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

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

1959Fu62: ^{13}C(α,α') E=20 MeV; scattering angle θ=45°, ^{13}C*(3.7 MeV) observed.
1960St02: ^{13}C(α,α'); measured not abstracted; ^{13}C deduced nuclear properties.
1963Ba05: ^{13}C(α,α'); measured not abstracted; deduced nuclear properties.
1966Ha19: ^{13}C(α,α'),(α,α') E=40.5 MeV; angular distributions were measured for a large number of excited states of ^{13}C.
1967Ar17: ^{13}C(α,α'),(α,α') E=33.4 MeV; angular distributions of elastic and inelastic scatterings were measured.
1971Co14: ^{13}C(α,α') E=15,18,20,28.4 MeV; measured $\sigma(\theta)$; deduced optical model parameters. Enriched targets.
1972Ku19,1974Ch58,1974Ku15: ^{13}C(α,α') E=26.6 MeV; measured $\sigma(\theta)$.
1973Ku18: ^{13}C(α,α') E=18,19,22,24,25,26.6 MeV; measured σ(E;θ); deduced reaction mechanism.
1974Fe08: ^{13}C(α,α'),(α,α') E=24 MeV; measured $\sigma(E_{\alpha'},\theta)$.
1976Ja17: ^{13}C(α,α') E=65 MeV; measured $\sigma(\theta)$.
1976Pa05: ^{13}C(α,α') E=30.9, 50.5 MeV; analyzed deformation.
1980Fu04: ^{13}C(α,α') E=22,36 MeV; measured $\sigma(E_\alpha,\theta)$. The line shape of the ^{13}C*(7.686 MeV;3/2$^+$) resonance is measured. Enriched target.
1981Pe08: ^{13}C(α,α') E=35.5 MeV; measured $\sigma(E_\alpha,\theta)$. ^{13}C levels deduced isoscalar, isovector transition amplitude ratio. DWBA, CCBA analyses.
1983Pi07: ^{13}C(α,$\alpha'\gamma$) E=32 MeV; measured E_γ, I_γ. Low energy prompt γ measurement technique.
1984De44: ^{13}C(α,α') E=24-35 MeV; measured α(^{12}C)(θ,ϕ). ^{13}C level deduced substate population probabilities.
1984DeZR: ^{13}C(α,α') E not given; measured (recoil nucleus)(α)-coin. ^{13}C levels deduced Γ_γ/Γ.
1985De11: 13C(α,$\alpha'\gamma$) E=24 MeV; measured E_γ, I_γ, recoil. ^{13}C levels deduced Γ_γ/Γ.
1987Ab03: ^{13}C(α,α_0) E=48.7, 54.1 MeV; measured $\sigma(\theta)$. ΔE-E telescopes. Optical model analyses.
1987Bu27: ^{13}C(α,α') E=50.5 MeV; measured σ.
1993AtZZ: ^{13}C(α,α') E=54.1,104,155 MeV; ^{13}C(α,α') E=54.1,104,155 MeV; measured Σ(E,θ); deduced model parameters. ^{13}C levels deduced B(λ). Coupled-channels analysis.
2001He22: ^{13}C(α,α') E=2.6-6.2 MeV; measured $\sigma(\theta)$.
2002Ar16: ^{13}C(α,α'),(α,α') E=25.5-35.15 MeV; measured elastic and inelastic $\sigma(\theta)$, excitation functions. Comparison with model predictions.
2006SaZP,2007SaZS: ^{13}C(α,α') E=400 MeV; measured E_α, I_α; deduced $\sigma(\theta)$, B(E0), B(E2), level properties: J, π.
2008He11: ^{13}C(α,α') E=2.6-6.2 MeV; measured radii, σ, $\sigma(\theta)$, S-factor.
2008Ka44: ^{13}C(α,α') E=388 MeV; measured E_α, I_α; deduced $\sigma(\theta)$, B(E0). Comparison with DWBA calculations.
2010KaZO,2010KaZZ: ^{13}C(α,α') E=388 MeV; measured E_α, $I_\alpha(\theta)$; deduced d$\sigma(\theta)$ to individual states, B(E0).
2014DeZW: ^{13}C(α,α') 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}C(α,α') E=65,90 MeV; measured reaction products; deduced $\sigma(\theta)$, rms radii. Comparison with available data.
2016Bu24: ^{13}C(α,α') E=26.6-65 MeV; measured reaction products, E_α, I_α; deduced $\sigma(\theta)$, optical model and semi-microscopic parameters.
2016DeZX: ^{13}C(α,α),(α,α') 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^π=1/2$^-$ 8.86 MeV state (diluted cluster) and of J^π=3/2$^-$ 9.90 MeV state (compact cluster).
2018Bu05: ^{13}C(α,α),(α,α') 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}C*(3.09, 8.86 MeV) are determined using Modified Diffraction Model (MDM) and are larger than that of the $^{13}C_{g.s.}$, 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}C*(9.9 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}C(α,α') E=388 MeV; measured E_α, $\sigma(\theta)$, deduced L, J, π.
2021De32: ^{13}C(α,α') E=65 and 90 MeV; measured angular distributions for θ=5° to 72° and 6°−40°, respectively. Searched for evidence of a Hoyle state analog in ^{13}C. Analyzed data for ^{13}C*(9.9, 11.080) and deduced radii.
2021In04: ^{13}C(α,α') E=388 MeV; measured E_α, $\sigma(\theta)$ for $\theta\approx$0° to 20.2° at the RCNP/Osaka using the Grand Raiden spectrometer. Populated states up to E_x=16 MeV, DWBA analysis focused mainly on E_x=10.5-13 MeV in a search for α

