x=S_n+E_{c.m.}(relativistic).

^b Values determined in (1973Ab07, 1972Ga13, 1983To19, 1985To02, 1987To03) are via a phase-shift analysis of available data.

$^{12}\text{C}(\text{n,p})$:res **1968Ri02,1972Bo73**

- 1953Kc50: $^{12}\text{C}(\text{n,p})$ E=90 MeV; measured different reaction channels using cloud-chamber and β -activity counting. Deduced σ , $\sigma(\text{E})$.
- 1958Kr65: $^{12}\text{C}(\text{n,p}_0)$ E=17.5 MeV; measured $\sigma=29.1$ mb 40.
- 1959Kr69: $^{12}\text{C}(\text{n,p})$ E=14.9-17.5 MeV; measured products; deduced σ , $\sigma(\text{E})$ using activation technique. No resonances reported. Deduced ^{12}B lifetime.
- 1968Ri02: $^{12}\text{C}(\text{n,p})$ E=14.5-22 MeV; measured $\sigma(\text{E})$. ^{13}C deduced resonances. Natural target.
- 1972Bo73: $^{12}\text{C}(\text{n,p})$ E=16-18 MeV; measured $\sigma(\text{E})$.
- 1975Mc19: $^{12}\text{C}(\text{n,p})$ E=56 MeV; measured $\sigma(\theta)$.
- 1979RoZV: $^{\text{nat}}\text{C}(\text{n,p})$ E=27.4,39.7,60.7 MeV; measured $\sigma(\text{E},\text{Ep},\theta\text{p})$.
- 1979SuZR: $^{12}\text{C}(\text{n,p})$ E=27.4, 39.7, 60.7 MeV; measured $\sigma(\text{E},\theta)$; deduced reaction mechanism.
- 1981NeZY: $^{12}\text{C}(\text{n,p})$ E=60 MeV; measured $\sigma(\text{Ep})$, $\sigma(\theta)$; deduced reaction mechanism.
- 1982De16: $^{12}\text{C}(\text{pol. n,p})$ E=18 MeV; measured ^{12}B β -decay asymmetry.
- 1983Su07: $^{12}\text{C}(\text{n,pX})$ E=27.4,39.7,60.7 MeV; measured $\sigma(\theta,\text{Ep})$.
- 1985Fr07: $^{12}\text{C}(\text{n,p})$ E=545 MeV; measured $\sigma(\theta,\text{Ep})$.
- 1987Fr16: $\text{C}(\text{n,p})$ E=300-580 MeV; measured light particle production $\sigma(\text{E},\theta)$ vs particle energy.
- 1988RaZX: $^{12}\text{C}(\text{n,p})$ E=30-150 MeV; measured $\sigma(\text{E})$.
- 2017PiZW: $^{12}\text{C}(\text{n,p}_0)$ E=18.9-20.7 MeV; measured $\sigma(\text{E})$.
- 2021Ku19: $^{12}\text{C}(\text{n,p}_0)$ E=16.25-21.75 MeV; measured $\sigma(\text{E})$.

Theory:

- 1974OI03: $^{12}\text{C}(\text{n,p})$; calculated σ . ^{13}C deduced resonances.
- 1972Ed01: $^{12}\text{C}(\text{n,p})$ E=14-15 MeV; compiled, studied cross sections.
- 1986Ko26: $^{12}\text{C}(\text{n,p})$ E=545 MeV; calculated decay probability distributions, $\sigma(\text{Ep},\theta)$.
- 1988Pe01: $^{12}\text{C}(\text{n,pX})$ E=27,40,61 MeV; calculated $\sigma(\theta,\text{Ep})$; deduced direct reaction component.
- 1989Br05: $^{12}\text{C}(\text{n,p})$ E=15-60 MeV; calculated $\sigma(\theta,\text{E})$.
- 2016Zu01: $^{12}\text{C}(\text{n,p})$ E<10 GeV; compiled and analyzed σ .
- 2020Pr08: $^{12}\text{C}(\text{n,p})$ E<20 MeV; calculated astrophysical reaction rates.

 ^{13}C Levels

<u>E(level)</u>	<u>Comments</u>
≈ 20500	E(level): (1968Ri02,1972Bo73: weak resonance).
≈ 22000	E(level): strong resonance with a peak cross section $\sigma=19$ mb (1968Ri02).

¹²C(n,n'),(n,n'γ):res

- 1958Hu18: ¹²C(n,n') E_n=4.4-8 MeV, four resonances are reported in the yield of 4.4 MeV γ-rays, at E_n=6.30,6.49,7.6,7.87 and 8.15 MeV, corresponding to ¹³C*(10.76,10.94,12.0,12.21,12.47 MeV). The differential cross section at 90° reaches a maximum of 60 mb/sr at 7.87 MeV.
- 1959Ha13: ¹²C(n,n'γ) E=4.6-9.8 MeV; measured the cross section for the production of 4.43 MeV γ rays. Ten resonances were observed in this energy range and the maximum cross section of 45 mb/sr was obtained at a neutron-energy of 8.1 MeV.
- 1960He10: ¹²C(n,n') E=14 MeV; measured the angular distribution of inelastically scattered neutrons from ¹²C*(9.6 MeV) for θ=30° to 150°. Time-of-flight measurement.
- 1962Ba25: ¹²C(n,n') E=15 MeV; measured σ(E,θ=40°).
- 1968Bo34: ¹²C(n,n') E=14-21 MeV; measured σ(E).
- 1970De14: ¹²C(n,n) E=17-20.5 MeV; measured σ(E;E_n',θ) for θ≈10° to 150°. Deduced optical model parameters, E_x=23 MeV resonance energy, J, π.
- 1970Dr11: ¹²C(n,n'γ) E=5.8-7.5 MeV; measured differential cross sections for inelastic scattering via ¹²C(4.4 MeV); θ=25° to 90°.
- 1972Ga13: C(n,n') E=3-7 MeV; measured σ(E;θ).
- 1974Po03: ¹²C(n,nγ) E=14.9 MeV; measured nγ-coin. ¹³C deduced threshold and level energies.
- 1987BeYP: ¹²C(pol. n,n') E=16.1 MeV; measured analyzing power. ¹³C deduced resonances, Γ, L.

Theory:

- 1970Ca13: ¹²C(n,n'γ) E<9 MeV; analyzed available data; deduced J, π.
- 1971LeZG: ¹²C(n,n'), calculated σ(θ), P(θ), phase shifts. Calculated resonance energies, Γ, J, π.
- 1982Kn02: ¹²C(n,n') E=0.0-9 MeV; analyzed data. Deduced levels, J, π, reduced widths. R-matrix analysis, comparison to model predictions.
- 2017HaZY: ¹²C(n,n') E=5.3-6.45 MeV; calculated σ, σ(θ), analyzing power.
- 2017Lo02: ¹²C(n,n') E=17.29 MeV; analyzed differential σ(θ) data.

¹³C Levels

E(level) ^a	J ^π	Γ	L	E _n (res.) (keV)	Comments
9522		<80 keV		4960	E _n (res.) (keV),Γ: From (1959Ha13).
9946		<80 keV		5420	E _n (res.) (keV),Γ: From (1959Ha13).
10463		200 keV		5980	E _n (res.) (keV),Γ: From (1959Ha13).
10758				6300	E _n (res.) (keV): From (1959Ha13).
10804		120 keV		6350	E _n (res.) (keV),Γ: From (1959Ha13).
10970		<80 keV		6530	E _n (res.) (keV): From E _{res} =6530 keV which is the average of 6490 keV (1958Hu18) and 6570 keV (1959Ha13).
					Γ: From (1959Ha13).
11080		<80 keV		6650	E _n (res.) (keV),Γ: From (1959Ha13).
11865		260 keV		7500	E _n (res.) (keV),Γ: From (1959Ha13).
11957				7600	E _n (res.) (keV): From (1958Hu18).
12178		180 keV		7840	E _n (res.) (keV): From E _{res} =7840 keV which is the average of 7870 keV (1958Hu18) and 7810 keV (1959Ha13).
					Γ: From (1959Ha13).
12460		220 keV		8145	E _n (res.) (keV): From E _{res} =8145 keV which is the average of 8150 keV (1958Hu18) and 8140 keV (1959Ha13).
					Γ: From (1959Ha13).
13534		500 keV		9310	E _n (res.) (keV),Γ: From (1959Ha13).
19798 92		≈100 keV	1	16.1×10 ³ I	E _n (res.) (keV): From E _{res} =16.1 MeV I (1987BeYP: however authors deduced E _x =19.9 MeV I). Γ,L: From (1987BeYP). The observed Γ corresponds to τ≈7×10 ⁻²¹ sec.
23.0×10 ³ 2	5/2 ⁻ ,1/2 ⁻ ,3/2 ⁺ ,7/2 ⁻	1.6 MeV		19600	E(level),J ^π ,Γ,E _n (res.) (keV): From (1970De14). J ^π : 5/2 ⁻ is included in (1970De14); yet they are unable to eliminate (1/2 ⁻ , 3/2 ⁺ , 7/2 ⁻).

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${}^{12}\text{C}(\mathbf{n},\mathbf{n}'),(\mathbf{n},\mathbf{n}'\gamma):\text{res}$ (continued) ${}^{13}\text{C}$ Levels (continued)

^a Level energies are deduced using ${}^{12}\text{C}$, ${}^{13}\text{C}$ and n masses from (2021Wa16: AME-2020) and the resonance energy $E_n(\text{res})$ except where noted. $E_x=S_n+E_{\text{c.m.}}$ (relativistic).

$^{12}\text{C}(\text{p},\pi^+)$ *Most relevant:*

- 1973Da24: $^{12}\text{C}(\text{p},\pi^+)$ E=185 MeV; measured $\sigma(E(\pi^+),\theta)$; deduced levels.
 1980So05: $^{12}\text{C}(\text{p},\pi^+)$ E=200 MeV; measured $\sigma(E(\pi^+))$; deduced reaction mechanism.
 1984Lo13: $^{12}\text{C}(\text{pol. p},\pi^+)$ E=200-250 MeV; measured $\sigma(\theta)$, analyzing power vs θ ; deduced isobar excitation role. Microscopic two-nucleon models.
 1985Bi04: $^{12}\text{C}(\text{p},\pi^+)$ E=201,180 MeV; measured $\sigma(\theta,E(\pi))$; deduced $\sigma(E)$.
 1987Ko01: $^{12}\text{C}(\text{pol. p},\pi^+)$ E=200 MeV; measured $\sigma(E(\pi))$, analyzing power vs θ ; deduced quasifree two nucleon collisions role. Magnetic spectrometer.

Others:

- 1970Do04: $^{12}\text{C}(\text{p},\pi^+)$ E=600 MeV; measured $\sigma(E_\pi)$.
 1971Da10: $^{12}\text{C}(\text{p},\pi^+)$ E=185 MeV; measured $\sigma(E(\pi^+),\theta)$.
 1977BeZY: $^{12}\text{C}(\text{p},\pi^+)$ E=148-160 MeV; measured σ .
 1978Au07: $^{12}\text{C}(\text{pol. p},\pi^+)$ E=200 MeV; measured $\sigma(\theta)$.
 1979Ma38: $^{12}\text{C}(\text{p},\pi^+)$ E=0.5-10 MeV above threshold; measured σ .
 1979Ma39: $^{12}\text{C}(\text{p},\pi^+)$ E=8-16 MeV above threshold; measured inclusive σ ; deduced A-dependence.
 1980Ho20: $^{12}\text{C}(\text{p},\pi^+)$ E=300 MeV; measured $\sigma(\theta)$; deduced structure, reaction process interplay.
 1980So05: $^{12}\text{C}(\text{p},\pi^+)$ E=200 MeV; measured $\sigma(E(\pi^+))$; deduced reaction mechanism.
 1981MaZT: $^{12}\text{C}(\text{pol. p},\pi^+)$ E=200 MeV; measured $\sigma(\theta)$, analyzing power vs θ . $^{12}\text{C}(\text{pol. p},\pi^+)$ E=330-425 MeV; measured σ (inclusive). Semiclassical model analysis.
 1981Sj02: $^{12}\text{C}(\text{pol. p},\pi^+)$ E=147-159 MeV; measured $\sigma(\theta)$, analyzing power vs θ .
 1981So04: $^{12}\text{C}(\text{p},\pi^+)$ E=156-200 MeV; measured $\sigma(\theta)$; deduced single-particle, two particle-one hole final state effects.
 1982Lo03: $^{12}\text{C}(\text{pol. p},\pi^+)$ E=200-250 MeV; measured $\sigma(\theta)$, analyzing power vs θ ; deduced analyzing power energy, structure dependences.
 1984GrZW: $^{12}\text{C}(\text{pol. p},\pi^+)$ E=170,183,190 MeV; measured $\sigma(\theta)$, analyzing power vs θ ; deduced P-, S-wave amplitude energy dependence, barrier penetration factor consistency effects.
 1986Fa03: $^{12}\text{C}(\text{pol. p},\pi^+)$ E=400,450 MeV; measured $\sigma(\theta,E(\pi^+))$, analyzing power vs θ , $E(\pi^+)$. Quasi-free model.
 1987Ho21: $^{12}\text{C}(\text{p},\pi^+)$ E=166,186 MeV; measured $\sigma(\theta)$. Recoil detection method.
 1987Hu08: $^{12}\text{C}(\text{p},\pi^+)$ E=250,354,489 MeV; measured $\sigma(\theta,E)$; deduced reaction mechanism.
 1988Ab05: $^{12}\text{C}(\text{p},\pi^+)$ E=1 GeV; measured $\sigma(\theta)$ vs pion momentum; deduced reaction mechanism.
 1989Ko21: $^{12}\text{C}(\text{pol. p},\pi^+)$ E=200 MeV; measured $\sigma(\theta)$ analyzing power vs θ deduced reaction mechanism. ^{13}C deduced levels, J, π . Shell model calculations.
 1996Ja25: $^{12}\text{C}(\text{p},\pi^+)$ E=166,294 MeV; measured $\sigma(\theta)$. High momentum transfer, recoil detection at a cooler ring.

Theory:

- 1971Re12: $^{12}\text{C}(\text{p},\pi^+)$ E=600 MeV; calculated σ .
 1972Am05: $^{12}\text{C}(\text{p},\pi^+)$ E=600 MeV; analyzed σ . Single-particle model.
 1973Di08: $^{12}\text{C}(\text{p},\pi^+)$ E=185 MeV; calculated $\sigma(E_{\pi^+},\theta)$.
 1973Ei01,1973Ei05: $^{12}\text{C}(\text{p},\pi^+)$ E=600 MeV; calculated σ .
 1973Ke02: $^{12}\text{C}(\text{p},\pi^+)$ E=185 MeV; calculated σ .
 1973Ro10: $^{12}\text{C}(\text{p},\pi^+)$ E=68,185 MeV; calculated $\sigma(\theta)$. DWBA.
 1974Ho13: $^{12}\text{C}(\text{p},\pi^+)$ E=185 MeV; calculated $\sigma(E(\pi^+),\theta)$.
 1974Mi06,1974Mi11: $^{12}\text{C}(\text{p},\pi^+)$ E=185 MeV; calculated $\sigma(\theta,E(\pi^+))$.
 1975No05: $^{12}\text{C}(\text{pol. p},\pi^+)$, calculated polarization.
 1976Le02: $^{12}\text{C}(\text{p},\pi^+)$ E=185 MeV; calculated σ . DWBA calculations.
 1976Mi14: $^{12}\text{C}(\text{p},\pi^+)$; calculated $\sigma(\theta)$.
 1977Gi06: $^{12}\text{C}(\text{p},\pi^+)$ E=185 MeV; calculated $\sigma(\theta)$.
 1977Ku21: $^{12}\text{C}(\text{p},\pi^+)$ E=185 MeV; calculated σ .
 1978Mi02: $^{12}\text{C}(\text{p},\pi^+)$ E=185 MeV; calculated $\sigma(\theta)$.
 1978Yo02: $^{12}\text{C}(\text{pol. p},\pi^+)$ E=200 MeV; calculated asymmetry.
 1981Bu18: $^{12}\text{C}(\text{p},\pi^+)$ E=730 MeV; calculated $\sigma(\theta)$, inclusive spectra. Isobar model, intranuclear cascade.
 1982Co07: $^{12}\text{C}(\text{pol. p},\pi^+)$ E=159,200 MeV; calculated $\sigma(\theta)$, A(θ). DWBA, Dirac equation, different pion-nucleon vertices.
 1984Gu27: $^{12}\text{C}(\text{p},\pi^+)$ E=threshold-325 MeV; calculated pion production $\sigma(E)$. Knockout model.

$^{12}\text{C}(\text{p},\pi^+)$ (continued)

1984Ke02: $^{12}\text{C}(\text{pol. p},\pi^+)$ E=200 MeV; calculated $\sigma(\theta)$, analyzing power vs θ . Isobar-doorway model.

1985Iq01: $^{12}\text{C}(\text{p},\pi^+)$ E=250,265,200 MeV; calculated $\sigma(\theta)$. Two-nucleon model, intermediate isobar effects.

1987Ku06, 1987KuZW: $^{12}\text{C}(\text{p},\pi^+)$ E \approx 200 MeV; calculated $\sigma(\theta)$ vs momentum transfer; deduced structure effects. Shell model.

1994Fa10: $^{12}\text{C}(\text{pol. p},\pi^+)$ E=200 MeV; analyzed $\sigma(\theta)$, analyzing power data.

 ^{13}C Levels

E(level)	J^π ^b	Comments
0 ^a	1/2 ⁻	
3089 ^a	1/2 ⁺	
3685 ^a	3/2 ⁻	E(level): Unresolved from nearby states.
3854 ^a	5/2 ⁺	E(level): Unresolved from nearby states.
6860 ^a	5/2 ⁺	
7490 ^a	(7/2 ⁺)	E(level): Unresolved from nearby states.
7550 ^a	5/2 ⁻	E(level): Unresolved from nearby states.
7686 ^a	3/2 ⁺	E(level): Unresolved from nearby states.
8400 ^a	3/2 ⁺	
9.50 $\times 10^3$ ^a	9/2 ⁺	
11.9 $\times 10^3$		E(level): Reported in (1987Ko01,1987Hu08,1989Ko21).
14 $\times 10^3$		E(level): Reported in (1985Bi04,1987Ko01,1987Hu08,1989Ko21).
21470		E(level): Reported in (1985Bi04,1987Ko01,1987Hu08,1989Ko21). J^π, T : (1987Ko01,1989Ko21) suggested $J^\pi=(7/2^+,9/2^+)$ with a preference for 7/2 ⁺ ; they discussed a potential 1/2, 3/2 isospin mixing for this level. On the other hand, (1994Fa10) suggests this is a 13/2 ⁻ level with a $(1d_{5/2})^2(1p_{3/2})^{-1}$ configuration.

^a Values listed in (1980So05). See also (1971Da10, 1980So05, 1981Sj02, 1987Ko01, 1989Ko21) for discussion on unresolved states.

^b From, for example, A_y measurements in (1989Ko21). See (1970Do04, 1971Da10, 1973Da24, 1978Au07, 1980Ho20, 1980So05, 1981Sj02, 1981So04, 1982Lo03, 1984Lo13, 1987Hu08, 1987Ko01, 1989Ko21, 1996Ja25) for angular distributions, differential cross sections, A_y measurements and for discussion on single and multi-step reaction processes.

$^{12}\text{C}(\text{d,p}),(\text{d,p}\gamma)$

- 1951St19: $^{12}\text{C}(\text{d,p})$; the Q-value (2716 keV 5) is determined.
- 1951Va09: $^{12}\text{C}(\text{d,p})$, E=1.51, 1.80 MeV; deduced $E_x=3686$ keV 11.
- 1952Th24: $^{12}\text{C}(\text{d,p}),(\text{d,p}\gamma)$ E=1-2 MeV; deduced $E_\gamma=3082$ keV 7 after correcting for doppler broadening, from the positron spectrum of internal conversion pairs.
- 1954Fr24: $^{12}\text{C}(\text{d,p})$ E=19 MeV; measured $d\sigma(\theta)$ to $^{13}\text{C}^*(0, 3.08, 3.89)$ MeV; $\theta_{\text{c.m.}}=20^\circ$ to 160° , deduced L, J.
- 1954Ho48: $^{12}\text{C}(\text{d,p})$ E=3.29 MeV; measured differential cross sections at $\theta=5^\circ-140^\circ$.
- 1955Be62: $^{12}\text{C}(\text{d,p})$ E=4.0 MeV; $E_\gamma=3.74$ MeV 3 and 3.84 MeV 3 were observed.
- 1954Sp01: $^{12}\text{C}(\text{d,p})$; four Q-values are determined corresponding to $^{13}\text{C}^*(0,3.090,3.684,3.855)$ with error range from 10 keV for the g.s. to 7 keV for the 3.855 state. The spacing between 3.684 and 3.855 level is 170 keV 3.
- 1955Kh35: $^{12}\text{C}(\text{d,p})$ E=3.76 MeV; $^{13}\text{C}^*(0,3.10,3.69,3.86)$ investigated; errors ± 10 -15 keV.
- 1955Mc75: $^{12}\text{C}(\text{d,p})$ E=14.8 MeV; measured yields for $\theta=9.8^\circ-86.6^\circ$. Observed 11 excited states at $^{13}\text{C}^*(0, 3.09, 3.68, 3.86, 6.87, 7.47, 7.53, 7.64, 8.4, 9.5, 9.90, 10.76)$ MeV, deduced L, J.
- 1956Do41: $^{12}\text{C}(\text{d,p})$; measured the reaction energies; Q=-0.960 MeV 2 and -1.130 MeV 2 for $^{13}\text{C}^*(3.68,3.86)$, respectively.
- 1956Gr37: $^{12}\text{C}(\text{d,p})$; measured angular distributions of protons to $^{13}\text{C}^*(0, 3.09, 3.68, 3.85)$; $\theta_{\text{c.m.}}\approx 5^\circ-45^\circ$. Deduced L, J.
- 1956Ma52: A scintillation spectrometer and a magnetic lens spectrometer have been used to study γ rays from excited states of ^{13}C at 3.84 and 3.68 MeV, produced in the reactions $^{12}\text{C}(\text{d,p})$ and $^{10}\text{B}(\alpha,\text{p})$. Transition energies have been measured as 169.5 keV 4, 3.844 MeV 15, and 3.69 MeV 2. The internal conversion coefficient for the 170 keV γ ray is $Y_e/Y_\gamma=1.4\times 10^{-4}$ 3. Lastly, γ decay branching ratios were deduced for $^{13}\text{C}^*(3.84)$.
- 1958Bo67,1958He47,1958Hi74,1958Ju39,1958Ju42: $^{12}\text{C}(\text{vec}(\text{d}),\text{vec}(\text{p}))$, measured analyzing powers to $^{13}\text{C}^*(0, 3.09, 3.86)$.
- 1958He47: $^{12}\text{C}(\text{vec}(\text{d}),\text{vec}(\text{p}))$ E=7.8 MeV; measured analyzing powers to $^{13}\text{C}^*(0, 3.09)$.
- 1958Mc63: $^{12}\text{C}(\text{d,p})$ $E_d(\text{res})=2.502$ and 2.735 MeV; angular distributions are analyzed to obtain the reduced neutron widths of $^{13}\text{C}^*(0,3.09)$ states. Deduced reduced widths θ_n^2 .
- 1959Ha29,1961Ha19: $^{12}\text{C}(\text{d,p})$ E=10.2,12.4,14.8 MeV; angular distributions to the $^{13}\text{C}^*(0, 3.09)$ states were obtained for $\theta_{\text{c.m.}}\approx 10^\circ-90^\circ$. Deduced L, g.s. reduced width θ_n^2 .
- 1960Al35: $^{12}\text{C}(\text{d,p})$; measured angular distributions.
- 1960Ch01,1960Ch12: $^{12}\text{C}(\text{d,p}_3\gamma)$ E=1.7-3.1 MeV; the cross section was obtained from the yield of the 170 keV γ -ray, transition of $^{13}\text{C}^*(3.85$ MeV:5/2⁺) $\rightarrow^{13}\text{C}^*(3.68$ MeV:3/2⁻).
- 1960Mo05: $^{12}\text{C}(\text{d,p}_{0-3})$ E=14.9-19.6 MeV; measured angular distributions for $\theta=15^\circ-165^\circ$. Deduced g.s. radius.
- 1960Za04,1960Za06: $^{12}\text{C}(\text{d,p}_{0-3})$ E=4.7-13.3 MeV; measured angular distributions.
- 1961Go29: $^{12}\text{C}(\text{d,p})$; measured the γ -ray energies for $^{13}\text{C}^*(3.09,3.68,3.86)$ with ≈ 15 keV resolution.
- 1961Ja23: $^{12}\text{C}(\text{d,p})$; reported $Q_0=2725$ keV 5 and $E_x=3093$ keV 6 for the first excited state.
- 1962Fl06: $^{12}\text{C}(\text{d,p}\gamma)$ E=2.80,3.23,3.70 MeV; measured p- $\gamma_{2,3}$ angular correlations at reaction angles near the stripping maximum. Tentative multipole mixtures assigned are $\Gamma(E2)/\Gamma_\gamma\leq 5\%$ for the $E_\gamma=3.68$ MeV and $\Gamma(E3)/\Gamma_\gamma\leq 2\%$ for the $E_\gamma=3.85$ MeV.
- 1962Si08: $^2\text{H}(^{12}\text{C},\text{p}\gamma)$ E=14 MeV; measured $\tau_m=7.5$ $^{+3}_{-2}$ ps for $^{13}\text{C}^*(3.85)$ using DSAM. Deduced the transition strengths of the competing decay modes.
- 1962SI04: $^{12}\text{C}(\text{d,p}_{0,2})$ E=27.7 MeV; measured angular distributions for $\theta\approx 20^\circ-100^\circ$, deduced L.
- 1962Zh01: $^{12}\text{C}(\text{d,p}_{0,1})$ E=6.6 MeV; measured angular distributions for $\theta\approx 20^\circ-80^\circ$.
- 1963Ev04: $^{12}\text{C}(\text{d,p}_{0,1})$, 5.5<E<12 MeV; measured angular distributions for $^{13}\text{C}^*(0, 3.09)$ at $\theta\approx 10^\circ-120^\circ$, proton polarization for $^{13}\text{C}^*(3.09)$ and p- γ correlations for $^{13}\text{C}^*(3.09, 3.68, 3.85)$.
- 1963Li09: $^{12}\text{C}(\text{d,p}_{0,1}\gamma)$ E=6.03 MeV; measured angular correlation function for $\theta\approx 20^\circ-160^\circ$.
- 1963Pi04: $^{12}\text{C}(\text{d,pn})$ E=4.66,4.90,5.46 MeV; searched for sequential 3-body breakup states; no evidence was observed for involvement of ^{13}C . See also (1968Bo02, 1973Sa03).
- 1963Va23: $^{12}\text{C}(\text{d,p}_{0,1})$ E=25.9 MeV; measured absolute differential cross sections $\theta_{\text{c.m.}}\approx 5^\circ-70^\circ$ and $30^\circ-140^\circ$, respectively.
- 1964Sc12: $^{12}\text{C}(\text{d,p}_{0,1})$ E=11.8 MeV; measured the angular distributions of protons at $\theta=10^\circ-165^\circ$. Deduced the reduced widths θ^2 .
- 1964Wa05: $^{12}\text{C}(\text{d,p})$; measured not abstracted; deduced nuclear properties.
- 1965Fi05: $^{12}\text{C}(\text{d,p}_{0-3})$ E=1.7,2.7,3.1,4.0 MeV.
- 1965Wa16: $^{12}\text{C}(\text{d,p})$; $^{13}\text{C}^*(3.09,3.68,3.85)\rightarrow 0$ transitions observed.
- 1965Wi11: $^{12}\text{C}(\text{d,p}_0)$ E=0.717-1.740 MeV; measured $\sigma(E;\theta)$ for $\theta_{\text{c.m.}}\approx 5^\circ-165^\circ$.
- 1966Be31: $^{12}\text{C}(\text{d,p}\gamma)$, ^{13}C ; measured p- γ angular correlation functions.
- 1966Ga09: $^{12}\text{C}(\text{d,p}_0)$ E=1.2-4.5 MeV; measured $\sigma(\text{Ep},\theta)$. ^{13}C deduced S-factors.
- 1966Ge03: $^{12}\text{C}(\text{d,p}_{2,3}\gamma)$ E=2.80,3.23,3.70 MeV; measured $\sigma(\text{Ep},\theta)$, $\sigma(\theta)$, $\theta_{\text{c.m.}}\approx 20^\circ-160^\circ$; deduced θ^2 , S-factors.
- 1966GI01: $^{12}\text{C}(\text{d,p}_{0-3})$ E=8,12 MeV; measured $\sigma(\text{Ep},\theta)$. ^{13}C deduced levels, L, J^π , S-factors, reduced width.

$^{12}\text{C}(\text{d,p}),(\text{d,p}\gamma)$ (continued)

- 1966Go15: $^{12}\text{C}(\text{d,p}\gamma)$; inconclusive results on mixing ratios are found from p- γ angular-correlation measurements, measured $^{13}\text{C}^*(3.85)$ γ branching ratio.
- 1966Ka05: $^{12}\text{C}(\text{d,p}\gamma)$ E=2.0-3.2 MeV; measured $\sigma(\text{E};\text{Ep},\theta\text{p},\theta\text{p}\gamma)$ for $\theta_{\text{c.m.}}\approx 30^\circ$ to 125° ; analyzed p- γ angular correlations, deduced reduced widths, J, π .
- 1966Kl05: $^{12}\text{C}(\text{d,p}_{0,1})$ E=0.9-1.75 MeV; measured angular distributions.
- 1966Ma25: $^{12}\text{C}(\text{pol. d,p})$; analyzed the asymmetry in the proton angular distributions.
- 1966Po11: $^{12}\text{C}(\text{d,p}\gamma)$ E=2.51 MeV; measured γ - γ coinc. from $^{13}\text{C}^*(3.85)$ MeV; deduced mixing ratios for $3.68\rightarrow 0$ and $3.85\rightarrow 0$.
- 1966Sc09: $^{12}\text{C}(\text{d,p}_{0-3})$ E=11,13 MeV; measured angular distributions for $\theta_{\text{c.m.}}\approx 10^\circ$ - 160° , analyzed J.
- 1967Au05: $^{12}\text{C}(\text{d,p}_0)$ E=63 MeV; measured $\sigma=65$ mb 5.
- 1967Me02: $^{12}\text{C}(\text{d,p})$ E=2.72, 2.8 MeV; measured $\tau=55$ fs 6 for $^{13}\text{C}^*(3.09)$.
- 1967Od01: $^{12}\text{C}(\text{d,p})$, measured $Q_0=2.7223$ MeV 61.
- 1967Po01: $^{12}\text{C}(\text{d,p}_{0,1})$ E=0.9-2.1 MeV; measured $\sigma(\text{Ep},\theta)$ for $\theta_{\text{c.m.}}\approx 20^\circ$ - 160° . Deduced reduced widths, S-factors, L(n), π .
- 1967Sc29: $^{12}\text{C}(\text{d,p}_{0,2})$ E=12 MeV; angular distributions ($d\sigma(\theta)$) for $\theta_{\text{c.m.}}\approx 15^\circ$ - 175° , deduced S-factors.
- 1968Al03: $^{12}\text{C}(\text{d,p})$, E(^{12}C)=15.0 MeV; measured $\tau_{\text{m}}<15$ fs for $^{13}\text{C}^*(3.09)$.
- 1968Co04: $^{12}\text{C}(\text{d,p})$ E=4.66 MeV; measured $\sigma(\theta=70^\circ)$.
- 1968Go14: $^{12}\text{C}(\text{d,p}\gamma)$; measured polarization of 170 keV γ rays.
- 1968Ho23: $^{12}\text{C}(\text{d,p}_{0-11})$ E=12.3-14.7 MeV; measured $\sigma(\text{Ep},\theta)$ for $\theta=20^\circ$ to 60° ; deduced reaction mechanism.
- 1968Ri16: $^{12}\text{C}(\text{d,p})$ E=1.79, 2.715, 3.60 MeV; measured $T_{1/2}<10$ fs and <26 fs for $^{13}\text{C}^*(3.08,3.68)$ via DSAM.
- 1968Yu01: $^{12}\text{C}(\text{pol. d,p}_{0,1})$ E=8 MeV; measured vector analyzing powers for $\theta\approx 10^\circ$ - 120° .
- 1969Al17: $^{12}\text{C}(\text{d,p})$ E=3.25 MeV; measured $E_\gamma=169.25$ keV 4 for $^{13}\text{C}^*(3.85\rightarrow 3.68)$.
- 1969Bo32: $^{12}\text{C}(\text{d,p}_0)$ E=0.9-2.0 MeV; measured $\sigma(\text{E})$, $\sigma(\text{E};\text{Ep},\theta)$ for $\theta=20^\circ$ - 140° .
- 1969Co02: $^{12}\text{C}(\text{d,p}_{0-3})$ E=5-10 MeV; measured $\sigma(\text{E},\theta)$, $\sigma(\text{E};\text{Ep},\theta)$ for $\theta=30^\circ$ - 160° .
- 1969Cu10: $^{12}\text{C}(\text{pol. d,p})$ E=7.7-10 MeV; measured vector analyzing power for $\theta=20^\circ$ - 170° .
- 1969Gu02: $^{12}\text{C}(\text{d,p}_0)$ E=4.5 MeV; measured $\sigma(\text{Ep},\theta)$, P(θ) for $\theta\approx 10^\circ$ - 165° ; deduced optical parameters.
- 1969So07: $^{12}\text{C}(\text{d,p})$ E=2.9,3.07,3.25 MeV; measured proton polarization(E, θ) for $\theta=30^\circ$ - 120° .
- 1970Al26: $^{12}\text{C}(\text{d,p}_0)$ E=1.4-2.3 MeV; measured $\sigma(\text{E};\theta)$ for $\theta=25^\circ$ - 160° .
- 1970Bo20: $^{12}\text{C}(\text{pol. d,p})$ E=1.4-2.4 MeV; measured proton polarization, determined sign, compared with (pol. d,n).
- 1970Ho37: $^{12}\text{C}(\text{d,p})$ E=14.6 MeV; measured $\sigma(\text{Ep})$; deduced phase shifts, levels up to $E_x=9.90$ MeV.
- 1970Le20: $^{12}\text{C}(\text{d,p}_0)$ E=3.31-3.69 MeV; measured $\sigma(\text{E};\theta)$ for $\theta_{\text{c.m.}}=10^\circ$ - 170° .
- 1970Za10: $^{12}\text{C}(\text{d,p})$ E=12.8 MeV; measured $\sigma(\text{Ep})$.
- 1971Bo44: $^{12}\text{C}(\text{d,p})$ E=2.7-3.1 MeV; measured vector analyzing power(E; θ).
- 1971Br44: $^{12}\text{C}(\text{d,p}_0)$ E=12.3 MeV; measured tensor analyzing power(θ) for $\theta=0^\circ$ - 50° .
- 1971Bu03: $^{12}\text{C}(\text{pol. d,p}_{0,1})$ E=12.35 MeV; measured $\sigma(\theta)$, proton analyzing powers, $\theta=20^\circ$ - 136° . DWBA analysis.
- 1971Du09: $^{12}\text{C}(\text{d,p}_{0,1,3})$ E=80 MeV; measured $\sigma(\theta)$ for $\theta=15^\circ$ - 50° ; deduced optical potentials, S-factors.
- 1971Pu01: $^{12}\text{C}(\text{d,p}_0)$ E=0.4-0.85 MeV; measured $\sigma(\text{E};\theta)$ for $\theta\approx 30^\circ$ - 150° ; deduced optical-model parameters, deduced S-factors.
- 1972Bl04: $^{12}\text{C}(\text{pol. d,p})$ E=4-6 MeV; measured proton analyzing powers for $\theta=10^\circ$ - 135° , deduced minimal influence from compound-nucleus resonance.
- 1972Bo56: $^{12}\text{C}(\text{pol. d,p}_{0,1})$ E=1.6-3.0 MeV; measured $\sigma(\text{Ep},\theta)$, vector analyzing power(90°); analyzed reaction mechanism.
- 1972Hu13: $^{12}\text{C}(\text{d,p}_0)$ E=0.4-1.35 MeV; measured $\sigma(\text{E};\theta)$ for $\theta=80^\circ$ - 160° .
- 1972Ma77: $^{12}\text{C}(\text{pol. d,p})$ E=1.9-3.0 MeV; measured vector analyzing power A(E, θ), analyzed reaction mechanism.
- 1972Pe11: $^{12}\text{C}(\text{pol. d,p})$ E=4-21 MeV; analyzed $\sigma(\theta)$ for $\theta=20^\circ$ - 160° , deduced S-factors.
- 1972SaYS: $^{12}\text{C}(\text{d,p})$ E=4.04 MeV; measured $\sigma(\theta)$.
- 1973Be25: $^{12}\text{C}(\text{d,p}_{0-3})$ E=2.5, 2.72 MeV; measured $\sigma(\theta)$, deduced S-factors.
- 1973Da17: $^{12}\text{C}(\text{pol. d,p}_{0-4,8-11})$ E=9.3,13.3,15.0 MeV; measured polarization parameters $iT_{11}(\text{Ed},\text{Ep},\theta)$, cross sections $\sigma(\text{Ed},\text{Ep},\theta)$ for $\theta=20^\circ$ - 150° , deduced S-factors, resonance widths.
- 1973Go02: $^{12}\text{C}(\text{d,p}\gamma)$ E=4.15 MeV; measured $p\gamma(\theta)$ angular correlations, deduced mixing ratio for $^{13}\text{C}^*(3.68\rightarrow 0)$.
- 1973Go03: $^{12}\text{C}(\text{d,p})$ E=14.0-15.5 MeV; measured $\sigma(\text{E};\text{Ep};\theta)$ for $\theta=60^\circ$ - 120° , deduced levels, level-width for $E_x=10.8$ - 12.1 MeV.
- 1973HaVB: $^{12}\text{C}(\text{d,p})$, measured $\sigma(\theta)$.
- 1973Jo10: $^{12}\text{C}(\text{pol. d,p}_0)$ E=12.3 MeV; measured analyzing powers $iT_{11}(\theta)$, $T_{20}(\theta)$, $T_{22}(\theta)$ for $\theta=0^\circ$ - 50° , analyzed reaction mechanism and deduced importance of deuteron d-state effects.
- 1973Le26: $^{12}\text{C}(\text{d,p}_0)$ E=1.13,1.17 MeV; measured $\sigma(\text{E},\theta)$, P(E, θ).
- 1973Me22: $^{12}\text{C}(\text{pol. d,p})$ E=5-12 MeV; measured $T_{20}(\text{E};\theta)$ for $\theta=0^\circ$ - 15° ; analyzed importance of deuteron d-state effects.

