^{13}C(e,e),(e,e′),(e,e′p)

History

Type	Author	Citation	Literature Cutoff Date
Full Evaluation	J. H. Kelley, C. G. Sheu and J. E. Purcell	NDS 198,1 (2024)	1-Aug-2024

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

Theory:
1972ThZF: ^{13}C(e,e′); compiled spectroscopic data.
1973Fe13: ^{12}C(e,e); analyzed data. ^{13}C rms radius was deduced from ^{12}C rms radius.
1973Ga19: ^{13}C(e,e′); calculated form factors, radii.
1974Be10: ^{13}C(e,e); calculated form factors.
1979Se06: ^{13}C(pol. e,e′) E=30,200 MeV/c,1 GeV/c; calculated σ(θ); deduced one-body transition densities.
1980Er01: ^{13}C(e,e′) E=70 MeV; calculated σ(Ee′); deduced giant M2 resonance, configuration, isospin splitting. Shell model.
1981De07: ^{13}C(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}C(e,e′); analyzed reaction data; deduced Majorana force role in GDR configuration splitting.
1981Li13: ^{13}C(e,e′); calculated M1 form factors. Nilsson model.
1981Su03: ^{13}C(e,e), calculated M1 form factors; deduced core polarization effects. Cohen-Kurath wave functions, one pion exchange currents.
1981Su08: ^{13}C(e,e); calculated M1 form factors. Core polarization.
1982Ch16: ^{13}C(e,e′); calculated transverse form factor. Cohen-Kurath wave function, DWIA model.
1983Ch15: ^{13}C(e,e),(e,e′); calculated transverse form factors.
1983Ma40: ^{13}C(e,e′); calculated transverse form factors; deduced pion wave distortion dependence, reaction dependent sensitivity to nuclear wave function.
1983Su10: ^{13}C(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}C(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.

^{13}C(e,e),(e,e′),(e,e′p) (continued)

1984Li25: ^{13}C(e,e′) E=196.5-225 MeV; analyzed σ(Ee′,θe′). The M4 strength in ^{13}C*(21.4 MeV) was reported. Since $^{13}C_{g.s.}$ neither has zero angular momentum nor zero isospin, J$^{\pi}$=7/2^{+} or 9/2^{+} and T=3/2 or 1/2 (1980Le17: ^{13}C(π,π); shell model calculation) this M4 transition poses a strong theoretical challenge.
1984LiZX: ^{13}C(e,e); calculated M1 form factor; deduced core deformation effects.
1985Hi04: ^{13}C(e,e),(e,e′); calculated form factors.
1985Sa06: ^{13}C(e,e′); calculated M1, E2 form factors.
1985Si05: ^{13}C(e,e),(e,e′); calculated form factors; deduced configuration mixing effects.
1986AmZX: ^{13}C(e,e′); analyzed form factors, $\sigma(\theta)$; deduced structure effects.
1986Do11: ^{13}C(pol. e,e),(pol. e,e′) E=400 MeV; calculated asymmetry, polarization ratio vs momentum transfer.
1987De43: ^{13}C(e,e); compilation of nuclear charge-density-distribution parameters.
1989Am02: ^{13}C(e,e′); calculated form factors.
1990Wo10: ^{13}C(e,e′); calculated form factors. Effective interactions, (0+2)$\hbar\omega$ space.
1991Be40: ^{13}C(e,e); analyzed longitudinal, transverse form factors. ^{13}C deduced single particle radial functions, virtual p-, n-decay vertex constants.
1991Er06: ^{13}C(e,e′); calculated longitudinal, transverse form factors.
1994Am01: ^{13}C(pol. e,e); calculated magnetic and Coulomb form factors, response functions. Meson exchange effects, polarized target.
1994Ch03: ^{13}C(e,e); analyzed charge form factor. Phenomenological, microscopic models, beam linear polarization.
1994Mo19: ^{13}C(e,e′); calculated response functions. Shell model wave functions, meson exchange effects, different target polarizations.
1997Ga31: ^{13}C(e,e); analyzed form factors; deduced meson exchange currents role. Calculated wavefunctions, potentials, binding energies, resonance E, Γ. Astrophysical processes discussed.
2023Sa29: ^{13}C(e,e),(e,e′); analyzed evidence for α clustering in ^{12,13}C.