^{13}C(α,α),(α,α′),(α,α′γ) (continued)

condensate states. Deduced isoscalar transition strengths. In addition to known states, a state at E_x=12.06 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. ΔL=1 states are reported at E_x=14.5 and 16.1 MeV; authors suggest the 16.1 MeV state is a candidate for the α condensate state. Find related discussion in (2008To18).

2022Go16: ^{13}C(α,α′) E=65, 90 MeV; measured E_α, σ(θ) for for $\theta_{c.m.}$≈8° to 65° and for states up to E_x≈11.8 MeV at the University of Jyvaskyla. Semi-Microscopic Dispersive Optical Model analysis. Mainly discussed scattering to $^{13}C^*$(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}C(α,α′) E=20,25 MeV; analyzed interference between states of transferred nucleus.
1974Ch58: ^{13}C(α,α′) E=26.6 MeV; analyzed σ(θ). The calculated and experimental angular distributions for (α,α′) transitions to the $^{13}C_{g.s.}$ state are discussed.
1977Sa19: ^{13}C(α,α′) E=40.5 MeV; calculated σ(θ) at forward angles.
1978Ze03: ^{13}C(α,α′) E=26.6 MeV; calculated σ(θ).
1983Go27: ^{13}C(α,α′) E=26.6; calculated σ(θ); deduced spin-orbit potential effects.
1988Le05: ^{13}C(α,α′)′ calculated resonances, Γ, α-particle strength distribution. Optical model.
1990Mu19: ^{13}C(α,α′) E=65 MeV; analyzed σ(θ); deduced model parameters. Microscopic overlap integrals, vertex form factors.
1992AtZU: ^{13}C(α,α′) E≈50-105 MeV; analyzed data. ^{13}C levels deduced B(λ) ratios. Harmonic-vibrational, other models.
2010DaZY: ^{13}C(α,α), (α,α′) E=388 MeV; calculated σ(θ); deduced radii for specified excited states.
2011De17: ^{13}C(α,α′) E=35.5 MeV; calculated σ(θ). ^{13}C deduced rms radii.
2011Og09: ^{13}C(α,α′), E(cm)<300 MeV; analyzed σ(θ) and difraction radii data; deduced abnormally large radii for excited states.
2011Og10: ^{13}C(α,α),(α,α′) $E_{c.m.}$=388 MeV; analyzed σ(θ); deduced rms radii, diffraction radii, neutron halos in the excited states. Modified diffraction model.
2017HaZY: ^{13}C(α,α′) E=2-5.7 MeV; calculated σ(θ). 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)[†‡]	Jπ[#]	L[#]	deformation β[#]	Comments
0	1/2−	0		R_{rms}=2.33 fm *3* (2018Bu05: E_α=29 MeV); see also 2.31 fm (2011DeZY,2014DeZW) and 2.33 fm (2015Og04: E_α=65,90 MeV).
3090	1/2+	1	0.19	B(E1)↑=0.096 *5* (2021In04) R_{rms}(fm)=3.04 *22* (2011DeZY), 2.92 *7* (2014DeZW), 2.98 *9* (2016DeZX: E_α=65 MeV), 2.88 *19* and ≥2.6 (NRM: Nuclear Rainbow Method) (2016DeZX: E_α=90 MeV), 2.7 *4* (2018Bu05).
3680	3/2−	2	0.17	B(E2)↑=0.00560 *20* (2021In04) B(E2)↓≈6 e^2fm^4 (1966Ha19); DWBA fit is rather poor. deformation β: See also β=0.54 (WS: Woods-Saxon form), 0.51 (DF: double folding calculation) at E_α=29 MeV and β=0.44 (WS), 0.4 (DF) at E_α=50 MeV (2016Bu24). B(E2)↑≈13.7 e^2fm^4, δ_2=1.05 fm (2022Go16).
3850	5/2+	3	0.31	B(E3)↑=0.000472 *26* (2021In04) B(E3)↑≈220 e^2fm^6, δ_3=0.82 fm (2022Go16).
6860	5/2+	3	0.042	$\Gamma_\gamma/\Gamma \le 3\times10^{-4}$ (1984DeZR,1985De11). Γ_γ≤1.5 eV using Γ=5.2 keV from (1982Kn02: ^{12}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 β=0.54 (WS), 0.51 (DF) at E_α=29 MeV (2016Bu24).
7490[@]				E(level): Unresolved in (1966Ha19,1974Fe08,1981Pe08,1984DeZR,1985De11). L: (1981Pe08) fits the unresolved $^{13}C^*$(7490+7550) angular distributions with ΔL=2 (J^π=3/2−,5/2−). The fit is rather poor. The Adopted Levels gives J^π=(7/2+) and 5/2−, respectively, which implies ΔL=3 and 2, respectively.