$^{12}\text{C}(\text{d,p}),(\text{d,p}\gamma)$ (continued)

- 1973Tr02, 1973TrZP: $^{12}\text{C}(\text{d,p}_1\gamma)$ E=0.8-2.1 MeV; measured $\sigma(E)$; analyzed γ -ray lines shape; deduced $\sigma(\theta)$, resonance interference.
- 1974Be48: $^2\text{H}(^{12}\text{C},\text{p}\gamma)$ E=15 MeV; measured $\text{p}\gamma(\theta)$, DSA, $\text{p}\gamma(\theta,t)$. Deduced $^{13}\text{C}^*(3.85\text{ MeV})$ $g=0.59$ 5 via time-differential recoil-in-vacuum, $\tau_m=12.4\text{ ps}$ 8 $\delta(E3/M2)=+0.12$ 4. See also (1973RaZH).
- 1974Da06: $^{12}\text{C}(\text{d},\text{p}_{0-3})$ E=2.61-2.82 MeV; measured $\sigma(E,\text{Ep},\theta(\text{p}))$ for $\theta=10^\circ-160^\circ$; deduced levels, L(n).
- 1974Gm01: $^{12}\text{C}(\text{d},\text{p}_{0,1,2})$ E=1.82-2.50 MeV; measured $\sigma(E,\text{Ep},\theta)$. ^{13}C levels deduced S-factors.
- 1974Jo14: $^{12}\text{C}(\text{d},\text{p})$; measured $Q=2721.9\text{ keV}$ 8.
- 1975Ra29: $^{12}\text{C}(\text{d},\text{p}\gamma)$ E=2.51 MeV; measured $E_\gamma(\theta(\gamma)=0^\circ)$ Doppler shift, recoil distance. Deduced $\tau_m(3.85)=13.0\text{ ps}$ 4.
- 1975Tr07: $^{12}\text{C}(\text{d},\text{p}\gamma)$ E=1.4-3.2 MeV; measured $\sigma(E,E_\gamma)$; deduced $\sigma(E,\text{Ep},\theta)$, levels energies up to $E_x=3854$, γ -branching.
- 1975ZaZS: $^{12}\text{C}(\text{d},\text{p})$ E=13.6 MeV; measured $\sigma(\theta)$.
- 1976Dy05: $^2\text{H}(^{12}\text{C},\text{p}\gamma)$ E=15.5 MeV; measured spin precession of $^{13}\text{C}^*(3.85)$, deduced transient magnetic field in Fe.
- 1977AnZO: $^{12}\text{C}(\text{d},\text{p})$ E<1.4 MeV; measured absolute $\sigma(E,\theta)$.
- 1977Ba39: $^{12}\text{C}(\text{pol. d,p})$ E=12.3 MeV; measured T_{20} , T_{22} ; analyzed importance of deuteron D-state, deduced J-mixing ratio.
- 1977He12: $^2\text{H}(^{12}\text{C},\text{p}\gamma)$ E=15 MeV; measured γ -ray Doppler patterns. Deduced τ_m of $^{13}\text{C}^*(3.85)=12.6\text{ ps}$ 3.
- 1977Ta08: $^{12}\text{C}(\text{d},\text{p}_{0-7})$ E=9.0 MeV; measured $\sigma(\theta)$ for $\theta\approx 30^\circ-170^\circ$ with an emphasis on $^{13}\text{C}^*(6.864(5/2^+), 7.677(3/2^+))$. Deduced J^π , Γ , S-factors; DWBA analysis.
- 1979Dy05: $^2\text{H}(^{12}\text{C},\text{p}\gamma)$ E=15.5,33 MeV; measured $\gamma(\theta,H)$, E_γ , I_γ .
- 1979Os11: $^{12}\text{C}(\text{d},\text{p}_1)$ E=1.5-3 MeV; measured $\sigma(E,\theta)$ $\theta\approx 60^\circ-160^\circ$. Analyzed reaction mechanism.
- 1979Si07: $^{12}\text{C}(\text{vec. d,p})$ E=2.34-2.74 MeV; measured $P(\theta)$; deduced spin-orbit potential parameters.
- 1979Wa24: $^{12}\text{C}(\text{d},\text{p})$ E=9 MeV; measured $\sigma(\theta)$. Optical model, zero-range DWBA, Hauser-Feshbach analyses.
- 1980Wa24: $^{12}\text{C}(\text{d},\text{p})$ E=2.51 MeV; measured E_γ , I_γ , $\gamma\gamma$ -coin, $\gamma(\theta)$. Deduced E_γ , level energies, γ -branching. Analyzed $T_{1/2}$, compared transition strengths via shell model.
- 1981Ru04: $^2\text{H}(^{12}\text{C},\text{p})$ E=15 MeV; measured $\text{p}\gamma(\theta)$, recoil. For $^{13}\text{C}^*(3.85)$ deduced $g=0.558$ 15 and $\tau_m=12.2\text{ ps}$ 4. Enriched target, recoil into vacuum, plunger technique. This gives $\mu=1.40$ 4 (2011StZZ).
- 1982Sa29: $^{12}\text{C}(\text{d},\text{p})$ E=9 MeV; measured $\sigma(\theta,\text{Ep})$. Deduced possible excitation of $^{13}\text{C}^*(8.2\text{ MeV}; 3/2^+)$ state.
- 1984Ha26: $^{12}\text{C}(\text{pol. d},\text{p}_{0-3})$ E=56 MeV; measured $\sigma(\theta)$, $A(\theta)$ for $\theta=10^\circ-70^\circ$. Deduced S-factors. DWBA, adiabatic model analyses.
- 1986Oh01: $^{12}\text{C}(\text{d},\text{p})$ E=30 MeV; measured $\sigma(\theta)$ for $\theta=10^\circ-85^\circ$. Deduced Γ , S-factors, shell model configurations for positive parity states below 10 MeV. CCBA, DWBA analysis.
- 1988La03: $^{12}\text{C}(\text{pol. d},\text{p}_{0-7})$ E=12 MeV; measured $\sigma(\theta)$, $iT_{11}(\theta)$, $T_{20}(\theta)$, $T_{21}(\theta)$, $T_{22}(\theta)$ for $\theta=15^\circ-85^\circ$. Deduced S-factors. DWBA analysis.
- 1989Ie01: $^{12}\text{C}(\text{pol. d},\text{pX})$ E=65 MeV; measured $\sigma(\theta,\text{p},\text{Ep})$, analyzed polarization transfer coefficient vs θ and reaction mechanism.
- 1990Pi05: $^{12}\text{C}(\text{d},\text{p})$ E=12.3 MeV; measured $\sigma(\theta)$ for $\theta=0^\circ-90^\circ$, deduced $Q=2721.803\text{ keV}$ 38 and E_x for $(\text{d},\text{p}_{1-4})$ reactions with $\Delta E\approx 0.06-0.5\text{ keV}$.
- 1991Le36: $^{12}\text{C}(\text{d},\text{p})$ E=735 keV-1.1 MeV; measured products, deduced $\sigma(\theta)$ at $\theta=150^\circ$.
- 1991We09: $^2\text{H}(^{12}\text{C},\text{p})$ E=6-9 MeV; measured $\sigma(\theta=120^\circ)$ vs E. High sensitivity analysis method.
- 1992Na17: $^{12}\text{C}(\text{d},\text{p}_0)$ E=160-300 keV; measured $\sigma(\theta)$ for $\theta=25^\circ-140^\circ$.
- 1993Qu04: $^{12}\text{C}(\text{d},\text{p})$ E=968 keV; measured $\sigma(\theta)$ for $\theta=10^\circ, 20^\circ$ and 30° .
- 1997Pa43: $^{12}\text{C}(\text{d},\text{p}\gamma)$ E=0.5-4 MeV; measured $\sigma(E_\gamma)$ for $\theta=170^\circ$; deduced excitation function.
- 1999A149: $^{12}\text{C}(\text{d},\text{p})$ E=223,250,308,332 keV; measured $\sigma(\theta)$ for $\theta=40^\circ-160^\circ$.
- 2000EI08: $^{12}\text{C}(\text{d},\text{p}\gamma)$ E=0.7-3.4 MeV; measured E_γ , I_γ at $\theta=135^\circ$; deduced thick target γ -ray yields.
- 2001Im02: $^{12}\text{C}(\text{d},\text{p})$ E=11.8 MeV; measured $\sigma(\theta)$, deduced S-factors, asymptotic normalization coefficient for $^{13}\text{C}^*(3.089\text{ MeV})$.
- 2001Li45,2001Li55,2002ZhZZ: $^{12}\text{C}(\text{d},\text{p})$ E=11.8 MeV; measured $\sigma(E,\theta)$ for $\theta\approx 5^\circ-140^\circ$. deduced ground and excited state asymptotic normalization coefficients, radii, halo features. Finite-range DWBA calculations.
- 2004Ch69: $^2\text{H}(^{12}\text{C},\text{p})$ E=20, 24 MeV; measured reaction products, Ep , Ip , thick target.
- 2004Ji10: $^{12}\text{C}(\text{d},\text{p})$ E<3 MeV; measured Ep , Ip ; deduced σ , $\sigma(\theta=150^\circ)$. Compared with available data.
- 2006Ko23: $^{12}\text{C}(\text{d},\text{p})$ E=900-2000 keV; measured $\sigma(\theta)$. Comparison with previous results.
- 2007Ko02: $^{12}\text{C}(\text{d},\text{p}_{0-3})$ E=900-2000 keV; measured Ep , $\sigma(E,\theta)$ for $\theta=135^\circ-170^\circ$.
- 2008Ja07, 2008Ki17: $^{12}\text{C}(\text{pol. d},\text{p}_{0,1,2+3})$ E=140,200,270 MeV; measured analyzing powers. Investigated deuterium spin structure. Compared results to model predictions.
- 2008Pa09: $^{12}\text{C}(\text{d},\text{p}_0)$ E=0.81-2.07 MeV; measured $\sigma(\theta)$ for $\theta=135^\circ, 160^\circ$.
- 2014Cs03,2016Cs02: $^{12}\text{C}(\text{d},\text{p}\gamma),(\text{d},\text{p})$ E<2 MeV; measured reaction products, E_γ , I_γ ; deduced σ , $\sigma(\theta=55^\circ)$.
- 2022Ho18: $^2\text{H}(^{12}\text{C},\text{p}_{0-3})$ E=111.4 MeV; measured reaction in inverse kinematics at TRIUMF/ISAC-II to validate experimental

$^{12}\text{C}(\text{d,p}),(\text{d,p}\gamma)$ (continued)

procedures.

Theory:

- 1969Pe09: $^{12}\text{C}(\text{d,p})$ E=7.26 MeV; calculated $\sigma(\theta)$, $P(\theta)$, vector analyzing power (θ) .
- 1970Do10: $^{12}\text{C}(\text{d,p}_0)$ E=12,15,26 MeV; analyzed $\sigma(\theta)$. Deduced S-factors. Absorption model.
- 1970Oh06: $^{12}\text{C}(\text{d,p})$ E=12 MeV; calculated $\sigma(\theta)$. Coupled channel theory.
- 1971BrYP: $^{12}\text{C}(\text{d,p})$ E=15 MeV; calculated $\sigma(\theta)$. Analyzed quasi-bound states, intermediate structure.
- 1972Go08: $^{12}\text{C}(\text{d,p}_0)$ E=51 MeV; calculated $\sigma(\theta)$, $P(\theta)$. Sudden approximation.
- 1973Co23: $^{12}\text{C}(\text{d,p})$; calculated $\sigma(E)$.
- 1973Co27: $^{12}\text{C}(\text{d,p})$; calculated, level energies.
- 1973CoYL: $^{12}\text{C}(\text{d,p})$; calculated $\sigma(E)$, ^{13}C deduced transitions.
- 1974St05: $^{12}\text{C}(\text{d,p})$; calculated $\sigma(E, \text{Ep}, \theta)$. Deduced second-order process contributions.
- 1975Gr12: $^{12}\text{C}(\text{d,p})$ E=12 MeV; calculated $\sigma(\text{Ep}, \theta)$, sudden approximation.
- 1975Hu01: $^{12}\text{C}(\text{d,p})$ E=8-10 MeV; calculated σ .
- 1975Is03: $^{12}\text{C}(\text{d,p})$ E=2.8 MeV; calculated $\sigma(\text{Ep}, \theta)$.
- 1975Se07: $^{12}\text{C}(\text{pol. d,p})$, analyzed data; deduced criteria for simplified polarization measurement analysis.
- 1975Za06: $^{12}\text{C}(\text{d,p})$; analyzed data; deduced σ dependence on J.
- 1976He17: $^{12}\text{C}(\text{d,p})$ E \leq 20 MeV; calculated $\sigma(\text{Ep}, \theta)$.
- 1976Os07: $^{12}\text{C}(\text{d,p})$; sub-Coulomb energy stripping; calculated σ for $^{13}\text{C}^*$ (3.09), deduced S-factors .
- 1976Sa04: $^{12}\text{C}(\text{pol. d,p})$ E=6-13.3 MeV; calculated $A(\theta)$. Surface reaction model.
- 1976Sh13: $^{12}\text{C}(\text{d,p})$ E=6-15 MeV; calculated $\sigma(\theta)$.
- 1977Se09: $^{12}\text{C}(\text{pol. d,p})$; calculated $A(\theta)$.
- 1982Go05: $^{12}\text{C}(\text{d,p})$ E=12 MeV; analyzed data. Deduced S-factors. DWBA, nuclear vertex constants.
- 1982Ta19: $^{12}\text{C}(\text{pol. d,p})$ E=9, 15 MeV; analyzed $\sigma(\theta)$, $A_y(\theta)$. Deduced Γ . Core excitation, CCBA analysis.
- 1982Th06: $^{12}\text{C}(\text{d,p})$ E=2.2, 2.71 MeV; calculated channel nonorthogonality effects.
- 1984Bl21: $^{12}\text{C}(\text{d,p})$ E=12 MeV; calculated $\sigma(\theta)$.
- 1984PeZW: $^{12}\text{C}(\text{d,p})$ E=17.7 MeV; analyzed S-factor data.
- 1996Ma36: $^{12}\text{C}(\text{d,p})$ E=12 MeV; calculated $\sigma(\theta)$; analyzed 2- and 3-body interaction features.
- 1998Ko11: $^{12}\text{C}(\text{pol. d,p})$, E at 9.1 GeV/c; analyzed $\sigma(\theta)$, $T_{20}(\theta)$, polarization transfer; deduced multiple scattering role.
- 2003Li50: $^{12}\text{C}(\text{d,p})$ E=11.8 MeV; analyzed data; deduced asymptotic normalization coefficients. See also (2001Kr12, 2001Nu03).
- 2004Ke08: $^{12}\text{C}(\text{d,p})$ E=15,30 MeV; calculated $\sigma(\theta)$. Comparisons with data.
- 2004Li41: $^{12}\text{C}(\text{d,p})$ E=4-56 MeV; analyzed $\sigma(\theta)$, S- factors. Johnson-Soper adiabatic and distorted-wave theories.
- 2005De33: $^{12}\text{C}(\text{d,p})$ E=7-60 MeV; calculated $\sigma(\theta)$, σ ; deduced reaction mechanism features. Coupled-channels approach.
- 2005Mu24: $^{12}\text{C}(\text{d,p})$ E=51 MeV; analyzed data; deduced S-factors.
- 2005Ts03: $^{12}\text{C}(\text{d,p})$. Survey of ground state neutron spectroscopic factors from (d,p) and (p,d) reactions.
- 2007Al28: $^{12}\text{C}(\text{d,p})$ E=4.66, 15, 56 MeV; calculated σ and A_y within few-body framework.
- 2009De02: $^{12}\text{C}(\text{d,p})$ E=30 MeV; calculated $\sigma(\theta)$, binding energies. Momentum-space three-body Faddeev-like equations.
- Comparison with experimental data.
- 2009De07: $^{12}\text{C}(\text{d,p})$ E=30 MeV; calculated differential cross sections, analyzing powers for polarized beam using local and nonlocal optical potentials parameters in the framework of Faddeev type scattering equations.
- 2010Ng02: $^{12}\text{C}(\text{d,p})$ E=2-80 MeV; calculated $\sigma(\theta)$ using adiabatic distorted-wave approximation (ADWA) and local energy approximation (LEA). Deuteron breakup and finite range effects.
- 2011Nu03: $^{12}\text{C}(\text{d,p})$ E=7, 12, 56 MeV; calculated $\sigma(E, \theta)$ using Faddeev AGS, and finite-range adiabatic wave approximation.
- 2012Up01: $^{12}\text{C}(\text{d,p})$ E=12, 56 MeV; calculated $\sigma(E, \theta)$ for elastic, transfer and breakup channels. Continuum-discretized coupled channels (CDCC) calculations. Comparison with exact three-body Faddeev formulation.
- 2013Ab06: $^{12}\text{C}(\text{d,p})$ E<2 MeV; analyzed available data; deduced $\sigma(\theta)$, yields. DWBA and R-matrix calculations.
- 2014Be47: $^{12}\text{C}(\text{d,p})$ E=11.8, 25.9, 30 MeV; analyzed differential $\sigma(E)$ data using coupled-reaction-channels method. Deduced S-factors, asymptotic normalization coefficients (ANCs), and rms radii of the last neutron, existence of neutron halos.
- 2014BeZU: $^{12}\text{C}(\text{d,p})$ E=12, 25, 30 MeV; calculated, analyzed $\sigma(\theta)$ to the first excited state. Deduced first excited state S-factor, asymptotic normalization coefficients, radii of last neutron, first excited state neutron halo.
- 2014Up02: Analyzed screening effects at astrophysical energies.
- 2015De38: $^{12}\text{C}(\text{d,p})$ E=12 MeV; calculated differential $\sigma(\theta)$. Faddeev-Alt-Grassberger-Sandhas (AGS) formalism with three-body model (proton+neutron+nuclear core) for proton-transfer reactions, and realistic CD Bonn potential.

¹²C(d,p),(d,pγ) (continued)

- 2015Ke07: ¹²C(d,p) E=30 MeV; calculated $\sigma(\theta)$ for 9.50-MeV, 9/2⁺ resonance; deduced best fit spectroscopic amplitudes and corresponding empirical mixing ratios for various state configurations. Coupled reaction channel calculation including the one- and two-step transfer via the ¹²C 4.44-MeV, 2⁺ state.
- 2016Ca20: ¹²C(d,p) E=56 MeV; calculated $\sigma(\theta,E)$, Ep, Ip using the post-form DWBA approximation.
- 2017Lo02: ¹²C(d,p) E=11.8 MeV; analyzed differential $\sigma(\theta)$ data using optical potential method.
- 2018Xu11: ¹²C(d,p) E=51.93 MeV; analyzed experimental $\sigma(\theta)$ distributions, spectroscopic amplitudes for neutrons in normal and high-lying single-particle components in the ground and excited states. Coupled reaction channel calculations.
- 2020SaZX: ¹²C(d,p) E=12 MeV; calculated $\sigma(E,\theta)$. DWBA model. Comparison with experimental data.
- 2020Vi06: ¹²C(d,p) E=3.4-25.9 MeV; calculated S-factors. Comparison with available data.
- 2022BI04: Discuss method to deduce ANCs from ¹²C(d,p) measurements.
- 2023Ga14: Global analysis of optical potential parameters for reactions on A=12-208.

¹³C Levels

E(level)	J ^{π} ^a	T _{1/2} or Γ	L	S ^a	Comments
0	1/2 ⁻		1	0.58 4	<p>$\mu=1.40$ 4 (1981Ru04)</p> <p>Q₀(keV)=2716 5 (1951St19), 2721 2 (1957Va11), 2725 5 (1961Ja23), 2722.3 61 (1967Od01), 2721.9 8 (1974Jo14), 2721.803 38 (1990Pi05), 2717 10(1954Sp01), 2722 (1997Pa43).</p> <p>J^{π}: See (1956Gr37, 1962Si08, 1964Sc12, 1966Gl01, 1966Ka05, 1966Po11, 1968Ho23, 1971Du09, 1973Go02, 1974Gm01, 1974St05, 1975Ra29, 1980Wa24, 1986Oh01, 1988La03, 2001Li45, 2002ZhZZ); see also J^{π}=1/2 (1968Yu01, 1972Pe11, 1973Jo10, 1973Me22), (1/2⁻, 3/2⁻) (1955Mc75).</p> <p>L: See (1954Fr24, 1955Mc75, 1956Gr37, 1961Ha19, 1964Sc12, 1966Ka05, 1968Ho23, 1968Yu01, 1972Pe11, 1973Jo10, 1973Me22, 1974Da06, 1974Gm01, 1974St05, 2001Li45, 2002ZhZZ).</p> <p>S: From (1972Pe11); see also S=0.8 (1966Gl01: average), 0.65 (1971Du09), 0.82 (1971Pu01), 1.1 (HD parameters) and 1.4 (MB parameters) (1973Da17), 0.9 (1974Gm01), 0.77 (1986Oh01).</p> <p>ANC=1.93 fm^{-1/2} 17; R_{rms}=3.39 fm 31 (2001Li45, 2001Li55, 2002ZhZZ).</p> <p>θ^2(average)=0.037 3 (1961Ha19), 0.035 (1964Sc12).</p>
3089.443 20	1/2 ⁺	<6.93 fs	0	0.36 2	<p>Q(keV)=-367.65 7 (1990Pi05), -366 (1951Va09), -373 10 (1954Sp01), -368 (1967Po01).</p> <p>E(level): From E_{γ}=3089.049 keV 20 measured in (1980Wa24); see also E_x=3090 keV 10 (1954Sp01), 3093 keV 6 (1961Ja23), 3088.45 keV 15 (1975Tr07: from E_{γ} measurement, relative to the adopted energy of 3684.15 keV 11 from (1970Aj04)), 3089.39 keV 7 (using Q=-367.65 keV 7 (1990Pi05) and Q₀=2721.74 keV from (2017Wa10)), 3100±(10-50) keV (1955Kh35).</p> <p>J^{π}: See (1955Mc75, 1956Gr37, 1962Si08, 1964Sc12, 1966Gl01, 1966Ka05, 1968Ho23, 1971Du09, 1973Da17, 1973Tr02, 1974Da06, 1974Gm01, 1974St05, 1975Ra29, 1980Wa24, 1986Oh01, 1988La03, 2001Im02, 2001Li45, 2002ZhZZ); see also J^{π}=1/2 (1954Fr24, 1968Yu01, 1972Pe11, 1973Jo10).</p> <p>J^{π}: 94.02% 0\otimess_{1/2} (1986Oh01).</p> <p>T_{1/2}: from τ<10 fs (1968Ri16); see also τ=55 fs 6 (1967Me02) and <15 fs (1968AI03: corresponds to a ratio of reduced E1 transition strengths in ¹³C and ¹³N of greater than 0.06) which is in disagreement with (1967Me02) but is consistent with expectations based on the mean life of the mirror state ¹³N*(2.37 MeV; 1/2⁺; radiative width=0.7 eV for E1 transitions to the 3/2⁻ g.s.).</p> <p>L: See (1954Fr24, 1955Mc75, 1956Gr37, 1961Ha19, 1964Sc12, 1966Ka05, 1967Po01, 1968Ho23, 1968Yu01, 1971Du09, 1972Pe11, 1973Jo10, 1974Da06, 1974Gm01, 1974St05, 2001Li45, 2002ZhZZ).</p> <p>S: From (1972Pe11); see also S=0.9 (1966Gl01: average), 1.1 (HD parameters) and 1.2 (MB parameters) (1973Da17), 0.29 (1974Gm01), 0.65 (1986Oh01), ANC=1.84 fm^{-1/2} 16 (2001Li45, 2001Li55, 2002ZhZZ); see also ANC²=3.65 fm⁻¹ 34(stat) 35(syst) (2001Im02) which agrees with (1994Oh02: ¹²C(n,γ));</p>

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¹²C(d,p),(d,pγ) (continued)

¹³C Levels (continued)

<u>E(level)</u>	<u>J^π^a</u>	<u>T_{1/2} or Γ</u>	<u>L</u>	<u>S^a</u>	<u>Comments</u>
3684.482 23	3/2 ⁻	<18 fs	1	0.10	<p>R_{rms}=5.04 fm 75 (2001Li45, 2001Li55, 2002ZhZZ). $\theta^2=0.0157$ (1964Sc12). Q=-0.969 MeV 10 (1951Va09), -0.967 MeV 10 (1954Sp01: the spacing between the 3684 and 3855 keV states is 170 keV 3), -0.960 MeV 2 (1956Do41: the spacing between 3684 and 3855 is 170 keV 15) and -962.73 keV 6 (1990Pi05). E(level): Derived from γ rays measured in (1980Wa24); see also E_x=3686 keV 11 (1951Va09), 3684 keV 10 (1954Sp01), 3690 keV 15 (1955Kh35: uncertainty is ± 10-15 keV), and 3684.47 keV 6 (using Q=-962.73 keV 6 (1990Pi05) and Q₀=2721.74 keV (2017Wa10)). J^π: See (1956Gr37, 1962Si08, 1966G101, 1966Ka05, 1966Po11, 1968Ho23, 1973Da17, 1973Go02, 1974Da06, 1974Gm01, 1974St05, 1975Ra29, 1976Dy05, 1980Wa24, 1986Oh01, 1988La03); see also J^π=(1/2⁻, 3/2⁻) (1955Mc75). T_{1/2}: from $\tau < 26$ fs (1968Ri16); see also $\tau < 300$ fs (1956Ma52). L: See (1955Mc75, 1956Gr37, 1966Ka05, 1974Da06, 1974Gm01, 1974St05). S: HD parameters (1973Da17); see also S=0.09 (1974Gm01), 0.14 (1986Oh01), 0.26 (1966G101: average) and 0.20 (1973Da17: MB parameters).</p>
3853.773 22	5/2 ⁺	8.7 ps 2	2		<p>Q=-1131.90 keV 20 (1990Pi05), -1130 keV 2 (1956Do41), -1138 keV 10 (1954Sp01). E(level): From γ rays measured in (1980Wa24); see also E_x=3855 keV 7 (1954Sp01), 3860 keV 15 (1955Kh35: E_x uncertainty is ± 10-15 keV), 3853.62 keV 15 (1969Al17: deduced by the separation energy between 3.85 and 3.68 states (E_γ=169.25 keV 4; neglect the small recoil energy E_R=1 eV) and the adopted level E_x=3684.37 keV 14 (weighted average of 3684.50 keV 17 (1967Pr10: ¹²C(n,γ)) and 3684.28 keV 14 (1968Sp01: ¹²C(n,γ))), 3853.55 keV 15 (1975Tr07: from E_γ measurement, relative to the adopted energy of 3684.15 keV 11 from (1970Aj04)), 3853.64 keV 20 (using Q=1131.90 keV 20 (1990Pi05) and Q₀=2721.74 keV from (2017Wa10)). J^π: See (1956Gr37, 1962Si08, 1966G101, 1966Ka05, 1966Po11, 1968Ho23, 1971Du09, 1973Da17, 1974Be48, 1974Da06, 1974Gm01, 1974St05, 1975Ra29, 1976Dy05, 1980Wa24, 1981Ru04, 1986Oh01, 1988La03, 2001Li45, 2002ZhZZ); see also J^π=(3/2, 5/2) (1954Fr24), (3/2⁺, 5/2⁺) (1955Mc75). J^π: 78.13% 0\otimesd_{5/2} (1986Oh01). T_{1/2}: From $\tau_m=12.55$ ps 30 which is the weighted average of ¹²C(d,p) values: 9.0 ps +25-15 (1968Ri16), 12.4 ps 8 (1974Be48), 13.0 ps 4 (1975Ra29), 12.6 ps 3 (1977He12) and 12.2 ps 4 (1981Ru04); see also $\tau=7.5$ ps +3-2 (1962Si08) and 12.5 ps 5: adopted by (1980Wa24: weighted average of 12.6 ps 7 (1977He12: but using higher uncertainty) and 12.4 ps 6 (weighted average of 10.7 ps 10 (1969He22: ¹⁰B(α,p)), 15.4 ps 20 (ref. 5 in 1968Al03, 1968LaZZ), and 9.9 ps 9 (1970Ga01: ¹⁰B(α,pγ))), and see 12.4 ps 8 (1974Be48), 13.0 ps 4 (1975Ra29), >0.3 ps (1956Ma52) and ≥ 1 ps (2000E108), . L: See (1954Fr24, 1955Mc75, 1956Gr37, 1966Ka05, 1968Ho23, 1974Da06, 1974Gm01, 1974St05, 2001Li45, 2002ZhZZ). S: S=0.8 (1966G101: average), 0.7 (1971Du09), 1.1 (HD parameters) and 1.4 (MB parameters) (1973Da17), 0.85 (1974Gm01), 0.58 (1986Oh01). ANC=0.15 fm^{-1/2} 1 (2001Li45, 2002ZhZZ), 0.149 fm^{-1/2} 12 (2001Li55); R_{rms}=3.68 fm 40 (2001Li45, 2001Li55, 2002ZhZZ).</p>
6864.04 46	5/2 ⁺	6 keV	0,2	0.017	<p>E(level): using Q=-4142.30 keV 46 (1990Pi05) and Q₀=2721.74 keV (2017Wa10). E_x(MeV) also reported at 6.86 (1968Ho23, 1970Ho37), 6.864 (1973Da17, 1986Oh01, 1988La03), 6.868 (1955Mc75), 6.87 (1969Co02, 1971Du09).</p>

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¹²C(d,p),(d,pγ) (continued)

¹³C Levels (continued)

<u>E(level)</u>	<u>J^π^a</u>	<u>T_{1/2} or Γ</u>	<u>L</u>	<u>S^a</u>	<u>Comments</u>
					J ^π : See (1968Ho23, 1973Da17, 1986Oh01, 1988La03); see also J ^π ≤5/2 ⁺ (1955Mc75). J ^π : 67.5% 2⊗s _{1/2} , 31.4% 2⊗d _{5/2} (1986Oh01). Γ: from (1977Ta08). L: From (1955Mc75). S: From (1986Oh01); see also S=0.02 (1988La03), 0.04 (1973Da17: HD parameters).
7470 20	7/2 ⁺				E(level): From (1955Mc75). E _x (MeV) also reported at 7.47 (1968Ho23, 1970Ho37), 7.50 (1969Co02, 1971Du09, 1973Da17), 7.492 (1986Oh01), 7.498 (1988La03). J ^π : From (1986Oh01). J ^π : 95.11% 2⊗d _{3/2} (1986Oh01).
7533 20	5/2 ⁻			0.009	E(level),Γ: from (1955Mc75). E _x (MeV) also reported at 7.53 (1968Ho23, 1970Ho37), 7.55 (1969Co02, 1971Du09, 1973Da17), 7.547 (1986Oh01, 1988La03). T _{1/2} or Γ: See also Γ≈5 keV (1977Ta08). J ^π : See (1968Ho23, 1986Oh01, 1988La03). S: From (1986Oh01); see also S=0.32 (1988La03).
7641 20	3/2 ⁺	60 keV 13		0.11	E(level),Γ: from (1955Mc75). E _x (MeV) also reported at 7.64 (1968Ho23, 1970Ho37), 7.68 (1969Co02, 1971Du09, 1973Da17), 7.686 (1986Oh01, 1988La03). Γ: Γ from Γ _{lab} =70 keV 15 (1955Mc75). See also Γ=80 keV (1977Ta08). J ^π : See (1968Ho23, 1986Oh01, 1988La03). J ^π : 29.7% 0⊗d _{3/2} , 68.3% 2⊗s _{1/2} (1986Oh01). S: From (1986Oh01); see also S=0.10 (1988La03).
8.4×10 ³ 3	3/2 ⁺	0.94 MeV 3	2	1.0	E(level),Γ: from (1955Mc75). E _x (MeV) also reported at 8.33 (1968Ho23, 1970Ho37, 1971Du09), 8.25 (1973Da17), 8.2 MeV (1986Oh01). Γ: Γ from Γ _{lab} =1.1 MeV 3 (1955Mc75). J ^π : See (1968Ho23, 1973Da17, 1986Oh01). J ^π : 40.0% 0⊗d _{3/2} , 37.8% 2⊗d _{5/2} (1986Oh01). L: From (1968Ho23). S: HD parameters (1973Da17).
8858	1/2 ⁻			0.5	E(level),J ^π : From (1973Da17). E _x (MeV)=8.82 also reported (1968Ho23, 1970Ho37). S: HD parameters (1973Da17).
9500 20	9/2 ⁺				E(level): From (1955Mc75). E _x (MeV) also reported at 9.50 (1968Ho23, 1970Ho37, 1984Pe24, 1984Pe24, 1986Oh01), 9.51 (1971Du09), 9.499 (1973Da17). J ^π : See (1984Pe24, 1986Oh01); see also J ^π =(3/2 ⁻) (1973Da17). J ^π : 88.7% 2⊗d _{5/2} (1986Oh01).
9897 20	3/2 ⁻			0.1	E(level): From (1955Mc75). E _x (MeV) also reported at 9.90 (1968Ho23, 1970Ho37), 9.899 (1973Da17). J ^π : From (1973Da17). S: HD parameters (1973Da17).
10755 5	7/2 ⁻	56 keV 2		0.026	E(level),Γ: from (1973Go03); E _x was measured with respect to the state E _x =9.499 MeV 4 (1970Aj04). See also E _x =10759 keV 20 (1955Mc75) and 10753 keV (1986Oh01). J ^π : From (1986Oh01). S: From (1986Oh01).
10818 5		24 keV 3			E(level),Γ: from (1973Go03). Unresolved E _x =10.81-11.02 MeV also reported in (1971Du09).
10997 8		82 keV 15			E(level),Γ: from (1973Go03).
11080 5	1/2 ⁻	<8 keV			E(level),Γ: from (1973Go03). E _x =11080 keV also reported in (1986Oh01). J ^π : From (1986Oh01).
11748 10		107 keV 14			E(level),Γ: from (1973Go03).
11851 5		68 keV 4			E(level),Γ: from (1973Go03).

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¹²C(d,p),(d,pγ) (continued)

¹³C Levels (continued)

<u>E(level)</u>	<u>T_{1/2} or Γ</u>	<u>Comments</u>
11970? 40	≈260 keV	E(level),Γ: from (1973Go03: possibly more than one level). E _x =11970 keV also reported in (1971Du09).
12108 5	81 keV 8	E(level),Γ: from (1973Go03).

^a From, for example, DWBA analysis of spectroscopic factors in (1986Oh01).

