^{12}C(p,γ)

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

1949Fo18: ^{12}C(p,γ) E≈456 keV; measured resonance γ-ray production. Deduced E_p=456.0 keV *20*, $\omega\gamma$=0.63 and Γ=35 keV.
1950Ba89: E=128-202 keV; measured activation σ.
1950Ha78: E=88-128 keV; measured activation σ.
1951Se67: E<2.5 MeV; measured thick target activation yield. Deduced resonances at 0.45 MeV and 1698 keV *5*; the later resonance has Γ_{lab}=70 keV *10*.
1952Se01: ^{12}C(p,γ) E=0.4-2.7 MeV; measured Eγ, Iγ. Deduced E_{res}=0.45 and 1.70 MeV with Γ_{lab}=35 and 70 keV, and $\omega\gamma$=0.67 and 1.39 eV, resp.
1953Ch34: ^{12}C(p,γ) measured $T_{1/2}$=602.9 s *19*.
1953Hu18: ^{12}C(p,γ) E≈450 keV; measured γ rays with a Geiger-Muller counter. Deduced E_{res}=456.8 keV *5* with $\Gamma_{lab.}$=39.5 keV *10*.
1954Wo09: ^{12}C(p,γ) E=1-3 MeV; measured E_γ, I_γ with a NaI(Tl) counter at θ=0° and 90°. Deduced resonance at $E_{res.}$=1.7 MeV; also found $\Gamma_{\gamma 1}$=0.04 eV and compared with $\Gamma_{\gamma 0}$=0.7 eV from (1952Se01).
1955Co57: E=5, 11 MeV; measured activation σ.
1957La15: E=85-130 keV; measured σ(E) for capture γ ray.
1957De22: ^{12}C(p,γ) and (d,n); measured activation cross sections in the few hundred keV range. Deduced $T_{1/2}$=10.02 min *10*.
1958Ar15: ^{12}C(p,γ); measured ^{13}N decay. Deduced $T_{1/2}$=597.6 s *18*.
1963Fi07: ^{12}C(p,$\gamma_{0,2}$) E=10-48.5 MeV; measured $\sigma(\theta)$ for θ=90°. Identified peaks in γ_0 associated with T=1/2 states at E_x=13, 20, (24), and 32.5 MeV; in addition γ_2 capture to the $^{13}N^*$(3.5 MeV) indicated a resonance at E_x=24.5 MeV.
1960He14, 1963VoZZ: ^{12}C(p,γ) E<700 keV, measured σ(E). Deduced first excited state at E_p=462 keV with θ_p^2=0.567 and $\omega\Gamma_\gamma$=0.63 eV (see 1992Hi14) and Γ_{lab}=35 keV.
1963Yo06: ^{12}C(p,γ) E=1.5-2.0 MeV; measured E_γ, I_γ at θ=0° to 135°. Deduced no participation of $^{13}N^*$(3.56: 5/2$^+$). Upper limit is σ=0.16 μb ($\omega\gamma$<0.006 eV) vs. σ=37 μb ($\omega\gamma$=1.06 eV) for $^{13}N^*$(3.51: 3/2$^-$). Analyzed angular distributions.
1968Bl17: ^{12}C(p,γ) E<5 MeV; measured $\sigma(E,E_\gamma)$ using Ge(Li) detectors. Reported resonance energies of E_{res}=459 keV and 1.697 MeV and $\Gamma_{c.m.}$=33.7 keV *20* and 61.9 keV *40* for $^{13}N^*$(2365,3502). (Uncertainty given in (1970Aj04) from (1968Bl18)).
1968Di04: ^{12}C(p,γ) E_x ≈ 15.07 MeV; measured decay γ rays with Li(Ge). For $^{13}N^*$(15.07) deduced $\Gamma_p\Gamma_\gamma/\Gamma$=5.5 eV *8*, J^π=3/2$^-$, T=3/2 and amplitude ratio E2/M1=−0.095 *7*. Branching ratios $\Gamma_{\gamma 1}/\Gamma_{\gamma 0}$<0.14 and $(\Gamma_{\gamma 2}+\Gamma_{\gamma 3})/\Gamma_{\gamma 0}$=0.84 *8*.