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^{13}C(α,α),(α,α′),(α,α′γ) (continued)

^{13}C Levels (continued)

E(level)[†‡]	J$^{\pi}$[#]	Γ	L[#]	deformation β[#]	Comments
7550[@]			(2)		B(E2)↑=0.00663 *24* (2021In04) 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).
7686[@] *6*	3/2$^+$	70 keV *5*	1	0.097	T=1/2 (1980Fu04). 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$^\pi$: 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					
10753	(7/2$^-$)				B(E4)↑=0.0000037 *14* (2021In04) E(level),J$^\pi$: Unresolved doublet (1981Pe08,2021In04).
10820	(5/2$^-$)		2	0.18	B(E2)↑=0.00017 *1* (2021In04) E(level),J$^\pi$: Unresolved doublet (1981Pe08,2021In04).
11010					B(E1)↑<0.023 (2021In04) E(level): From (2014DeZW).
11080	(1/2$^-$)		0	0.15	B(E0)↑=19.2 3 (2021In04). J$^\pi$: (1981Pe08) report a ΔL=2 J$^\pi$=(3/2$^-$,5/2$^-$) angular distribution, but we take ΔL=0 J$^\pi$=(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$^\pi$: (1981Pe08) report a ΔL=2 J$^\pi$=(3/2$^-$) angular distribution, but we take ΔL=3 J$^\pi$=(7/2$^+$), which is reported in (2020InZZ, 2021In04).
12055[&] *1*	1/2$^-$&(3/2,5/2)$^-$	38 keV *4*	0+2		B(E2)↑=0.00022 *1* (2021In04) E(level): Unresolved doublet. B(E0)↑=1.7 3 (2021In04).

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

^{13}C Levels (continued)

E(level)[†‡]	J^{π}[#]	Γ	L[#]	deformation β[#]	Comments
12282[&] *5*	1/2−	122 keV *22*	0		B(E0)↑=4.1 4 (2021In04). E(level),Γ,L: From (2021In04).
12450[&] *3*	1/2−	<70 keV	0		B(E0)↑=4.9 4 (2021In04). E(level),Γ,L: From (2021In04). E(level): See also the broad ≈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.
12601[&] *3*	1/2−	<70 keV	0		B(E0)↑=3.1 2 (2021In04). E(level),Γ,L: From (2021In04).
12775[&] *4*	1/2−	<70 keV	0		B(E0)↑=0.92 5 (2021In04). E(level),Γ,L: From (2021In04).
14.5×10[3][&] *1*	1/2+,3/2+		1		B(E1)↑=6.9 *7* (2021In04) E(level),J^{π},L: From (2021In04).
15110	3/2−		2		T=3/2 (1981Pe08)
16080	7/2+		3	<0.1	
16.1×10[3][&] *1*	(1/2+,3/2+)		1		B(E1)↑=2.1 *8* (2021In04) E(level),J^{π},L: From (2021In04). E(level): Suggested as a possible candidate for α condensed state.

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

‡ 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).

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

@ Unresolved in (1985De11) who determined $\Gamma_{\gamma}/\Gamma \leq 3\times10^{-4}$ (1984DeZR,1985De11) for the unresolved group. In their discussion, they considered various scenerios depending upon which of the levels ^{13}C*(7.49,7.55,7.69) is populated.

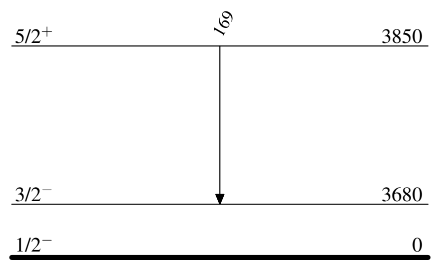
& Uncertainties in the level energies are statistical only. These results, obtained using the Grand Raiden (1999Fu12), were collected with a peak FWHM of 170 keV; peak energy resolution should be dominated by the focal plane energy calibration and is estimated by a reasonable ΔE≈3 keV.

$\gamma(^{13}C)$

E_{γ}	E_i(level)	J^{π}_i	E_f	J^{π}_f
169	3850	5/2+	3680	3/2−

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

Level Scheme



$^{13}_{6}C_{7}$