γ(¹³C)

<u>E_i(level)</u>	<u>J_i^π</u>	<u>E_γ</u>	<u>I_γ</u>	<u>E_f</u>	<u>J_f^π</u>	<u>Mult.</u>	<u>δ</u>	<u>Comments</u>
3089.443	1/2 ⁺	3089.049 20	100	0	1/2 ⁻	E1		E _γ : Measured (1980Wa24); see also E _γ =3082 keV 7 (corrected for Doppler shift) and 3097 keV 5 (uncorrected) (1952Th24), 3110 keV 12 (1961Go29). E _γ also reported in (1960Go19, 1961Go29, 1968Al03, 1995Ro28, 1997Pa43: E _{thres} =428 keV, 2000E108, 2014Cs03, 2014Cs08). I _γ : See (1962Si08,1966Ka05); the absolute E _γ yield is 1.55 7 (2000E108). Mult.: See (1952Th24,1962Si08, 1966Ka05,1968Al03). Γ _γ >0.066 eV (1968Ri16: Doppler shift).
3684.482	3/2 ⁻	595.013	0.75 4	3089.443	1/2 ⁺	E1		E _γ : From 595.013 keV 11, which is from the level-energy difference derived from γ rays measured in (1980Wa24). I _γ : From (1980Wa24); see also I _γ =1.6% 3 (1975Tr07), 1% (1966Ka05) and 0.6% (1962Si08). Mult.: See (1962Si08, 1966Ka05). E _γ : From (1956Ma52). See 3683.921 keV 23, which is from the level-energy difference derived from γ rays measured in (1980Wa24). See also E _γ =3740 keV 30 (1955Be62: corrected for Doppler shift (required)), 3687 keV 15 (1961Go29), 3760 keV 20 (1955Be62: uncorrected), 3690 keV 20 (1956Ma52: uncorrected). E _γ also observed in (1960Go19, 1961Go29, 1962Si08, 1966Ka05, 1966Po11, 1973Go02, 1975Tr07, 1997Pa43: E(thres)=1122 keV, 2000E108, 2014Cs03). I _γ : From (1980Wa24); see also I _γ =98.4% 3 (1975Tr07), 99% (1966Ka05) and 100% (1962Si08). The absolute E _γ yield is 1.14 6 (2000E108). Γ _γ >0.025 eV (1968Ri16: Doppler
		3675 15	99.25 4	0	1/2 ⁻	E2+M1	-0.096 +30-21	

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<u>¹²C(d,p),(d,pγ) (continued)</u>								
<u>γ(¹³C) (continued)</u>								
<u>E_i(level)</u>	<u>J_i^π</u>	<u>E_γ</u>	<u>I_γ</u>	<u>E_f</u>	<u>J_f^π</u>	<u>Mult.</u>	<u>δ</u>	<u>Comments</u>
3853.773	5/2 ⁺	169.300 4	36.3 6	3684.482	3/2 ⁻	E1		shift). Γ(E2)/Γ _γ </≈5% (1962FI06). Mult.: See (1962Si08, 1966Ka05, 1966Po11, 1973Go02). δ: From -0.096 +30-21 (1966Po11). See also δ= -0.154 54 (1973Go02). E _γ : Measured (1980Wa24); see also E _γ =169.5 keV 4 (1956Ma52), 169.25 keV 4 (1969Al17: recoil energy E _R =1 eV), 169.3 keV (2000El08), 170 keV (1962Si08, 1966Po11, 1968Go14, 1976Dy05, 1997Pa43). E _γ also reported in (1960Ch01, 1960Ch12, 1966Go15, 1966Ka05, 1975Ra29, 1975Tr07). I _γ : From (1980Wa24); see also I _γ =37% 4 (1966Go15: the γ-ray intensity ratio, (total 3.68)/3.85=0.59 7), 36.0% 7 (1975Tr07), 24% 5 (1956Ma52: the γ-ray intensity ratio, (total 3.68)/3.85=0.46), 24% (1962Si08, 1966Ka05, 1966Po11), 30% (1975Ra29). Mult.: See (1962Si08, 1966Ka05). M1 cannot be excluded although the internal conversion coefficient, 1.4×10 ⁻⁴ 3, is consistent with E1 (1956Ma52). M ² (E1)=0.01 W.u. (1962Si08). E _γ : Measured (1980Wa24). E _γ also reported in (1962Si08, 1966Go15, 1966Ka05, 1975Ra29, 1975Tr07). I _γ : From (1980Wa24); see also I _γ =0.93% 20 (1962Si08), 0.6% 2 (1975Tr07), 1% (1966Go15, 1966Ka05, 1975Ra29), not detected (1956Ma52: <3%, 1966Po11). Mult.: See (1962Si08, 1966Ka05). M ² (E2)=2.00 W.u. (1962Si08). E _γ : 3853.170 keV 22, which is from the level-energy difference derived from γ rays measured in (1980Wa24); see also E _γ =3860 keV 20 (1955Be62: uncorrected for Doppler shift (not required)), 3844 keV 15 (1956Ma52), 3863 keV 15 (1961Go29), 3840 keV 30 (1955Be62: corrected for Doppler shift). E _γ also reported in (1960Go19, 1961Go29, 1962Si08, 1966Go15, 1966Ka05, 1966Po11, 1968Al03, 1974Be48, 1975Ra29, 1975Tr07, 1977He12, 1997Pa43: E(threshold)=1321 keV, 2000El08, 2014Cs03). No γ-rays are observed with E _γ =3.9-5.8 MeV with intensity >10% of the 3.85 MeV γ-ray (1955Be62). I _γ : From (1980Wa24); see also I _γ =62% 4 (1966Go15), 63.4% 8 (1975Tr07), 75% (1962Si08,1966Ka05), 76% (1966Po11) and 69% (1975Ra29). The absolute E _γ yield is 6.92 4 (2000El08).
		764.316 10	1.20 4	3089.443	1/2 ⁺	E2		
		3853.170	62.5 6	0	1/2 ⁻	E3+M2	+0.12 3	

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$^{12}\text{C}(\text{d,p}),(\text{d,p}\gamma)$ (continued)

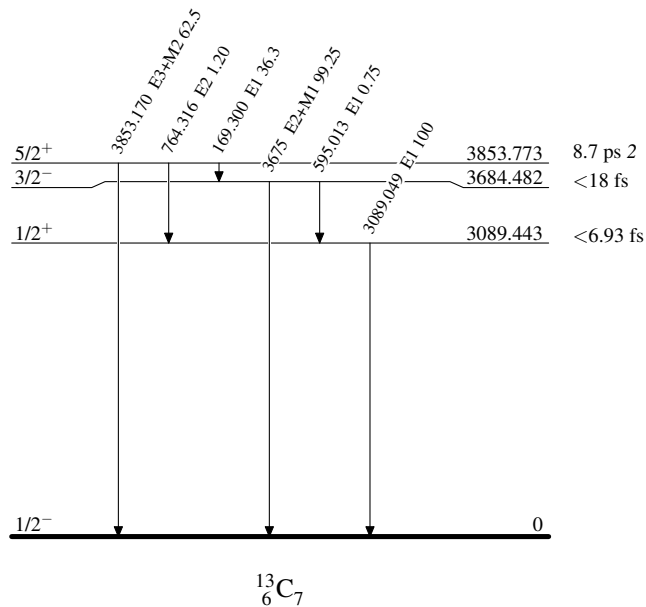
$\gamma(^{13}\text{C})$ (continued)

<u>$E_i(\text{level})$</u>	<u>E_γ</u>	Comments
		$\omega=0.61$ rad/ps 5 which leads to the nuclear g-factor=0.59 5 (1974Be48); see also g-factor=0.558 15 (1981Ru04) and g-factor=0.60 5 (1973RaZH). The sign was found to be negative (1976Dy05). $M^2(\text{E}3)=3.3 +42-20$ single-particle unit or 17.5 W.u. +225-104 (one standard deviation) (1966Po11), $M^2(\text{M}2)=0.90$ W.u. (1962Si08). $M^2(\text{E}3)=2.0$ 10 single-particle unit (1975Ra29) using $\Gamma(\text{E}3,\text{single particle})=2.6\times 10^{-7}$ eV (1966Po11). $\Gamma(\text{E}3,\text{single particle})=2.6\times 10^{-7}$ eV (1966Po11), $\Gamma(\text{E}3)=5.2\times 10^{-7}$ eV 26 (1975Ra29), $\Gamma(\text{M}2)=3.61\times 10^{-5}$ eV 23 (1975Ra29) using BR=69% 4 (average value of (1956Ma52,1966Go15) and the mixing ratio E3/M2=+0.12 3 (1966Po11)). $\Gamma(\text{E}3)/\Gamma_\gamma < \approx 2\%$ (1962Fl06). δ : From (1966Po11). $\beta_0=4.40\%$ 5 (1977He12: average). $\Gamma_\gamma(\text{Doppler shift})=8.8\times 10^{-5}$ eV 30 (1962Si08), 4.4×10^{-5} eV 6 (1968Al03): see Table VI in (1968Ri16), 7.3×10^{-5} eV 16 (1968Ri16).

$^{12}\text{C}(\text{d,p}),(\text{d,p}\gamma)$

Level Scheme

Intensities: % photon branching from each level



$^{12}\text{C}(\text{t,d}), ^{13}\text{C}(\text{t,t}), (\text{t,t}')$ 1966G101, 1988Si08

1961Ba10: $^{12}\text{C}(\text{t,d}_0)$ E=5.5 MeV; measured angular distribution.

1966G101: $^{12}\text{C}(\text{t,d})$ E=8,12 MeV; measured $\sigma(E_d, \theta)$; ^{13}C deduced levels, reduced width. Enriched ^{13}C targets.

1988Si08: $^{12}\text{C}(\text{t,d}), ^{13}\text{C}(\text{t,t}), (\text{t,t}')$ E=38 MeV; measured $\sigma(\theta)$; deduced potential parameters. ^{13}C levels deduced β_2, β_4 , single particle Γ of the resonances, spectroscopic factors. Optical DWBA analyses.

1961Ba10: $^{12}\text{C}(\text{t,d}_0)$; analyzed ^{13}C production.

2008Za05: $^{12}\text{C}(\text{t,d})$; calculated energy and angular distributions.

2007Li55: $^{13}\text{C}(\text{t,t}')$ E<40 MeV; analyzed elastic scattering σ and angular distribution data to obtain a set of global optical model potential parameters. Compared results to other calculations.

2009Pa07: $^{13}\text{C}(\text{t,t})$ E=38 MeV; analyzed $\sigma(\theta)$ using global optical model potential GDP08; deduced set of global optical potential parameters.

2015Pa10: $^{13}\text{C}(\text{t,t})$ E=4-118.5 MeV; analyzed $\sigma(\theta)$ for 142 sets of experimental data; deduced optical model parameters.

 ^{13}C Levels

E(level) ^a	J ^a	C ² S (Finite Range=0) ^a	Comments
0 ^b	1/2 ^{-b}	0.74	$\beta_2 = -0.428$ 40, $\beta_4 = -0.20$ 10 (1988Si08). C ² S (Finite Range=0): See also S=0.81 (1966G101).
3088 ^b	1/2 ^{+b}	0.28	C ² S (Finite Range=0): See also S=0.90 (1966G101).
3684 ^b	3/2 ^{-b}	0.14	C ² S (Finite Range=0): See also 0.28 (1966G101).
3854 ^b	5/2 ^{+b}	0.61	C ² S (Finite Range=0): See also S=0.77 (1966G101).
6860 ^c	5/2 ^{+c}	0.03	
7490	7/2 ⁺	0.03	
7550 ^c	5/2 ^{-c}	0.02	
7690?	3/2 ⁺	0.015	
8200	3/2 ⁺	0.014	
9500	9/2 ⁺	0.006	
10750	7/2 ⁻	0.09	

^a From DWBA analysis of spectroscopic factors in (1988Si08): $^{12}\text{C}(\text{t,d})$.

^b Also reported in (1966G101 and 1988Si08): $^{13}\text{C}(\text{t,t}')$.

^c Also reported in (1988Si08): $^{13}\text{C}(\text{t,t}')$.

$^{12}\text{C}(^3\text{He},2\text{p})$

[1971St21,1971StZL](#): $^{12}\text{C}(^3\text{He},2\text{p})$ E=40 MeV; measured $\sigma(E(p1), \theta(p1), \theta(p2))$, $\sigma(\theta)$; deduced p-p final-state interaction contribution. The angular distributions for the transitions to $^{13}\text{C}^*(0,3.85)$ have been studied.

[1974No01](#): $^{12}\text{C}(^3\text{He},2\text{p})$ E=12,13.5,14 MeV; measured $\sigma(E_p, \theta)$, $pp(\theta)$. The sequential proton decay of via various ^{14}N states to $^{13}\text{C}_{g.s.}$ was measured.

[1976StYX](#): $^{12}\text{C}(^3\text{He},2\text{p})$ E=60 MeV; measured σ .

[1980StZO](#): $^{12}\text{C}(^3\text{He},2\text{p})$ E=60 MeV; measured $\sigma(E(^2\text{He}), \theta(^2\text{He}))$ via pp-coin; deduced final state interaction effects. Zero-range, exact finite-range, microscopic DWBA calculations. Kinematically complete coincidence measurement, charge exchange reaction.

[1980Aa01, 1984Aa01](#): $^{12}\text{C}(^3\text{He},2\text{p})$ E=52 MeV; measured inclusive $\sigma(\theta_p)$, $\sigma(E_p)$, $\sigma(\theta_1, \theta_2, E_{p1})$, $\sigma(\theta_1, \theta_2)$; deduced reaction mechanism, σ vs target mass. Quasifree breakup calculations.

[1986Ka44](#): $^{12}\text{C}(\text{pol. } ^3\text{He},2\text{p})$ E=33 MeV; measured $\sigma(\theta)$, analyzing power vs E1, E2, θ_1 , θ_2 ; deduced j-dependence. Deduced level normalization. Sequential breakup model analysis. $^{13}\text{C}^*(3.85)$ is strongly populated. $^{13}\text{C}^*(0,8.0(\text{broad}),9.5)$ have also been populated.

 ^{13}C Levels

E(level)	Comments
0	Q=-2.77 MeV (1971St21). E(level): Reported in (1971St21,1974No01,1986Ka44).
3850	E(level): Reported in (1971St21,1986Ka44 : strongly populated).
≈ 8000	Γ =broad (1986Ka44).
9500	E(level): Reported in (1986Ka44).

${}^{12}\text{C}(\alpha, {}^3\text{He})$

1969Ga11: ${}^{12}\text{C}(\alpha, {}^3\text{He}_0)$ E=56 MeV; measured $\sigma(\theta)$ for $\theta_{\text{c.m.}}=15^\circ$ to 60° ; deduced relative S for $(\alpha, {}^3\text{He})$.

1972Ha08: ${}^{12}\text{C}(\alpha, {}^3\text{He}_0)$ E=104 MeV; measured $\sigma(\theta)$ for $\theta_{\text{c.m.}}\approx 11^\circ$ to 70° ; deduced normalization factors, absolute S.

1973Sm03: ${}^{12}\text{C}(\alpha, {}^3\text{He})$ E=139 MeV; measured $\sigma(E\alpha, \theta)$, $\sigma(E({}^3\text{He}), \theta)$ for $\theta_{\text{c.m.}}\approx 5^\circ$ to 60° . Deduced spectroscopic strengths of S(g.s.)= $0.69 \pm 15\%$ and S(3.85)= $0.40 \pm 15\%$.

1994Da32: ${}^{12}\text{C}(\alpha, {}^3\text{He})$ E=90 MeV; measured $\sigma(\theta)$ for $\theta_{\text{c.m.}}=10^\circ$ to 90° ; deduced far-side component role, rainbow effect evidence.

1995Da08: ${}^{12}\text{C}(\alpha, {}^3\text{He}){}^{13}\text{C}_{\text{g.s.}}$, E=90 MeV; measured $\sigma(\theta)$; deduced nuclear rainbow effect evidence, model parameters. Fuller's model, near/far-side formalism.

2021Ki07: $\text{C}(\alpha, {}^{13}\text{C}\gamma)$ E=50-90 MeV; measured $\sigma(E_\alpha, E_\gamma)$ for $E_\gamma=3685, 3854$ keV.

Theory:

1974Ha32: ${}^{12}\text{C}(\alpha, {}^3\text{He})$ E=139 MeV; calculated $\sigma(\theta)$, recoil effects.

 ${}^{13}\text{C}$ Levels

<u>E(level)</u>	<u>J^{π}</u>	<u>L</u>	<u>S</u>	<u>Comments</u>
0	1/2 ⁻	1	1.38	E(level): See (1969Ga11, 1972Ha08, 1973Sm03, 1994Da32, 1995Da08). J ^{π} , L, S: From DWBA analysis in (1972Ha08). See also S=1.15-1.4 in (1969Ga11).
3090				E(level): Reported in (1994Da32).
3685				E(level): Reported in (1994Da32).
3850				E(level): See (1983Sm03, 1994Da32).

${}^{12}\text{C}({}^7\text{Li}, {}^6\text{Li}), ({}^8\text{Li}, {}^7\text{Li})$

- 1973Sc26: ${}^{12}\text{C}({}^7\text{Li}, {}^6\text{Li})$ E=34,36 MeV; measured $\sigma(\theta)$ for $\theta_{\text{c.m.}}=15^\circ$ to 70° . FRDWBA, deduced optical model parameters.
- 1979Ze01: ${}^{12}\text{C}({}^7\text{Li}, {}^6\text{Li})$ E=48 MeV; measured $\sigma(\theta)$ for $\theta_{\text{c.m.}}=5^\circ$ to 90° ; deduced optical-model parameters. ${}^{13}\text{N}$, ${}^{13}\text{C}$ deduced S-factors. Enriched targets, finite range DWBA analysis.
- 1982Ta23: ${}^{12}\text{C}({}^7\text{Li}, {}^6\text{Li})$ E=36,32,28 MeV; measured yield vs particle energy, $\sigma(\theta)$ for $\theta=7.5^\circ$ to 50° , fusion σ , breakup σ vs E; deduced reaction mechanism.
- 1984Mo06: ${}^{12}\text{C}(\text{pol. } {}^7\text{Li}, {}^6\text{Li})$ E=21.1 MeV; measured $\sigma(\theta)$, $T_{20}(\theta)$, $T_{21}(\theta)$, $T_{22}(\theta)$ for $\theta \approx 30^\circ$ to 110° . Optical model analysis.
- 1986Co02: ${}^{12}\text{C}({}^7\text{Li}, {}^6\text{Li})$ E=34 MeV; measured particle spectra, $\sigma(\theta)$ for $\theta=20^\circ$ to 120° ; deduced potential parameters. ${}^{13}\text{C}$ levels deduced S-factors.
- 1989Be28: ${}^{12}\text{C}({}^8\text{Li}, {}^7\text{Li})$ E=13 MeV; measured $\sigma(\theta)$, $\sigma(E({}^7\text{Li}))$; deduced astrophysical abundance implications.
- 1989BeZY: ${}^{12}\text{C}({}^8\text{Li}, {}^7\text{Li})$ E=14.3 MeV; measured $\sigma(\theta)$. Radioactive beams.
- 1993Be22: ${}^{12}\text{C}({}^8\text{Li}, {}^7\text{Li})$ E \approx 13-20 MeV; measured $\sigma(\theta)$.

Theory:

- 1973DuZP: ${}^{12}\text{C}({}^7\text{Li}, {}^6\text{Li})$ E=36 MeV; calculated $\sigma(E, \theta)$, $\sigma(E({}^6\text{Li}), \theta)$.
- 1973Ku12: ${}^{12}\text{C}({}^7\text{Li}, {}^6\text{Li})$ E=36 MeV; calculated $\sigma(\theta)$, cluster model DWBA analysis.
- 1976Ku06: ${}^{12}\text{C}({}^7\text{Li}, {}^6\text{Li})$ E=36 MeV; analyzed anomalous $\sigma(\theta)$.
- 1988Ke07: ${}^{12}\text{C}({}^7\text{Li}, {}^6\text{Li})$ E=34 MeV; analyzed $\sigma(\theta)$; deduced reaction mechanism.
- 2002Ke04: ${}^{12}\text{C}(\text{pol. } {}^7\text{Li}, {}^6\text{Li})$ E=34 MeV; measured $\sigma(E, \theta)$, analyzing powers. Coupled channels analysis.
- 2002Ke11: ${}^{12}\text{C}({}^7\text{Li}, {}^6\text{Li})$ E=34 MeV; analyzed $\sigma(\theta)$. ${}^{13}\text{C}$ deduced neutron binding potential radius, possible core deformation.

 ${}^{13}\text{C}$ Levels

E(level)	$J^\pi{}^b$	L^c	S^b	Comments
0 ^a	1/2 ⁻	0,1,2	0.65 6	S: See also 0.80 (1979Ze01,1993Be22).
3090 ^a	1/2 ⁺	1	0.75 8	S: See also 0.9 (1973Sc26: estimated), and 0.44 (1979Ze01).
3680	3/2 ⁻		0.17	E(level), J^π , S: From (1979Ze01).
3850 ^a	5/2 ⁺	1,2,3	0.68 10	S: See also 1.0 (1973Sc26: estimated), 0.74 (1979Ze01), 1.1 (1993Be22).
6.86 $\times 10^3$				
7600				E(level): Unresolved multiplet.
9.5 $\times 10^3$				

^a Angular distributions to these states were studied; some higher-energy states were also observed (1973Sc26,1979Ze01,1986Co02).

^b From DWBA analysis of spectroscopic factors in (1986Co02), except where noted. In (1993Be22) S are deduced from normalization to FRDWBA calculations assuming (${}^8\text{Li}, {}^7\text{Li}_{\text{g.s.}}$) is the dominant transfer mode. We assume ${}^8\text{Li}_{\text{g.s.}} \rightarrow {}^7\text{Li}_{\text{g.s.}} + n$ has S=1.0.

^c From (1973Sc26).

$^{12}\text{C}(^9\text{Be}, ^8\text{Be})$

- 1970Ba49: $^9\text{Be}(^{12}\text{C}, ^{13}\text{C})$ $E=12,15$ MeV; measured $\sigma(\theta)$ for $\theta_{\text{c.m.}} \approx 70^\circ$ to 150° . Deduced neutron S.
- 1977St20: $^{12}\text{C}(^9\text{Be}, ^8\text{Be})$ $E=50$ MeV; measured $\sigma(\theta)$. ^{13}C levels.
- 1978MaZR, 1978Ma44: $^9\text{Be}(^{12}\text{C}, ^8\text{Be})$ $E_{\text{c.m.}}=10-15$ MeV; measured $\sigma(\theta)$ for $\theta=13^\circ$ to 75° .
- 1979Bo06: $^9\text{Be}(^{12}\text{C}, ^8\text{Be})$ $E_{\text{c.m.}}=11.4-14.8$ MeV; measured excitation curves, $\sigma(\theta(^8\text{Be}))$ for $\theta \approx 11^\circ$ to 165° . DWBA analysis, n-, α -transfer, compound nucleus formation.
- 1979Ja05: $^{12}\text{C}(^9\text{Be}, ^8\text{Be})$ $E=20$ MeV; measured $\sigma(\theta)$ for $\theta_{\text{c.m.}} \approx 10^\circ$ to 140° . Deduced S for n-, α -transfer. Finite range DWBA.
- 1981Hu12: $^9\text{Be}(^{12}\text{C}, ^8\text{Be})$ $E_{\text{c.m.}}=6-15$ MeV; measured $\sigma(\theta, E)$; deduced deviation function confidence limits.
- 1982Hu06: $^{12}\text{C}(^9\text{Be}, ^8\text{Be})$ $E_{\text{c.m.}}=5.9-15.4$ MeV; measured $\sigma(E)$ for $\theta=7.5^\circ$ and 27.5° .
- 1982Ta21: $^9\text{Be}(^{12}\text{C}, ^8\text{Be})$ $E_{\text{c.m.}} \approx 4-7$ MeV; measured $\sigma(\theta)$ vs E ; deduced sub-Coulomb molecular resonances.

Theory:

- 1981La15: $^9\text{Be}(^{12}\text{C}, ^8\text{Be})$ $E_{\text{c.m.}}=6-15$ MeV; calculated $\sigma(E)$; deduced resonance structure. Statistical model, energy-dependent deviation function.
- 1983DeZW: $^9\text{Be}(^{12}\text{C}, ^8\text{Be})$, E not given; calculated production σ ; deduced reaction mechanism. Statistical model.
- 1983Ka17: $^{12}\text{C}(^9\text{Be}, ^8\text{Be})$ $E=20-45$ MeV; analyzed $\sigma(\theta)$; deduced higher order processes role. Optical model, DWBA, potential scattering, direct interaction interference, incoherent compound nucleus contribution.

 ^{13}C Levels

E(level)	J^π ^a	S^a	Comments
0	$1/2^-$	1.15	E(level), J^π : listed in (1977St20, 1982Hu06). See also (1970Ba49, 1978Ma44, 1979Bo06, 1979Ja05, 1982Ta21). S: See also $S=0.80$ (1970Ba49).
3086	$1/2^+$	0.95	E(level), J^π : listed in (1977St20, 1982Hu06). See also (1970Ba49, 1979Bo06, 1979Ja05). S: See also $S=1.02$ (1970Ba49).
3680	$3/2^-$	0.20	E(level), J^π : listed in (unresolved: 1982Hu06, 1978Ma44). See also (1979Bo06, 1979Ja05).
3850	$5/2^+$	1.02	E(level), J^π : listed in (1977St20, 1982Hu06:unresolved). See also (1970Ba49, 1978Ma44:unresolved, 1979Bo06, 1979Ja05). S: See also $S=0.89$ (1970Ba49).
6860	$5/2^+$		E(level), J^π : From (1977St20, 1978Ma44): 6.87 MeV.
7500 ^b			E(level): From (1977St20). See also (1978Ma44: cluster of states near 7.55 MeV).
8200	$3/2^+$		E(level), J^π : From (1977St20).
9500 ^b			E(level): From (1977St20).
10800 ^b			E(level): From (1977St20).

^a From DWBA analysis of spectroscopic factors in (1979Ja05), except where noted.

^b Some states are not associated with Adopted Levels because inadequate details for association are given in the literature.

$^{12}\text{C}(^{11}\text{B},^{10}\text{B}),(^{12}\text{C},^{11}\text{C})$

Also includes $^{12}\text{C}(^{14}\text{N},^{13}\text{N})$, $^{12}\text{C}(^{17}\text{O},^{16}\text{O})$, $^{12}\text{C}(^{18}\text{O},^{17}\text{O})$ reactions.

1967Bi06: $^{12}\text{C}(^{14}\text{N},^{13}\text{N})$ E=148 MeV; measured ^{13}N energy spectrum at $\theta=18^\circ$ to 28° at the Yale linear accelerator. Observed states at $^{13}\text{C}^*(0,3.89,7.6,9.5\text{ MeV})$; discussed configurations.

1967Po13: $^{12}\text{C}(^{11}\text{B},^{10}\text{B})$ E=115.9 MeV; measured ^{10}B energy spectrum at $\theta_{\text{lab}}=8.5^\circ$ at the Yale linear accelerator. Populated states at $^{13}\text{C}^*(0,3.85,5.8\text{ MeV})$.

1974An36: $^{12}\text{C}(^{11}\text{B},^{10}\text{B}),(^{12}\text{C},^{11}\text{C})$ E=114 MeV from the AERE Harwell cyclotron; measured particle spectra, $\sigma(E,\theta)$ for $\theta\approx 10^\circ$ to 60° . Deduced levels, J, π , spectroscopic amplitudes.

1978Ch16: $^{12}\text{C}(^{17}\text{O},^{16}\text{O}),(^{18}\text{O},^{17}\text{O})$ E_{c.m.}=12.6-14.0 MeV from the Weizmann Institute Tandem; measured $\sigma(\theta)$ for $\theta\approx 40^\circ$ to 140° ; deduced reaction mechanisms, S, ^{12}C natural targets.

1979Fu04: $^{12}\text{C}(^{12}\text{C},^{11}\text{C})$ E=93.9 MeV; measured $\sigma(\theta)$. DWBA analysis.

1989HeZU: $^{12}\text{C}(^{12}\text{C},^{11}\text{C})$ E=344.5 MeV; measured $\sigma(\theta)$; deduced model parameters, spectroscopic factor. DWBA analysis.

1992Ja10: $^{12}\text{C}(^{12}\text{C},^{11}\text{C})$ E=344.5 MeV from the JULIC cyclotron; measured particle spectra, $\sigma(\theta)$ for $\theta\approx 10^\circ$ to 35° . Deduced single particle transfer spectroscopic factors, products of spectroscopic factor, $\text{C}^2\text{S}_1\cdot\text{C}^2\text{S}_2$. DWBA analyses.

2013Ca25: XUNDL dataset compiled by TUNL, 2014.

The authors measured angular distributions for the one-neutron transfer reaction $^{12}\text{C}(^{18}\text{O},^{17}\text{O})^{13}\text{C}$. Data were analyzed via exact finite range Coupled Reaction Channel Calculations (CRCC) based on a parameter free double folding potential. This reaction study is part of a greater work, which included measurements on $^{13}\text{C}(^{18}\text{O},^{17}\text{O})^{14}\text{C}$ and $^{12}\text{C}(^{18}\text{O},^{16}\text{O})^{14}\text{C}$. As a result, a detailed analysis of the two-neutron transfer reaction was carried out.

Beams of E(^{18}O)=84 MeV ions, from the INFN Catania impinged on $50\text{ }\mu\text{g}/\text{cm}^2$ targets of either ^{12}C (pure) or ^{13}C (99% enrichment). Reaction products were analyzed using the MAGNEX spectrometer with $\theta_{\text{lab}}=8^\circ, 12^\circ$ and 18° . Angular distributions were analyzed. In the one-neutron transfer reaction a complex relation of levels in the carbon and oxygen residuals is excited which makes interpretation non-trivial.

 ^{13}C Levels

E(level)	J π^a	L b	S a	Comments
0	1/2 $^-$	1	0.78 10	E(level),J $^\pi$: (1974An36,1992Ja10,2013Ca25); see also (1967Bi06,1967Po13). S: From (1978Ch16: $^{13}\text{C}_{\text{g.s.}}=^{12}\text{C}_{\text{g.s.}}\times 1p_{1/2}$); see also 0.66 (1974An36), 0.52 (1992Ja10).
3090 10	1/2 $^+$	0	0.90 17	E(level),J $^\pi$: (2013Ca25); see also (1974An36). S: From (1978Ch16: $^{13}\text{C}^*(3.09)=^{12}\text{C}_{\text{g.s.}}\times 2s_{1/2}$); see also 1.17 (1974An36).
3680	3/2 $^-$	1	0.21	E(level),J $^\pi$,S: (1974An36).
3850 10	5/2 $^+$	2	0.48	E(level),J $^\pi$: (2013Ca25); see also (1967Bi06,1967Po13,1974An36,1992Ja10). S: From (1992Ja10); see also 1.07 (1974An36).
6860 10	5/2 $^+$			E(level),J $^\pi$: (2013Ca25).
7490	7/2 $^+$		0.052	E(level),J $^\pi$,S: (1992Ja10).
7550	5/2 $^-$		0.108	E(level),J $^\pi$,S: (1992Ja10).
7690 10	3/2 $^+$	2	0.09	E(level),J $^\pi$: (2013Ca25); see also (1967Bi06: weak peak,1974An36: E $_{\text{x}}=7680\text{ keV}$). S: From (1974An36).
8250	3/2 $^+$	2	0.67	E(level),J $^\pi$,S: (1974An36).
9500 10	9/2 $^+$		0.047	E(level),J $^\pi$: (2013Ca25); see also (1992Ja10) and (1967Bi06: J $^\pi=7/2^-$). S: From (1992Ja10).

^a From DWBA analyses of spectroscopic factors in (1974An36,1992Ja10,2013Ca25).

^b From (1974An36).

$^{12}\text{C}(^{13}\text{C}, ^{13}\text{C}), (^{13}\text{C}, \text{X})$ **2016Ka37**

- 1977Gu07:** $^{12}\text{C}(^{13}\text{C}, ^{13}\text{C})$ E=12 MeV; measured $\sigma(\theta)$ for $\theta=39^\circ$ to 136° at Heidelberg Tandem accelerator. DWBA analysis. Deduced a model-independent value of $C^2=2.55$ 10 for the asymptotic normalization of the $1p_{1/2}$ neutron wave function. Using this, and a bound-state wave function obtained from analysis of electron elastic scattering, the absolute spectroscopic factor $S=0.81$ 4 was deduced.
- 1985Bo39:** $^{12}\text{C}(^{13}\text{C}, ^{13}\text{C}), (^{13}\text{C}, ^{13}\text{C}')$ E=240 MeV; measured $\sigma(\theta)$ for $\theta_{c.m.}\leq 60^\circ$ using the VICKSI spectrometer in Berlin; analyzed refractive scattering and nuclear rainbow effects for $^{13}\text{C}^*(0, 3.85 \text{ MeV})$.
- 1986Ba80:** $^{12}\text{C}(^{13}\text{C}, ^{13}\text{C}), (^{13}\text{C}, ^{13}\text{C}')$ E \approx 50 MeV; measured $\sigma(\theta)$ for $\theta=20^\circ$ to 160° . Deduced reaction mechanism.
- 1991Fu10:** $\text{C}(^{13}\text{C}, \text{X})$ E \approx 33 MeV/nucleon; measured total reaction cross section.
- 2000Fa12, 2000Fa17:** $\text{C}(^{13}\text{C}, \text{X})$ E \approx 33.4 MeV/nucleon; measured total reaction cross section.
- 2001Oz03:** $\text{C}(^{13}\text{C}, ^{13}\text{C})$ E \approx 960 MeV; measured interaction cross section. Deduced matter radius of 2.28 fm 4. See also (2001Oz04).
- 2010Al10:** $^{13}\text{C}(^{12}\text{C}, ^{13}\text{C})$ E=10.6 MeV/nucleon; σ and $\sigma(\theta)$ for $\theta_{c.m.}\leq 60^\circ$ using the Texas A&M MDM spectrometer; deduced optical model parameters and asymptotic normalization coefficients (ANC) $C^2_{p1/2}=2.24 \text{ fm}^{-1}$ 11. They average their value with those from other reactions to obtain $C^2_{p1/2}=2.31 \text{ fm}^{-1}$ 8; with this value they analyze stellar reaction rates.
- 2016Ka37:** XUNDL dataset compiled by TUNL, 2017.
- The authors carried out a systematic study of the charge changing cross sections of ≈ 900 MeV/nucleon carbon isotopes on a carbon target and analyzed the data to obtain the proton and matter radii of $^{12-19}\text{C}$.
- A beam of 828 MeV/nucleon ^{13}C ions was produced by fragmenting either a 1 GeV/nucleon ^{20}Ne beam or 1 GeV/nucleon ^{40}Ar beam on a thick beryllium target at the GSI/FRS facility. After magnetic separation, the ^{13}C beam particles were identified event-by-event using a multi-sampling ionization chamber and the time-of-flight between two scintillators. The beam then passed through a thick carbon target before being reanalyzed in a second multi-sampling ionization chamber that measured the Z of ions after the target. In the analysis, the ratio of the charge changing events to the non-charge changing events was determined and used to obtain σ_c , the charge changing cross section. For ^{13}C , $\sigma_c=726 \text{ mb}$ 7 was determined.
- The data were then compared with a finite-range Glauber model to obtain root-mean-square radii for the proton distribution and for the matter distribution. The results from the systematic study across $^{12-19}\text{C}$ is then compared with various models and comments are given on the development of neutron skins and neutron halos.

Theory:

- 1973Vo04:** $^{12}\text{C}(^{13}\text{C}, ^{13}\text{C})$; calculated $\sigma(\theta)$, particle, hole transfer.
- 1975De09:** $^{13}\text{C}(^{12}\text{C}, ^{12}\text{C}), ^{13}\text{C}(^{12}\text{C}, ^{12}\text{C}), ^{13}\text{C}(^{14}\text{C}, ^{14}\text{C})$ E=7.8-12.6 MeV; analyzed data and deduced optical model parameters.
- 1984Vo11:** $^{12}\text{C}(^{13}\text{C}, ^{13}\text{C})$ E $_{c.m.}$ =5-20 MeV; calculated $\sigma(\theta)$ vs E. $^{12}\text{C}(^{13}\text{C}, ^{13}\text{C}')$ E $_{c.m.}$ =7.8,9.88 MeV; calculated $\sigma(\theta)$, P(θ), σ . Coupled reaction channels model, valence nucleon molecular orbiting.
- 2019Ay05:** $^{12}\text{C}(^{13}\text{C}, ^{13}\text{C})$ E<300 MeV; analyzed available σ data; deduced the real part of the optical potential using the double folding model.
- 2021Do04:** $^{12}\text{C}(^{13}\text{C}, ^{13}\text{C})$ E=7.8, 14.2 MeV; used CDCC model to calculate exchange effects in scattering reactions.
- 2023Ma02:** $^{12}\text{C}(^{13}\text{C}, ^{13}\text{C})$; analyzed mass asymmetry and charge asymmetry effects in elastic scattering of light nuclei.
- 2022Ay05:** $^{12,14}\text{C}(^{13}\text{C}, ^{13}\text{C})$; optical model analysis of elastic scattering of carbon isotopes, analyzed results from different NN interactions.

^{13}C Levels

E(level)	J^π	S	Comments
0	$1/2^-$	0.81 4	S: From (1977Gu07). $R_{r.m.s.}^{\text{protons}}=2.30 \text{ fm}$ 4, $R_{r.m.s.}^{\text{matter}}=2.28 \text{ fm}$ 4 (2016Ka37). ANC is $C^2_{p1/2}=2.24 \text{ fm}^{-1}$ 11 (2010Al10).
3.85×10^3	$5/2^-$		E(level): See discussion in (1985Bo39).

¹²C(¹⁴N, ¹³N)

- 1969Vo01,1970Vo02: ¹²C(¹⁴N, ¹³N) E=78 MeV; measured $\sigma(E(^{13}\text{N}), E(^{13}\text{C}), \theta)$, $\sigma(\theta)$ for $\theta=5^\circ-37^\circ$. DWBA analysis.
 1974De03: ¹²C(¹⁴N, ¹³N) E=100 MeV; measured $\sigma(E(^{13}\text{N}), \theta)$ for $\theta_{\text{c.m.}}=10^\circ$ to 35° . ¹³C deduced levels, L.
 1975Na15: ¹²C(¹⁴N, ¹³N) E=155 MeV; measured $\sigma(\theta)$ for $\theta=20^\circ$ to 50° . ¹³C levels deduced S-factors.
 1975Vo05: ¹²C(¹⁴N, ¹³N) E=155 MeV; measured $\sigma(\theta)$ for $\theta_{\text{c.m.}}=20^\circ$ to 50° .
 1976Ba16: ¹²C(¹⁴N, ¹³N) E=28,32,34,36 MeV; measured $\sigma(E(^{13}\text{N}), \theta)$ at $\theta_{\text{c.m.}} \approx 40^\circ$ to 90° ; deduced angular symmetry violation, existence of complex (2-step) reaction mechanism.
 1981LiZV: ¹²C(¹⁴N, ¹³N) E=53.5 MeV; measured $\sigma(\theta)$. DWBA analysis.
 1983Qu02: ¹²C(¹⁴N, ¹³N) E=48 MeV; measured $\sigma(E1, E2, \theta_1, \theta_2)$; deduced reactions σ , proton rapidity plot. Dalitz plot analysis, analyzed projectile fragmentation, light particle emission.
 1997Zi05: ¹²C(¹⁴N, ¹³N); measured $\sigma(\theta)$ for $\theta_{\text{c.m.}}=10^\circ$ to 70° ; deduced reaction mechanism. Coupled reaction channels analysis.

Theory:

- 1969Do07: ¹²C(¹⁴N, ¹³N); calculated $\sigma(\theta)$ with recoil damping.
 1973De02: ¹²C(¹⁴N, ¹³N); calculated $\sigma(\theta)$; analyzed recoil effects. DWBA.
 1973De35: ¹²C(¹⁴N, ¹³C)¹³N; calculated $\sigma(\theta)$, S-factors, recoil effects.
 1974Br18: ¹²C(¹⁴N, ¹³N) E=78 MeV; calculated recoil, finite range effects.
 1974Br37: ¹²C(¹⁴N, ¹³N)¹³C_{g.s.} E=78,100,150 MeV; calculated $\sigma(E(^{13}\text{N}), \theta)$.
 1975Re04: ¹²C(¹⁴N, ¹³N) E=78 MeV; calculated σ .
 1976Ku06: ¹²C(¹⁴N, ¹³N) E=100 MeV; analyzed anomalous $\sigma(\theta)$.
 1976Na09: ¹²C(¹⁴N, ¹³N) E=155 MeV; calculated $\sigma(\theta)$.
 1978Na15: ¹²C(¹⁴N, ¹³N) E=100 MeV; calculated $\sigma(\theta)$. DWBA, CCBA, finite range.
 1979Do13: ¹²C(¹⁴N, ¹³N) E=78 MeV; calculated $\sigma(\theta)$. DWBA with recoil, strong absorption, eikonal-like representation of elastic scattering.
 1983Os08: ¹²C(¹⁴N, ¹³N) E=100 MeV; analyzed $\sigma(\theta)$; deduced model parameters. ¹³C levels deduced S-factors.
 1984Bi21: ¹²C(¹⁴N, ¹³N) E=70 MeV; calculated $\sigma(\theta)$.
 1988Ka27: ¹²C(¹⁴N, ¹³N) E=68 MeV; analyzed $\sigma(\theta)$.
 2002Ke11: ¹²C(¹⁴N, ¹³N) E=100 MeV; analyzed $\sigma(\theta)$. ¹³C deduced neutron binding potential radius, possible core deformation. Coupled channels approach.

