^{12}C(α,α') 2011Fr02,2014Ma37

History

Type	Author	Citation	Literature Cutoff Date
Full Evaluation	J. H. Kelley, J. E. Purcell and C. G. Sheu	NP A968,71 (2017)	1-Jan-2017

1968Ag03: ^{12}C(α,α) E=20-24 MeV, measured σ(E,θ).
1968Cl04: ^{12}C(α,α) E=2.800-6.600 MeV, measured σ(E_α,θ).
1968Mo08: ^{12}C(α,α_0) E=6.6-8.5 MeV, measured σ(E_α,θ).
1969Ag06: ^{12}C(α,α) E=20-24 MeV, measured σ(E,θ). Deduced interaction radii.
1969Ga11: ^{12}C(α,α_0) E=56 MeV, measured σ(θ).
1969Ha14: ^{12}C(α,α) E=104 MeV, measured σ(θ). Deduced phase shifts, optical potentials.
1970Mo06: ^{12}C(α,α),(α,α') E=19-30 MeV, measured σ(E,θ).
1970Op01: ^{12}C(α,α),(α,α') E=8.5-10.5 MeV, measured σ(E,θ).
1970Ta12: ^{12}C(α,α),(α,α') E_α=166 MeV, measured σ(E_α,θ). Deduced optical model parameters. ^{12}C levels deduced deformation parameters β(L).
1971Ba64: ^{12}C(α,α),(α,$\alpha'\gamma$) E=42 MeV, measured σ(θ), σ(θ,θ($\alpha'\gamma$)). Deduced optical model parameters.
1971Op01: ^{12}C(α,α_0),(α,α'),(α,$\alpha'\gamma$) E_α=8.5-10.5 MeV, measured σ(E_α,θ), Doppler profiles.
1971Ra24: ^{12}C(α,α) E=10.0 to 10.3 MeV, measured σ(E,θ). Deduced phase shifts.
1972Br30: ^{12}C(α,α) E=166 MeV, measured σ(E_α,θ). ^{12}C deduced neutron radii.
1972Bu09: ^{12}C(α,α) E=32.5 MeV, measured σ($E_{\alpha 0}$,θ) σ($E_{\alpha 1}$,θ), $\alpha\gamma$(θ,ϕ). Deduced polarization parameters partial inelastic σ.
1972Ha08: ^{12}C(α,α_0) E=104 MeV, measured σ(θ). Deduced normalization factors.
1972Ku19: ^{12}C(α,α) E=26.6 MeV, measured σ(θ).
1972Ma01: ^{12}C(α,α_0) E=4.0-13.3 MeV, measured σ(E_α,θ).
1972Oe01,1973Oe01: ^{12}C(α,α),(α,α') E=24,29 MeV, measured σ(θ). Deduced shell structure effects.
1973Ku18: ^{12}C(α,α) E=18,19,22,24,25,26.6 MeV, measured σ(E,θ). Deduced reaction mechanism.
1973Ma03: ^{12}C(α,α_0),(α,α') E=8.5-10.5 MeV, measured σ(E_α,θ).
1973Sm03: ^{12}C(α,α),(α,α') E=139 MeV, measured σ(E_α,θ), σ(E(^{3}He),θ). ^{12}C deduced optical potential, inelastic transition strengths.
1974Ch58: ^{12}C(α,α) E=26.6 MeV, analyzed σ(θ).
1974Da22: ^{12}C(α,α) E=3-10 MeV, measured σ(E,θ).
1974Ku15: ^{12}C(α,α) E=26.6 MeV, measured σ(θ).
1974Pi11: ^{12}C(α,α) E=12-40 MeV, analyzed σ(E).
1974Za10: ^{12}C(α,α) measured σ(E).
1975Br06: ^{12}C(α,α) E<5.5 MeV, measured σ, γ-γ-coin.
1975Da10: ^{12}C(α,α) E=3-10 MeV, measured σ(E,θ). Deduced phase shifts.
1976Kn05: ^{12}C(α,α)E$\approx$150 MeV, measured σ(θ).
1976Pa05: ^{12}C(α,α),(α,α') E=39.0,50.5 MeV, measured σ(θ). Deduced Blair phase shifts. ^{12}C deduced deformation β.
1976Pa25: ^{12}C(α,α),(α,α') E=30-50 MeV, measured σ(E,θ). ^{12}C deduced sign of β.
1977En01: ^{12}C(α,α) E=20-24 MeV, measured σ(E,θ).
1979Ar05: ^{12}C(α,α) E=17-23 MeV, measured σ(E_α).
1981Be19: ^{12}C(α,α) E=15-25 MeV, measured σ(θ,E).
1981Bu21: ^{12}C(α,α),(α,α') E=19-31 MeV, measured σ(θ), E_γ, $\alpha\gamma$(θ). Deduced reaction mechanism.
1981Fr11: ^{12}C(α,α) E=17.39-20.5 MeV, measured σ(E_α,θ).
1981Gr17: ^{12}C(α,α) E=4.745-6,6.25-9.33 MeV, analyzed σ(θ). Deduced optical model parameters.
1981Wi16: ^{12}C(α,α) E=120-172.5 MeV, measured σ(θ). Deduced model parameters.
1982Am02: ^{12}C(α,α),(α,α') E=10.5-20 MeV, measured σ(E_α), σ(θ) vs E.
1982Fr10: ^{12}C(α,α) E=3.5-3.62 MeV, measured σ(θ) vs E. R-matrix analysis.
1982Wa23: ^{12}C(α,α) E=5,6 MeV, measured σ(θ). Deduced glory scattering effect.
1983Ar12: ^{12}C(α,α),(α,α') E=28-42 MeV, measured σ(E), σ(θ).
1985Ko11: ^{12}C(α,α) E=3.54-3.64 MeV, measured σ(θ) vs E.
1986Pi01: ^{12}C(α,α),(α,α') E=120 MeV, measured σ(θ). Deduced ground state trasnition densities, multipole moments.
1987Ab03: ^{12}C(α,α) E=48.1,54.1 MeV, measured σ(θ). Deduced optical model parameters.
1987Pl03: ^{12}C(α,α_0) E=1-66 MeV, measured σ(E,θ). Deduced astrophysical S-factor vs E.
1989Ai02: ^{12}C(α,α),(α,α') E=29.3-50.5 MeV, measured σ(θ). Deduced α-particle clustering evidence.