^{13}C 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$^{\pi}$†	Γ	Multipolarity†	Comments
0	1/2^{-}			T=1/2 (1967Pe07,1989Mi01) J$^{\pi}$: From (1967Pe07,1989Mi01). The ^{13}C rms nuclear charge radius $<r^2>^{1/2}_{Ch.}$=2.384 fm *47* and the charge radius ratio $R_{Ch.}$(^{13}C/^{12}C)=0.995 *8* (1971Be25); $R_{Ch.}$(^{13}C/^{12}C)=0.975 *2* (1971Ya02); $<r^2>^{1/2}_{Ch.}$(^{13}C)=2.452 fm *47* (1973Fe13: relative to $<r^2>^{1/2}_{Ch.}$(^{12}C)=2.462 fm *22*). The magnetic rms radius is $<r^2>^{1/2}_{M}$=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$^{\pi}$: From (1970Wi04,1989Mi01). Multipolarity: From (1970Wi04,1987Hi09,1989Mi01). Γ: From (1975Ra22). $\Gamma_{\gamma0}$=0.68 eV *23*; $\Gamma_{\gamma0}/\Gamma_W$(E1)=0.62 W.u. (1970Wi04). B(C1,↑) W.u.=0.047 *5* (1989Mi01). A priv. comm. with D.J. Millener (DJM), see Table 13.12 in (1991Aj01), indicates $\Gamma_{\gamma0}$=0.52 eV and B(E1,↓) 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‡	T=1/2 (1971Ya02,1989Mi01)

Continued on next page (footnotes at end of table)

^{13}C(e,e),(e,e′),(e,e′p) (continued)

^{13}C Levels (continued)

E(level)	J^{π} †	Γ	Multipolarity†	Comments
				E(level): From (1969Wi22,1970Wi04). J^{π}: From (1969Wi22,1970Wi04,1971Ya02,1989Mi01,1992Co07). Multipolarity: From (1969Wi22,1970Wi04,1989Mi01); see also (1992Co07: M1). Multipolarity: MR (δ)=0.100 *8* from (1969Wi22,1970Wi04). $\Gamma_{\gamma0}$(M1)=0.36 eV *5*; $\Gamma_{\gamma0}$(E2)=3.6×10^{-3} eV *4*; $\Gamma_{\gamma0}$(M1)/Γ_W=0.339 W.u.; $\Gamma_{\gamma0}$(E2)/Γ_W=3.52 W.u. (1969Wi22,1970Wi04). B(M1,↑) W.u.=0.57 *6*=1.02 μ_N^2 *11* (1992Co07: transition radius=2.48 fm *19*). B(C2,↑) W.u.=7.1 *3* (1989Mi01).
3850	5/2+		M2+E3	E(level),J^{π}: From (1970Wi04,1989Mi01,1992Co07). Multipolarity: From (1989Mi01). B(M2,↑) W.u.=0.64 *25*=5.8 μ_N^2fm^2 *22* (1992Co07: transition radius=1.7 fm *11*; alternate B(M2,↑) W.u.=1.16 *20*=10.5 μ_N^2fm^2 *10* with fixed transition radius 3.2 fm). B(C3,↑) W.u.=3.9 *3* (1989Mi01). A priv. comm. with D.J. Millener (DJM), see Table 13.12 in (1991Aj01), indicates $\Gamma_{\gamma0}$=6×10^{-8} eV and B(C3,↓) W.u.=1.3 *2*: see comment on ^{13}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). $\Gamma_{\gamma0}$(M2)=6.9×10^{-5} eV *36*; $\Gamma_{\gamma0}$(M2)/Γ_W=0.055 W.u. (1969Wi22,1970Wi04). B(C3,↑) W.u.=0.32 *9* (1989Mi01). A priv. comm. with D.J. Millener (DJM), see Table 13.12 in (1991Aj01), indicates $\Gamma_{\gamma0}$=3×10^{-7} eV and B(C3,↓) W.u.=0.10 *6*: see comment on ^{13}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). $\Gamma_{\gamma0}$(E2)=0.115 eV *7*; $\Gamma_{\gamma0}$(M3)=1.01×10^{-5} eV *61*; $\Gamma_{\gamma0}$(E2)/Γ_W=3.15 W.u.; $\Gamma_{\gamma0}$(M3)/Γ_W=35 W.u. (1969Wi22,1970Wi04). B(C2,↑) 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). $\Gamma_{\gamma0}$(E0)=2.09 fm^2 *38* (monopole matrix element in fm^2); $\Gamma_{\gamma0}$(M1)=3.4 eV *5*; $\Gamma_{\gamma0}$(M1)/Γ_W=0.23 W.u. (1969Wi22,1970Wi04). B(C0,↑) 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).