¹³C Levels

E(level) ^a	J ^{π} ^a	L ^a	C ₂ ² S ₂ ^a	Comments
0	1/2 ⁻	0,1	0.72	E(level), J ^{π} : See (1974De03, 1975Na15). L: (1974De03, 1975Na15). C ₂ ² S ₂ : deduced from C ₁ ² S ₁ C ₂ ² S ₂ =0.50 (1975Na15) and assuming C ₁ ² S ₁ given by (1967Co32). See also the product S-factor=0.51 (1974De03) and 0.53 (1973De35).
3090	1/2 ⁺	1		E(level), J ^{π} : See (1974De03, 1975Na15). L: (1974De03).
3680	3/2 ⁻			E(level): See (1974De03, 1975Na15, 1997Zi05). J ^{π} : See (1974De03, 1975Na15).
3850	5/2 ⁺	2,3		E(level): See (1974De03, 1975Na15, 1997Zi05). J ^{π} : See (1974De03, 1975Na15). L: (1975Na15).
6870	5/2 ⁺		0.57	E(level), J ^{π} : See (1975Na15). C ₂ ² S ₂ : deduced from C ₁ ² S ₁ C ₂ ² S ₂ =0.39 (1975Na15) and assuming C ₁ ² S ₁ given by (1967Co32). See also the product S-factor=0.37 (1974De03).
7.3×10 ³ 3				E(level): Unresolved group including ¹³ C* (6.86+7.50+7.55+7.68) from (1974De03). Level not placed in Adopted Levels.

^a From DWBA analysis in, for example, (1974De03, 1975Na15) as noted.

$^{13}\text{C}(\gamma,\gamma')$

- 1968Ro02:** $^{13}\text{C}(\gamma,\gamma')$; measured the mean lifetime of $^{13}\text{C}^*$ (3089), $\tau_m=1.5$ fs 2.
1969Ra20: $^{13}\text{C}(\gamma,\gamma')$ E<3.8 MeV; measured $\sigma(E\gamma',\theta)$. Deduced level-width. Resonance fluorescence.
1975Ra22: $^{13}\text{C}(\gamma,\gamma')$ $E_{\text{brem.}}=3.19$ MeV; measured $\Gamma(^{13}\text{C}^*(3.086))=0.39$ eV 6 using nuclear resonant scattering.
1991Li12: $^{13}\text{C}(\gamma,\gamma')$ E=4.1 MeV bremsstrahlung; measured $E\gamma$, $I\gamma$. Nuclear resonance fluorescence technique, Monte Carlo simulations.
1993Mo23: $^{13}\text{C}(\gamma,\gamma')$ E=4.7 MeV bremsstrahlung; measured precise $E\gamma$, $I\gamma$. Deduced Γ_0 . Self-absorption technique, enriched target, amorphous ^{13}C absorbers. They give some commentary on the thermal corrections that were overlooked by other reports.
2000Ka08: $^{13}\text{C}(\gamma,\gamma')$ E=6.7 MeV bremsstrahlung; measured $E\gamma$, $I\gamma$, γ polarization.

 ^{13}C Levels

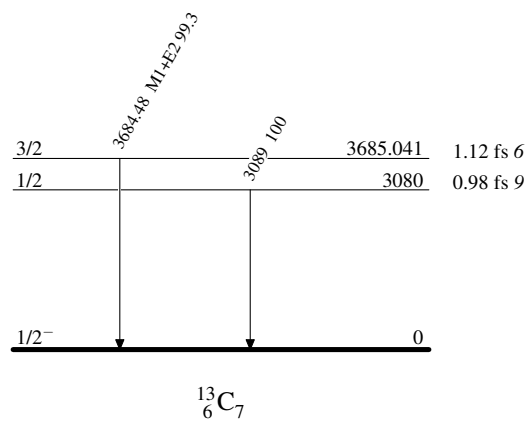
E(level)	J^π	$T_{1/2}$	Comments
0	$1/2^-$		J^π : From Adopted Levels.
3080 30	$1/2$	0.98 fs 9	E(level): From (1975Ra22); see also $E_x=3089$ keV (1968Ro02,1991Li12,1993Mo23). J^π : See (1993Mo23). $T_{1/2}$: From $\tau=1.42$ fs 13 corresponding to $\Gamma=0.464$ eV 42 which is the weighted average of 0.463 eV 56 and 0.413 eV 50 from (1968Ro02), 0.537 eV 42 (1993Mo23: using $\Gamma_0/\Gamma=1$ and $T_e=930$ K) and 0.39 eV 6 (1975Ra22).
3685.041 20	$3/2$	1.12 fs 6	E(level): deduced from the measured $E\gamma$ (1991Li12); see also (1969Ra20,1993Mo23). J^π : See (1993Mo23). $T_{1/2}$: From $\tau=1.61$ fs 9 obtained from the average of $\tau=1.59$ fs 13 (1991Li12: $\Gamma_0^2/\Gamma=0.408$ eV 26) and $\tau=1.63$ fs 12 (1993Mo23: $\Gamma=0.403$ eV 30 using $\Gamma_0/\Gamma=1$, $T_e=930$ K). See also $\tau=1.50$ fs 14 (1969Ra20: $\Gamma=0.44$ eV 4), but this value is omitted because the authors neglected thermal effects; see (1993Mo23) and footnote 20 in (1969Ra20).

 $\gamma(^{13}\text{C})$

$E_i(\text{level})$	J_i^π	E_γ	I_γ	E_f	J_f^π	Mult.	Comments
3080	$1/2$	3089	100	0	$1/2^-$		
3685.041	$3/2$	3684.48 2	99.3 7	0	$1/2^-$	M1+E2	E_γ, I_γ : (1991Li12). Mult.: From angular distribution, $A_2=0.104$ (1969Ra20).

$^{13}\text{C}(\gamma,\gamma')$ Level Scheme

Intensities: % photon branching from each level



$^{13}\text{C}(\gamma, \mathbf{n}), (\gamma, \mathbf{n}\gamma), (\gamma, \mathbf{p})$

- 1956Co72, 1957Co57: $^{13}\text{C}(\gamma, \mathbf{n}), (\gamma, \mathbf{p})$; the neutron yield up to $E_\gamma=41$ MeV was measured using bremsstrahlung photons, and the photoproton yield was also measured using activation techniques. Measured $\sigma(E)$. Deduced broad peaks at $E_x=13.5$ MeV 10 and 25.5 MeV 2 with $\Gamma=5$ MeV 1 and 10 MeV 2, respectively.
- 1960Ed01: Using the mixture of $E_\gamma=6.13, 6.9$ and 7.1 MeV γ rays from the $^{19}\text{F}(\text{p}, \alpha\gamma)$ reaction at $E_p=874$ keV, the $E_\gamma \approx 6.4$ MeV cross section for $^{13}\text{C}(\gamma, \mathbf{n})$ was found to be 94.1 mb 10.
- 1961Ko01: $^{13}\text{C}(\gamma, \mathbf{n})$; measured not abstracted; deduced nuclear properties.
- 1964De12: $^{13}\text{C}(\gamma, \mathbf{p})$ $E=17\text{-}32$ MeV; measured $\sigma(E)$ for photonproton emission using activation techniques. Deduced peaks at $E_x=18.5, 20.0, 23.5, 26.0, 29$ MeV.
- 1964Gr40: $^{13}\text{C}(\gamma, \mathbf{n})$ $E=5.4\text{-}10.8$ MeV; measured photoneutron production; deduced $\sigma(E)$. Resonances near ≈ 7.7 MeV are evident.
- 1965Be48: $^{13}\text{C}(\gamma, \mathbf{n})$ $E_{\text{brem.}}=13.6$ MeV; measured $\sigma(E, \theta)$ for $\theta=77^\circ$ and 157° . Observed peaks corresponding to $E_x=7.8, 8.9, 10.9, 12.9$ MeV.
- 1970Fu09: $^{13}\text{C}(\gamma, \mathbf{n})$ $E_{\text{brem.}}=14.5$ MeV; measured $\sigma(E; \theta)$, observed peaks corresponding to $E_x=6.2, 7.5, 8.2, 9.1, 11$ and 13 MeV; deduced integrated σ . Analyzed pygmy resonance region.
- 1971Mu11: $^{13}\text{C}(\gamma, \mathbf{n}\gamma)$ $E_{\text{brem.}}=21, 28$ MeV; measured $\sigma(E; E_\gamma)$. Analyzed $^{12}\text{C}^*(15.11)$ [$J^\pi=1^+$; $T=1$] population following neutron emission from the $T=3/2$ component of the ^{13}C giant resonance.
- 1975Pa09: $^{13}\text{C}(\gamma, \mathbf{n}\gamma'), (\gamma, \mathbf{p}\gamma')$ $E < 44$ MeV; measured $\sigma(E, E_\gamma')$, analyzed population of ^{12}C and ^{12}B states. Deduced giant resonance structure. $^{12}\text{C}^*(4.4)$ is populated most strongly at $^{13}\text{C}^*(13$ MeV). A low-energy giant resonance component around 22 MeV decays to ^{12}B states, while a higher-energy component around 28 MeV decays to ^{12}C states.
- 1976Ko22: $^{13}\text{C}(\gamma, \mathbf{n})$ $E=4.8\text{-}25$ MeV; measured yield curve; deduced $\sigma(E_\gamma, \mathbf{n})$, integrated σ . ^{13}C deduced resonances, Γ . Observed peaks at $E_x=7.7, (8.2), (9.1), (10.0), 11, 13, 15, (16.5) 20.5, 24.0$ MeV.
- 1977Wo04: $^{13}\text{C}(\gamma, \mathbf{n})$ $E=6\text{-}35.5$ MeV; measured $\sigma(E)$. ^{13}C deduced resonances, Γ . Observed peaks at $E_x=7.71, 7.88, 8.87, 9.49, 9.69, 11.0, 12.08, (13.62), (15.09), 15.13, 16.94, 17.95$ MeV.
- 1979Ju01: $^{13}\text{C}(\gamma, \mathbf{n})$ $E=7.6\text{-}41.8$ MeV; measured $4\pi^-$ neutron yield, integrated $\sigma(\gamma, \mathbf{n})$, $\sigma(\gamma, 2\mathbf{n})$; deduced isospin splitting of giant resonance. Observed peaks at $E_x=7.8, 9, 10, 11, 10.5, 13.8, 16.5, 17.8, 20.8, 24$ (GR), 30, 37 MeV. Discussion on pygmy and giant resonance regions.
- 1979Wo06: $^{13}\text{C}(\gamma, \mathbf{n})$ $E=7.6\text{-}24$ MeV; measured photoneutron angular distributions, deduced $\sigma(E_\gamma, \mathbf{n})$, angular distribution coefficients. $E_{\text{brem.}} \leq 12$ MeV: $\theta=56^\circ$ to 144° ; $E_{\text{brem.}} \leq 16$ MeV: $\theta=75^\circ$ to 145° and $E_{\text{brem.}} \leq 18.4$ to 24.6 MeV: $\theta=48^\circ$ to 160° . Reported levels at $E_x=7.70$ MeV: $J^\pi=3/2^+$, 7.95: $3/2^+$, 8.95: $(1/2^-)$, 10.0: $(3/2^-)$, 11.0: $(1/2^+)$ and 12.05: $(3/2^+)$.
- 1980Ho11: $^{13}\text{C}(\gamma, \mathbf{n}_0)$ $E=6.5\text{-}9.3$ MeV; measured $\sigma(\theta)$, $\theta=90^\circ, 135^\circ$; deduced Γ_γ . High-resolution R-matrix analysis. Reported on $E_x=7.56, 7.69, 8.19, 8.89$ MeV.
- 1982Ki09: $^{13}\text{C}(\gamma, \mathbf{n})$ $E=5\text{-}25$ MeV; analyzed $\sigma(E)$. ^{13}C deduced GDR isospin splitting.
- 1983Zu02: $^{13}\text{C}(\gamma, \mathbf{p})$ $E=17.5\text{-}28$ MeV; measured $\sigma(E)$ for photonproton emission using activation techniques. Deduced peaks at $E_x=18.6, (19.7), 20.7, (22), 23.5, 24.5, (26)$ MeV. Compared with (1979Ju01).
- See (1999Su12) for related discussion and analysis of the ^{13}C pygmy and giant resonances.

Theory:

- 1969Au06: $^{13}\text{C}(\gamma, \mathbf{n})$ $E < 17$ MeV; analyzed $\sigma(E)$ data, deduced resonant contributions.
- 1972Go27: $^{13}\text{C}(\gamma, \mathbf{n}), (\gamma, \mathbf{p})$ $E < 30$ MeV; calculated $\sigma(E)$; analyzed giant resonance.
- 1972Ha16: $^{13}\text{C}(\gamma, \mathbf{n})$; derived isospin sum rules for photonuclear reactions.
- 1973KiZI, 1974Ki03: $^{13}\text{C}(\gamma, \mathbf{n})$; calculated $\sigma(E_n)$ in GDR region.
- 1974Ma10: $^{13}\text{C}(\gamma, \mathbf{n})$; calculated giant dipole resonance, isospin splitting.
- 1977Al18: $^{13}\text{C}(\gamma, \mathbf{X})$; calculated σ . ^{13}C calculated resonances, T. Two-particle, one-hole shell model.
- 1977Ho32: $^{13}\text{C}(\gamma, \mathbf{np})$ $E=10\text{-}35$ MeV; calculated $\sigma(E)$.
- 1977Ma06: $^{13}\text{C}(\gamma, \mathbf{n})$; calculated σ . ^{13}C calculated GDR decay properties.
- 1979Ho17: $^{13}\text{C}(\gamma, \mathbf{n})$ $E=10\text{-}35$ MeV; calculated $\sigma(E)$. Continuum shell model, 3 particle-2 hole configurations.
- 1993Mc02: $^{13}\text{C}(\gamma, \mathbf{n})$ $E < 36$ MeV; analyzed $\sigma(E)$; deduced isospin component splitting.
- 2017Dz03: $^{13}\text{C}(\gamma, \mathbf{p})$ $E=18\text{-}30$ MeV; analyzed $\sigma(E)$. Compared with experimental results.
- 2024Ut01: $^{13}\text{C}(\gamma, \mathbf{n})$ $E < 18$ MeV; measured photoneutron cross sections at NewSUBARU. TALYS analysis.

$^{13}\text{C}(\gamma,\text{n}),(\gamma,\text{n}\gamma),(\gamma,\text{p})$ (continued) ^{13}C Levels

E(level) ^a	J ^{π} ^a	Γ ^b	Comments
7560	5/2 ⁻		$\Gamma_{\gamma 0}=0.110$ eV 15 (1980Ho11) E(level): From (1980Ho11). E2 transition (1980Ho11).
7690	3/2 ⁺	60 keV	$\Gamma_{\gamma 0}=0.6$ eV 1 (1980Ho11); $\Gamma_{\text{n}}=0.17$ MeV (1980Ho11) E1 transition (1980Ho11). Γ : See also 0.6 MeV (1976Ko22).
8200	3/2 ⁺	375 keV	$\Gamma_{\gamma 0}=7.0$ eV 9 (1980Ho11); $\Gamma_{\text{n}}=1.11$ MeV (1980Ho11) E1 transition (1980Ho11).
8860	1/2 ⁻	175 keV	$\Gamma_{\gamma 0}=5.4$ eV 5 (1980Ho11); $\Gamma_{\text{n}}=0.17$ MeV (1980Ho11) M1 transition (1980Ho11).
9500	(3/2 ⁻)	<90 ^c keV	E(level): From (1977Wo04). J ^{π} : From (1970Aj04).
9897	3/2 ⁻	<100 ^c keV	
10996	1/2 ⁺	<150 ^c keV	Γ : See also 0.4 MeV (1976Ko22).
12106	3/2 ⁺	150 keV	
13000?		3.3 MeV	Γ : From (1976Ko22).
13570		500 keV	E(level): See also 13.5 MeV 10 with $\Gamma=5$ MeV 1 (1956Co72, 1957Co57).
13760			E(level): From (1979Ju01).
14983		400 keV	Γ : See also 0.54 MeV (1976Ko22).
≈15120	3/2 ⁻	<135 ^c keV	T=3/2 (1977Wo04,1979Ju03) $\Gamma_{\gamma 0}=19.7$ eV 20 (1979Ju01) E(level): See (1977Wo04,1979Ju03).
16950		<400 ^c keV	
17920		<450 ^c keV	
20.8×10 ³		3.9 MeV	E(level): (1979Ju01). See also E _x =20.5 MeV (1976Ko22). Γ : From (1976Ko22). Γ value is uncertain.
24×10 ³ 2		10 MeV 2	E(level), Γ : From (1957Co57). See also (1956Co72).
≈30×10 ³			E(level): (1979Ju01).
≈37×10 ³			E(level): weak resonance (1979Ju01). Not placed in Adopted Levels.

^a From the R-matrix analysis of (1980Ho11) and the Legendre polynomial analysis of (1979Wo06). See (1976Ko22, 1977Wo04, 1979Ju01, 1979Wo06, 1980Ho11).

^b From (1977Wo04) except where noted.

^c From (1977Wo04: system resolution).

${}^{13}\text{C}(\gamma, \text{p})$ 1983Zu02

1956Co72,1957Co57: ${}^{13}\text{C}(\gamma, \text{p})$ $E_\gamma \approx 5$ to 42 MeV; a broad $\Gamma \approx 6$ MeV giant resonance structure near $E_\gamma = 25.5$ MeV has been reported.

1964De12: ${}^{13}\text{C}(\gamma, \text{p})$ $E_\gamma \approx 15$ to 32 MeV; structures are reported at $E_\gamma = 18.5, 20.0, 23.5, 26.0$ and 29.0 MeV. The dominant peak is near 23.5 MeV with $\Gamma \approx 3$ MeV.

1964Ko09: ${}^{13}\text{C}(\gamma, \text{p})$ $E_{\text{brem.}} = 31.5$ MeV; the energy spectra of photoprotons was investigated.

1975Pa09: ${}^{13}\text{C}(\gamma, \text{p}\gamma')$ $E < 44$ MeV; measured $\sigma(E, E_{\gamma'})$. Deduced giant resonance structure.

1983Zu02: ${}^{13}\text{C}(\gamma, \text{p})$ $E = 17.5$ -28 MeV bremsstrahlung; measured $\sigma(E)$. Deduced GDR isospin splitting, $T_<$ and $T_>$ appear to be split by 6.8 MeV. Activation technique.

Theory:

1972Go27: ${}^{13}\text{C}(\gamma, \text{p})$ $E < 30$ MeV; calculated $\sigma(E)$; analyzed giant resonance structure.

1973KiZI, 1973KiZJ: ${}^{13}\text{C}(\gamma, \text{p})$; calculated $\sigma(E_{\text{p}})$.

1977Ma06: ${}^{13}\text{C}(\gamma, \text{p})$; calculated σ . ${}^{13}\text{C}$ calculated GDR decay properties.

1993Mc02: ${}^{13}\text{C}(\gamma, \text{p})$ $E < 36$ MeV; analyzed $\sigma(E)$; deduced isospin component splitting.

2017Dz03: ${}^{13}\text{C}(\gamma, \text{p})$ $E < 50$ MeV; analyzed photoproton σ for applications.

 ${}^{13}\text{C}$ LevelsE(level)^a

18600^b
19700?
20700^b
22000?
23500
24500
26000?

^a From (1983Zu02). In (1964De12) structures are reported at $E_\gamma = 18.5, 20.0, 23.5$ ($\Gamma \approx 3$ MeV), 26.0, 29.0 MeV. See also a broad maximum at $E_\gamma \approx 25.5$ MeV with $\sigma = 8.8$ mb (1956Co72,1957Co57) and $\Gamma \approx 6$ MeV (1957Co57). The integrated cross section from $E_\gamma = 17.5$ (threshold) to 28 MeV is 36 MeV·mb 5 (1983Zu02).

^b State has a significant $T_>$ component (1983Zu02).

$^{13}\text{C}(\text{e,e}),(\text{e,e}'),(\text{e,e}'\text{p})$

- 1967Pe07: $^{13}\text{C}(\text{e,e}')$ E=40-65 MeV; the M1 radiation widths from $^{12}\text{C}(15.11)$ and $^{13}\text{C}^*(15.11)$ to the ground states were determined to be 36 eV 3 and 25 eV 7, respectively.
- 1969To05: $^{13}\text{C}(\text{e,e}')$; measured $\sigma(\text{E},\theta)$ for $^{13}\text{C}^*(3.08)$. Discussed transition probabilities.
- 1969Wi22: $^{13}\text{C}(\text{e,e}')$ E=36-65 MeV; measured $\sigma(\text{E};\text{Ee}')$. Deduced levels, level-width, γ -mixing, deduced $\text{B}(\text{E}/\text{M},\lambda\downarrow)$.
- 1970He24: $^{13}\text{C}(\text{e,e})$ E=120,170,200,250,350,500,750 MeV; measured $\sigma(\text{E};\theta)$. Deduced nuclear charge distribution.
- 1970Wi04: $^{13}\text{C}(\text{e,e}')$ E=36-75 MeV; measured $\sigma(\text{E};\text{Ee}'\theta)$. Deduced levels, level-width, transition radii.
- 1970WoZX: $^{13}\text{C}(\text{e,e}'\text{p})$ E=45,43 MeV; measured $\sigma(\text{Ep},\theta(\text{p}))$. Deduced giant resonance structure.
- 1971Be25: $^{13}\text{C}(\text{e,e})$ E=30,60 MeV; measured $\sigma(\theta)$. Deduced rms nuclear charge radii.
- 1971Be51: $^{13}\text{C}(\text{e,e}')$ E=55,77,81,106 MeV; measured $\sigma(\text{Ee}')$. ^{13}C deduced resonances, level-width, giant resonance structure.
- 1971Sh09: $^{13}\text{C}(\text{e,e}'\text{p})$ E=43 MeV; measured $\sigma(\text{Ep},\theta(\text{p}))$. Deduced giant resonance structure. Enriched targets.
- 1971Ya02: $^{13}\text{C}(\text{e,e}),(\text{e,e}')$ E=40-125 MeV; measured $\sigma(\text{E};\theta)$, $\sigma(\text{E};\text{Ee}'\theta)$; Discussed form factors, level-width, γ -mixing, rms charge radius.
- 1974LaYT,1975La23: $^{13}\text{C}(\text{e,e}')$ E=35-90 MeV; measured $\sigma(\text{E};\theta=180^\circ)$. ^{13}C deduced parameters of nuclear ground-state magnetization distribution. Deduced magnetic rms radius.
- 1974LaZH: $^{13}\text{C}(\text{e,e}')$ E=40-90 MeV; measured $\sigma(\text{Ee},\text{Ee}'\theta,\text{H})$. Discussed μ .
- 1982Hi07: $^{13}\text{C}(\text{e,e})$ E=80-338 MeV; measured $\sigma(\text{E},\theta)$. Deduced M1 form factor. Shell model.
- 1986Hi06: $^{13}\text{C}(\text{e,e}')$ E=78-338 MeV; measured $\sigma(\text{E},\theta)$. Deduced form factors, isoscalar, isovector transition amplitudes for M4 transitions. Shell model.
- 1986HuZX: $^{13}\text{C}(\text{e,e}),(\text{e,e}')$; measured form factors.
- 1987Hi09: $^{13}\text{C}(\text{e,e}')$ E=80-485 MeV; measured $\sigma(\text{E}(e'),\theta)$. Deduced transverse excitation form factors. Shell model.
- 1989Mi01: $^{13}\text{C}(\text{e,e}')$ E=45-340 MeV; measured $\sigma(\text{E},\theta)$. Data from (1969Wi22,1970Wi04: Darmstadt) were included in the analysis. Deduced longitudinal, transverse form factors, multipole matrix elements. Shell model.
- 1991Mi13: $^{13}\text{C}(\text{e,e}')$, measured elastic σ upper limit. Deduced M1 form factor high-q enhancement. Shell model.
- 1992Co07: $^{13}\text{C}(\text{e,e}')$ E=28.5-56.5 MeV; measured $\sigma(\text{E}(e''),\sigma(\theta)$, transverse form factors. Deduced $\text{B}(\lambda)$.
- 1994Zu01: $^{13}\text{C}(\text{e,e}'\text{p})$ E=21-23 MeV; measured proton yields vs E, $\theta=90^\circ$; deduced $\sigma(\theta)$ for (γ,p) reaction. Deduced GDR, decay features, isospin splitting effects.

Theory:

- 1972ThZF: $^{13}\text{C}(\text{e,e}')$; compiled spectroscopic data.
- 1973Fe13: $^{12}\text{C}(\text{e,e})$; analyzed data. ^{13}C rms radius was deduced from ^{12}C rms radius.
- 1973Ga19: $^{13}\text{C}(\text{e,e}')$; calculated form factors, radii.
- 1974Be10: $^{13}\text{C}(\text{e,e})$; calculated form factors.
- 1979Se06: $^{13}\text{C}(\text{pol. e,e}')$ E=30,200 MeV/c, 1 GeV/c; calculated $\sigma(\theta)$; deduced one-body transition densities.
- 1980Er01: $^{13}\text{C}(\text{e,e}')$ E=70 MeV; calculated $\sigma(\text{Ee}')$; deduced giant M2 resonance, configuration, isospin splitting. Shell model.
- 1981De07: $^{13}\text{C}(\text{e,e})$; calculated M1 form factors; deduced possible critical opalescence effects. Static limit, coupled integral equations, effective spin operators. (1983Si11) also discussed (1981De07).
- 1981Is11: $^{13}\text{C}(\text{e,e}')$; analyzed reaction data; deduced Majorana force role in GDR configuration splitting.
- 1981Li13: $^{13}\text{C}(\text{e,e}')$; calculated M1 form factors. Nilsson model.
- 1981Su03: $^{13}\text{C}(\text{e,e})$, calculated M1 form factors; deduced core polarization effects. Cohen-Kurath wave functions, one pion exchange currents.
- 1981Su08: $^{13}\text{C}(\text{e,e})$; calculated M1 form factors. Core polarization.
- 1982Ch16: $^{13}\text{C}(\text{e,e}')$; calculated transverse form factor. Cohen-Kurath wave function, DWIA model.
- 1983Ch15: $^{13}\text{C}(\text{e,e}),(\text{e,e}')$; calculated transverse form factors.
- 1983Ma40: $^{13}\text{C}(\text{e,e}')$; calculated transverse form factors; deduced pion wave distortion dependence, reaction dependent sensitivity to nuclear wave function.
- 1983Su10: $^{13}\text{C}(\text{e,e})$; calculated M1 form factors; deduced Landau-Migdal parameter momentum transfer dependence. Short-range correlations, particle-hole, isobar-hole excitation exchange effects.
- 1984Do20: $^{13}\text{C}(\text{e,e})$; study the elastic magnetic electron scattering and how it has come to be a useful tool for studying the spatial distributions of convection and magnetization currents in the nuclear ground state.
- 1984Li25: $^{13}\text{C}(\text{e,e}')$ E=196.5-225 MeV; analyzed $\sigma(\text{Ee}'\theta,\theta')$. The M4 strength in $^{13}\text{C}^*(21.4 \text{ MeV})$ was reported. Since $^{13}\text{C}_{\text{g.s.}}$ neither has zero angular momentum nor zero isospin, $J^\pi=7/2^+$ or $9/2^+$ and $T=3/2$ or $1/2$ (1980Le17: $^{13}\text{C}(\pi,\pi)$; shell model calculation) this M4 transition poses a strong theoretical challenge.

¹³C(e,e),(e,e'),(e,e'p) (continued)

- 1984LiZX: ¹³C(e,e); calculated M1 form factor; deduced core deformation effects.
 1985Hi04: ¹³C(e,e),(e,e'); calculated form factors.
 1985Sa06: ¹³C(e,e'); calculated M1, E2 form factors.
 1985Si05: ¹³C(e,e),(e,e'); calculated form factors; deduced configuration mixing effects.
 1986AmZX: ¹³C(e,e'); analyzed form factors, $\sigma(\theta)$; deduced structure effects.
 1986Do11: ¹³C(pol. e,e),(pol. e,e') E=400 MeV; calculated asymmetry, polarization ratio vs momentum transfer.
 1987De43: ¹³C(e,e); compilation of nuclear charge-density-distribution parameters.
 1989Am02: ¹³C(e,e'); calculated form factors.
 1990Wo10: ¹³C(e,e'); calculated form factors. Effective interactions, $(0+2)\hbar\omega$ space.
 1991Be40: ¹³C(e,e); analyzed longitudinal, transverse form factors. ¹³C deduced single particle radial functions, virtual p-, n-decay vertex constants.
 1991Er06: ¹³C(e,e'); calculated longitudinal, transverse form factors.
 1994Am01: ¹³C(pol. e,e); calculated magnetic and Coulomb form factors, response functions. Meson exchange effects, polarized target.
 1994Ch03: ¹³C(e,e); analyzed charge form factor. Phenomenological, microscopic models, beam linear polarization.
 1994Mo19: ¹³C(e,e'); calculated response functions. Shell model wave functions, meson exchange effects, different target polarizations.
 1997Ga31: ¹³C(e,e); analyzed form factors; deduced meson exchange currents role. Calculated wavefunctions, potentials, binding energies, resonance E, Γ . Astrophysical processes discussed.
 2023Sa29: ¹³C(e,e),(e,e'); analyzed evidence for α clustering in ^{12,13}C.

¹³C Levels

Authors have been inconsistent in how they have presented the transition strengths. The early work found in (1969Wi22, 1970Wi04) presented partial widths and transition strengths in the downward formalism, while the later works, such as (1989Mi01, 1992Co07) presented transition strengths in the expected upward formalism from inelastic scattering reactions.

E(level)	J ^{π} ^a	Γ	Multipolarity ^a	Comments
0	1/2 ⁻			T=1/2 (1967Pe07,1989Mi01) J ^{π} : From (1967Pe07,1989Mi01). The ¹³ C rms nuclear charge radius $\langle r^2 \rangle_{\text{Ch}}^{1/2} = 2.384$ fm 47 and the charge radius ratio $R_{\text{Ch}}(^{13}\text{C}/^{12}\text{C}) = 0.995$ 8 (1971Be25); $R_{\text{Ch}}(^{13}\text{C}/^{12}\text{C}) = 0.975$ 2 (1971Ya02); $\langle r^2 \rangle_{\text{Ch}}^{1/2} (^{13}\text{C}) = 2.452$ fm 47 (1973Fe13: relative to $\langle r^2 \rangle_{\text{Ch}}^{1/2} (^{12}\text{C}) = 2.462$ fm 22). The magnetic rms radius is $\langle r^2 \rangle_{\text{M}}^{1/2} = 3.3$ fm 3 (1975La23). The form factor for M1 elastic scattering is discussed in (1982Hi07, 1987Hi09, 1991Mi13).
3080 30	1/2 ⁺	0.39 eV 6	E1	E(level): From (1970Wi04). J ^{π} : From (1970Wi04,1989Mi01). Multipolarity: From (1970Wi04,1987Hi09,1989Mi01). Γ : From (1975Ra22). $\Gamma_{\gamma 0} = 0.68$ eV 23; $\Gamma_{\gamma 0} / \Gamma_{\text{W}}(E1) = 0.62$ W.u. (1970Wi04). $B(\text{C}1, \uparrow)$ W.u. = 0.047 5 (1989Mi01). A priv. comm. with D.J. Millener (DJM), see Table 13.12 in (1991Aj01), indicates $\Gamma_{\gamma 0} = 0.52$ eV and $B(\text{E}1, \downarrow)$ W.u. = 0.047 10: noting the uncertainty is double the statistical errors given in (1989Mi01); (DJM) does not understand why the uncertainties were doubled.
3690 20	3/2 ⁻		M1+E2 ^b	T=1/2 (1971Ya02,1989Mi01) E(level): From (1969Wi22,1970Wi04). J ^{π} : From (1969Wi22,1970Wi04,1971Ya02,1989Mi01,1992Co07). Multipolarity: From (1969Wi22,1970Wi04,1989Mi01); see also (1992Co07:)

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$^{13}\text{C}(\text{e,e}),(\text{e,e}'),(\text{e,e}'\text{p})$ (continued)				
^{13}C Levels (continued)				
E(level)	J^π ^a	Γ	Multipolarity ^a	Comments
				M1). Multipolarity: MR (δ)=0.100 8 from (1969Wi22,1970Wi04). $\Gamma_{\gamma_0}(\text{M1})=0.36$ eV 5; $\Gamma_{\gamma_0}(\text{E2})=3.6\times 10^{-3}$ eV 4; $\Gamma_{\gamma_0}(\text{M1})/\Gamma_{\text{W}}=0.339$ W.u.; $\Gamma_{\gamma_0}(\text{E2})/\Gamma_{\text{W}}=3.52$ W.u. (1969Wi22,1970Wi04). B(M1, \uparrow) W.u.=0.57 6=1.02 μ_{N}^2 11 (1992Co07: transition radius=2.48 fm 19). B(C2, \uparrow) W.u.=7.1 3 (1989Mi01).
3850	5/2 ⁺		M2+E3	E(level), J^π : From (1970Wi04,1989Mi01,1992Co07). Multipolarity: From (1989Mi01). B(M2, \uparrow) W.u.=0.64 25=5.8 $\mu_{\text{N}}^2\text{fm}^2$ 22 (1992Co07: transition radius=1.7 fm 11; alternate B(M2, \uparrow) W.u.=1.16 20=10.5 $\mu_{\text{N}}^2\text{fm}^2$ 10 with fixed transition radius 3.2 fm). B(C3, \uparrow) W.u.=3.9 3 (1989Mi01). A priv. comm. with D.J. Millener (DJM), see Table 13.12 in (1991Aj01), indicates $\Gamma_{\gamma_0}=6\times 10^{-8}$ eV and B(C3, \downarrow) W.u.=1.3 2: see comment on $^{13}\text{C}^*$ (3.09).
6850 60	5/2 ⁺		M2+E3	E(level): From (1969Wi22,1970Wi04); see also $E_x=6860$ keV (1989Mi01). J^π : From (1969Wi22,1970Wi04,1989Mi01). Multipolarity: From (1989Mi01); see also (1969Wi22,1970Wi04: M2). $\Gamma_{\gamma_0}(\text{M2})=6.9\times 10^{-5}$ eV 36; $\Gamma_{\gamma_0}(\text{M2})/\Gamma_{\text{W}}=0.055$ W.u. (1969Wi22,1970Wi04). B(C3, \uparrow) W.u.=0.32 9 (1989Mi01). A priv. comm. with D.J. Millener (DJM), see Table 13.12 in (1991Aj01), indicates $\Gamma_{\gamma_0}=3\times 10^{-7}$ eV and B(C3, \downarrow) W.u.=0.10 6: see comment on $^{13}\text{C}^*$ (3.09).
7490	7/2 ⁺		E3+M4	E(level), J^π , Multipolarity: From (1989Mi01).
7547 3	5/2 ⁻		E2+M3	T=1/2 (1971Ya02,1989Mi01) E(level): From (1989Mi01); see also $E_x=7540$ keV 20 (1969Wi22,1970Wi04), 7550 keV (1971Ya02). J^π : From (1969Wi22,1970Wi04,1971Ya02,1989Mi01). Multipolarity: From (1970Wi04,1989Mi01). $\Gamma_{\gamma_0}(\text{E2})=0.115$ eV 7; $\Gamma_{\gamma_0}(\text{M3})=1.01\times 10^{-5}$ eV 61; $\Gamma_{\gamma_0}(\text{E2})/\Gamma_{\text{W}}=3.15$ W.u.; $\Gamma_{\gamma_0}(\text{M3})/\Gamma_{\text{W}}=35$ W.u. (1969Wi22,1970Wi04). B(C2, \uparrow) W.u.=10.8 3 (1989Mi01: the dominant 7.55 level is not resolved from the much weaker 7.49 and 7.69 levels).
7690	3/2 ⁺		E1+M2	E(level), J^π , Multipolarity: From (1989Mi01); see also $E_x=7680$ keV (1970Wi04).
7830				E(level): From (1970Wi04) where a tail on the 7.54 MeV level is interpreted as a new level; this is not reported in other studies and is not adopted.
8200	3/2 ⁺		E1+M2	E(level), J^π , Multipolarity: From (1989Mi01).
8860 20	1/2 ⁻	190 keV 35	E0+M1	T=1/2 (1989Mi01) E(level): From (1969Wi22,1970Wi04); see also $E_x=8860$ keV (1971Ya02,1989Mi01). J^π : From (1969Wi22,1970Wi04,1989Mi01). Γ : From (1970Wi04). Multipolarity: From (1969Wi22,1970Wi04,1989Mi01). $\Gamma_{\gamma_0}(\text{E0})=2.09$ fm ² 38 (monopole matrix element in fm ²); $\Gamma_{\gamma_0}(\text{M1})=3.4$ eV 5; $\Gamma_{\gamma_0}(\text{M1})/\Gamma_{\text{W}}=0.23$ W.u. (1969Wi22,1970Wi04). B(C0, \uparrow) W.u.=0.66 2 (1989Mi01).
9500 7	9/2 ⁺		M4(+E5)	T=1/2 (1986Hi06,1987Hi09) E(level): From (1989Mi01); see also $E_x=9500$ keV (1971Ya02,1986Hi06,1987Hi09). J^π , Multipolarity: From (1986Hi06,1987Hi09,1989Mi01). Multipolarity: In (1986Hi06) the electromagnetic components were deduced from the transverse form factors. Only an upper limit on electromagnetic

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<u>¹³C(e,e),(e,e'),(e,e'p) (continued)</u>				
<u>¹³C Levels (continued)</u>				
E(level)	J ^π ^a	Γ	Multipolarity ^a	Comments
9900 30	3/2 ⁻		M1+E2 ^b	strength was obtained, consistent with expectations for E5. B(M4,↑) W.u.=77 3 (1989Mi01). E(level): From (1969Wi22,1970Wi04); see also E _x =9900 keV (1989Mi01). J ^π , Multipolarity: From (1969Wi22,1970Wi04,1989Mi01). Multipolarity: MR (δ)=0.44 8 from (1969Wi22). Γ _{γ0} (M1)=0.32 eV 5; Γ _{γ0} (E2)=6.3×10 ⁻³ eV 2I; Γ _{γ0} (M1)/Γ _W =0.0159 W.u.; Γ _{γ0} (E2)/Γ _W =0.045 W.u. (1969Wi22,1970Wi04). B(C2,↑) W.u.=0.11 2 (1989Mi01).
10460? 10860	5/2 ⁺		M2+E3	E(level), J ^π , Multipolarity: From (1989Mi01). E(level): From (1970Wi04) where a slight enhancement is observed in the cross section. This group is not reported in other measurements and is not considered in the Adopted Levels.
11080 5	1/2 ⁻		E0+M1	E(level): From (1989Mi01); see also E _x =11070 keV 20 (1969Wi22,1970Wi04), 11100 keV (1971Be51). J ^π : From (1989Mi01); see also J ^π =(1/2 ⁻ , 3/2 ⁻) (1969Wi22,1970Wi04,1971Be51). Multipolarity: From (1969Wi22,1970Wi04,1989Mi01). Results for J ^π =3/2 ⁻ are presented, but they are not relevant now.
11750	3/2 ⁻		M1	Γ _{γ0} (E0)=2.6 fm ² 3 (monopole matrix element in fm ²); Γ _{γ0} (M1)=1.0 eV 2; Γ _{γ0} (M1)/Γ _W =0.0359 (1969Wi22,1970Wi04). T=1/2 (1989Mi01) E(level): From (1989Mi01); see also E _x =11720 keV (1971Ya02), 11800 keV (1969Wi22,1970Wi04,1971Be51). J ^π : From (1969Wi22,1970Wi04,1971Be51,1989Mi01). Multipolarity: From (1970Wi04); see also (1989Mi01: M1+E2). Γ _{γ0} (M1)=3.45 eV 86; Γ _{γ0} (M1)/Γ _W =0.100 (1970Wi04).
11845 5	7/2 ⁺	144 keV 5	E3+M4	E(level), J ^π , Γ, Multipolarity: From (1989Mi01). B(C3,↑) W.u.=27.5 for the unresolved doublet (11.85+11.95).
11950	5/2 ⁺		M2+E3	E(level), J ^π , Multipolarity: From (1989Mi01). See also E _x =11970 keV (1971Ya02). B(C3,↑) W.u.=27.5 for the unresolved doublet (11.85+11.95).
12187 10		109 keV 48		E(level), Γ: From (1989Mi01).
12438 12		160 keV 37		E(level), Γ: From (1989Mi01). See also E _x =12320 keV (1971Ya02), (12300) keV (1971Be51: possibly 12400 keV state).
13760				E(level): From (1971Ya02).
14390 15		281 keV 65		E(level), Γ: From (1989Mi01).
14582 10		227 keV 41		E(level), Γ: From (1989Mi01).
14983 10		380 keV 53		E(level), Γ: From (1989Mi01).
15106 2	3/2 ⁻		M1+E2 ^b	T=3/2 (1967Pe07,1971Ya02,1989Mi01) E(level): From (1989Mi01); see also E _x =15110 keV 20 (1969Wi22,1970Wi04), 15110 keV (1967Pe07,1971Be51,1971Ya02). J ^π : From (1967Pe07,1969Wi22,1970Wi04,1971Be51,1971Ya02,1989Mi01). Γ _{γ0} (M1)= 25 eV 7 (1967Pe07), Γ _{γ0} (M1)=22.7 eV 27; Γ _{γ0} (E2)=0.59 eV 1I; Γ _{γ0} (M1)/Γ _W =0.313 W.u.; Γ _{γ0} (E2)/Γ _W =0.50 W.u. (1969Wi22,1970Wi04). Multipolarity: From (1969Wi22,1970Wi04,1989Mi01); see also (1967Pe07: M1). Multipolarity: MR (δ)= 0.161 17 from (1969Wi22,1970Wi04).
15526 11		147 keV 23		E(level), Γ: From (1989Mi01).
16080 7	7/2 ⁺	148 keV 13	E3+M4	T=1/2 (1986Hi06) E(level), Γ: From (1989Mi01). See also E _x =16080 keV (1986Hi06: probably unresolved). J ^π , Multipolarity: From (1986Hi06).
16183? 28		40 keV 20		E(level), Γ: From (1989Mi01); see also E _x =16200 keV, Γ=300 keV (1971Be51).