1968Ri16: ^{12}C(p,γ) E≈0.459 MeV; measured Γ_γ(2.37 MeV)=0.45 eV *5* and Γ_{lab}=34 keV *1* via DSAM, which implies τ=1.47 fsec *15*. A private communication in (1973Cl04) establishes this Γ is a lab value. Analysis given in (1992Hi14) indicates Γ_γ is a c.m. value.
1970Di09: ^{12}C(p,γ) E=14.2 MeV, characterized detector array with decay from 15.07 MeV level.
1972Ha32: ^{12}C(p,γ_0) E=8.6-16.3 MeV; measured σ(E). Deduced destructive interference, Deduced resonances, widths. States are reported at E_{res}=9.01, 10.62, 13.12 and 14.50 MeV (E_x=10.25, 11.74, 14.04 and 15.31 MeV) with Γ=280 keV *100*, 220 keV *50*, 170 keV *20* and 380 keV *150* (assumed lab in 1981Aj01), and with $\Gamma_{p0}\Gamma_{\gamma 0}$=0.17 keV^2 *9*, 0.28 keV^2 *10*, 0.47 keV^2 *12* and 0.21 keV^2 *8*, respectively.
1973Cl14: ^{12}C(p,γ) E=480, 600, 1750 keV; measured $\sigma(E_p,E_\gamma)$.
1973Me12: ^{12}C(p,γ) E=9-24 MeV; measured σ(Eγ). Deduced low-energy states as in (1972Ha32). Reported at E_{res}=9.01 MeV *15*, 10.62 MeV *12*, 12.5 MeV *2*, 13.12 MeV *9* and 14.5 MeV *2* (E_x=10.25, 11.74, 13.5, 14.04 and 15.31). The Γ and $\Gamma_{p0}\Gamma_{\gamma 0}$ are also given along with $\Gamma_{\gamma 0}$≥0.6 eV, ≈4.2 eV, 3.7 eV *10* and ≥0.5 eV, respectively. Various assumptions are described in finding $\Gamma_{\gamma 0}$. Also analyzed ^{12}C(p,p$'\gamma_{12.71,15.11}$) yield curves where resonances at E_p=15.27, 19.35, 20.55 and 22.2 MeV were found (see ^{12}C(p,p$'$)).
1974Al16: ^{12}C(p,γ) E=1.65 GeV, Measured $\sigma(E_\gamma)$.
1974Bl06: ^{12}C(p,γ) E=600 keV; measured I_γ, E_γ. Deduced $^{13}N^*$(2364) resonance width $\Gamma_{c.m.}$=33.3 keV *18*.
1974Ro29: ^{12}C(p,γ) E=150-3000 keV, Measured σ(E), E_γ, I_γ, for θ=0° and 90°. Deduced levels at E_p=457 keV *1* and 1699 keV *2* with Γ=39 keV *2* and 65 keV *3*, respectively. Also C^2S(0,2366,3512,3547)=0.49 *15*(l=1), 1.02 *15*(l=0), <0.5(l=1) and ≤1.0(l=2), respectively, and δ_R(E2/M1)(3.5 MeV)=−0.09 *2*. Lastly, the branching ratio I_γ(3512→2366)=8% *1* was obtained. An associated lab report (1975FoZD) indicates $\Gamma_{\gamma 0}$=0.64 eV *7* but insufficient details can be understood; see also (1978BaXY).
1975Ma21: ^{12}C(p,γ) E=14.2-14.3 MeV; measured resonance γ0 yield from $^{13}N^*$(15.07). Deduced $\Gamma_{p0}\Gamma_{\gamma 0}/\Gamma$=5.79 eV; deduced E2/M1 intensity ratio of 0.013 *5*. In (1975Ma21) Γ_γ and reduced transition strengths are deduced from ^{11}B(^{3}He,nγ) data after making several assumptions.