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1990Ar24: ^{12}C(α,α) E=28 MeV, measured $\sigma(E_{\alpha})$.
1990To09: ^{12}C(α,α) E=0.4-1.8 MeV, measured yield vs E.
1991Go25: ^{12}C(α,α) E=90,139 MeV, measured $\sigma(\theta)$. Deduced model parameters.
1991Ku30: ^{12}C(α,α),(α,α') E=39 MeV, analyzed $\sigma(\theta)$. Deduced model parameters, Blair phase shift role.
1994Da16: ^{12}C(α,α) E=5.5-5.8 MeV, measured σ(E), resonance enhnacement factor.
1994Da32: ^{12}C(α,α),(α,α') E=72-90 MeV, measured $\sigma(\theta)$. Deduced far-side component role, rainbow effect evidence.
1994Mo30: ^{12}C(α,α) E=4.2 GeV, measured differential σ vs momentum transfer. Deduced matter radii.
1994Yo06: ^{12}C(α,α) E=5.5-8 MeV, measured σ(E). Deduced resonant σ(peak) deviations from Rutherford formula for ^{12}C.
1995Da08: ^{12}C(α,α),(α,α') E=90 MeV, measured $\sigma(\theta)$. Deduced nuclear rainbow evidence, model parameters.
1997Go10: ^{12}C(α,α) E=89.1 MeV, measured $\sigma(\theta)$ vs E.
1999Bo58: ^{12}C(α,α) E=50.5 MeV, measured $\sigma(\theta)$. Deduced potential parameters.
2001Bu20: ^{12}C(α,α) E=2.6-8.2 MeV, measured $\sigma(\theta)$, S-factor following R-matrix calculations.
2002Ar16: ^{12}C(α,α),(α,α') E=25.5-35.15 MeV, measured elastic and inelastic $\sigma(\theta)$, excitation functions.
2002Ti03: ^{12}C(α,α) E=2.6-8.2 MeV, measured $\sigma(\theta)$. Deduced interaction radius. R-matrix analysis.
2003Jo07: ^{12}C(α,α),(α,α') E=240 MeV, measured E_{α}, $\sigma(\theta)$, $\sigma(E,\theta)$. ^{12}C deduced transitions B(EL), energy-weighted sum rules.
2009Da22: ^{12}C(α,α),(α,α') E=60,104,110,139,166,172.5,240 MeV, analyzed elastic and inelastic scattering cross section and $\sigma(\theta)$. Deduced nuclear rms radii for excited states in ^{12}C.
2009Ti02: ^{12}C(α,α) E=2.6-8.2 MeV, measured E_{α}, I_{α}, $\sigma(\theta)$. Deduced phase shifts using R-matrix analysis.
2010Og03: ^{12}C(α,α') $E_{c.m.}\approx$45-300 MeV, measured particle spectra, angular distributions. Deduced ground and excited state diffraction radii, radii.
2011Ga08: ^{12}C(α,α') E=386 MeV, measured E_{α}, I_{α}. Deduced Isoscalar Giant Monopole Resonance (ISGMR) strength.
2011Fr02: ^{12}C(α,3α) E=22-30 MeV, measured E_{α}, I_{α}, ^{12}C-α angular correlations. ^{12}C deduced levels, J, π, Γ. Possible collective excitation of Hoyle state.
XUNDL dataset compiled by TUNL, 2011.
At E_{α}=22-30 MeV the ^{12}C(α,3α)^{4}He and ^{9}Be(α,3α)n reactions were studied in search of ^{12}C resonances above E_x=7 MeV that could have structures related to the Hoyle state. The α-particle beams impinged on a 45 μg/cm^2 target and the coincident 3α events were detected in an array of 5 cm×5 cm position sensitive Si strip detectors that covered $-55°\leq\theta\leq50°$. The 3α kinematics determined the ^{12}C excitation energies. The analysis was further constrained to separately consider both, events populating natural parity states involving ^{12}C*→^{8}Be$_{g.s.}$(J^{π}=0$^+$)+α and events that excluded ^{12}C*→^{8}Be$_{g.s.}$+α. The excitation spectra in both cases are compared. A state consistent with E_x=13.3 MeV *2* and Γ=1.7 MeV *2* is found; analysis of the angular correlations from the ^{12}C(α,3α) reaction support J^{π}=4$^+$ for the new state.