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$^{13}\text{C}(\text{e},\text{e}),(\text{e},\text{e}'),(\text{e},\text{e}'\text{p})$ (continued) ^{13}C Levels (continued)

E(level)	J^π ^a	Γ	Multipolarity ^a	Comments
16900?				E(level): From (1971Be51).
17700		300 keV		E(level), Γ : From (1971Be51).
18300		400 keV		E(level), Γ : From (1971Be51).
18497? 10		91 keV 23		E(level), Γ : From (1989Mi01).
18699 5		98 keV 11		E(level), Γ : From (1989Mi01); see also $E_x=18700$ keV, $\Gamma=1200$ keV(1971Be51).
19300		500 keV		E(level), Γ : From (1971Be51). See also $E_x=19150$ keV (1971Ya02).
20021 13		232 keV 27		E(level), Γ : From (1989Mi01).
20100		700 keV		E(level), Γ : From (1971Be51).
20429 8		112 keV 23		E(level), Γ : From (1989Mi01).
20500		400 keV		T=1/2 E(level), Γ : From (1971Be51). In (1971Be51) the giant resonance region is characterized by two dominant components, a lower structure centered around 20.5 MeV with $\Gamma\approx 3$ MeV and a higher structure centered around 24.5 MeV with $\Gamma\approx 4$ MeV. T: probably 1/2 although the 4 MeV splitting of the two giant resonance components is somewhat smaller than expected (1971Be51).
21300		400 keV		E(level), Γ : From (1971Be51).
21466 8	(7/2 ⁺ ,9/2 ⁺)	268 keV 14	M4	T=3/2 (1986Hi06) E(level), Γ : From (1989Mi01). See also $E_x=21470$ keV (1986Hi06). J^π : From (1986Hi06). Multipolarity: From (1986Hi06).
21800?				E(level): From (1971Sh09).
22200		1100 keV		E(level), Γ : From (1971Be51).
23000				E(level): giant resonance at 23 MeV via the p_4 channel (1994Zu01).
24700		600 keV		T=(3/2) E(level), Γ : From (1971Be51). See also $E_x=24200$ keV (1971Sh09), and (1994Zu01). T: probably 3/2 although the 4 MeV splitting of the two giant resonance components is somewhat smaller than expected (1971Be51).
25500		500 keV		E(level): From (1971Be51,1971Sh09). Γ : From (1971Be51).
27300		600 keV		E(level), Γ : From (1971Be51). See also $E_x=27500$ keV (1971Sh09).
28100		500 keV		E(level), Γ : From (1971Be51).
29400?		1200 keV		E(level), Γ : From (1971Be51).
31500				E(level): From (1971Sh09).

^a Deduced from fits to the experimental longitudinal and transverse form factors. The $E\lambda$ and $M\lambda$ components are obtained from the transverse form factors, whilst the $C\lambda$ components are obtained from the longitudinal form factors and have a non-trivial relation to the $E\lambda$ components. J is deduced from the $E\lambda$ and $M\lambda$ components.

^b In some cases, mixing ratios have been obtained from the $B(E\lambda)$ and $B(M\lambda)$ strengths. These are listed amongst the level properties since no γ rays are reported in these experiments.

¹³C(n,n),(n,n'),(n,n'γ)

- 1979G112: ¹³C(n,n) E=slow; measured spin-dependent scattering length using the pseudomagnetism method.
 1979Ko26: ¹³C(n,n) E=0.51,0.68 MeV; measured small angle scattering; deduced coherent scattering length (*b*=6.19 fm 9). Free scattering cross section of ¹³C σ₀=4.16 b 13.
 1982Da05: ¹³C(n,n),(n,n') E=10-18 MeV; measured σ(*θ*) for *θ*=30° to 150°, σ(E_n). Legendre polynomial, optical model analyses.
 1983Da22: ¹³C(n,n) E=7-15 MeV; measured σ(*θ*) for *θ*=30° to 150°; deduced spherical optical model parameters.
 1983G107: ¹³C(n,n) E=thermal; measured neutron phase shift, precession angle vs target polarization, σ(absorption). Deduced spin-dependent part of scattering length.
 1985Pe10: ¹³C(n,n) E=24 MeV; measured σ(*θ*) vs E for *θ*=20° to 160°. Microscopic optical model.
 1987Re01: ¹³C(n,n),(n,n') E=4.55-10.99 MeV; measured σ(*θ*_n,E_n); deduced levels, decay characteristics. Tof.
 1988Re09: ¹³C(n,n),(n,n') E=8.25 MeV; measured neutron spectra. Multiple scattering analysis.
 1989Re01: ¹³C(n,n),(n,n') E=4.5-11 MeV; measured σ(*θ*); deduced ¹³C(n,α)¹⁰Be σ. R-matrix analysis.
 2008Ha27: ¹³C(n,n); comparison of levels. Measured branching ratios for the neutron decay of ¹⁴C states to ¹³C*0[1/2⁻], 3.089[1/2⁺]+3.684[3/2⁻]+3.854[5/2⁺].
 2012Pr13: ¹³C(n,n) E<20 MeV; calculated neutron thermal σ, Westcott factors, resonance integrals and their uncertainties using evaluated neutron libraries; deduced neutron-induced reaction σ deficiencies. Comparison with experimental data Atlas of Neutron Resonances.

Theory:

- 1977No07: ¹³C(n,n) E=low; calculated scattering parameters.
 1985We02: ¹³C(n,n),(n,n'), E_{cm}≈0.5-10 MeV; calculated σ(E); deduced potential parameters. Continuum shell model.
 1994Sa73: ¹³C(n,n) E=11 MeV; calculated neutron spectra. Experimental MACHO code simulation.
 1998Kr25: ¹³C(n,n) E=10,30,50 MeV; calculated optical potentials; deduced spin-orbit, spin-spin, tensor contributions. Hartree-Fock method, Skyrme forces.
 1999Kr12: ¹³C(n,n), calculated optical potential for nucleus-nucleon scattering. Hartree-Fock theory.
 2005MaZR: ¹³C(n,n') E≈1-11 MeV; analyzed data; deduced parameters. R-matrix analysis.
 2005WaZV: ¹³C(n,n) E<3 GeV; analyzed σ.
 2019Aq01: ¹³C(n,n) E=9-16 MeV; calculated elastic scattering σ(*θ*) MeV using nonlocal OMP; deduced potential parameters (dependent on target and energy), constant set of nonlocal parameters using fitting to the data.

¹³C Levels

E(level)	J ^π ^a	Comments
0	1/2 ⁻	E(level): See (1982Da05,1982ReZX,1985Pe10,1989Re01,2008Ha27,2021Mc05).
3090	1/2 ⁺	E(level): See (1982Da05,1982ReZX,1989Re01,2008Ha27,2021Mc05). E(level): branching ratios and the total decay widths of ¹⁴ C excited states decaying to ¹³ C*(0,3.09+3.68+3.85)+n are deduced (2008Ha27).
3685	3/2 ⁻	E(level): See (1982Da05,1982ReZY,1989Re01,2021Mc05).
3854	5/2 ⁺	E(level): See (1982ReZY,1989Re01,2021Mc05).
6864		E(level): The decay from ¹⁴ C*(16.72 MeV) to ¹³ C*(6.864)+n was studied but the branching ratio could not be determined (2008Ha27).
7547		E(level): This level is involved in the 2n sequential decay of E _x ≈15.8-18.4 MeV ¹⁴ C states; it mainly neutron decays to ¹² C _{g.s.} ; Γ _n ≈1.2 keV (1987Re01).

^a From R-matrix analysis in (1989Re01).

γ(¹³C)

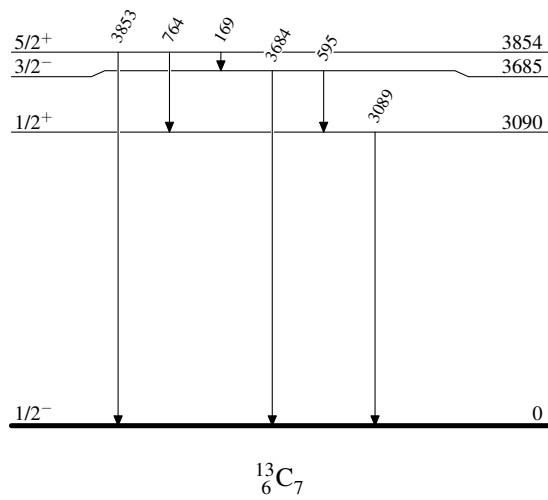
E _γ ^a	E _i (level)	J _i ^π	E _f	J _f ^π
169	3854	5/2 ⁺	3685	3/2 ⁻
595	3685	3/2 ⁻	3090	1/2 ⁺
764	3854	5/2 ⁺	3090	1/2 ⁺
3089	3090	1/2 ⁺	0	1/2 ⁻

Continued on next page (footnotes at end of table)

$^{13}\text{C}(\text{n,n}),(\text{n,n}'),(\text{n,n}'\gamma)$ (continued) $\gamma(^{13}\text{C})$ (continued)

E_γ^a	$E_i(\text{level})$	J_i^π	E_f	J_f^π
3684	3685	$3/2^-$	0	$1/2^-$
3853	3854	$5/2^+$	0	$1/2^-$

^a From (2021Mc05).

 $^{13}\text{C}(\text{n,n}),(\text{n,n}'),(\text{n,n}'\gamma)$ Level Scheme

$^{13}\text{C}(\text{p,p}),(\text{p,p}'),(\text{p,pn})$

- 1957Ba29: $^{13}\text{C}(\text{p,p}')$, angular distributions of the 3.09 MeV γ -rays are isotropic for $E_p=3.7$ to 4.2 MeV, consistent with the assignment $J=1/2$ to $^{13}\text{C}^*(3.09)$. Angular distributions of the 3.68 MeV radiation have also been studied near the $E_p=4.5$ MeV resonance.
- 1957Zi09: $^{13}\text{C}(\text{p,p})$ $E=1.5-3.4$ MeV; measured reaction products, E_p , I_p , $\sigma(\theta)$ for $\theta=45^\circ$ to 148.9° .
- 1960Ba35: $^{13}\text{C}(\text{p,p}'\gamma)$ $E=3.6-5$ MeV; angular distributions of the 3.09 MeV γ -rays are isotropic for up to $E_p=5$ MeV consistent with the assignment $J=1/2$ for the ground state.
- 1966Ge03: $^{13}\text{C}(\text{p,p}_0)$ $E=1.55-2.38$ MeV; measured $\sigma(\theta)$ for $\theta_{c.m.}=20^\circ$ to 170° .
- 1968Ri16: $^{13}\text{C}(\text{p,p}')$ $E=4.1,4.125,4.55$ MeV; measured Doppler-shift attenuation. Deduced $T_{1/2}$ of $^{13}\text{C}^*(3.09, 3.68 \text{ MeV})$.
- 1969Gu02: $^{13}\text{C}(\text{p,p})$ $E=7$ MeV; measured $\sigma(E,\theta)$, $P(\theta)$ for $\theta_{c.m.}\approx 25^\circ$ to 160° ; deduced optical parameters. Natural, enriched targets.
- 1971Ot02: $^{13}\text{C}(\text{p,pn})$ $E=7.9-12.5$ MeV; measured $\sigma(E;E_p,\theta(p),\theta(n))$; deduced singlet deuteron contribution. One or more ^{13}C states at $E_x=7.5$ MeV seem to be involved in the sequential decay.
- 1971Ri13: $^{13}\text{C}(\text{p,p}'\gamma(3.09,3.68,3.85 \text{ MeV}))$ $E=3-17$ MeV; measured $\sigma(E)$.
- 1971Va29: $^{13}\text{C}(\text{p,p}_1)$ $E=6.36,6.48$ MeV; measured $\sigma(Ep',\theta)$.
- 1972Gr02: $^{13}\text{C}(\text{pol. p,p}_{0,1})$ $E=30.4$ MeV; measured $\sigma(\theta)$, $P(\theta)$, analyzing power(θ) for $\theta_{c.m.}=25^\circ$ to 170° ; formulated effective interaction. Enriched targets.
- 1973DeYW, 1975De26: $^{13}\text{C}(\text{p,p}),(\text{p,p}'\gamma),(\text{p,d})$ $E=6$ MeV; measured $\sigma(Ep,\theta)$. Deduced level configurations.
- 1974Mi05: $^{13}\text{C}(\text{p,pn})$ $E=46$ MeV; measured $\sigma(Ep,\theta)$.
- 1978BI02: $^{13}\text{C}(\text{p,p}')$ $E=0.8$ GeV; measured $\sigma(\theta)$ for $\theta_{c.m.}=2^\circ$ to 40° . Reported states up to 11.9 MeV. Discussed deformation length. Optical potential, DWBA analysis.
- 1978We13: $^{13}\text{C}(\text{pol. p,p}_0)$, measured $\sigma(E,\theta)$ for $E=9.1-18.4$ MeV and for $\theta=30^\circ$ to 155° , measured $A(E,\theta)$ for $E=10-17.5$ MeV. See further discussion in (1985Pe10).
- 1979AI26: $^{13}\text{C}(\text{p,p}_0)$ $E=1$ GeV; measured $\sigma(\theta)$ for $\theta_{c.m.}=5^\circ$ to 25° . Deduced nuclear density parameters, quadrupole effects. Glauber theory.
- 1980Fa07: $^{13}\text{C}(\text{p,p}),(\text{p,p}')$ $E=35.2$ MeV; measured $\sigma(\theta)$ for $\theta_{c.m.}\approx 30^\circ$ to 180° ; deduced optical-model parameters.
- 1981Me02: $^{13}\text{C}(\text{pol. p,p})$ $E=200$ MeV; measured $\sigma(\theta)$, analyzing power vs θ for $\theta=10^\circ$ to 120° .
- 1982Co08: $^{13}\text{C}(\text{p,p}),(\text{p,p}')$ $E=135$ MeV; measured $\sigma(\theta)$ for $\theta=8^\circ$ to 80° and for states below $E_x=11$ MeV. Deduced possible configurations of $^{13}\text{C}^*(8.86, 11.08 \text{ MeV})$. Optical model, DWBA analyses.
- 1982Ri05: $^{13}\text{C}(\text{p,p}')$ $E=135$ MeV; measured $\sigma(\theta)$ for $\theta_{c.m.}=10^\circ$ to 85° . Analyzed angular momentum transfer, configuration of $^{13}\text{C}^*(9.50)$. Microscopic DWBA analysis. Deduced $J^\pi=9/2^+$.
- 1984Se12: $^{13}\text{C}(\text{pol. p,p}')$ $E=547$ MeV; measured $\sigma(Ep')$, $\sigma(\theta)$, analyzing power vs θ for $\theta_{c.m.}=5^\circ$ to 35° and for $^{13}\text{C}^*(0,3.09, 3.68,3.86,6.86,7.55,8.86,9.50)$. DWIA analysis, shell model transition densities.
- 1985AI16: $^{13}\text{C}(\text{p,p}_0)$ $E=1$ GeV; measured $\sigma(\theta)$; deduced model parameters, rms matter radii $=2.394$ fm.
- 1985BI22: $^{13}\text{C}(\text{p,p}_0),(\text{pol. p,p}_0)$ $E=0.8$ GeV; measured $\sigma(\theta)$, analyzing power vs θ for $\theta_{c.m.}\approx 5^\circ$ to 50° ; deduced optical potential parameters.
- 1985Ki07: $^{13}\text{C}(\text{p,p}'\gamma)$ $E=2.4-4.2$ MeV; measured thick target relative γ yields, E_γ , I_γ . Particle induced prompt gamma emission analysis.
- 1986Oh03: $^{13}\text{C}(\text{pol. p,p}')$ $E=35$ MeV; measured $\sigma(\theta)$, $A(\theta)$ for $\theta_{c.m.}\approx 20^\circ$ to 120° and for $^{13}\text{C}^*(0,3.09, 3.68,3.86)$. Compared with analogous (p,n) reactions, analyzed isoscalar component. Enriched target. DWBA analysis.
- 1988Ba30: $^{13}\text{C}(\text{p,p}_0)$ $E=30.95$ MeV; measured $\sigma(\theta)$ for $\theta=10^\circ$ to 160° .
- 1988Co05: $^{13}\text{C}(\text{p,p}),(\text{p,p}')$ $E=135$ MeV; $^{13}\text{C}(\text{pol. p, p}),(\text{pol. p,p}')$ $E=119$ MeV; measured $\sigma(\theta)$, $A(\theta)$ for $\theta_{c.m.}\approx 5^\circ$ to 90° . Analyzed states up to 23 MeV. Optical model, DWA analyses, density-dependent t-matrices.
- 1989Vo05: $^{13}\text{C}(\text{pol. p,p}_0)$ $E=72$ MeV; measured $\sigma(\theta)$, $A(y)(\theta)$ for $\theta\approx 20^\circ$ to 160° ; deduced optical model potential.
- 1990Ho06: $^{13}\text{C}(\text{pol. p,p})$ $E=494$ MeV; measured $\sigma(\theta)$, analyzing powers, spin rotation depolarization observables for $\theta\approx 5^\circ$ to 37° ; deduced phenomenological Dirac optical potentials. Calculated relativistic impulse approximation optical potentials.
- 1990Ho22: $^{13}\text{C}(\text{pol. p,p})$ $E=497.5$ MeV; measured spin correlation parameter, target analyzing power vs θ for $\theta\approx 12^\circ$ to 30° . Dynamic nuclear polarization technique, polarized, cooled target, enriched ethylene glycol target.
- 1990Vo02,1991Vo03: $^{13}\text{C}(\text{pol. p,p}_0)$ $E=72$ MeV; measured depolarization parameter vs θ for $\theta_{c.m.}\approx 34^\circ$ to 69° ; deduced nucleon-nucleus, spin-spin interaction evidence and effects. Optical model.
- 1993YuZX: $^{13}\text{C}(\text{p,p})$ $E=200$ MeV; measured $\sigma(\theta)$ at backward angles; deduced optical potential parameters. DWIA analysis.
- 1996Ho08: $^{13}\text{C}(\text{pol. p,p})$ $E=500$ MeV; measured polarization transfer parameter $D(\text{NN})$. Non-relativistic DWBA analysis, coupled-channels Dirac, relativistic DWBA analyses.
- 1996Yu02: $^{13}\text{C}(\text{p,p})$ $E=200$ MeV; measured spectra, $\sigma(\theta)$ for $\theta_{c.m.}=160^\circ$ to 180° ; deduced model parameters. DWIA analysis.

${}^{13}\text{C}(\text{p,p}),(\text{p,p}'),(\text{p,pn})$ (continued)

- 1998Hu29: ${}^1\text{H}({}^{13}\text{C}, {}^{13}\text{C}), {}^{13}\text{C}(\text{p,p})$ E=2.8-11.2 MeV; measured products, Deduced $\sigma(\theta)$. $E_{\text{res}}=0.511$ MeV. Thick Target Inverse Kinematics.
- 2003An11: ${}^{13}\text{C}(\text{p,p})$ E=22 MeV; ${}^{13}\text{C}(\text{p,p}')$ E=22 MeV; measured $\sigma(\theta)$ for $\theta=9^\circ$ to 130° . Deduced ${}^{13}\text{C}^*$ (3.09 MeV) neutron halo structure, related features. Microscopic DWBA analysis, compared with related data.
- 2013Ba56: ${}^{13}\text{C}(\text{p,p})$ E=0.8-2.4 MeV; measured reaction products, Ep, Ip; deduced σ , yields; compared with available data.
- 2022Ci07: ${}^{13}\text{C}(\text{p,p}')$ Ep=135 MeV at the CCB at IFJ PAN in Krakow. Populated the $E_x=21.47$ MeV stretched resonance in ${}^{13}\text{C}$ and analyzed its decay branches and structure. Scattered protons were measured at $\theta=36^\circ$ using the KRATTA array, while branches for particle emission were deduced either by direct measurement with a position sensitive Si detector or by measurement of γ rays from the deexcitation of the ${}^{12}\text{B}$ or ${}^{12}\text{C}$ remnants. Evidence for neutron and proton decay branches was observed, but no evidence was found for d or α emission. Neutron emission to proceeds to ${}^{12}\text{C}(15.11 \text{ MeV}; J=1^+, T=1)$, suggesting $T=3/2$ for the ${}^{13}\text{C}$ state. Results were compared with a gamow Shell Model calculation; observed decay branches are consistent with $J^\pi=7/2^+$, but a $7/2^+ + 9/2^+$ doublet cannot be excluded.
- 2023Hu21: ${}^{13}\text{C}(\text{p,p}')$ E=800 MeV; analyzed small angle elastic scattering data; deduced matter density distributions and r.m.s. matter radii. The free-parameter fit for ${}^{13}\text{C}$ yielded $R_m^{\text{f.m.s.}}=2.374 \text{ fm}$.

Theory:

- 1973Ka04: ${}^{13}\text{C}(\text{p,p}')$, calculated integral cross sections for low-lying levels.
- 1974Av02: ${}^{13}\text{C}(\text{p,d}),(\text{p,pn})$ E=12,17 MeV; calculated $\sigma(\text{Ed},\theta)$, $\sigma(\text{Ep},\theta)$; deduced singlet deuteron effects.
- 1978Al36: ${}^{13}\text{C}(\text{p,p})$ E=1 GeV; calculated $\sigma(\theta)$. Glauber theory, n, p-density parameters from electron scattering data.
- 1982Ba14: ${}^{13}\text{C}(\text{p,p}')$ E=6 MeV; calculated $\sigma(\theta)$. Triangle diagram method, Coulomb effects.
- 1983Pe14: ${}^{13}\text{C}(\text{p,p}')$ E=26.1 MeV; analyzed $\sigma(\theta)$. ${}^{13}\text{C}$ levels deduced differences in excitation probabilities from other charge exchange reaction data.
- 1986AmZX: ${}^{13}\text{C}(\text{p,p})$, analyzed form factors, $\sigma(\theta)$; deduced structure effects.
- 1986Ra05: ${}^{13}\text{C}(\text{pol. p,p})$ E=500 MeV; calculated $\sigma(\theta)$, polarization, other parameters vs θ ; deduced relativistic effects role.
- 1988GoZH: ${}^{13}\text{C}(\text{p,p})$ E=10-20 MeV; analyzed $\sigma(\theta)$; deduced optical model parameters.
- 1988KuZL: ${}^{13}\text{C}(\text{p,p}),(\text{pol. p,p})$ E=0.8 GeV; calculated $\sigma(\theta)$, $A(\theta)$. Multi-scattering diffraction theory.
- 1988Ra08: ${}^{13}\text{C}(\text{pol. p,p})$ E=500 MeV; calculated $\sigma(\theta)$, $P(\theta)$, spin observables; deduced target nucleus relativistic effects role. Relativistic dynamics, pseudovector coupling.
- 1989Am02: ${}^{13}\text{C}(\text{p,p}')$ E=135 MeV; analyzed data; deduced degree of M1 quenching. Shell model, medium corrected DWA.
- 1989Am05: ${}^{13}\text{C}(\text{pol. p,p})$ E=547 MeV; calculated $\sigma(\theta)$, analyzing power vs θ . Nonrelativistic optical model potential.
- 1989BeXT: ${}^{13}\text{C}(\text{pol. p,p}),(\text{pol. p,p}')$ E=135,547,800 MeV; calculated $\sigma(\theta,E)$, analyzing power vs θ . Diffraction model.
- 1989Go14: ${}^{13}\text{C}(\text{p,p})$ E=13.5-17.5 MeV; calculated $\sigma(\theta)$, $P(\theta)$; deduced model parameters. Phenomenological, folding model potentials.
- 1989Ku07: ${}^{13}\text{C}(\text{pol. p,p})$ E=547-1000 MeV; calculated $\sigma(\theta)$, polarization observables vs θ . Multiple diffraction scattering theory.
- 1989Ku14: ${}^{13}\text{C}(\text{p,p})$ E=550,800 MeV; calculated $\sigma(\theta)$, polarization observables vs θ . Polarized target.
- 1989Ku32: ${}^{13}\text{C}(\text{pol. p,p})$ E=0.8,1 GeV; calculated $\sigma(\theta)$, analyzing power vs θ . Diffraction model.
- 1990Du01: ${}^{13}\text{C}(\text{pol. p,p})$ E=1.13-1.17 MeV; calculated $\sigma(E)$, analyzing power vs E.
- 1990He32: ${}^{13}\text{C}(\text{pol. p,p})$ E=65 MeV; analyzed depolarization parameter; deduced nucleon-nucleus spin-spin interaction features.
- 1990St32: ${}^{13}\text{C}(\text{pol. p,p})$ E=65,72 MeV; compiled data analysis; deduced Gamow-Teller type transition extraction possibility.
- 1991Br28: ${}^{13}\text{C}(\text{p,p}),(\text{pol. p,p})$ E \leq 1.17 MeV; calculated $\sigma(\theta)$, analyzing power vs E. Double-folding interaction potential, multi-step direct compound nuclear reactions.
- 1991Mc03: ${}^{13}\text{C}(\text{pol. p,p})$ E=497 MeV; compiled, reviewed data analyses; deduced nucleon-nucleus interaction features, spin-effects, spin-isospin modes role.
- 1992Ra02: ${}^{13}\text{C}(\text{pol. p,p})$ E=497.5 MeV; calculated polarization observables. Shell model configurations. Pauli blocking.
- 1993By02: ${}^{13}\text{C}(\text{p,p})$ E=72 MeV; calculated $\sigma(\theta)$; deduced nucleon-nucleon bound state role.
- 1993Ra05: ${}^{13}\text{C}(\text{pol. p,p})$ E=500 MeV; calculated $\sigma(\theta)$, analyzing power, polarization transfer observables vs θ . Relativistic impulse approximation, density dependent nucleon-nucleon effective interaction.
- 1994Me14: ${}^{13}\text{C}(\text{pol. p,p})$ E=500,574 MeV; calculated $\sigma(\theta)$, depolarization parameter, other spin observables vs θ . Relativistic Schrodinger equation, microscopic, momentum space optical potentials.
- 1997Do01: ${}^{13}\text{C}(\text{pol. p,p})$ E=200 MeV; analyzed $\sigma(\theta)$, polarization observables data. Microscopic model.
- 1998Ki17: ${}^{13}\text{C}(\text{p,p})$ E=1 GeV; analyzed $\sigma(\theta)$; deduced neutron halo role. Glauber theory.
- 1998Kr25: ${}^{13}\text{C}(\text{p,p})$ E=10,30,50 MeV; calculated optical potentials; deduced spin-orbit, spin-spin, tensor contributions. Hartree-Fock method, Skyrme forces.

$^{13}\text{C}(\text{p,p}),(\text{p,p}'),(\text{p,pn})$ (continued)

- 1999Kr12: $^{13}\text{C}(\text{p,p})$, calculated optical potential for nucleus-nucleon scattering. Hartree-Fock theory.
- 2000De61: $^{13}\text{C}(\text{p,p})$ E=30 MeV; E=40 MeV; calculated $\sigma(\theta)$, $A_y(\theta)$. Optical potential, comparison with data.
- 2001Mi20: $^{13}\text{C}(\text{pol. p,p})$, $E^*\approx 9$ MeV; calculated longitudinal and transverse analyzing powers.
- 2002Mo28: $^{13}\text{C}(\text{p,p})$ E=10 MeV; calculated $\sigma(\theta)$; deduced continuum effects. Continuum discretized coupled channels formalism.
- 2004Be16: $^{13}\text{C}(\text{p,p})$ E=500,547,800 MeV; calculated $\sigma(\theta)$, polarization observables. Multiple diffractive scattering theory, comparison with data.
- 2004Be35: $^{13}\text{C}(\text{p,p})$ E=500 MeV; calculated $\sigma(\theta)$, analyzing powers, other polarization observables.
- 2005Ko28: $^{13}\text{C}(\text{p,p})$ E \approx 800-1100 MeV; analyzed $\sigma(\theta)$; deduced black-sphere radius parameters.
- 2009De02: $^{13}\text{C}(\text{p,p})$ E=35 MeV; calculated $\sigma(\theta)$, binding energies. Momentum-space three-body Faddeev-like equations. Comparison with experimental data.
- 2009De07: $^{13}\text{C}(\text{p,p})$ E=35 MeV; calculated differential cross sections, analyzing powers for polarized beam using local and nonlocal optical potentials parameters in the framework of Faddeev type scattering equations. Comparison with experimental data.
- 2009De13: $^{13}\text{C}(\text{pol. p,p})$ E=17.5, 35 MeV; calculated $\sigma(\theta)$, analyzing powers using Faddeev-type model. Compared various optical potentials with experimental data.
- 2009We04: $^{13}\text{C}(\text{p,p})$ E=25-155 MeV; analyzed σ , $\sigma(\theta)$ using isospin dependent global nucleon-nucleus optical model. $^{13}\text{C}(\text{pol. p,p})$, E=30-152 MeV; analyzed vector analyzing powers using isospin dependent global nucleon-nucleus optical model.
- 2012Du11: $^{13}\text{C}(\text{p,p})$ E=250-770 keV; analyzed $\sigma(\theta)$ measurements; deduced S-wave phase shift, triplet states in the resonance region.
- 2015Be12: $^{13}\text{C}(\text{p,p}),(\text{p,p}')$ E<200 MeV; calculated charge radii and densities, form factors, $\sigma(\theta)$, scattering parameters, polarization. Multiple diffraction scattering theory (MDST) and the α -cluster model with dispersion, comparison with experimental data.
- 2017Ka45: $^{13}\text{C}(\text{p,p})$ E=71,100,200,300,425,550,650 MeV; calculated σ , $\sigma(\theta)$. Comparison with available data.
- 2018We08: $^{13}\text{C}(\text{p,p})$ E=70,72 MeV; calculated $\sigma(\theta)$, σ ; deduced optical model parameters. Comparison with experimental data.
- 2018Zh31: $^{13}\text{C}(\text{p,p}')$ E=0.6,0.8,1.0 GeV; calculated $\sigma(\theta)$, analyzing power to $(1/2)^+$ and $(5/2)^+$ levels using Glauber Multiple Scattering Theory and DWBA. Compared with available data.
- 2021An01, 2021An13: $^{13}\text{C}(\text{p,p})$ E<5 MeV; calculated σ ; deduced optical model potential, S-factors in the folding model, using a realistic density dependent nucleon-nucleon interaction.
- 2022Vo02: $^{13}\text{C}(\text{p,p})$ E=200 MeV; calculated $\sigma(\theta)$ and $A_y(\theta)$.

 ^{13}C Levels

<u>E(level)^a</u>	<u>J^{πb}</u>	<u>T or Γ^c</u>	<u>L</u>	<u>Comments</u>
0	1/2 ⁻			E(level): See (1978Bi02,1982Co08,1984Se12,1985Ki07,1986Oh03,1988Co05,2003An11). Analyzing power A_y was also measured (1984Se12).
3089	1/2 ⁺	<6.93 fs		B(E1) \uparrow =0.00014 (1988Co05) E(level): See (1957Ba29, 1960Ba35, 1968Ri16, 1978Bi02, 1982Co08, 1984Se12, 1985Ki07, 1986Oh03, 1988Co05, 2003An11). The analysis in (2003An11) indicates the existence of neutron halo in this state.
3685	3/2 ⁻	<18 fs	2	T _{1/2} : From τ <10 fs (1968Ri16). B(M1) \uparrow =1.42 (1988Co05); B(E2) \uparrow =0.131 (1988Co05) B(E2) \uparrow : See also 0.066 (1982Co08). E(level): See (1957Ba29, 1960Ba35, 1968Ri16, 1978Bi02, 1982Co08, 1984Se12, 1986Oh03, 1988Co05, 2003An11). Analyzing power A_y was also measured (1984Se12). T _{1/2} : From τ <26 fs (1968Ri16).
3854	5/2 ⁺		3	L: transfer L (1984Se12). Spin transfer $\Delta S=0$ (1984Se12). B(E1) \uparrow =0.0303 (1988Co05); B(M2) \uparrow =0.131 E(level): See (1982Co08,1984Se12,1986Oh03,1988Co05,2003An11). Analyzing power A_y was also measured (1984Se12).
6864	5/2 ⁺			L: transfer L (1984Se12). Spin transfer $\Delta S=0$ (1984Se12). B(M2) \uparrow =0.0153 (1988Co05) E(level): See (1978Bi02,1982Co08: weak,1984Se12,1988Co05). Analyzing power A_y was also measured (1984Se12).
7547	5/2 ⁻		2	B(E2) \uparrow =0.175 (1988Co05); B(M3) \uparrow =0.518 B(E2) \uparrow : See also 0.058 (1982Co08). E(level): See (1978Bi02,1982Co08,1988Co05). L: transfer L (1984Se12). Spin transfer $\Delta S=0$ (1984Se12).