^{12}C(p,γ) (continued)

1976Be28: ^{12}C(p,γ) E=9-24 MeV; measured $\sigma(E_p,\theta)$ for $\theta\approx45°$ to 135°. Deduced resonances structures in γ_0 capture at E_p=9.01 MeV *15* with $\Gamma\approx300$ keV, E_p=17.5 MeV with $\Gamma\approx1$ MeV, E_x=20.8 MeV with $\Gamma\approx4$ MeV and E_p=23 MeV with $\Gamma\approx1$ MeV. The discussion was sometimes ambiguous when listing E_p vs. E_x. See additional reference to E_x=11.74. Their results for capture to excited states are complicated by high backgrounds. For γ_1 capture they find a resonance at $E_p\approx21.8$ MeV, which gives $E_x\approx22$ MeV; (1981Aj01) gave $E_x\approx20$ MeV for this peak, but Fig. 10 and related discussion clarify the issue. Further, in (1981Aj01) an E_p=23 MeV group is connected to E_x=23 MeV (accepted in the Adopted Levels), but this corresponds better to the E_x=23.3 MeV state. The authors report no strong resonances in γ_{2+3} They discuss other relevant measurements.

1976Fe11: ^{12}C(p,p$'\gamma$(4.44,12.7,15.1)), ^{12}C(p,$\gamma_{0,2,3}$) E=16-40 MeV; measured σ(E). Observed resonances at E_p=20, 27, 32 MeV ($E_x\approx20.4$, 26.8, 31.5 MeV). The 20 MeV resonance is seen in all channels, while the 27 MeV state is not seen in capture reactions. The 32 MeV resonance is seen in ^{12}C(p,p$'\gamma$(4.44)) and in the capture reactions.

1977Fr20: ^{12}C(p,γ) E=150-350 keV; measured yield, deduced Q=1943.31 keV *32*, calibrated accelerator.

1977He26: ^{12}C(p,γ) E$\approx$774 keV; measured γ-ray spectrum, deduced Q=1944.01 keV *22*.

1977Ma16: ^{12}C(p,γ) E$\approx$14.25 MeV; measured thick target yield at θ=125°. Combined results with ^{11}B(^{3}He,n). Deduced $\Gamma_{p0}\Gamma_{\gamma0}/\Gamma$=5.79 eV *20*. Also determined E2/M1 intensity ratio of 0.013 *5*. Matches (1975Ma21) analysis. Significant discussion of ^{13}N parameters when additional observables are considered.

1979Ko05: ^{12}C(p,γ) E=40 MeV; measured E_γ, I_γ. Deduced unconfirmed evidence for excited states around E_x=8.1, 12, 16.1 MeV.

1980An40: ^{12}C(p,γ) E=0.8-2 MeV; measured thick target yield via activation technique. Deduced τ_m=862.76 sec *88*.

1980He04: ^{12}C(vec p,γ_0) E=10-17 MeV; measured $\sigma(E_p,\theta(\gamma))$ for θ=43° to 137°, deduced asymmetry. Deduced (E1/E2) ratios in σ(E) in energy region below the GDR.

1980Sn01: ^{12}C(vec p,γ) E=5-30 MeV; measured σ(E) Deduced GDR, T=3/2 M1(E2) interference.

1984Bl10: ^{12}C(p.$\gamma_{0,2,3}$), (vec p,γ) E=24-80 MeV; measured $\sigma(\theta)$, analyzing power vs θ for θ=30° to 150°. Deduced reaction mechanism.

1984Po13: ^{12}C(p,γ) E=1.5-2 MeV; measured $\sigma(E_\gamma$,E). Deduced coherent energy width effect.

1985Br06: ^{12}C(vec p,γ) E=1.6-1.8 MeV; measured A(E,θ), γ-ray yield vs E. R-Matrix analysis in region of ^{13}N*(3.5 MeV).

1985Ki07: ^{12}C(p,γ) E=2.4-4.2 MeV; measured thick target yields.

1985Wa12: ^{12}C(p,γ) E=14.26 MeV; measured E_γ, I_γ, analyzed NaI response function to high-energy γ rays.

1986Ai04: ^{12}C(p,γ) E<14.7 MeV; measured σ via activation technique.

1987La11: ^{12}C(p,γ) E=40, 65, 85 MeV; measured E_γ, I_γ; deduced σ(E).