Continued on next page (footnotes at end of table)

^{13}C(e,e),(e,e′),(e,e′p) (continued)

^{13}C Levels (continued)

E(level)	J^{π}†	Γ	Multipolarity†	Comments
				Multipolarity: In (1986Hi06) the electromagnetic components were deduced from the transverse form factors. Only an upper limit on electromagnetic strength was obtained, consistent with expectations for E5. B(M4,↑) W.u.=77 *3* (1989Mi01).
9900 *30*	$3/2^-$		M1+E2‡	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). $\Gamma_{\gamma 0}$(M1)=0.32 eV *5*; $\Gamma_{\gamma 0}$(E2)=6.3×10^{-3} eV *21*; $\Gamma_{\gamma 0}$(M1)/Γ_W=0.0159 W.u.; $\Gamma_{\gamma 0}$(E2)/Γ_W=0.045 W.u. (1969Wi22,1970Wi04). B(C2,↑) W.u.=0.11 *2* (1989Mi01).
10460?	$5/2^+$		M2+E3	E(level),J^{π},Multipolarity: From (1989Mi01).
10860				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. $\Gamma_{\gamma 0}$(E0)=2.6 fm^2 *3* (monopole matrix element in fm^2); $\Gamma_{\gamma 0}$(M1)=1.0 eV *2*; $\Gamma_{\gamma 0}$(M1)/Γ_W=0.0359 (1969Wi22,1970Wi04).
11750	$3/2^-$		M1	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). $\Gamma_{\gamma 0}$(M1)=3.45 eV *86*; $\Gamma_{\gamma 0}$(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‡	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). $\Gamma_{\gamma 0}$(M1)= 25 eV *7* (1967Pe07), $\Gamma_{\gamma 0}$(M1)=22.7 eV *27*; $\Gamma_{\gamma 0}$(E2)=0.59 eV *11*; $\Gamma_{\gamma 0}$(M1)/Γ_W=0.313 W.u.; $\Gamma_{\gamma 0}$(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).

Continued on next page (footnotes at end of table)

^{13}C(e,e),(e,e′),(e,e′p) (continued)

^{13}C Levels (continued)

E(level)	J$^{\pi}$ †	Γ	Multipolarity †	Comments
				J$^{\pi}$,Multipolarity: From (1986Hi06).
16183? *28*		40 keV *20*		E(level),Γ: From (1989Mi01); see also E_x=16200 keV, Γ=300 keV (1971Be51).
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, Γ=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 Γ≈3 MeV and a higher structure centered around 24.5 MeV with Γ≈ 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$^{\pi}$: 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).

† Deduced from fits to the experimental longitudinal and transverse form factors. The Eλ and Mλ components are obtained from the transverse form factors, whilst the Cλ components are obtained from the longitudinal form factors and have a non-trivial relation to the Eλ components. J is deduced from the Eλ and Mλ components.

‡ In some cases, mixing ratios have been obtained from the B(Eλ) and B(Mλ) strengths. These are listed amongst the level properties since no γ rays are reported in these experiments.