Continued on next page (footnotes at end of table)

$^{13}\text{C}(\text{p,p}),(\text{p,p}'),(\text{p,pn})$ (continued) ^{13}C Levels (continued)

E(level) ^a	J ^π ^b	T or Γ ^c	L	Comments
7686				
8200				
8860	1/2 ⁻		0	B(M1)↑=0.418 (1988Co05) E(level): See (1982Co08,1984Se12,1988Co05). Analyzing power A _y was also measured (1984Se12). L: Transfer L (1984Se12). Spin transfer ΔS=0 (1984Se12).
9500	9/2 ⁺		4	E(level): See (1982Co08,1982Ri05,1984Se12,1988Co05). Analyzing power A _y was also measured (1984Se12). J ^π : See also (1982Ri05). L: From (1982Ri05: a pure 1p _{3/2} to 1d _{5/2} neutron transition). B(M1)↑=0.058 (1988Co05); B(E2)↑=0.0016 (1988Co05)
9897	3/2 ⁻			
10753	7/2 ⁻			
10818				
10996				
11080	1/2 ⁻			B(M1)↑=0.065 (1988Co05)
11748				
11851	7/2 ⁺			J ^π : Assigned by (1988Co05).
11920	60 (5/2 ⁺)	200 keV		E(level): From (1978BI02); see also (1988Co05). J ^π : Assigned by (1988Co05); see also J ^π =(5/2,7/2) ⁺ (1978BI02).
12106	≤5/2	80 keV		J ^π : Assigned by (1988Co05).
12190	10 ≤5/2	110 keV 50		E(level),Γ: from (1988Co05, S. Collins, Ph.D. thesis, and B. Spicer, private communication). J ^π : Assigned by (1988Co05).
12438		160 keV		
13280?				E(level): Possibly seen at E _p =135 MeV (1988Co05).
13410				
13570?				E(level): Possibly seen at E _p =135 MeV (1988Co05).
13760?				E(level): Possibly seen at E _p =135 MeV (1988Co05).
14130		210 keV		
14390		300 keV		
14582	(7/2,9/2) ⁺	250 keV		J ^π : Assigned by (1988Co05).
14983	(5/2 ⁺)	410 keV		J ^π : Assigned by (1988Co05).
15108	3/2 ⁻			B(M1)↑=1.12 (1988Co05); B(E2)↑=0.0189 (1988Co05) T=3/2 T: Value listed in (1982Co08).
15526		220 keV		E(level): See (1982Co08,1988Co05). Γ: From (1988Co05).
16080	(7/2 ⁺)	220 keV		E(level),Γ: From (1988Co05). J ^π : Assigned by (1988Co05).
16150				E(level): Reported in (1982Co08) and possibly seen at E _p =135 MeV (1988Co05).
16950?				E(level): Possibly seen at E _p =135 MeV (1988Co05).
17360?				E(level): Possibly seen at E _p =135 MeV (1988Co05).
17699	(3/2 ⁻ ,5/2)			J ^π : Assigned by (1988Co05); L=2 or 3 was consistent, but 7/2 ⁺ was considered unlikely because of the shape at small angles.
18300?				E(level): Possibly seen at E _p =135 MeV (1988Co05).
18699	(3/2,5/2) ⁺			E(level): See (1988Co05). J ^π : Assigned by (1988Co05).
19500				
19900?				E(level): Possibly seen at E _p =135 MeV (1988Co05).
20021				
20429				
20.93×10 ³	10	0.24 MeV 10		E(level),Γ: from (1988Co05, S. Collins, Ph.D. thesis, and B. Spicer, private communication).
21280				
21466	(7/2,9/2) ⁺	270 keV 20		T=3/2

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¹³C(p,p),(p,p'),(p,pn) (continued)

¹³C Levels (continued)

E(level) ^a	J ^π ^b	T or Γ ^c	Comments
			Γ _n /Γ=0.24 5 Γ _{p0} /Γ≤0.23; Γ _{p1} /Γ=0.69 6 Γ: Γ and partial widths from (2022Ci07). Γ _p : Γ _{p2+3} /Γ=0.07 2. Γ _n : Decay is to ¹² C(15.11 MeV: J ^π =1 ⁺ , T=1). T: From (2022Ci07). J ^π : Assigned by (1988Co05). J ^π : Assigned by (1988Co05).
21810	≥5/2		
22.20×10 ³	10 ≤5/2	1.1 MeV 5	E(level),Γ: from (1988Co05, S. Collins, Ph.D. thesis, and B. Spicer, private communication). J ^π : Assigned by (1988Co05).
23000	≤5/2		J ^π : Assigned by (1988Co05).

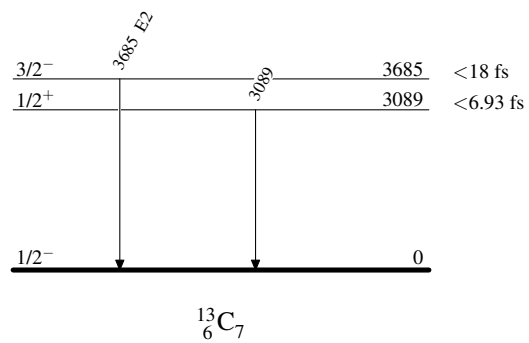
^a Level-energy values listed in, for example, (1982Co08,1988Co05). Angular distributions were studied.

^b Values from, for example, DWBA analysis of (p,p') and (pol. p,p') angular distributions from (1982Co08,1988Co05) except where noted.

^c Γ values from (1988Co05) except where noted.

γ(¹³C)

E _γ	E _i (level)	J _i ^π	E _f	J _f ^π	Mult.	Comments
3089	3089	1/2 ⁺	0	1/2 ⁻		Γ _γ >0.066 eV (1968Ri16: Doppler shift method). E _γ : See also (1985Ki07). Angular distributions of E _γ =3.09 MeV are isotropic, consistent with the J=1/2 assignment for 3.09 MeV state (1957Ba29,1960Ba35).
3685	3685	3/2 ⁻	0	1/2 ⁻	E2	Γ _γ >0.025 eV (1968Ri16: Doppler shift method). Angular distributions of E _γ were studied (1957Ba29, 1960Ba35).

$^{13}\text{C}(\text{p,p}),(\text{p,p}'),(\text{p,pn})$ Level Scheme

¹³C(³He,³He),(³He,³He') **1969Ba06,1981Pe08,2000Bu25**

- 1966Kc08: ¹³C(³He,³He), E(³He)=12, 15 and 18 MeV; angular distributions have been studied.
 1967Ar17: ¹³C; deduced nuclear properties.
 1968We15: ¹³C(³He,³He) E(³He)=6-8 MeV; measured $\sigma(\theta)$, deduced optical model parameters.
 1969Ar08: ¹³C(³He,³He) E=36 MeV; measured $\sigma(\theta)$; deduced optical model parameters.
 1969Ar10: ¹³C(³He,³He') E≈36 MeV; measured $\sigma(E(^3\text{He}'),\theta)$. ¹³C deduced deformation parameters.
 1969Ba06: ¹³C(³He,³He') E=40-50 MeV; measured $\sigma(E(^3\text{He}'),\theta)$; deduced optical model parameters. ¹³C deduced levels.
 1969Zu02: ¹³C(³He,³He) E=15 MeV, measured $\sigma(\theta)$. Enriched, natural targets.
 1970Nu02: ¹³C(³He,³He) E=14 MeV; measured $\sigma(\theta)$; deduced optical model parameters.
 1973LuZL: ¹³C(³He,³He) E=20 MeV polarized ³He, measured $\sigma(\theta)$.
 1975Ha33: ¹³C(³He,³He) E=15 MeV; measured $\sigma(\theta)$; deduced optical parameters.
 1976Ma26: ¹³C(³He,³He) E=18,20,24.5 MeV; measured $\sigma(\theta)$ at backwards angles.
 1977Pe23: ¹³C(³He,³He) E=20 MeV; measured $\sigma(E(^3\text{He}),\theta)$.
 1980PeZV: ¹³C(³He,³He') E=43.6 MeV; measured $\sigma(\theta)$. ¹³C levels deduced analog character. DWBA analysis.
 1980Tr02: ¹³C(³He,³He) E=41 MeV; measured $\sigma(\theta)$. Optical model analysis.
 1981Pe08: ¹³C(³He,³He') E=43.6 MeV; measured $\sigma(E(^3\text{He}),\theta)$. ¹³C levels deduced isoscalar, isovector transition amplitude ratio. DWBA, CCBA analyses.
 1986Dr03: ¹³C(³He,³He) E=33 MeV; measured $\alpha(\theta)$, A(θ); deduced optical model parameters. ¹³C*(0,3.68,7.55).
 1987BuZR: ¹³C(³He,³He) E=39.6 MeV; measured $\sigma(\theta)$. Optical model.
 1992Ad06: ¹³C(³He,³He) E=50,60 MeV; measured $\sigma(\theta)$; deduced model parameters.
 1994Bu01: ¹³C(³He,³He) E=37.9 MeV; measured $\sigma(\theta)$; deduced optical model parameters, rainbow mechanism.
 2000Bu13: ¹³C(³He,³He) E=50,60 MeV; measured $\sigma(\theta)$. Comparison with optical model calculations with energy-dependent terms.
 2000Bu25, 2002Th01: ¹³C(³He,³He), ¹³C(³He,³He') E=37.9 MeV; measured $\sigma(\theta)$, $\sigma(E,\theta)$; deduced optical model parameters. ¹³C deduced levels, J, π , configurations. Comparisons with model predictions.

Theory:

- 1986Ze04: ¹³C(³He,³He) E=16-22 MeV; calculated $\sigma(\theta)$; deduced model parameters. Optical model.
 1987Ra36: ¹³C(³He,³He) E=41 MeV; analyzed $\sigma(\theta)$; deduced model parameters.
 1990De31: ¹³C(³He,³He) E=39.6, 12 MeV; analyzed $\sigma(\theta)$; deduced model parameters, rainbow characteristics.
 2009Pa07: ¹³C(³He,³He) E=450 MeV; analyzed $\sigma(\theta)$ using global optical model potential GDP08; deduced set of global optical potential parameters.
 2011Og09: ¹³C(³He,³He), E(cm)<300 MeV; analyzed $\sigma(\theta)$ and diffraction radii data; deduced abnormally large radii for the ¹³C*(3.09;1/2⁺) state located 1.86 MeV below the neutron emission threshold.
 2011Og10: ¹³C(³He,³He) E=39.6 MeV; analyzed $\sigma(\theta)$; deduced rms radii, diffraction radii, neutron halos in the excited states. Modified diffraction model.
 2014El01: ¹³C(³He,³He), ¹³C(³He,³He') E=37.9 MeV; calculated σ , $\sigma(\theta)$; deduced deformation parameters from the best fit. M3Y-Reid effective interaction, comparison with available data.
 2015Pa10: ¹³C(³He,³He) E=4-118.5 MeV; analyzed $\sigma(\theta)$ for 142 sets of experimental data; deduced optical model parameters.
 2016De39: ¹³C(³He,³He') E=43.6 MeV; ¹³C(³He,³He), E=39.6 MeV; analyzed available data, discussed ¹³C*(3.09) radius.

¹³C Levels

T: From (1969Ba06).

E(level) ^a	J ^{π} ^b	L ⁱ	deformations β^c	Comments
0 ^e				
3.09×10 ³ ^{efg}	1/2 ⁺	1	0.113	T=1/2
3.68×10 ³ ^{efg}	3/2 ⁻	2	0.166	T=1/2 E(level): Unresolved with 3.85 MeV level in (1969Ba06).
3.85×10 ³ ^{efg}	5/2 ⁺	3	0.172	T=1/2 E(level): Unresolved with 3.68 MeV level in (1969Ba06).
6.86×10 ³ ^{ef}	5/2 ⁺	3	0.055	

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$^{13}\text{C}(^3\text{He},^3\text{He}),(^3\text{He},^3\text{He}')$ 1969Ba06,1981Pe08,2000Bu25 (continued)

^{13}C Levels (continued)				
E(level) ^a	J ^π ^b	L ⁱ	deformations β ^c	Comments
7.49×10 ³ ^f				E(level): Unresolved with 7.55 MeV level.
7550 ^{efg}	5/2 ⁻	2		T=1/2 E(level): Unresolved with 7.49 MeV level; the higher state is 5/2 ⁻ ; T=1/2 (1969Ba06). ΔL=2&3 for the unresolved pair.
7.68×10 ³ ^{de}	3/2 ⁺	1	0.065	
8860 ^{fg} 30	1/2 ⁻	0	0.050	T=1/2
9500 ^{ef} 30	9/2 ⁺	5	0.072	
9.897×10 ³ ^d		2		
10.75×10 ³ ^d		2	^h	E(level): Unresolved with 10.82 MeV level (1981Pe08).
10.82×10 ³ ^d		2	^h	E(level): Unresolved with 10.75 MeV level (1981Pe08).
11.08×10 ³ ^f	(3/2 ⁻ ,5/2 ⁻)	2	0.046	J ^π : From the ΔL=2 angular distributions seen in (1981Pe08). E(level): Weakly populated (1969Ba06).
11840 ^{fg} 30	(7/2 ⁺)		0.12	T=1/2 J ^π : In (1981Pe08) this level is identified with L=2 and J ^π =(3/2 ⁻), while in, for example (2000Bu25) it is identified with L=3 and 7/2 ⁺ .
15.11×10 ³ ^f		2	0.065	
16.0×10 ³ ^d		3	0.062	

^a E_x from (1969Ba06) except where noted.

^b From DWBA and shell model analysis in (2000Bu25,2002Th01), except where noted.

^c From (1981Pe08).

^d Reported in (1981Pe08).

^e Also reported in (1986Dr03).

^f Also reported in (1981Pe08).

^g Also reported in (2000Bu25,2002Th01).

^h The deformations β value for the unresolved states at E_x=10.8 MeV is 0.035 (1981Pe08).

ⁱ From (1981Pe08,2000Bu25).

$^{13}\text{C}(\alpha,\alpha),(\alpha,\alpha'),(\alpha,\alpha'\gamma)$

- 1959Fu62: $^{13}\text{C}(\alpha,\alpha')$ E=20 MeV; scattering angle $\theta=45^\circ$, $^{13}\text{C}^*(3.7\text{ MeV})$ observed.
- 1960St02: $^{13}\text{C}(\alpha,\alpha')$; measured not abstracted; ^{13}C deduced nuclear properties.
- 1963Ba05: $^{13}\text{C}(\alpha,\alpha')$; measured not abstracted; deduced nuclear properties.
- 1966Ha19: $^{13}\text{C}(\alpha,\alpha'),(\alpha,\alpha')$ E=40.5 MeV; angular distributions were measured for a large number of excited states of ^{13}C .
- 1967Ar17: $^{13}\text{C}(\alpha,\alpha'),(\alpha,\alpha')$ E=33.4 MeV; angular distributions of elastic and inelastic scatterings were measured.
- 1971Co14: $^{13}\text{C}(\alpha,\alpha')$ E=15,18,20,28.4 MeV; measured $\sigma(\theta)$; deduced optical model parameters. Enriched targets.
- 1972Ku19,1974Ch58,1974Ku15: $^{13}\text{C}(\alpha,\alpha')$ E=26.6 MeV; measured $\sigma(\theta)$.
- 1973Ku18: $^{13}\text{C}(\alpha,\alpha')$ E=18,19,22,24,25,26.6 MeV; measured $\sigma(E;\theta)$; deduced reaction mechanism.
- 1974Fe08: $^{13}\text{C}(\alpha,\alpha'),(\alpha,\alpha')$ E=24 MeV; measured $\sigma(E_{\alpha'},\theta)$.
- 1976Ja17: $^{13}\text{C}(\alpha,\alpha')$ E=65 MeV; measured $\sigma(\theta)$.
- 1976Pa05: $^{13}\text{C}(\alpha,\alpha')$ E=30.9, 50.5 MeV; analyzed deformation.
- 1980Fu04: $^{13}\text{C}(\alpha,\alpha')$ E=22,36 MeV; measured $\sigma(E_{\alpha},\theta)$. The line shape of the $^{13}\text{C}^*(7.686\text{ MeV};3/2^+)$ resonance is measured. Enriched target.
- 1981Pe08: $^{13}\text{C}(\alpha,\alpha')$ E=35.5 MeV; measured $\sigma(E_{\alpha},\theta)$. ^{13}C levels deduced isoscalar, isovector transition amplitude ratio. DWBA, CCBA analyses.
- 1983Pi07: $^{13}\text{C}(\alpha,\alpha'\gamma)$ E=32 MeV; measured E_{γ} , I_{γ} . Low energy prompt γ measurement technique.
- 1984De44: $^{13}\text{C}(\alpha,\alpha')$ E=24-35 MeV; measured $\alpha(^{12}\text{C})(\theta,\phi)$. ^{13}C level deduced substate population probabilities.
- 1984DeZR: $^{13}\text{C}(\alpha,\alpha')$ E not given; measured (recoil nucleus)(α)-coin. ^{13}C levels deduced Γ_{γ}/Γ .
- 1985De11: $^{13}\text{C}(\alpha,\alpha'\gamma)$ E=24 MeV; measured E_{γ} , I_{γ} , recoil. ^{13}C levels deduced Γ_{γ}/Γ .
- 1987Ab03: $^{13}\text{C}(\alpha,\alpha_0)$ E=48.7, 54.1 MeV; measured $\sigma(\theta)$. ΔE -E telescopes. Optical model analyses.
- 1987Bu27: $^{13}\text{C}(\alpha,\alpha')$ E=50.5 MeV; measured σ .
- 1993AtZZ: $^{13}\text{C}(\alpha,\alpha')$ E=54.1,104,155 MeV; $^{13}\text{C}(\alpha,\alpha')$ E=54.1,104,155 MeV; measured $\Sigma(E,\theta)$; deduced model parameters. ^{13}C levels deduced $B(\lambda)$. Coupled-channels analysis.
- 2001He22: $^{13}\text{C}(\alpha,\alpha')$ E=2.6-6.2 MeV; measured $\sigma(\theta)$.
- 2002Ar16: $^{13}\text{C}(\alpha,\alpha'),(\alpha,\alpha')$ E=25.5-35.15 MeV; measured elastic and inelastic $\sigma(\theta)$, excitation functions. Comparison with model predictions.
- 2006SaZP,2007SaZS: $^{13}\text{C}(\alpha,\alpha')$ E=400 MeV; measured E_{α} , I_{α} ; deduced $\sigma(\theta)$, $B(E0)$, $B(E2)$, level properties: J , π .
- 2008He11: $^{13}\text{C}(\alpha,\alpha')$ E=2.6-6.2 MeV; measured radii, σ , $\sigma(\theta)$, S-factor.
- 2008Ka44: $^{13}\text{C}(\alpha,\alpha')$ E=388 MeV; measured E_{α} , I_{α} ; deduced $\sigma(\theta)$, $B(E0)$. Comparison with DWBA calculations.
- 2010KaZO,2010KaZZ: $^{13}\text{C}(\alpha,\alpha')$ E=388 MeV; measured E_{α} , $I_{\alpha}(\theta)$; deduced $d\sigma(\theta)$ to individual states, $B(E0)$.
- 2014DeZW: $^{13}\text{C}(\alpha,\alpha')$ E=65 MeV; measured E_{α} , $I_{\alpha}(\theta)$; deduced resonances, $\sigma(\theta)$ to discrete states, neutron halo radius to excited states using MDM (modified diffraction model).
- 2015Og04: $^{13}\text{C}(\alpha,\alpha')$ E=65,90 MeV; measured reaction products; deduced $\sigma(\theta)$, rms radii. Comparison with available data.
- 2016Bu24: $^{13}\text{C}(\alpha,\alpha')$ E=26.6-65 MeV; measured reaction products, E_{α} , I_{α} ; deduced $\sigma(\theta)$, optical model and semi-microscopic parameters.
- 2016DeZX: $^{13}\text{C}(\alpha,\alpha),(\alpha,\alpha')$ E=65,90 MeV [inelastic scattering to 3.09 MeV state in ^{13}C]; measured E_{α} , $I_{\alpha}(\theta)$; deduced $\sigma(\theta)$; calculated $\sigma(\theta)$ using optical model; calculated $1/2^+$ 3.09 MeV state neutron halo radius using MDM (Modified Diffraction Model), NRM (Nuclear Rainbow Method) and ANC (Asymptotic Normalization Coefficients). Compared with published radii of $J^{\pi}=1/2^-$ 8.86 MeV state (diluted cluster) and of $J^{\pi}=3/2^-$ 9.90 MeV state (compact cluster).
- 2018Bu05: $^{13}\text{C}(\alpha,\alpha),(\alpha,\alpha')$ E=29 MeV; measured reaction products, E_{α} , I_{α} ; deduced $\sigma(\theta)$, diffraction and rms radii, J , π . The radii of the excited states $^{13}\text{C}^*(3.09, 8.86\text{ MeV})$ are determined using Modified Diffraction Model (MDM) and are larger than that of the $^{13}\text{C}_{\text{g.s.}}$, confirming the suggestion that the 8.86 MeV ($1/2^-$) state could be an analog of the Hoyle state in ^{12}C and the 3.09 MeV ($1/2^+$) state has a neutron halo. $^{13}\text{C}^*(9.9\text{ MeV})$ state is a possible "exotic" excited state. Comparison with theoretical calculations. See discussion on a ^{13}C analog of the Hoyle state in (2010Og03, 2010OgZZ, 2020Ch06, 2021Sh42).
- 2020InZZ: $^{13}\text{C}(\alpha,\alpha')$ E=388 MeV; measured E_{α} , $\sigma(\theta)$, deduced L , J , π .
- 2021De32: $^{13}\text{C}(\alpha,\alpha')$ E=65 and 90 MeV; measured angular distributions for $\theta=5^\circ$ to 72° and 6° - 40° , respectively. Searched for evidence of a Hoyle state analog in ^{13}C . Analyzed data for $^{13}\text{C}^*(9.9, 11.080)$ and deduced radii.
- 2021In04: $^{13}\text{C}(\alpha,\alpha')$ E=388 MeV; measured E_{α} , $\sigma(\theta)$ for $\theta\approx 0^\circ$ to 20.2° at the RCNP/Osaka using the Grand Raiden spectrometer. Populated states up to $E_x=16\text{ MeV}$, DWBA analysis focused mainly on $E_x=10.5$ - 13 MeV in a search for α condensate states. Deduced isoscalar transition strengths. In addition to known states, a state at $E_x=12.06\text{ MeV}$ has isoscalar monopole and dipole character, while other states at $E_x=12.3, 12.5, 12.6$ and 12.8 MeV have isoscalar monopole character. Notably, no evidence of the 12.14 MeV state was observed. $\Delta L=1$ states are reported at $E_x=14.5$ and 16.1 MeV ; authors suggest the 16.1

$^{13}\text{C}(\alpha,\alpha),(\alpha,\alpha'),(\alpha,\alpha')\gamma$ (continued)

MeV state is a candidate for the α condensate state. Find related discussion in (2008To18).

2022Go16: $^{13}\text{C}(\alpha,\alpha')$ E=65, 90 MeV; measured E_α , $\sigma(\theta)$ for for $\theta_{c.m.}\approx 8^\circ$ to 65° and for states up to $E_x\approx 11.8$ MeV at the University of Jyväskylä. Semi-Microscopic Dispersive Optical Model analysis. Mainly discussed scattering to $^{13}\text{C}^*(0, 3.09, 3.68, 7.55, 8.86, 9.9, 10.996, 11.08$ MeV). Deduced deformation lengths and reduced transition strengths.

Theory:

1971Te10: $^{13}\text{C}(\alpha,\alpha')$ E=20,25 MeV; analyzed interference between states of transferred nucleus.

1974Ch58: $^{13}\text{C}(\alpha,\alpha')$ E=26.6 MeV; analyzed $\sigma(\theta)$. The calculated and experimental angular distributions for (α,α') transitions to the $^{13}\text{C}_{g.s.}$ state are discussed.

1977Sa19: $^{13}\text{C}(\alpha,\alpha')$ E=40.5 MeV; calculated $\sigma(\theta)$ at forward angles.

1978Ze03: $^{13}\text{C}(\alpha,\alpha')$ E=26.6 MeV; calculated $\sigma(\theta)$.

1983Go27: $^{13}\text{C}(\alpha,\alpha')$ E=26.6; calculated $\sigma(\theta)$; deduced spin-orbit potential effects.

1988Le05: $^{13}\text{C}(\alpha,\alpha')$ calculated resonances, Γ , α -particle strength distribution. Optical model.

1990Mu19: $^{13}\text{C}(\alpha,\alpha')$ E=65 MeV; analyzed $\sigma(\theta)$; deduced model parameters. Microscopic overlap integrals, vertex form factors.

1992AtZU: $^{13}\text{C}(\alpha,\alpha')$ E \approx 50-105 MeV; analyzed data. ^{13}C levels deduced B(λ) ratios. Harmonic-vibrational, other models.

2010DaZY: $^{13}\text{C}(\alpha,\alpha)$, (α,α') E=388 MeV; calculated $\sigma(\theta)$; deduced radii for specified excited states.

2011De17: $^{13}\text{C}(\alpha,\alpha')$ E=35.5 MeV; calculated $\sigma(\theta)$. ^{13}C deduced rms radii.

2011Og09: $^{13}\text{C}(\alpha,\alpha')$, E(cm)<300 MeV; analyzed $\sigma(\theta)$ and diffraction radii data; deduced abnormally large radii for excited states.

2011Og10: $^{13}\text{C}(\alpha,\alpha),(\alpha,\alpha')$ E $_{c.m.}$ =388 MeV; analyzed $\sigma(\theta)$; deduced rms radii, diffraction radii, neutron halos in the excited states. Modified diffraction model.

2017HaZY: $^{13}\text{C}(\alpha,\alpha')$ E=2-5.7 MeV; calculated $\sigma(\theta)$. Calculations using R-matrix; results compared with available data.

 ^{13}C Levels

R_{rms} radius determined by MDM (Modified Diffraction Method) except where noted.

E(level) ^{ab}	J^π ^c	L^c	deformation β^c	Comments
0	1/2 ⁻	0		$R_{\text{rms}}=2.33$ fm 3 (2018Bu05: $E_\alpha=29$ MeV); see also 2.31 fm (2011DeZY,2014DeZW) and 2.33 fm (2015Og04: $E_\alpha=65,90$ MeV).
3090	1/2 ⁺	1	0.19	B(E1) $\uparrow=0.096$ 5 (2021In04) R_{rms} (fm)=3.04 22 (2011DeZY), 2.92 7 (2014DeZW), 2.98 9 (2016DeZX: $E_\alpha=65$ MeV), 2.88 19 and ≥ 2.6 (NRM: Nuclear Rainbow Method) (2016DeZX: $E_\alpha=90$ MeV), 2.7 4 (2018Bu05).
3680	3/2 ⁻	2	0.17	B(E2) $\uparrow=0.00560$ 20 (2021In04) B(E2) $\downarrow\approx 6$ e ² fm ⁴ (1966Ha19); DWBA fit is rather poor. deformation β : See also $\beta=0.54$ (WS: Woods-Saxon form), 0.51 (DF: double folding calculation) at $E_\alpha=29$ MeV and $\beta=0.44$ (WS), 0.4 (DF) at $E_\alpha=50$ MeV (2016Bu24).
3850	5/2 ⁺	3	0.31	B(E2) $\uparrow\approx 13.7$ e ² fm ⁴ , $\delta_2=1.05$ fm (2022Go16). B(E3) $\uparrow=0.000472$ 26 (2021In04)
6860	5/2 ⁺	3	0.042	B(E3) $\uparrow\approx 220$ e ² fm ⁶ , $\delta_3=0.82$ fm (2022Go16). $\Gamma_\gamma/\Gamma\leq 3\times 10^{-4}$ (1984DeZR,1985De11). $\Gamma_\gamma\leq 1.5$ eV using $\Gamma=5.2$ keV from (1982Kn02: $^{12}\text{C}(n,x)$). (1985De11) indicates that the most probable channel for the decay of this state is the E1 transition to the 3.69 MeV, 3/2 ⁻ level. deformation β : See also $\beta=0.54$ (WS), 0.51 (DF) at $E_\alpha=29$ MeV (2016Bu24).
7490 ^d				E(level): Unresolved in (1966Ha19,1974Fe08,1981Pe08,1984DeZR,1985De11). L: (1981Pe08) fits the unresolved $^{13}\text{C}^*(7490+7550)$ angular distributions with $\Delta L=2$ ($J^\pi=3/2^-,5/2^-$). The fit is rather poor. The Adopted Levels gives $J^\pi=(7/2^+)$ and 5/2 ⁻ , respectively, which implies $\Delta L=3$ and 2, respectively.
7550 ^d		(2)		B(E2) $\uparrow=0.00663$ 24 (2021In04)

Continued on next page (footnotes at end of table)

¹³C(α,α),(α,α′),(α,α′γ) (continued)

¹³C Levels (continued)

<u>E(level)^{ab}</u>	<u>J^{πc}</u>	<u>Γ</u>	<u>L^c</u>	<u>deformation β^c</u>	<u>Comments</u>
					E(level): Unresolved in (1966Ha19,1974Fe08, 1981Pe08,1984DeZR,1985De11). B(E2; IS(isoscalar transition))=77 fm ⁴ 8 (2007SaZS); B(E2)↓≈6 e ² fm ⁴ (1966Ha19); DWBA fit is rather poor. deformation β: See also β=0.54 (WS), 0.51 (DF) at E _α =29 MeV and β=0.44 (WS), 0.4 (DF) at E _α =50 (2016Bu24). B(E2)↑≈20.5 e ² fm ⁴ , δ ₂ =1.02 fm (2022Go16). T=1/2 (1980Fu04).
7686 ^d 6	3/2 ⁺	70 keV 5	1	0.097	E(level),Γ: From (1980Fu04).
8860	1/2 ⁻		0	0.10	B(E0)↑=29.6 23 (2021In04). B(E0,IS)=55 fm ⁴ 6 (2007SaZS); see also preliminary results B(E0,IS)=37 fm ⁴ 6 (2008Ka04) and 42 fm ⁴ 6 (2010KaZO,2010KaZZ). R _{rms} (fm)=2.63 12 (2011DeZY), 2.68 10 (2014DeZW), ≥2,5 (NRM, R _α =65, 90 MeV) and 2.63 16 (E _α =90 MeV) (2016DeZX), 2.50 32 (exotic state) (2018Bu05). B(E0)↑≈0.65 e ² , δ ₀ =0.14 fm (2022Go16).
9500	9/2 ⁺		5	0.16	Intense neutron decay to the 1st excited state of ¹² C with probability 20% 10 assuming the angular distribution of the neutrons is isotropic.
9900	3/2 ⁻				J ^π : From (2015Og04), suggested rotational band member. R _{rms} (fm)=2.00 14 (2014DeZW), 2.02 14 (E _α =65 MeV) and 1.76 23 (E _α =90 MeV) both from (2015Og04). E(level): Exotic state (2018Bu05). B(E2)↑≈0.22 e ² fm ⁴ , δ ₂ =0.22 fm (2022Go16).
10460					B(E4)↑=0.0000037 14 (2021In04)
10753	(7/2 ⁻)				E(level),J ^π : Unresolved doublet (1981Pe08,2021In04).
10820	(5/2 ⁻)		2	0.18	B(E2)↑=0.00017 1 (2021In04)
11010					E(level),J ^π : Unresolved doublet (1981Pe08,2021In04).
11080	(1/2 ⁻)		0	0.15	B(E1)↑<0.023 (2021In04) E(level): From (2014DeZW). B(E0)↑=19.2 3 (2021In04). J ^π : (1981Pe08) report a ΔL=2 J ^π =(3/2 ⁻ ,5/2 ⁻) angular distribution, but we take ΔL=0 J ^π =(1/2 ⁻), which is reported in (2007SaZS, 2008Ka44, 2010KaZO, 2010KaZZ, 2020InZZ). B(E0,IS)=35 fm ⁴ 4 (2007SaZS); see also preliminary results 18 fm ⁴ 3 (2008Ka44) and 23 fm ⁴ 3 (2010KaZO,2010KaZZ).
11748					B(E2)↑=0.00056 16 (2021In04)
11850	(7/2 ⁺)		3	0.35	B(E3)↑=0.00074 8 (2021In04) J ^π : (1981Pe08) report a ΔL=2 J ^π =(3/2 ⁻) angular distribution, but we take ΔL=3 J ^π =(7/2 ⁺), which is reported in (2020InZZ, 2021In04).
12055 ^e 1	1/2 ⁻ & (3/2,5/2) ⁻	38 keV 4	0+2		B(E2)↑=0.00022 1 (2021In04) E(level): Unresolved doublet.
12282 ^e 5	1/2 ⁻	122 keV 22	0		B(E0)↑=1.7 3 (2021In04). B(E0)↑=4.1 4 (2021In04).
12450 ^e 3	1/2 ⁻	<70 keV	0		E(level),Γ,L: From (2021In04). B(E0)↑=4.9 4 (2021In04).

Continued on next page (footnotes at end of table)

$^{13}\text{C}(\alpha,\alpha),(\alpha,\alpha'),(\alpha,\alpha'\gamma)$ (continued) ^{13}C Levels (continued)

<u>E(level)^{ab}</u>	<u>J^{πc}</u>	<u>Γ</u>	<u>L^c</u>	<u>deformation β^c</u>	<u>Comments</u>
12601 ^e 3	1/2 ⁻	<70 keV	0		E(level), Γ ,L: From (2021In04). E(level): See also the broad \approx 12.5 MeV state reported in (2008Ka44,2010KaZO,2010KaZZ), which is presently associated with E _x =12.3, 12.5, 12.6 and 12.8.
12775 ^e 4	1/2 ⁻	<70 keV	0		B(E0) \uparrow =3.1 2 (2021In04). E(level), Γ ,L: From (2021In04). B(E0) \uparrow =0.92 5 (2021In04).
14.5 \times 10 ^{3e} 1	1/2 ⁺ ,3/2 ⁺		1		E(level), Γ ,L: From (2021In04). B(E1) \uparrow =6.9 7 (2021In04).
15110	3/2 ⁻		2		E(level),J ^{π} ,L: From (2021In04). T=3/2 (1981Pe08)
16080	7/2 ⁺		3	<0.1	
16.1 \times 10 ^{3e} 1	(1/2 ⁺ ,3/2 ⁺)		1		B(E1) \uparrow =2.1 8 (2021In04). E(level),J ^{π} ,L: From (2021In04). E(level): Suggested as a possible candidate for α condensed state.

^a Values listed in, for example, (1981Pe08) except where noted.

^b For levels reported, see (1959Fu62, 1966Ha19, 1967Ar17, 1974Fe08, 1980Fu04, 1981Pe08, 1983Pi07, 1984De44, 1984DeZR, 1985De11, 2002Ar16, 2006SaZP, 2007SaZS, 2008Ka44, 2010KaZO, 2010KaZZ, 2011DeZY, 2014DeZW, 2015Og04, 2016Bu24, 2016DeZX, 2018Bu05).

^c From DWBA analysis in (1981Pe08) except where noted.

^d Unresolved in (1985De11) who determined $\Gamma_\gamma/\Gamma \leq 3 \times 10^{-4}$ (1984DeZR,1985De11) for the unresolved group. In their discussion, they considered various scenerios depending upon which of the levels $^{13}\text{C}^*(7.49,7.55,7.69)$ is populated.

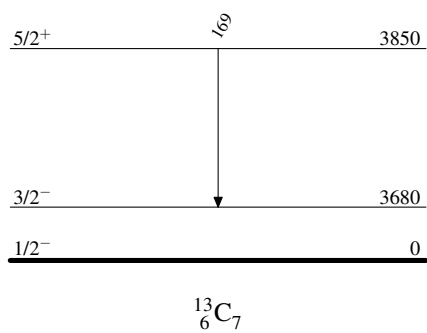
^e Uncertainties in the level energies are statistical only. These results, obtained using the Grand Raiden (1999Fu12), were collected with a peak FWHM of 170 keV; peak energy resolution should be dominated by the focal plane energy calibration and is estimated by a reasonable $\Delta E \approx 3$ keV.