2013Ra20: XUNDL dataset compiled by TUNL, 2013.
At E_{α}=60 MeV, the complete 4α-particle kinematics were studied at the Variable Energy Cyclotron Centre in Kolkata and permitted an evaluation of the different decay mechanisms (i.e. sequential or direct 3-body decay), which has become a controversial topic. The beam impinged on a 90 μg/cm^2 self supporting ^{12}C target. Inelastically scattered α-particles were detected at backward angles of θ=88°−132° in a position sensitive ΔE-E Si detector telescope while α-particles from the decay of corresponding ^{12}C* recoils were detected by a set of position sensitive ΔE-E Si telescope. Only events with full 4α kinematics detected were analyzed; this was about 20,000 events. Analysis of the lowest relative energy between any two pairs (sensitive to ^{8}Be$_{g.s.}$), the root-mean-square energy deviation, and the radial projection of the symmetric Dalitz plot were analyzed to determine branching ratios for the various decay modes. The efficiencies for the decay modes were determined via Monte Carlo simulation and found to be ≈0.8-0.9 %. The decay of this state is 99.1% consistent with α decay to ^{8}Be$_{g.s.}$ and 0.9% direct decay into 3α particles.
2014Ma37: XUNDL dataset compiled by TUNL, 2014.
The high-lying ^{12}C states were studied using the ^{12}C(^{4}He,3α)^{4}He reaction at 40 MeV at the Birmingham MC40 cyclotron facility. The beam impinged on a 100 μg/cm^2 carbon target. The α-particles from breakup of unbound states in ^{12}C were detected using an array of four position sensitive Si detectors that covered roughly θ_{lab}=20° to 70° and −70° to −20°. In the analysis the full momentum kinematics of all breakup α-particles was determined by the detection of any 3 α-particles. The kinematic reconstruction was used to determine the ^{12}C excitation energies, and a Dalitz plot was created to discriminate the role of ^{8}Be states in the reactions. Previously known states at E_x=7.65, 9.64, 10.84 and 14.08 MeV were observed along with a new state at E_x=22.4 MeV *2*. The angular correlations of breakup α-particles were analyzed leading to a J^{π}=5$^-$ assignment for the new state. Finally there is discussion on the ground state rotational band that indicates members of ^{12}C*(0,0$^+$; 4439,2$^+$; 9641,3$^-$; 14083,4$^+$; and 22400,5$^-$). Other band structures are discussed as well, along with the J^{π}=4$^{\pm}$ parity doublet near E_x=14 MeV.
2017Sm03: XUNDL dataset compiled by TUNL, 2018.