 $\gamma(^{13}\text{C})$

<u>E_{γ}</u>	<u>E_i(level)</u>	<u>J_i^{π}</u>	<u>E_f</u>	<u>J_f^{π}</u>
169	3850	5/2 ⁺	3680	3/2 ⁻

$$\underline{^{13}\text{C}(\alpha,\alpha),(\alpha,\alpha'),(\alpha,\alpha')\gamma}$$

Level Scheme



${}^{13}\text{C}({}^6\text{Li}, {}^6\text{Li}), ({}^7\text{Li}, {}^7\text{Li})$

- 1969Be90: ${}^{13}\text{C}({}^6\text{Li}, {}^6\text{Li}), ({}^7\text{Li}, {}^7\text{Li})$ E=20 MeV; measured $\sigma(\theta_{\text{c.m.}})$ for $\theta \approx 40^\circ - 110^\circ$. Deduced Optical Model parameters.
- 1972Ba52: ${}^{13}\text{C}({}^6\text{Li}, {}^6\text{Li})$ E=28 MeV; measured $\sigma(\theta)$ for $\theta \approx 15^\circ - 90^\circ$. Deduced Optical Model parameters.
- 1973Sc26: ${}^{13}\text{C}({}^6\text{Li}, {}^6\text{Li}), ({}^7\text{Li}, {}^7\text{Li})$ E=34, 36 MeV; measured elastic and inelastic scattering for $\sigma(\theta)$ and $\theta \approx 15^\circ$ to 80° . Finite-range DWBA analysis.
- 1976Po02: ${}^{13}\text{C}({}^6\text{Li}, {}^6\text{Li}), ({}^7\text{Li}, {}^7\text{Li})$ E=4-13 MeV; measured $\sigma(\theta)$ for $\theta \approx 15^\circ - 90^\circ$, optical model analysis.
- 1978Dr07: ${}^{13}\text{C}(\text{pol. } {}^6\text{Li}, {}^6\text{Li}), (\text{pol. } {}^7\text{Li}, {}^7\text{Li})$ E=9 MeV; E=28 MeV; measured $\sigma(\theta)$ for $\theta \approx 20^\circ - 100^\circ$.
- 1979Ze01: ${}^{13}\text{C}({}^6\text{Li}, {}^6\text{Li})$ E=40 MeV; measured $\sigma(\theta)$ for $\theta \approx 10^\circ - 70^\circ$.
- 1987Co02, 1987Co16: ${}^{13}\text{C}({}^7\text{Li}, {}^7\text{Li}), ({}^7\text{Li}, {}^7\text{Li}')$ E=34 MeV; measured $\sigma(\theta)$ for $\theta \approx 10^\circ - 170^\circ$. Folding model analysis.
- 1988DeZT, 1992DeZQ, 1994De43: ${}^{13}\text{C}({}^6\text{Li}, {}^6\text{Li})$ E=93 MeV; measured $\sigma(\theta)$ for $\theta = 14^\circ$ to 163° , analyzed rainbow effects.
- 1989De34: ${}^{13}\text{C}({}^6\text{Li}, {}^6\text{Li})$ E=93 MeV; measured $\sigma(\theta)$ for $\theta \approx 10^\circ - 120^\circ$ also studied $({}^6\text{Li}, {}^6\text{He})$. DWBA analysis.
- 2000Tr01: ${}^{13}\text{C}({}^7\text{Li}, {}^7\text{Li})$ E=63, 130 MeV; measured elastic $\sigma(\theta)$ for $\theta_{\text{c.m.}} \approx 5^\circ$ to 70° . Also measured ${}^{13}\text{C}({}^{14}\text{N}, {}^{14}\text{N})$ for E=162 MeV, and several other reactions. Optical model analysis. Deduced global optical model parameters and applied results to $({}^7\text{Be}, {}^8\text{B})$ transfer reactions and the ${}^7\text{Be}(p, \gamma)$ problem.
- 2004Ca46, 2004CaZZ: ${}^{13}\text{C}({}^6\text{Li}, {}^6\text{Li})$ E=54 MeV, ${}^{13}\text{C}({}^7\text{Li}, {}^7\text{Li})$ E=63, 130 MeV; measured elastic scattering $\sigma(\theta)$ for $\theta = 10^\circ$ to 80° . Also measured ${}^{13}\text{C}({}^7\text{Li}, {}^8\text{Li})$ transfer reaction. Analyzed refractive scattering via optical model analysis.
- 2012Li14: ${}^{13}\text{C}({}^7\text{Li}, {}^7\text{Li})$ E=34 MeV; measured elastic scattering $\sigma(\theta)$ for $\theta_{\text{c.m.}} = 10^\circ$ to 45° . DWBA analysis.
- 1976St22: ${}^{13}\text{C}({}^6\text{Li}, d\alpha)$; calculated $d+\alpha$ angular correlations.
- 1991Bo48: ${}^{13}\text{C}({}^6\text{Li}, {}^6\text{Li}), ({}^7\text{Li}, {}^7\text{Li})$; analyzed utility of lithium beam studies for Rutherford backscattering analysis of materials.
- 2018Xu01: ${}^{13}\text{C}({}^7\text{Li}, {}^7\text{Li})$; developed a global optical potential model for ${}^7\text{Li}$ scattering up to 200 MeV.
- 2020Ch17: ${}^{13}\text{C}({}^7\text{Li}, {}^7\text{Li})$; developed a microscopic optical potential model for ${}^7\text{Li}$ scattering up to 450 MeV.
- 2022Mi16: ${}^{13}\text{C}({}^6\text{Li}, {}^6\text{Li})$ E=38 MeV; analyzed refractive scattering for lithium beams in a laser polarizing field.
- 2022Xu14: ${}^{13}\text{C}({}^6\text{Li}, {}^6\text{Li})$ E=4-210 MeV; developed a global optical potential model for ${}^6\text{Li}$ scattering on $1p$ -shell nuclei.
- 2023Ma02: ${}^{13}\text{C}({}^6\text{Li}, {}^6\text{Li}), ({}^7\text{Li}, {}^7\text{Li})$; analyzed mass asymmetry and charge asymmetry effects in elastic scattering of light nuclei.
- 2024Xu04: ${}^{13}\text{C}({}^7\text{Li}, {}^7\text{Li})$; developed a global optical potential model for ${}^7\text{Li}$ scattering on p -shell nuclei for E=4.5 to 132 MeV.

 ${}^{13}\text{C}$ Levels

E(level)	J^π ^a	Comments
0	$1/2^-$	E(level): Angular distributions analyzed in $({}^6\text{Li}, {}^6\text{Li})$ and $({}^7\text{Li}, {}^7\text{Li})$.
3.09×10^3 ^b		L: L=1 $({}^6\text{Li}, {}^6\text{Li})$ (1973Sc26).
3.68×10^3 ^b	$3/2^-$	$\delta_2 = -1.30$ (1987Co02).
7.55×10^3 ^b	$5/2^-$	$\delta_2 = -1.00$ (1987Co02).

^a From folding model analysis of (1987Co02, 1987Co16).^b Angular distributions analyzed in coupled-channels $({}^7\text{Li}, {}^7\text{Li})$ analysis of (1987Co02).

${}^{13}\text{C}({}^9\text{Be}, {}^9\text{Be}), ({}^9\text{Be}, {}^9\text{Be}')$

1990Ba16: ${}^{13}\text{C}({}^9\text{Be}, {}^9\text{Be}), ({}^9\text{Be}, {}^9\text{Be}')$ E=50.46 MeV; measured $\sigma(\theta)$ for $\theta_{\text{c.m.}} \approx 10^\circ$ to 170° . Deduced α -cluster spectroscopic strengths. DWBA analysis, α -cluster form factors.

Theory:

1998Gr21: ${}^{13}\text{C}({}^9\text{Be}, {}^9\text{Be})$ E=27 MeV; calculated $\sigma(\theta)$; deduced optical model parameters, nuclear compressibility constant.

 ${}^{13}\text{C}$ Levels

T: From DWBA analysis in (1990Ba16).

<u>E(level)^a</u>	<u>J^{π}^a</u>	<u>L_{α}=2 α-cluster spectroscopic strengths</u>	<u>Comments</u>
0	1/2 ⁻	0.407	T=1/2 L _{α} =2 α -cluster spectroscopic strengths: From (1990Ba16). $\sigma(7^\circ-90^\circ)=1777$ mb 250 and $\sigma(90^\circ-170^\circ)=0.39$ mb 12.
3680	3/2 ⁻	0.0214	T=1/2 L _{α} =2 α -cluster spectroscopic strengths: From (1990Ba16); see also 0.235 for L _{α} =0 (1990Ba16). $\sigma(10^\circ-90^\circ)=6.5$ mb 98 and $\sigma(90^\circ-170^\circ)=0.38$ mb 11.
7550	5/2 ⁻	0.0014	T=1/2 L _{α} =2 α -cluster spectroscopic strengths: From (1990Ba16); see also 0.212 for L _{α} =4 (1990Ba16). $\sigma(10^\circ-92^\circ)=4.93$ mb 74 and $\sigma(92^\circ-170^\circ)=0.31$ mb 12.

^a From DWBA analysis in (1990Ba16).

${}^{13}\text{C}({}^{11}\text{B}, {}^{11}\text{B})$

2003Me13: ${}^{13}\text{C}({}^{11}\text{B}, {}^{11}\text{B}), ({}^{11}\text{B}, {}^{11}\text{B}')$ E=45 MeV; measured $\sigma(\theta)$ for $\theta \approx 20^\circ$ to 170° . Optical model and coupled-reaction-channels analysis; deduced optical model and deformation parameters.

 ${}^{13}\text{C}$ Levels

<u>E(level)^a</u>	<u>J^{π}^a</u>	<u>L^a</u>	<u>Comments</u>
0	1/2 ⁻		
3088	1/2 ⁺	1	
3684	3/2 ⁻	2	
3854	5/2 ⁺	3	
6864	5/2 ⁺	3	
7490	7/2 ⁺	3	
7547	5/2 ⁻	2	$\delta_\lambda=0.90$ fm, $\beta_\lambda=0.31$ (2003Me13).
7680	3/2 ⁺	1	
8200	3/2 ⁺	1	

^a From coupled-reaction-channels model analysis in (2003Me13).

${}^{13}\text{C}({}^{18}\text{O}, {}^{18}\text{O})$

[2010Ru13](#): ${}^{13}\text{C}({}^{18}\text{O}, {}^{18}\text{O}), ({}^{18}\text{O}, {}^{18}\text{O}')$ E=105 MeV; measured reaction products; deduced partial σ , optical model parameters, spectroscopic amplitudes.

[2011Ru04](#): XUNDL dataset compiled by TUNL, 2011.

The authors measured the angular distribution of ${}^{18}\text{O}$ and ${}^{13}\text{C}$ recoils from ${}^{13}\text{C} + {}^{18}\text{O} \rightarrow {}^{13}\text{C} + {}^{18}\text{O}$ reactions. A beam of E(${}^{18}\text{O}$)=105 MeV ions from the Warsaw University Cyclotron impinged on a $500 \mu\text{g}/\text{cm}^2$ ${}^{13}\text{C}$ target that was enriched to 90%. The recoils were detected in a $\Delta\text{E-E}$ telescope. The ${}^{13}\text{C}$ and ${}^{18}\text{O}$ elastic and inelastic data were analyzed with other data at $E_{\text{cm}}=6.29\text{-}13.94$ MeV, and optical potential parameters were deduced.

[2023Ma02](#): ${}^{13}\text{C}({}^{18}\text{O}, {}^{18}\text{O})$; analyzed mass asymmetry and charge asymmetry effects in elastic scattering of light nuclei.

 ${}^{13}\text{C}$ Levels

E(level)	J^{π^a}
0	$1/2^-$
3.09×10^3	$1/2^+$
3.68×10^3 ^b	$3/2^-$
3.85×10^3 ^b	$5/2^+$

^a From coupled-reaction-channels model analysis in ([2011Ru04](#)).

^b Unresolved.

$^{13}\text{C}(\pi,\pi),(\pi,\pi')$

- 1976DyZY: $^{13}\text{C}(\pi^+,\pi^+)$ E=50 MeV; measured $\sigma(\theta)$.
- 1977AmZZ: $^{13}\text{C}(\pi^+,\pi^+),(\pi^+,\pi^+')$ E=50 MeV; measured σ .
- 1978Dy01: $^{13}\text{C}(\pi^+,\pi^+)$ E=50 MeV; measured $\sigma(\theta)$; deduced isotopic effects. Optical model analysis.
- 1978EiZZ: $^{13}\text{C}(\pi^+,\pi^+)$ E=50 MeV; measured σ .
- 1979De34: $^{13}\text{C}(\pi^\pm,\pi^\pm),(\pi^\pm,\pi^\pm')$ E=162 MeV; measured $\sigma(\theta)$. ^{13}C deduced pure n, p transitions. Shell-model, weak coupling-model configurations.
- 1979GyZZ: $^{13}\text{C}(\pi^-\pi^-)$ E=29 MeV; measured ratios of $\sigma(\theta)$ for ^{12}C and ^{13}C targets. Optical model analysis.
- 1979Jo08: $^{13}\text{C}(\pi^-\pi^-)$ E=29.2-49.5 MeV; measured $\sigma(\theta)$. ^{13}C deduced neutron radius relative to ^{12}C . Neutron rms radius is 2.35 fm. Optical model analysis.
- 1979MaYZ: $^{13}\text{C}(\pi^-\pi^-)$ E=30,50 MeV; analyzed $\sigma(\theta)$. ^{13}C deduced model dependence of neutron radius. Optical model, absorption parameter constraints, different pion-nucleon phase shifts, modified harmonic oscillator density distribution. Found the neutron rms radius is 2.372 fm +15-22.
- 1979MaZB: $^{13}\text{C}(\pi^-\pi^-)$ E=30,50 MeV; measured $\sigma(\theta)$. ^{13}C deduced neutron radii. Optical model, global fit parameters.
- 1979Sc25: $^{13}\text{C}(\pi^\pm,\pi^\pm),(\pi^\pm,\pi^\pm')$ E=180 MeV; measured $\sigma(\theta)$. ^{13}C levels deduced $\sigma(\pi^-)/\sigma(\pi^+)$.
- 1979TrZR: $^{13}\text{C}(\pi^+,\pi^+')$ E=116,162,180,200,240 MeV; measured $\sigma(E,\theta)$. ^{13}C deduced levels, J, π .
- 1980Sc30: $^{13}\text{C}(\pi^\pm,\pi^\pm')$ E=148,180,230 MeV; measured $\sigma(\theta)$. High resolution pion spectrometer.
- 1980Th01: $^{13}\text{C}(\pi^\pm,\pi^\pm')$ E=162 MeV; measured π^+/π^- asymmetry.
- 1981Se08: $^{13}\text{C}(\pi^\pm,\pi^\pm')$ E=100-300 MeV; measured $\sigma(\theta,E)$. ^{13}C deduced dominant $\Delta S=1$ transitions. One-step mechanism, fixed scatterer impulse approximation.
- 1981SeZX: $^{13}\text{C}(\pi^\pm,\pi^\pm),(\pi^\pm,\pi^\pm')$ E=162 MeV; measured $\sigma(\theta)$; deduced $\sigma(\pi^-)/\sigma(\pi^+)$. ^{13}C levels deduced B(E2). Optical, collective model analyses.
- 1982An18: $^{13}\text{C}(\pi^\pm,\pi^\pm),(\pi^\pm,\pi^\pm')$ E=100 MeV; measured $\sigma(\theta)$.
- 1982Se04: $^{13}\text{C}(\pi^\pm,\pi^\pm')$ E=162 MeV; measured $\sigma(\theta)$. ^{13}C levels deduced L. Microscopic DWIA analysis, shell model wave functions.
- 1983B111: $^{13}\text{C}(\pi^\pm,\pi^\pm)$ E=65,80 MeV; measured $\sigma(\theta)$; deduced isospin effects, pion-nucleus optical potential parameters.
- 1983Se15: $^{13}\text{C}(\pi^\pm,\pi^\pm),(\pi^\pm,\pi^\pm')$ E=162 MeV; measured $\sigma(\theta)$. ^{13}C levels deduced neutron, proton B(λ) components. Optical, collective model analyses.
- 1984An11: $^{13}\text{C}(\pi^\pm,\pi^\pm),(\pi^\pm,\pi^\pm')$ E=100 MeV; measured $\sigma(\theta)$, $\sigma(E,\pi)$. Isobar-hole model analysis.
- 1987MiZX: $^{13}\text{C}(\pi^\pm,\pi^\pm')$ E=65,50 MeV; measured $\sigma(\theta)$; deduced medium corrections energy dependence.
- 1988Mi02: $^{13}\text{C}(\pi^\pm,\pi^\pm),(\pi^\pm,\pi^\pm')$ E=65 MeV; measured $\sigma(\theta)$. ^{13}C levels deduced deformation lengths, $\sigma(\pi^-)/\sigma(\pi^+)$ enhancement features; deduced deformation length. Comparison with DWIA calculations with ρ -squared medium corrections.
- 1990Se04: $^{13}\text{C}(\pi^-\pi^-)$ E=30,50 MeV; measured $\sigma(\theta)$ for elastic scattering; deduced optical model fits. ^{13}C enriched targets, range spectrometer. DWBA analysis.
- 1990Ye06,1991Ye01: $^{13}\text{C}(\pi^\pm,\pi^\pm)$ E=114-226 MeV; measured analyzing power vs θ . Polarized target. DWIA analyses.
- 1992Br02: $^{13}\text{C}(\pi^\pm,\pi^\pm),(\pi^\pm,\pi^\pm')$ E=100 MeV; measured analyzing power. Polarized target. Model analysis.
- 1994Ye06: $^{13}\text{C}(\pi^\pm,\pi^\pm)$ E=130-180 MeV; $^{13}\text{C}(\pi^+,\pi^+)$ E=223 MeV; $^{13}\text{C}(\pi^-\pi^-)$ E=226 MeV; measured analyzing power $A_y(\theta)$, $\sigma(\theta)$ for elastic scattering; deduced spin-flip transition quadrupole component role. Polarized, unpolarized targets. DWIA, optical, and Δ -hole models.

Theory:

- 1977Fu10: $^{13}\text{C}(\pi^+,\pi^+)$; calculated scattering.
- 1980Ch08: $^{13}\text{C}(\pi^+,\pi^+')$ E=120-226 MeV; calculated $\sigma(\theta)$. Coupled-channels, momentum space.
- 1980Ei01: $^{13}\text{C}(\pi^+,\pi^+')$ E=75-200 MeV; calculated $\sigma(\theta)$; deduced connection between charge exchange, inelastic scattering processes near (3,3) resonance. Optical potential, eikonal approximation.
- 1980Le02: $^{13}\text{C}(\pi^\pm,\pi^\pm')$ E=162 MeV; calculated $\sigma(\theta)$.
- 1980Le17: $^{13}\text{C}(\pi^\pm,\pi^\pm')$ E=162 MeV; calculated $\sigma(\theta)$; deduced structure effects. DWIA, momentum space.
- 1980Sa04: $^{13}\text{C}(\pi^\pm,\pi^\pm)$ E=150 MeV; calculated $\sigma(\theta)$. Isobar-doorway optical potential.
- 1981HaZU: $^{13}\text{C}(\pi^\pm,\pi^\pm)$, analyzed data; deduced excess neutron density distributions.
- 1981Li02: $^{13}\text{C}(\pi^\pm,\pi^\pm)$ E=180 MeV; calculated $\sigma(\theta)$. Coupled-channels method, single charge exchange mechanism, pion absorption.
- 1981Mo11: $^{13}\text{C}(\pi^\pm,\pi^\pm)$ E=resonance; calculated $(\sigma(\pi^-)-\sigma(\pi^+))/(\sigma(\pi^-)+\sigma(\pi^+))$; deduced isospin effects in pion-nucleon scattering amplitude.
- 1983Li15: $^{13}\text{C}(\pi^-\pi^-)$ E=180 MeV; calculated $\sigma(\theta)$. DWIA, core excitation, eikonal distorted waves.

$^{13}\text{C}(\pi,\pi),(\pi,\pi')$ (continued)

- 1984HiZX: $^{13}\text{C}(\pi,\pi')$; analyzed data. ^{13}C deduced M4 excitation isoscalar, isovector transition densities.
 1986AmZX: $^{13}\text{C}(\pi,\pi')$; analyzed form factors, $\sigma(\theta)$; deduced structure effects.
 1988ChZU: $^{13}\text{C}(\pi^\pm,\pi^\pm')$ E=50-100 MeV; calculated σ asymmetry. Polarized target. DWIA.
 1990G109: $^{13}\text{C}(\pi^+,\pi^+)$ E=132 MeV; compiled data analyses.
 1993Si15: $^{13}\text{C}(\pi^\pm,\pi^\pm)$ E=114-226 MeV; analyzed $\sigma(\theta)$, analyzing power data.
 1995Av07: $^{13}\text{C}(\pi^-, \pi^-)$ E=132,226 MeV; calculated $\sigma(\theta)$, asymmetry vs θ in some cases. Polarized targets, spin effects.
 1995Ku04: $^{13}\text{C}(\pi^\pm,\pi^\pm),(\pi^\pm,\pi^\pm')$ E=114-226 MeV; analyzed $\sigma(\theta)$, asymmetry data; deduced first-order core polarization effects related features. DWIA.
 1999Ta33: $^{13}\text{C}(\pi^+,\pi^+)$ E=162-223 MeV; calculated $\sigma(\theta)$, $\text{Ay}(\theta)$. $^{13}\text{C}(\pi^-, \pi^-)$ E=114-226 MeV; calculated $\text{Ay}(\theta)$. Isobar-doorway state model, comparisons with data.
 2004Sa28: $^{13}\text{C}(\pi^\pm,\pi^\pm)$ E \approx 80-800 MeV; analyzed $\sigma(\theta)$; deduced strong absorption model parameters.

 ^{13}C Levels

E(level) ^a	J^π ^a	L	Comments
0	$1/2^-$		E(level): See (1978Dy01, 1979De34, 1979Sc25, 1982AnZW, 1982Se04, 1983B111, 1983Se15, 1988Mi02, 1984An11, 1990Se04, 1994Ye06).
3090	$1/2^+$		E(level): See (1979De34, 1982Se04, 1994Ye06).
3680	$3/2^-$	2	E(level): See (1979De34, 1979Sc25, 1981Se08, 1982AnZW, 1982Se04, 1983Se15, 1988Mi02, 1984An11, 1994Ye06). L: L transfer (1981Se08, 1982Se04, 1988Mi02). Spin transfer $\Delta S=0$ (1981Se08, 1988Mi02). The extracted deformation lengths (βR) in fm: (βR) ₊ =1.34 11, (βR) ₋ =1.40 25; (βR) _{avg} =1.37 14, (βR) ₊ / βR) ₋ =0.95 20 (1988Mi02). See also (1983Se15).
3850	$5/2^+$		E(level): See (1979De34, 1982Se04, 1994Ye06).
6860			E(level): See (1994Ye06).
7490	$7/2^+$		E(level): See (1979De34, 1983Se15).
7550	$5/2^-$	2	E(level): See (1979De34, 1979Sc25, 1981Se08, 1982AnZW, 1982Se04, 1983Se15, 1988Mi02, 1984An11, 1994Ye06). L: L transfer (1981Se08, 1982Se04, 1988Mi02). $\Delta S=0$ (1981Se08, 1988Mi02). The extracted deformation lengths (βR) in fm: (βR) ₊ =1.30 10, (βR) ₋ =1.10 10; (βR) _{avg} =1.19 7, (βR) ₊ / βR) ₋ =1.18 12 (1988Mi02).
8860	$1/2^-$	0	E(level): See (1982Se04, 1988Mi02, 1994Ye06). L: L transfer (1988Mi02). $\Delta S=0$ (1988Mi02), $\Delta S=1$ (1982Se04). The extracted deformation lengths (βR) in fm: (βR) ₊ =0.10 1, (βR) ₋ =0.09 1; (βR) _{avg} =0.095 10, (βR) ₊ / βR) ₋ =1.11 15 (1988Mi02).
9500	$9/2^+$		E(level): See (1979De34, 1979Sc25, 1981Se08, 1982AnZW, 1982Se04, 1988Mi02, 1984An11, 1994Ye06). J^π : Assigned by (1982Se04). The enhancement factor $\sigma(\pi^-)/\sigma(\pi^+) \approx 9$ is consistent with a pure neutron transition and a $9/2^+$ assignment (1979De34); see also (1982Se04). The transitions to $^{13}\text{C}^*(9.5)$ is enhanced by a factor of 4.0 +20-7 in π^- scattering indicating an almost pure neutron transition (1979Sc25). $\Delta S=1$ (1981Se08).
11700			E(level): See (1979Sc25, 1984An11).
11820	$(5/2^+, 7/2^+)$	3	E(level): See (doublet: 1982Se04, 1983Se15, 1988Mi02 and 1994Ye06). J^π : Assigned by (1982Se04, 1983Se15, 1988Mi02). L: L transfer (1982Se04, 1983Se15, 1988Mi02). $\Delta S=0$ (1988Mi02). The extracted deformation lengths (βR) in fm: (βR) ₊ =1.48 13, (βR) ₋ =1.02 7; (βR) _{avg} =1.23 8, (βR) ₊ / βR) ₋ =1.45 16 (1988Mi02).
14800			E(level): See (1984An11). Probably the same state reported at $E_x=15$ MeV in (1979Sc25).
16050 50	$9/2^+$		E(level): From (1982Se04); see also $E_x=16050$ keV (1981Se08), ≈ 16000 (1979De34: a group of states). J^π : Assigned by (1982Se04); see also $J^\pi=(9/2^+, 7/2^+)$ (1981Se08). $\Delta S=1$ (1981Se08, 1982Se04).
17500			E(level): See (1979Sc25).
17920 50	$(9/2^+, 7/2^+)$		E(level): From (1982Se04); see also $E_x=17920$ keV (1981Se08). J^π : Assigned by (1981Se08, 1982Se04).

Continued on next page (footnotes at end of table)

$^{13}\text{C}(\pi,\pi),(\pi,\pi')$ (continued) ^{13}C Levels (continued)

<u>E(level)^a</u>	<u>J^{π}^a</u>	<u>Comments</u>
21370 50	(9/2 ⁺ , 7/2 ⁺)	$\Delta S=1$ (1981Se08,1982Se04). E(level): From (1982Se04); see also $E_x=21370$ keV (1981Se08). J^π : Assigned by (1981Se08,1982Se04). $\Delta S=1$ (1981Se08,1982Se04). The π^-/π^+ asymmetry near 21.5 MeV suggests that there is isospin mixing between T=1/2 and 3/2 states of $J^\pi=7/2^+$ and/or 9/2 ⁺ (1982Se04).
21600 50	(9/2 ⁺ , 7/2 ⁺)	E(level): From (1982Se04); see also $E_x=21600$ keV (1981Se08). J^π : Assigned by (1981Se08,1982Se04). $\Delta S=1$ (1981Se08,1982Se04).
≈ 22000		E(level): See (1979De34,1979Sc25); probably a group of states. Not placed in Adopted Levels. The centroid of a group of states near 22 MeV is found in ($\pi^-, \pi^{-'}$) at a higher excitation energy than in ($\pi^+, \pi^{+'}$) (1979De34).

^a From shell model and DWIA analyses in (1982Se04) and (1979De34), except where noted.

¹⁴C(p,d) 1990Ya01

- 1963Le03: ¹⁴C(p,d) E=17.6-20 MeV; measured $\sigma(\theta)$ for $\theta \approx 10^\circ$ to 50° . Deduced reduced width θ^2 .
 1966Gl01: ¹⁴C(p,d) E=8,12 MeV; measured $\sigma(\text{Ed},\theta)$. ¹³C deduced levels, L, reduced width. Enriched ¹⁴C target.
 1971Cu01: ¹⁴C(p,d) E=14.5 MeV; measured $\sigma(\text{Ed},\theta)$ for $\theta_{\text{c.m.}} \approx 20^\circ$ to 120° . Deduced S.
 1975Ce04: ¹⁴C(p,d) E=27 MeV; measured $\sigma(\theta)$ for $\theta \approx 5^\circ$ to 50° . Deduced S. DWBA analysis.
 1990Ya01: ¹⁴C(p,d) E=35,40.1 MeV; measured $\sigma(\text{E}_d,\theta)$ for $\theta=10^\circ$ to 80° . Deduced S.
 2023Be20: ¹H(¹⁴C,d) E=12 MeV/nucleon; measured reaction products using the ANL AT-TPC with the HELIOS magnet. Reported preliminary E vs θ plot for low-lying states.
 2023Ay06: ¹H(¹⁴C,d) E=12 MeV/nucleon; gave general comments on kinematic reconstruction of excitation energies for active-target time projection chamber measurements.

¹³C Levels

E(level) ^a	J ^{π} ^a	L	C ² S ^a	Comments
0	1/2 ^{-b}	1	1.85	E(level),J ^{π} : See (1963Le03,1966Gl01,1971Cu01,1975Ce04,1990Ya01). L: From (1963Le03). C ² S: From (1990Ya01); see also spectroscopic factors S=1.4 (1975Ce04). Different analyses are presented in (1971Cu01) who find S=1.27 (LZR (local zero range); cut-off radius R=0 fm), 1.58 (LZR; R=2 fm), 1.41 (NLFR (non-local finite range); R=0 fm). Reduced width $\theta^2=0.063$ (1963Le03), 0.038 (1966Gl01).
3090	1/2 ^{+e}	0	0.03	E(level),J ^{π} : See (1963Le03,1975Ce04,1990Ya01). L: From (1963Le03). C ² S: From (1990Ya01); see also spectroscopic factors S=0.02 (1975Ce04). Reduced width $\theta^2=0.017$ 9 (1963Le03).
3680	3/2 ^{-c}	1	1.70	E(level),J ^{π} : See (1963Le03,1971Cu01,1975Ce04,1990Ya01). L: From (1963Le03). C ² S: From (1990Ya01); see also spectroscopic factors S=1.8 (1975Ce04). Different analyses are presented in (1971Cu01) who find S=1.52 (LZR; R=0 fm), 1.81 (LZR; R=2 fm), 1.97 (NLFR; R=0 fm). Reduced width $\theta^2=0.051$ 5 (1963Le03).
3850	5/2 ^{+d}	2	0.15	E(level),J ^{π} : See (1963Le03,1975Ce04,1990Ya01). L: From (1963Le03). C ² S: From (1990Ya01); see also spectroscopic factors S=0.13 (1975Ce04). Reduced width $\theta^2=0.026$ +7-13 (1963Le03).
6860	5/2 ^{+d}		0.04	
7560	5/2 ^{-g}		0.08	
7690	3/2 ^{+f}		0.02	
8200	3/2 ^{+f}		0.05	
8860	1/2 ^{-b}		0.02	
9500	9/2 ^{+h}		0.1	
9900	3/2 ^{-c}		0.04	
11000	1/2 ^{+e}		0.01	
11080	1/2 ^{-b}		0.10	
11750	3/2 ^{-c}		0.13	
13280	3/2 ^{-c}		0.15	
15110	3/2 ^{-c}		1.18	T=3/2 T: (1990Ya01).

^a From DWBA analysis of spectroscopic factors in (1990Ya01).

^b 0p_{1/2} neutron pickup (1990Ya01).

^c 0p_{3/2} neutron pickup (1990Ya01).

^d 0d_{5/2} neutron pickup (1990Ya01).

 $^{14}\text{C}(\text{p,d})$ **1990Ya01 (continued)** ^{13}C Levels (continued)

- e* $1s_{1/2}$ neutron pickup (1990Ya01).
- f* $0d_{3/2}$ neutron pickup (1990Ya01).
- g* $(0f_{5/2})$ neutron pickup (1990Ya01).
- h* $(0g_{9/2})$ neutron pickup (1990Ya01).

$^{14}\text{C}(\mathbf{d},\mathbf{t})$

1966Gl01: $^{14}\text{C}(\mathbf{d},\mathbf{t})$ E=12 MeV; measured $\sigma(\theta)$. Deduced levels, J, Spectroscopic factors, reduced widths θ^2 .

1976We01: $^{14}\text{C}(\text{pol. d,t})$ E=14 MeV; measured $\sigma(E,\theta)$, polarization parameters A(Et, θ) for $\theta \approx 20^\circ$ to 105° . Deduced S. Enriched targets.

 ^{13}C Levels

Preferred S values from (1976We01) are listed; authors suggest $\pm 50\%$ uncertainties are a realistic estimation.

<u>E(level)^a</u>	<u>Jπ^a</u>	<u>S^a</u>	<u>Comments</u>
0	1/2 ⁻	1.00	$\sigma(\theta=10^\circ)=42.4$ (1966Gl01: no units).
3086	1/2 ⁺	0.06	$\sigma(\theta=10^\circ)=2.5$ (1966Gl01: no units).
3684	3/2 ⁻	1.0	$\sigma(\theta=10^\circ)=8.3$ (1966Gl01: no units).
3854	5/2 ⁺	0.08	$\sigma(\theta=10^\circ)=1.3$ (1966Gl01: no units).

^a From DWBA analysis of spectroscopic factors in (1976We01).

$^{14}\text{C}(^3\text{He},\alpha)$

[1966Ba13](#): $^{14}\text{C}(^3\text{He},\alpha)$ E=39.8-44.8 MeV; measured $\sigma(\theta)$ for $\theta=15^\circ$ to 80° .

[1971Co14](#): $^{14}\text{C}(^3\text{He},\alpha)$ E=6, 8 and 10 MeV; measured $\sigma(\theta)$ for $\theta\approx 30^\circ$ to 160° . Deduced optical model parameters.

[1971Ke08](#), [1972Ke08](#): $^{14}\text{C}(^3\text{He},\alpha)$ E=2-5.5 MeV; measured $\sigma(\theta)$ for $\theta=20^\circ$ to 160° . Analyzed resonances in $\alpha_{0,1,2,3}$.

[1984RoZQ](#): $^{14}\text{C}(^3\text{He},\alpha)$ E=25.05 MeV; measured $\sigma(\theta)$ for $\theta=13^\circ$ to 46° at the BIG KARL spectrometer in Julich; populated

$^{13}\text{C}^*$ (15.102 MeV, T=3/2).

[1994Bu01](#): $^{14}\text{C}(^3\text{He},\alpha)$ E=37.9 MeV; measured $\sigma(\theta)$ for $\theta_{c.m.}\approx 8^\circ$ – 160° . Analyzed rainbow scattering.

 ^{13}C Levels

<u>E(level)^a</u>	<u>J^{π}^a</u>	<u>Comments</u>
0	1/2 ⁻	T=1/2 (1966Ba13) p _{1/2} neutron picked up.
3080		E(level): Reported in (1971Ke08).
3680	3/2 ⁻	T=1/2 (1966Ba13) p _{3/2} neutron picked up.
3854		E(level): From (1972Ke08).
15108 14	3/2 ⁻	T=3/2 (1966Ba13) E(level),J ^{π} : See also (1984RoZQ). p _{3/2} neutron picked up.

^a From ([1966Ba13](#)), except where noted. A J dependence is found in the ([1966Ba13](#)) analysis of ($^3\text{He},\alpha$) angular distributions.

$^{14}\text{N}(\gamma,\text{p})$

- 1962Ko23: $^{14}\text{N}(\gamma,\text{p})$ E=17-90 MeV; measured products, ^{13}C deduced $\sigma(\text{E})$, $\sigma(\theta)$.
 1970Sh06: $^{14}\text{N}(\gamma,\text{pn})$ E<15-30 MeV; measured $\sigma(\text{E};\text{En})$. ^{13}C levels deduced neutron de-excitation.
 1970Th01: $\text{N}(\gamma,\text{X})$ E<29 MeV; measured $\sigma(\text{E};\text{E}\gamma)$; deduced integrated σ .
 1971BeWW: $^{14}\text{N}(\gamma,\text{p})$ E<26 MeV; measured $\sigma(\text{E};\text{E}\text{p},\theta)$.
 1972Ca34: $^{14}\text{N}(\gamma,\text{p}_0)$ E≤17-25 MeV MeV; measured $\sigma(\text{E};\text{En})$; deduced integrated σ .
 1972Ge11: $^{14}\text{N}(\gamma,\text{p})$ E<15.5-29.5 MeV; measured $\sigma(\text{E};\text{En})$; deduced integrated σ .
 1974Ba37: $^{14}\text{N}(\gamma,\text{p})$ E=18-26 MeV; measured $\sigma(\text{E}\gamma,\text{E}\text{p},\theta)$.
 1984PyZZ, 1985Ku01: See for discussion on $^{14}\text{C}(\gamma,\text{n})$ E<36 MeV.
 1993Ir01: $^{14}\text{N}(\gamma,\text{p})$ E≤ 60 MeV; measured $\sigma(\text{E}\gamma,\text{E}\text{p},\theta)$ for $\theta=60^\circ$ to 120° . Compared results with direct-knockout calculations.
 Assumed p-shell proton knockout.

Theory:

- 1973Ki05: $^{14}\text{N}(\gamma,\text{X})$; calculated $\sigma(\text{E})$.
 1972Go23: $^{14}\text{N}(\gamma,\text{p})$ E<30 MeV; calculated $\sigma(\text{E};\text{E}\text{p})$.
 1975Ch44: $^{14}\text{N}(\gamma,\text{p})$; analyzed σ .
 1978Di12: $^{14}\text{N}(\gamma,\text{p}),(\gamma,\text{np})$; calculated σ .

 ^{13}C Levels

<u>E(level)^a</u>	<u>J^π^a</u>	<u>Comments</u>
0	1/2 ⁻	E(level),J ^π : See (1974Ba37,1972Ca34,1993Ir01).
3090	1/2 ⁺	E(level),J ^π : See (1970Th01).
3680	3/2 ⁻	E(level),J ^π : See (1970Th01,1974Ba37,1993Ir01).
3850	5/2 ⁺	E(level),J ^π : See (1970Th01).
7550	5/2 ⁻	E(level),J ^π : See (1970Sh06,1972Ge11,1993Ir01). A large fraction of the $^{14}\text{N}(\gamma,\text{p})^{13}\text{C}^* \rightarrow ^{12}\text{C}+\text{n}$ neutron yield appears to be associated with sequential decay via $^{13}\text{C}^*(7.75,8.86,11.80)$ (1970Sh06,1972Ge11).
8860	1/2 ⁻	E(level),J ^π : See (1972Ge11,1993Ir01).
11800	3/2 ⁻	E(level),J ^π : See (1970Sh06,1972Ge11,1993Ir01).

^a From shell model analysis of proton knock-out reactions in (1970Th01,1993Ir01).

${}^{14}\text{N}(\mu^-, \nu\text{n})$

1973Ki12: ${}^{14}\text{N}(\mu^-, \nu\text{n})$ E=slow; calculated population of nuclides and levels. See also (1990Ch13).

2002St01: ${}^{14}\text{N}(\mu^-, \nu\text{n})$ E=slow; measured E_γ , I_γ ; deduced yields, level population.

 ${}^{13}\text{C}$ Levels

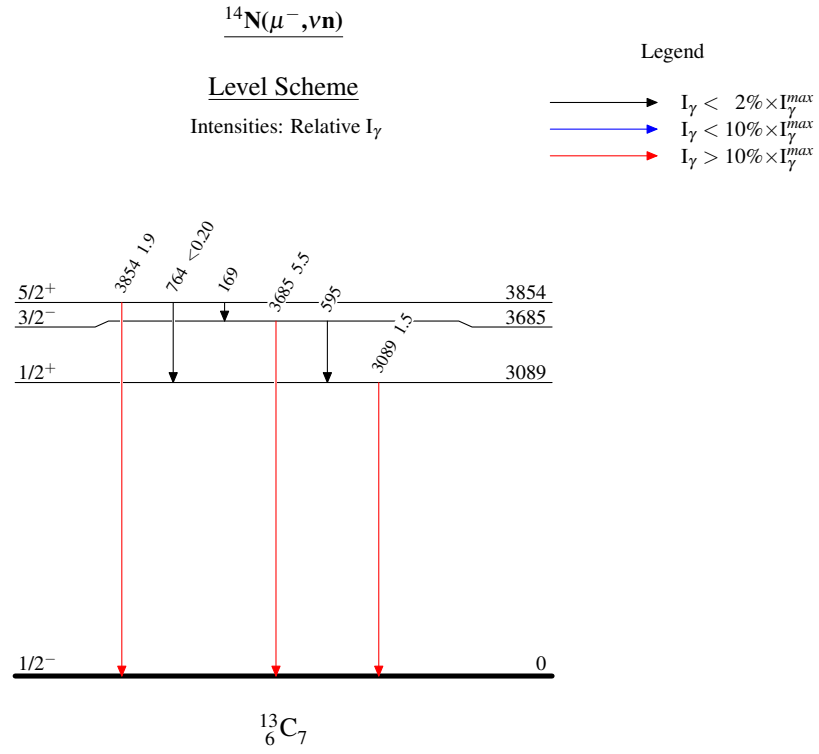
<u>E(level)^a</u>	<u>J^π^a</u>
0	1/2 ⁻
3089	1/2 ⁺
3685	3/2 ⁻
3854	5/2 ⁺

^a From (2002St01) and Adopted Levels.

 $\gamma({}^{13}\text{C})$

<u>E_γ</u>	<u>I_γ^a</u>	<u>E_i(level)</u>	<u>J_i^π</u>	<u>E_f</u>	<u>J_f^π</u>
169		3854	5/2 ⁺	3685	3/2 ⁻
595		3685	3/2 ⁻	3089	1/2 ⁺
764	<0.20	3854	5/2 ⁺	3089	1/2 ⁺
3089	1.5 3	3089	1/2 ⁺	0	1/2 ⁻
3685	5.5 2	3685	3/2 ⁻	0	1/2 ⁻
3854	1.9 2	3854	5/2 ⁺	0	1/2 ⁻

^a %I_γ per captured μ^- .



$^{14}\text{N}(\mathbf{n},\mathbf{d}),(\mathbf{n},\mathbf{d}\gamma)$

- 1952Li24: $^{14}\text{N}(\mathbf{n},\mathbf{x})$ E=14.1 MeV; analyzed gas cloud chamber data.
 1957Ca07: $^{14}\text{N}(\mathbf{n},\mathbf{d}_{0,2})$ E=14 MeV; measure the absolute differential cross sections at seven laboratory angles $\theta_{\text{lab}}=0^\circ-65^\circ$.
 1963Za01: $^{14}\text{N}(\mathbf{n},\mathbf{d})$ E=14.1 MeV; measured angular distributions of deuterons corresponding to $^{13}\text{C}^*(0,3.09,3.68 \text{ MeV})$ states; $\theta=0^\circ$ to 150° .
 1967An08: $^{14}\text{N}(\mathbf{n},\mathbf{d}_0)$ E=14.4 MeV; measured angular distributions for $\theta=20^\circ$ to 100° .
 1967Fe06: $^{14}\text{N}(\mathbf{n},\mathbf{d}_{0,2})$ E=14.1,14.8 MeV; measured angular distributions for $\theta=0^\circ$ to 100° .
 1968Mi02: $^{14}\text{N}(\mathbf{n},\mathbf{d}_0)$ E= 4.4 MeV; measured $\sigma(\text{Ed},\theta)$; deduced S. Natural targets.
 1971Ny03: $^{14}\text{N}(\mathbf{n},\mathbf{x}\gamma)$ E=15 MeV; measured E_γ , $\sigma(E_\gamma)$; deduced levels. Ge(Li) detector.
 1979SuZR: $^{14}\text{N}(\mathbf{n},\mathbf{d})$ E=27.4,39.7,60.7 MeV; measured $\sigma(\text{E},\theta)$; deduced reaction mechanism. Hauser-Feshbach calculation.
 1981NeZY: $^{14}\text{N}(\mathbf{n},\mathbf{d})$ E=60 MeV; measured $\sigma(\theta)$; deduced reaction mechanism. DWBA analysis, Goldhaber-Teller form factor.

Theory:

- 1971Mi12: $^{14}\text{N}(\mathbf{n},\mathbf{d})$; analyzed $\sigma(\theta)$; deduced S.
 1971Mi18: $^{14}\text{N}(\mathbf{n},\mathbf{d})$; calculated $\sigma(\theta)$.

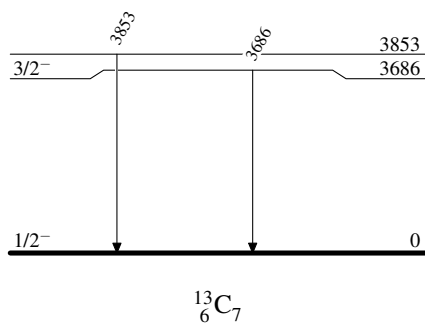
 ^{13}C Levels

E(level)	J^π^a	L^a	S^a	Comments
0	$1/2^-$	1	0.92 9	$Q_0=-5320 \text{ keV}$ (1967Fe06,1968Mi02). E(level): Reported in (1957Ca07,1963Za01,1967An08,1967Fe06,1968Mi02). J^π : (1967Fe06); see also (1963Za01: ($1/2^-$)). L: See (1963Za01,1967Fe06,1968Mi02). S: (1967Fe06). See also S=1.41 (1963Za01), 2 (1968Mi02). $\theta^2=0.065$ (1963Za01), 0.042 4 (1967Fe06). $C^2S=0.46$ 4 (1967Fe06).
3090				E(level): not observed.
3686	$3/2^-$	1	3.0	$Q=-9000 \text{ keV}$ (1967Fe06). E(level): See (1957Ca07,1963Za01,1967Fe06,1971Ny03). J^π : (1967Fe06); see also (1963Za01: ($3/2^-$)). L: See (1963Za01,1967Fe06). S: (1963Za01). $\theta^2=0.12$ (1963Za01).
3853				E(level): (1971Ny03).

^a From Butler theory and DWBA analyses in (1963Za01,1967Fe06).

 $\gamma(^{13}\text{C})$

E_γ	$E_i(\text{level})$	J_i^π	E_f	J_f^π	Comments
3686 3	3686	$3/2^-$	0	$1/2^-$	E_γ : (1971Ny03).
3853 3	3853		0	$1/2^-$	E_γ : (1971Ny03).

$^{14}\text{N}(\mathbf{n},\mathbf{d}),(\mathbf{n},\mathbf{d}\gamma)$ Level Scheme

${}^{14}\text{N}(\text{p},2\text{p})$

- 1958Ty49: ${}^{14}\text{N}(\text{p},2\text{p})$ E=185 MeV; measured absolute σ for the reaction versus binding energy of the removed proton.
 1961Cl09: ${}^{14}\text{N}(\text{p},2\text{p})$ E=150 MeV; measured σ_{total} .
 1965De21: ${}^{14}\text{N}(\text{p},2\text{p})$ E=19 MeV; measured $\sigma(\text{Ep},\theta(1),\theta(2))$, pp-coin.
 1966Ty01: ${}^{14}\text{N}(\text{p},2\text{p})$ E=460 MeV; measured $\sigma(\text{Ep};\theta)$, Q.
 1970We09: ${}^{14}\text{N}(\text{p},2\text{p})$ E=46 MeV; measured $\sigma(\text{Ep},\theta)$.
 1970WeZW: ${}^{14}\text{N}(\text{p},2\text{p})$ E=46 MeV; measured $\sigma(\text{Ep},\theta(\text{p}))$.
 1986VdZY: ${}^{14}\text{N}(\text{p},2\text{p})$ E=50 MeV; measured σ . ${}^{13}\text{C}$ deduced resonances. Nuclear emulsion technique.

Theory:

- 1965Ba21: ${}^{14}\text{N}(\text{p},2\text{p})$; calculated the neutron width of the ${}^{13}\text{C}^*(J^\pi=5/2^-)$ level.
 1972Ch21: ${}^{14}\text{N}(\text{p},2\text{p})$ E=46 MeV; calculated $\sigma(\theta)$. Distorted-wave t-matrix approximation.
 1974OIZR: ${}^{14}\text{N}(\text{p},2\text{p})$ E=46 MeV; calculated $\sigma(\theta)$.
 1979Ki10: ${}^{14}\text{N}(\text{p},2\text{p})$; calculated σ . Particle-hole excitation model, analyzed high-lying hole states.
 1979Ma20: ${}^{14}\text{N}(\text{pol. p},2\text{p})$; calculated $\sigma(\theta)$ for quasifree scattering; deduced structure of initial, final nuclear states.
 1981Fe04: ${}^{14}\text{N}(\text{pol. p},2\text{p})$ E=320 MeV; calculated effective polarization. Quasifree scattering, shell, cluster models.
 1984Vd02: ${}^{14}\text{N}(\text{p},2\text{p})$ E=50 MeV; calculated $\sigma(\text{Ep}1,\text{Ep}2)$, deduced residual level production σ . Quasielastic, two-step process model.
 1986Os08: ${}^{14}\text{N}(\text{p},2\text{p})$ E=46,47,50 MeV; calculated $\sigma(\text{E}1,\theta1,\theta2)$. T-matrix approximation.
 1990Go34: ${}^{14}\text{N}(\text{p},2\text{p})$ E=46 MeV; analyzed $\sigma(\theta1,\theta2)$; deduced noncoplanarity role. T-matrix approach.
 1990Lo18: ${}^{14}\text{N}(\text{p},2\text{p})$ E=46 MeV; calculated $\sigma(\theta1,\theta2,\text{E}1)$.

 ${}^{13}\text{C}$ Levels

E(level)	J^π ^a	Comments
0	$1/2^-$	E(level): corresponding to ejection of $p_{1/2}$ proton (1958Ty49,1966Ty01) with binding energy $E_b \approx 7$ MeV (1958Ty49), 7.5 MeV 5 (1966Ty01); also reported in (1965De21,1970We09,1986VdZY).
3100		E(level): See (1961Cl09,1986VdZY).
3680	$3/2^-$	E(level): See (1961Cl09,1966Ty01,1970We09,1986VdZY). $E_b=11.5$ MeV (1966Ty01).
7500	$5/2^-$	E(level): See (1970We09).
7800		E(level): corresponding to ejection of $p_{3/2}$ proton (1958Ty49,1966Ty01) with $E_b \approx 15$ MeV (1958Ty49: $E_x \approx 8$ MeV), 15.3 MeV 5 (1966Ty01).
11900	$3/2^-$	E(level): See (1970We09).
12300		E(level): corresponding to ejection of $p_{3/2}$ proton with $E_b=19.8$ MeV 6 (1966Ty01).

^a From Distorted Wave T-matrix Approximation analysis of the quasi-elastic scattering reaction mechanism in (1970We09).

$^{14}\text{N}(\text{d}, ^3\text{He})$

1968Ga13: $^{14}\text{N}(\text{d}, ^3\text{He})$ E=28 MeV; measured $\sigma(\theta)$ to g.s; DWBA analysis for comparison of (d, ^3He),(d,t) cross sections.

1968Hi01: $^{14}\text{N}(\text{d}, ^3\text{He})$ E=52 MeV; measured $\sigma(\text{E}(^3\text{He}),\theta)$, ^{13}C deduced levels, J, π , S. Natural targets.

1970PiZV: $^{14}\text{N}(\text{d}, ^3\text{He})$ E=20.13 MeV; measured $\sigma(\theta)$; deduced optical model parameters.

1974Lu06: $^{14}\text{N}(\text{pol. d}, ^3\text{He})$ E=15 MeV; measured $\sigma(\text{E}(^3\text{He}),\theta)$, A(θ). ^{13}C g.s. deduced S, J-dependence, J-admixtures. DWBA analysis. Natural, enriched targets.

1981Ma14: $^{14}\text{N}(\text{pol. d}, ^3\text{He})$ E=52 MeV; measured $i\text{T}_{11}(\text{E}(^3\text{He}),\theta)$ for $^{13}\text{C}^*(0,7.55 \text{ MeV})$. Enriched targets. DWBA, Nilsson model analyses.

 ^{13}C Levels

E(level)	J^π ^a	C ² S	Comments
0^b	$1/2^-$	0.63	L=1 (1974Lu06).
3.09×10^3 ^c			
3.68×10^3	$3/2^-$	0.16	E(level): The 3.85 MeV; $J^\pi=5/2^+$ state is not resolved from the 3.68 MeV state, but it is reasonable to assume only a small contribution to the 3.7 MeV group with regard to the weak excitation of the other positive-parity states (1968Hi01).
6.87×10^3 ^c		1.55	
7.55×10^3	$5/2^-$	0.63	
8.85×10^3	$1/2^-$		The sum of the cross section of the $^{13}\text{C}^*(8.85+9.51)$ states is identical with the angular distribution of the unresolved states that appear at $^{13}\text{N}^*(9.2)$.
9.51×10^3	$(3/2^-)$	0.13	J^π : $9/2^+$ is accepted in the Adopted Levels. J^π : In (1968Hi01), the known $^{13}\text{N}^*(8.9+9.4 \text{ MeV})$ states are unresolved, but their angular distributions and cross section sum are compared with the resolved $^{13}\text{C}^*(8.9+9.5 \text{ MeV})$ states. The authors first indicate the $^{13}\text{C}^*(9.5 \text{ MeV})$ state does not have a "pick-up pattern" as would be expected, and later they suggest a complex configuration that can explain the spectroscopic factor. The discussion shows reservations, and their conclusions are based on comparison with an unresolved group of states in ^{13}N .
11.90×10^3 15	$3/2^-$	0.95	

^a From comparison of (d, ^3He) and (d,t) mirror states in (1968Hi01) $\Delta\text{E} \approx 100 \text{ keV}$. C²S is from Figure 7 of (1968Hi01).

^b See also (1974Lu06). The spectroscopic factors, C²S, extracted for the reaction $^{14}\text{N}(\text{d}, ^3\text{He})^{13}\text{C}_{\text{g.s.}}$ agree within 5% to those for the reaction $^{14}\text{N}(\text{d}, \text{t})^{13}\text{N}_{\text{g.s.}}$.

^c Weakly populated.

$^{14}\text{N}(t,\alpha)$ **1962Si04**

1962Si04: $^{14}\text{N}(t,\alpha)$ E=2.6 MeV; α spectra were measured at $\theta_{\text{lab}}=30^\circ$ and 90° with a double-focusing magnetic spectrometer. ^{13}C levels up to 12 MeV were analyzed.

1964Sc09: $^{14}\text{N}(t,\alpha)$ E=1-2 MeV; measured differential cross sections for $^{13}\text{C}^*(0,3.085,3.680+3.850,6.868)$.

 ^{13}C Levels

E(level)	Γ^e	Comments
0		
3085 ^c		E(level): Reported (1962Si04,1964Sc09).
3680 ^{cd}		
3850 ^{cd}		
6868 ^c	<30 keV	
7498 ^{cd}		
7553 ^{cd}		
7680 ^{cd}		
8860 ^a 20	145 keV 20	
9509 ^b	<30 keV	
9897 ^b	<30 keV	
10736 ^a 20	<30 keV	
10809 ^a 20	<30 keV	
11000 ^a 20	<30 keV	
11078 ^a 20	<30 keV	
11721 ^a 30	125 keV 20	
12131 ^a 30	125 keV 30	

^a From (1962Si04).

^b Used as energy references for other E_x in (1962Si04).

^c Reported in (1962Si04,1964Sc09).

^d Unresolved.

^e From (1962Si04). Level widths have had an instrumental width of 65 keV unfolded from them and are estimated to be <30 keV where the instrumental width was dominant (1962Si04).

$^{15}\text{N}(p, ^3\text{He})$ 1968F103

1964Ce03,1966Ce02: $^{15}\text{N}(p, ^3\text{He})$ E=43.7 MeV; experiments were performed at the Berkeley 88-inch cyclotron. Emitted ^3He particles from a pure ^{15}N gas target were simultaneously detected by a (dE/dx)-E counter telescope which fed a particle identifier. The typical resolution (FWHM) is 150 keV.

1968F103: A 43.7-MeV proton beam has been used to induce (p,t) and (p, ^3He) reactions on a ^{15}N target. Transitions to mirror final states of ^{13}N and ^{13}C have been investigated over 15 MeV of excitation and several new spin and parity assignments have been made. The DWBA predictions of angular distributions for these $^{15}\text{N}(p,t)^{13}\text{N}$ and $^{15}\text{N}(p,^3\text{He})^{13}\text{C}$ reactions were generally found to reproduce experiment well. See also (1968F102).

1970Ha23: $^{15}\text{N}(\text{pol. } p, ^3\text{He})$ E=44 MeV; measured $\sigma(\theta)$, analyzing power(θ). ^{13}C transitions deduced L.

1974Ma12,1973MaZH: $^{15}\text{N}(p, ^3\text{He})$ E=43.8 MeV; measured $\sigma(E(^3\text{He}),\theta)$, $A(\theta)$. Analyzed $^{13}\text{C}^*(0,3.68,7.55,15.1)$, L.

1974Pi05: $^{15}\text{N}(p, ^3\text{He})$ E=20-45 MeV; measured $\sigma(E(^3\text{He}),\theta)$, deduced optical model parameters. ^{13}C levels deduced L, J, π .

1975Mi01: $^{15}\text{N}(p, ^3\text{He})$ E=26.8-43.1 MeV; measured $\sigma(E(^3\text{He}),\theta)$.

1982RaZU: $^{15}\text{N}(p, ^3\text{He})$ E=45 MeV; measured $\sigma(\theta)$.

 ^{13}C Levels

E(level) ^a	J ^{π} ^a	L ^{ac}	Comments
0	1/2 ⁻	0,2	E(level): Also reported in (1964Ce03, 1966Ce02, 1974Ma12, 1974Pi05, 1975Mi01, 1982RaZU).
3080 20	1/2 ⁺		
3680 ^b 10	3/2 ⁻	0,2	E(level): Also reported in (1964Ce03, 1966Ce02, 1974Ma12, 1974Pi05, 1975Mi01, 1982RaZU, 1970Ha23). Reported as a doublet by (1974Pi05); the 3.68 MeV gives the dominant contribution, see (1968F103).
6870 ^b 15	5/2 ⁺		
7550 20	5/2 ⁻	2	E(level): Also reported in (1964Ce03, 1966Ce02, 1974Ma12, 1974Pi05, 1975Mi01, 1982RaZU, 1970Ha23).
8860 ^d 60	1/2 ⁻	0,2	
9520 ^d 30	(3/2 ⁻)	2	J ^{π} : 9/2 ⁺ in Adopted Levels. Note: the authors were somewhat "puzzled" by the absence of the ^{13}N mirror in the (p,t) reaction and by this state's appreciable cross section. E(level),J ^{π} : From (1982RaZU).
10750	7/2 ⁻		
11090 50	(1/2 ⁻)	0,2	
11800 ^d 30	(3/2 ⁻)	0,2	
12400 ^d 50	7/2 ⁻	2	
15110 ^b 20	3/2 ⁻	2	T=3/2 (1968F103) E(level): See also E _x =15103 keV 45 (1964Ce05, 1966Ce02). E(level): Also reported in (1974Ma12, 1982RaZU).

^a From DWBA analysis of (p, ^3He) and (p,t) mirror partners and comparison of related differential cross sections (1968F103).

^b Considered known E_x in the energy analysis (1968F103).

^c From (1968F103,1974Ma12).

^d Also reported in (1982RaZU).

$^{15}\text{N}(\text{d},\alpha)$

- 1951Ma08: $^{15}\text{N}(\text{d},\alpha)$ E=1.4 MeV; measured Q values; deduced ^{13}C excited states.
- 1957Wa01: $^{15}\text{N}(\text{d},\alpha)$ E=14.8 MeV; α -particle groups corresponding to level energies in ^{13}C up to 9.9 MeV excitation were observed at $\theta=12.6^\circ, 18^\circ, 30^\circ$. Reported $d\sigma/d\Omega(18^\circ)$ for all states.
- 1958Fi27,1959Fi30: $^{15}\text{N}(\text{d},\alpha_0)$ E=21 MeV; measured $\sigma(\theta)$ for $\theta_{\text{c.m.}}=-20^\circ$ to 140° . The angular distribution of the ground-state α particles shows a relative maximum at $\theta_{\text{c.m.}}=70^\circ$.
- 1961Ja23: $^{15}\text{N}(\text{d},\alpha)$; deduced $Q_0=7675$ keV 9 and $E_x=3100$ keV 20 and 3695 keV 10 for the 1st and the 2nd excited states, respectively.
- 1961Lo10: $^{15}\text{N}(\text{d},\alpha)$; the reaction was studied at $\theta_{\text{lab}}=90^\circ$, measured Q_0 value of 7675 keV 9. See also (1961Lo02).
- 1965Ma59: $^{15}\text{N}(\text{d},\alpha_{0,1})$ E=1.2-2.5 MeV; measured $\sigma(\theta)$ for $\theta_{\text{lab.}}=30^\circ$ to 150° .
- 1966St16: $^{15}\text{N}(\text{d},\alpha_0)$ E=1.0-1.2 MeV; measured the angular distributions of the α particles.
- 1968Pr04: $^{15}\text{N}(\text{d},\alpha_{0,1})$ E=20.9 MeV; measured the angular distributions of the α particles for $\theta_{\text{c.m.}}=20^\circ$ to 110° .
- 1974WeZT: $^{15}\text{N}(\text{d},\alpha)$; measured $\sigma(E\alpha)$. ^{13}C deduced levels.
- 1976Ca28: $^{15}\text{N}(\text{d},\alpha_{0,1})$ E<3 MeV; measured $\sigma(E,E\alpha,\theta)$ for $\theta=71^\circ$ to 146° .
- 1986Sa41: $^{15}\text{N}(\text{d},\alpha_0)$ E=804 keV-1.2 MeV; measured products, ^{13}C deduced $\sigma(\theta=150^\circ)$.
- 1996Vi12: $^{15}\text{N}(\text{d},\alpha_0)$ E=0.4-2 MeV; measured $\sigma(E,\theta)$ for $\theta_{\text{c.m.}}=85^\circ$ to 160° . Comparison with earlier results.

 ^{13}C Levels

E(level) ^a	L	Comments
0	2	E(level): See (1951Ma08, 1957Wa01, 1958Fi27, 1959Fi30, 1961Ja23, 1961Lo10, 1966St16, 1968Pr04, 1976Ca28, 1986Sa41, 1996Vi12). $Q_0=7681$ keV 6 (1951Ma08), 7675 keV 9 (1961Ja23,1961Lo10). L: See (1968Pr04).
3084 5		E(level): Weighted average of 3083 keV 5 (1951Ma08) and 3100 keV 20 (1961Ja23); see also (1957Wa01,1968Pr04,1976Ca28). $Q_1=4598$ keV 4 (1951Ma08).
3681 7		E(level): Weighted average of 3677 keV 5 (1951Ma08) and 3695 keV 10 (1961Ja23); see also (1957Wa01,1976Ca28). $Q_2=4004$ keV 3 (1951Ma08).
3860		E(level): See (1957Wa01,1976Ca28).
6870		
7470 ^b		
7530 ^b		
7640 ^b		
8800 40		
9500		
9900		

^a Values listed in (1957Wa01) except where noted.^b Unresolved triplet.

$^{16}\text{O}(\text{n},\alpha),(\text{n},\alpha\gamma)$

- 1952Li24: $^{16}\text{O}(\text{n},\alpha)$ E=14.1 MeV; measured products, ^4He ; deduced σ , $\sigma(E)$. $^{13}\text{C}^*(3.0,3.7 \text{ MeV})$ states are found.
- 1961Ci01: $^{16}\text{O}(\text{n},\alpha_0)$ E=14.4 MeV; measured angular distributions.
- 1963Da12: $^{16}\text{O}(\text{n},\alpha_0)$ E=5.0-8.8 MeV; $^{16}\text{O}(\text{n},\alpha_1)$ E=7.6-8.7 MeV; $^{16}\text{O}(\text{n},\alpha_{2,3})$ E=8.1-8.7 MeV; measured $\sigma(E)$.
- 1963Se08: $^{16}\text{O}(\text{n},\alpha)$ E=14 MeV; measured α -particle angular distributions $\sigma(E,\theta)$.
- 1965Ch13: $^{16}\text{O}(\text{n},\alpha)$ E=14.5 MeV; measured $\sigma(E_\alpha,\theta)$. This reaction leading to about 4 MeV excitation of ^{13}C has been studied.
- 1966Mc14: $^{16}\text{O}(\text{n},\alpha_0)$ E=14.1 MeV; measured $\sigma(E_\alpha,\theta)$, the absolute differential cross sections for the transitions to the $^{13}\text{C}_{\text{g.s.}}$ Natural targets.
- 1967Hs04: $^{16}\text{O}(\text{n},\alpha)$ E=14.1 MeV; measured $\sigma(E_\alpha,\theta)$. The angular distributions of the α -particle groups leading to $^{13}\text{C}^*(0,3.08 \text{ and } 3.68+3.85 \text{ MeV})$ are observed. Natural target.
- 1968Le11: $^{16}\text{O}(\text{n},\alpha)$ E=14.9 MeV; measured $\sigma(E_\alpha,\theta)$. The angular distributions have been obtained from 20° to 160° for the transitions $^{16}\text{O}(\text{n},\alpha_0)^{13}\text{C}$ and are compared to the predictions of direct interaction mechanisms. Natural targets.
- 1968Ma10: $^{16}\text{O}(\text{n},\alpha)$ E=14.1 MeV; measured $\sigma(E_\alpha,\theta)$. Absolute differential cross sections were measured for the (n,α) transitions to the ground state of ^{13}C and to an unresolved triplet of known levels at $E_x=3.09, 3.68$ and 3.86 MeV . Natural target.
- 1968Si06: The differential cross section of $^{16}\text{O}(\text{n},\alpha_0)$ and $^{16}\text{O}(\text{n},\alpha_{1+2+3})$ has been measured at $28 E_n$ energies between 14.8 and 18.8 MeV with 60 keV energy spread at $\theta=0^\circ-156^\circ$.
- 1969AjZZ,1970Aj03: $^{16}\text{O}(\text{n},\alpha)$ E=14 MeV; measured $\sigma(E_\alpha,\theta)$. Angular distributions of the unresolved group of α -particles corresponding to three levels of ^{13}C at $E_x=3.09, 3.68$ and 3.86 MeV were measured.
- 1970Br17,1971Br33,1972Br50: $^{16}\text{O}(\text{n},\alpha)$ E=13.9 MeV; measured $\sigma(E_n;\theta=0^\circ)$.
- 1971Ny03: $^{16}\text{O}(\text{n},\alpha\gamma)$ E=15 MeV; measured E_γ , $\sigma(E_\gamma)$. ^{13}C , deduced levels from $E_\gamma=3.685 \text{ MeV } 3$ and $3.855 \text{ MeV } 3$.
- 1972Ki12: $^{16}\text{O}(\text{n},\alpha)$ E=4.9 MeV; measured $\sigma(\theta)$.
- 1973Bo26: $^{16}\text{O}(\text{n},\alpha)$ E=14.1 MeV; measured $\sigma(E_\alpha,\theta)$. The angular distributions of the α_0 and α_{1+2+3} groups for this reactions have been measured.
- 1978No04: $^{16}\text{O}(\text{n},\alpha\gamma)$ E=7-10.5 MeV; measured $\sigma(E,E_\gamma)$. The production of 3.09 and $3.68+3.85\text{-MeV}$ gamma rays has been studied.
- 2008GiZY: $^{16}\text{O}(\text{n},\alpha_0)$ E=3.95-9 MeV; measured E_α , I_α ; deduced $\sigma(E^*)$.
- 2001Ne09: $^{16}\text{O}(\text{n},\alpha\gamma)$ E=4-200 MeV; measured E_γ , I_γ , photon production $\sigma(E)$, $\sigma(\theta)$. Comparison with model calculations, previous measurements.
- 2011KhZW: $^{16}\text{O}(\text{n},\alpha_0)$ E=5.2-6.2 MeV; deduced σ .
- 2023PaZV: Description of the GELINA NTOF facility at Geel.

Theory:

- 1989Br05: $^{16}\text{O}(\text{n},\alpha)$ E=15-60 MeV; calculated $\sigma(\theta_1,E_1)$.
- 1995Ch84: $^{16}\text{O}(\text{n},\alpha)$ E=6.2-10.5 MeV; analyzed σ , $\sigma(\theta)$.
- 2008VaZT: $^{16}\text{O}(\text{n},\alpha)$ E \approx 3-10 MeV; calculated σ ; evaluated σ .
- 2020FIZY: $^{16}\text{O}(\text{n},\alpha)$ E<20 MeV; analyzed available data; deduced recommended σ .
- 2021Pr01, 2022Pr01: Deduced $^{16}\text{O}(\text{n},\alpha_0)$ by analyzing $^{13}\text{C}(\alpha,\text{n})$ for $E_\alpha=2.0\text{-}6.2 \text{ MeV}$.
- 2022Ab20: $^{16}\text{O}(\text{n},\alpha)$; analyzed (n,α) data from reactions on 133 targets listed in EXFOR; developed semi-empirical formula for cross sections. Compared with other σ models.
- 2023Pa09: Global analysis on (n,α) systematics and reaction mechanism.

 ^{13}C Levels

E(level)	J^π ^a	$T_{1/2}$ or Γ ^b	Comments
0	$1/2^-$		E(level): Reported in (1961Ci01, 1966Mc14, 1967Hs04, 1968Le11, 1968Ma10, 1968Si06, 1971Br33, 1973Bo26, 2008GiZY, 2011KhZW, 2012Kh05).
3090 ^c	$1/2^+$	1.07 fs	E(level): Reported in (1952Li24, 1967Hs04, 1971Br33).
3686 ^{cd} 3	$3/2^-$	1.10 fs	E(level): Derived from γ -ray measurements (1971Ny03); also reported in (1952Li24).
3856 ^{cd} 3	$5/2^+$	8.60 ps	E(level): Derived from γ -ray measurements (1971Ny03).
8860	$1/2^-$	150 keV	E(level): Reported in (2001Ne09).

^a From Adopted Levels.

$^{16}\text{O}(\text{n},\alpha),(\text{n},\alpha\gamma)$ (continued)

^{13}C Levels (continued)

^b Listed in (2001Ne09).

^c Also reported in (1968Ma10, 1968Si06, 1970Aj03, 1973Bo26: unresolved triplet).

^d Also reported in (1967Hs04, 1971Br33: unresolved doublet).

$\gamma(^{13}\text{C})$

E_γ	I_γ^a	$E_i(\text{level})$	J_i^π	E_f	J_f^π	Comments
169	58.4 12	3856	5/2 ⁺	3686	3/2 ⁻	E_γ : Measured in (2001Ne09). I_γ : From (2001Ne09).
764	1.4 4	3856	5/2 ⁺	3090	1/2 ⁺	E_γ : Measured in (2001Ne09). I_γ : From (2001Ne09).
3090		3090	1/2 ⁺	0	1/2 ⁻	E_γ : Measured in (2001Ne09); observed in (1978No04).
3685 3		3686	3/2 ⁻	0	1/2 ⁻	E_γ : Measured in (1971Ny03); see also (2001Ne09).
3855 3	100.0 15	3856	5/2 ⁺	0	1/2 ⁻	E_γ : Measured in (1971Ny03); see also (2001Ne09). I_γ : From (2001Ne09).
8857		8860	1/2 ⁻	0	1/2 ⁻	E_γ : Measured in (2001Ne09).

^a Relative intensities.

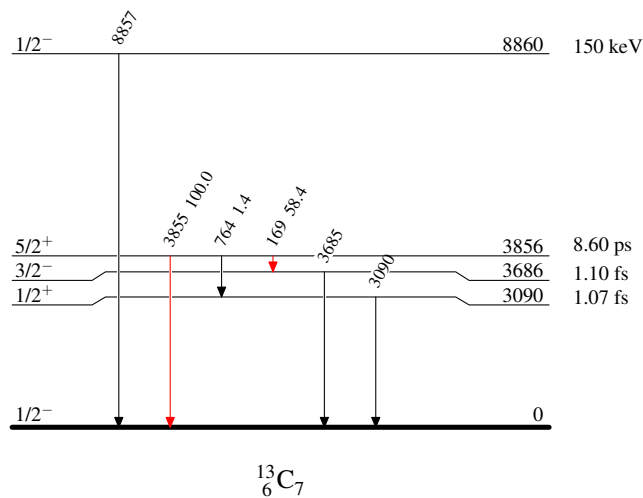
$^{16}\text{O}(\text{n},\alpha),(\text{n},\alpha\gamma)$

Level Scheme

Intensities: Relative I_γ

Legend

- $I_\gamma < 2\% \times I_\gamma^{\text{max}}$
- $I_\gamma < 10\% \times I_\gamma^{\text{max}}$
- $I_\gamma > 10\% \times I_\gamma^{\text{max}}$



$^{16}\text{O}(\text{p},\text{p}^3\text{He})$

1973Be36: $^{16}\text{O}(\text{p},\text{p}^3\text{He})$ E=29, 39 and 62 MeV; analyzed particle knockout systematics.

1975Gr40, 1977Gr04: $^{16}\text{O}(\text{p},\text{p}^3\text{He})$ E=75 MeV; also $^{12}\text{C}(\text{p},\text{p}^3\text{He})$ measured p^3He -coin; compared reaction on ^{12}C and ^{16}O , deduced S. Indicate the reaction mechanism is more complex than quasifree knockout.

 ^{13}C Levels

<u>E(level)</u>	<u>J^{π^a}</u>	<u>L^a</u>	<u>S^a</u>
0	$1/2^-$	1	1.57
3090	$1/2^+$		
3680	$3/2^-$	1	2.29
3850	$5/2^+$		
7600 ^b			

^a From DWIA analysis of spectroscopic factors in (1975Gr40,1977Gr04). S is normalized to the predicted spectroscopic factor of the $^{12}\text{C} \rightarrow ^9\text{B}_{\text{g.s.}}$ transition.

^b Some states are not associated with Adopted Levels because inadequate details for association are given in the literature.

 ${}^{16}\text{O}(\alpha, \alpha^3\text{He})$ [1982Sa24](#)

[1982Sa24](#): ${}^{16}\text{O}(\alpha, \alpha^3\text{He})$ E=139.2 MeV; measured $\sigma(E_\alpha, E_{3\text{He}}, \theta_\alpha, \theta_{3\text{He}})$. Deduced L, S. DWIA analysis. see also ([1982SaZU](#)).

 ${}^{13}\text{C}$ Levels

<u>E(level)</u>	<u>J^{π}^a</u>	<u>L^a</u>	<u>S^a</u>
0	1/2 ⁻	1	55
3680	3/2 ⁻		

^a From DWIA analysis in ([1982Sa24](#)).

 ${}^{20}\text{Ne}(n,2\alpha)$ **1971Ka18**

1966Pe08: ${}^{20}\text{Ne}(n,2\alpha)$ E=14.2 MeV; gas-chamber study; analyzed Q.

1971Ka18: ${}^{20}\text{Ne}(n,2\alpha)$ E=14.3 MeV; ionization chamber active target; measured Q.

 ${}^{13}\text{C}$ Levels

<u>E(level)</u>	<u>Cross Section (mb)</u>	<u>Comments</u>
0	41.8 <i>8I</i>	Q ₀ =-7.00 MeV 2 (1971Ka18); see also Q=-6.94 MeV (1966Pe08). Cross Section (mb): (1971Ka18 : relative to ${}^{12}\text{C}(n,\alpha_0)=76$ mb <i>II</i>).

 ${}^{93}\text{Nb}({}^{12}\text{C}, {}^{13}\text{C})$ **2020Na24**

2020Na24: ${}^{93}\text{Nb}({}^{12}\text{C}, {}^{13}\text{C})$ E=65 MeV; measured kinetic-energy spectra of projectile-like fragments (PLFs) and target-like fragments (TLFs), $\sigma(\theta)$ of PLF and TLF fragments for $\theta \approx 20^\circ$ to 80° ; deduced spectroscopic factors and other structure data.

 ${}^{13}\text{C}$ Levels

<u>E(level)^a</u>	<u>J^{π}^a</u>	<u>S^a</u>
0	1/2 ⁻	0.274
3680	3/2 ⁻	1.750

^a From the FRESKO coupled reaction-channels analysis of (2020Na24).

$^{159}\text{Tb}(^{19}\text{F}, ^{13}\text{C}), ^{154}\text{Sm}(^{16}\text{O}, ^{13}\text{C})$ 1986So10

1986So10: $^{159}\text{Tb}(^{19}\text{F}, ^{13}\text{C})$ E=181 MeV at the ORNL/HHIRF; measured $^{13}\text{C}+\gamma$ -coin for γ rays detected in the ORNL spin spectrometer and for ^{13}C detected in Si $\Delta\text{E-E}$ charged particle telescopes at $\theta=20^\circ$ and 30° . Deduced particle-bound ejectile yields; excited state population. Discussed reaction temperature.

2022Ro09: $^{154}\text{Sm}(^{16}\text{O}, ^{13}\text{C}_{\text{g.s.}})$ E=85 MeV; measured reaction products using a $\Delta\text{E-E}$ telescope at the Bhabha Atomic Research Centre in Mumbai. Obtained differential cross sections for $\theta_{\text{c.m.}} \approx 55^\circ$ to 75° . Discussed multi-nucleon transfer reaction mechanism.

 ^{13}C LevelsE(level)^a

0
3090
3680

^a From 1986So10.

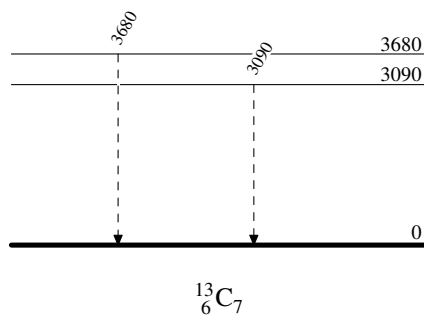
 $\gamma(^{13}\text{C})$

<u>E_γ^a</u>	<u>$E_i(\text{level})$</u>	<u>E_f</u>
(3090)	3090	0
(3680)	3680	0

^a From level-energy difference.

 $^{159}\text{Tb}(^{19}\text{F}, ^{13}\text{C}), ^{154}\text{Sm}(^{16}\text{O}, ^{13}\text{C})$ 1986So10

Legend

Level Scheme-----► γ Decay (Uncertain)

$^{165}\text{Ho}(^{14}\text{N},n)^{12}\text{C}$

[1987Ki05](#): $^{165}\text{Ho}(^{14}\text{N},n)^{12}\text{C}$ E=490 MeV at the MSU/NSCL; measured $^{12}\text{C}+n$ relative velocity spectra for colinear events along $\theta=10^\circ$ and 30° . Neutrons were measured using NE 213 scintillators while Si ΔE -E telescopes measured the ^{12}C ions. Deduced levels, Γ .

 ^{13}C Levels

<u>E(level)</u>	<u>Γ</u>	<u>Comments</u>
6864	6 keV	E(level), Γ : From (1987Ki05). $^{13}\text{C}^*(6864)\rightarrow n+^{12}\text{C}_{\text{g.s.}}$ with $E_{\text{decay}}=1.918$ MeV.
9500	5 keV	E(level), Γ : From (1987Ki05). $^{13}\text{C}^*(9500)\rightarrow n+^{12}\text{C}^*(4439)$ with $E_{\text{decay}}=0.114$ MeV.

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