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A beam of 40 MeV ^{4}He ions, from the University of Birmingham MC40 cyclotron, impinged on a 100 μg/cm^{2} ^{nat}C target that was rotated 40° w.r.t. the incident beam and was positioned at the center of a scattering chamber. A 5 cm×5 cm position sensitive Si ΔE-E telescope covered θ=−73° to −108° and detected the inelastically scattered α particles, while an array of four more position sensitive Si detectors were arrange in a quadrant formation covering θ=10° to 53° that optimized the detection of the 3α particles resulting from the 3-body breakup of ^{12}C*(7.65 MeV). A reconstruction of the excitation energy for 3α coincidence events was dominated by the ^{12}C*(7.65 MeV) state with a broad background that is associated with the E_x=10.3 MeV group.

An evaluation of the ^{12}C*(7.65 MeV) events using a Dailitz plot analysis and comparison with Monte Carlo simulations reveals the branching ratios for various breakup configurations.

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The branching ratios for decay of 12C*(7650)    are:
     (2017Sm03)     (2013Ra20)
     DDΦ<0.047%     =(0.60 9)%      3α  Direct Decay in phase space
     DDE<0.026%     =(0.3 1)%       3α  Direct Decay into equal energies
     DDL<0.004%     =(0.01 3)%      3α  Direct Decay into a linear chain
     SD>99.923%     ≈99.1%         (Sequential Decay)
This sequential decay component is consistent with previous
expectations; any substantial change in this assumption would directly
affect the astrophysically important triple α  rate for 12C
production.
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^{12}C Levels

See deformation parameters listed in (2017Ke05).

E(level)	J$^{\pi}$	T$_{1/2}$	Comments
0†			
4.4×10^{3}†			
7.65×10^{3}†‡			R$_{r.m.s.}$≈2.89 fm *4* (2008De35,2009Da22,2010Og03,2011Og10,2013Og05). Decay mechanisms were analyzed; the decay is >99.92% via sequential α-decay to ^{8}Be$_{g.s.}$ and <0.047% via direct decay into 3α-particles (2017Sm03). Also see (2013Ra20) who found the decay of this state is 99.1% consistent with α decay to ^{8}Be$_{g.s.}$ and 0.9% direct decay into 3α particles.
9.64×10^{3}†@			
9.75×10^{3}‡ *15*	2^{+}	0.75 MeV *15*	E(level): See discussion in (2012Fr05). See also E$_x$=9.84 MeV *6* and Γ=1.01 MeV *15* in (2011It08). R$_{r.m.s.}$≈3.07 fm *13* (2008De35,2009Da22,2010Og03,2011Og10,2013Og05).
9.93×10^{3}# *3*	0^{+}	2.71 MeV *8*	
10.84×10^{3} @			
≈11.1×10^{3}?	2^{+}		E(level),J$^{\pi}$: From (2010Hy01).
≈11.2×10^{3}?	0^{+}		E(level),J$^{\pi}$: From (2010Hy01).
11.46×10^{3}? *2*	2^{+}		E(level),J$^{\pi}$: From (2003Jo07).
11.8×10^{3}			
13.3×10^{3}‡@ *2*	(4^{+})	1.7 MeV *2*	J$^{\pi}$: Analysis of the 3α angular correlations is consistent with J$^{\pi}$=4^{+}. It is suggested that the E$_x$=7.65 MeV(0^{+}), 13.3 MeV(4^{+}) and an unobserved J$^{\pi}$=2^{+} state near 9.4 MeV form a rotational band (2011Fr02).
14.08×10^{3}†@	4^{+}		J$^{\pi}$: From (1977Mc07).
15.3×10^{3}			
≈17×10^{3}			E(level): From (2011Fr02).
18.4×10^{3}			
21.6×10^{3}			
22.4×10^{3}† *2*	5^{-}		E(level),J$^{\pi}$: From (2014Ma37) and analysis of 3 α-particle angular correlations.
24.0×10^{3}			

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$^{12}C(\alpha,\alpha')$ **2011Fr02,2014Ma37 (continued)**

^{12}C Levels (continued)

E(level)	Comments
26.2×10^3	E(level): From (1987Ki16).
$27.\times10^3$	E(level): See Table 12.17 in (1980Aj01).
29.2×10^3	E(level): From (1987Ki16).

† Suggested members of a rotational band (2014Ma37).

‡ Suggested members of a rotational band (2011Fr02).

From analysis in (2011It08), this group is suggested as a $J^{\pi}=0^+_3+0^+_4$ doublet with $E_x(0^+_3)$=9.04 MeV *9* and Γ=1.45 MeV *18* and $E_x(0^+_4)$=10.56 MeV *6* and Γ=1.42 MeV *8*. The group was group was previously reported with E_x=9.93 MeV *3* with Γ=2.71 MeV *8* (2003Jo07).

@ From natural parity states involving $^{12}C^*\rightarrow{}^8Be_{g.s.}(J^{\pi}=0^+)+{}^4He$ (2011Fr02).