1987Po09: ^{12}C(p,γ) E=400-2500 keV; measured E_γ, I_γ $\sigma(E_\gamma,\theta=90°)$. Observed decay radiations from ^{13}N*(2316, 3512) from thick target study. Found a deviation from expected γ-ray energies from E_x=3512 level. E_γ=1123 and 3500 keV *2* were observed while E_γ=1146 and 3512 keV were expected. Continued with a 15 μg/cm^2 target and measured E_γ at θ=0° and 90°. Found Doppler shifted E_γ(0°)=3517 keV *2* and E_γ(90°)=3500 keV *2*; A more detailed study is given in (1991Po18).

1987Re11: ^{12}C(p,γ) E=140 MeV; measured $\sigma(E_\gamma,\theta)$.

1987Se13: ^{12}C(p,γ) E=220-340 keV; measured γ-ray yields.

1988Ha04: ^{12}C(vec p,γ) E=20-100 MeV; measured $E_{\gamma0}$, I_γ, σ(E,θ), $A_y(\theta)$ for θ=30° to 150°. Deduced GDR at E_x=20.40 MeV with Γ=3.5 MeV.

1989Ki21: ^{12}C(p,γ) E=1.5-1.9 MeV; measured E_γ, I_γ, γ yield vs E. Deduced E_{res}=1688.7 keV *7* with E_γ=3501.5 keV, and Γ=65.6 keV *18* for a thick target measurement. E_{res}=1689 keV *2* was deduced for a thin target measurement.

1990Co34: ^{12}C(p,$\gamma_{0,2+3}$) E=27 MeV; measured E_γ.

1991Ca25: ^{12}C(p,γ) E=14.24 MeV; measured γ-ray spectrum.

1991Co07: ^{12}C(p,γ) E_x=19.6-47 MeV; measured σ(E,θ), deduced dipole resonances for γ_0 at E_x=14.0, 20.6, 32.0 MeV with Γ=12.0, 1.2, 10.0 MeV, respectively; for γ_{2+3} at E_x=24.5 and 35.0 with Γ=3.5, 14.0 MeV, respectively.

1991Po18: ^{12}C(p,γ) E=1.69-1.75 MeV; study of the $E_x\approx3500$ keV region where E_p, E_γ and I_γ were measured for θ=0° to 90°. The aim is to resolve discrepancies between identification of the $E_x\approx3500$ keV state at E_{res}=1688 keV (1987Po09,1989Ki21) vs other studies that found E_{res}=1699 keV (see 1986Aj01). Target thicknesses varying from 20-50 μg/cm^2 along with a thick 2mm thick plate of carbon were used to measure the excitation function and produced γ rays. Similarly, on the thick target, the Doppler shifted spectrum was measured over θ=0° to 140°. Considering all measurement, E_{res}=1686 keV *1* was found. Widths of Γ=63.6 keV *15* and Γ=62.2 keV *15* were deduced for the different measurements (referenced as half-width in E_p spectrum so assumed as lab frame). Additionally, an anomolous slope was observed in the Doppler function.

1991Zh31: ^{12}C(p,γ) E=0.6-0.9 MeV; measured E_γ, I_γ analyzed suitability for PIGE analysis.

1992Hi14: ^{12}C(p,γ) E=400-480 keV; measured σ(E) at Canberra. Deduced resonance at $E_p\approx424$ with $\Gamma_{c.m.}\approx36.4$ and Γ_γ=0.53 eV *5*. Compared with prior works and discussed astrophysical reaction rates.

1994Zu05: ^{12}C(p,γ) E=40-54 MeV; measured σ(E,θ) for θ=30° to 148°. Observed capture to states up to 11 MeV, i.e. E_x=0,

^{12}C(p,γ) (continued)

2.37. 3.50+3.55, 6.36, 7.38, 7.90, 9.0, 10.36 MeV. Analyzed reaction mechanism.
1997Br19: ^{12}C(p,γ_{0-3}) E=98, 176 MeV; measured $\sigma(\theta)$ for $\theta\approx40°-100°$: γ_{3+4} unresolved. Analyzed reaction mechanism.
1997Ko24: ^{12}C(p,γ) E=72,140 MeV; measured $\sigma(E_\gamma,\theta)$. Analyzed γ emission.
2023Sk01, 2023Sk02, 2023SkZZ: ^{12}C(p,γ) E=320-620 keV; measured σ(E) at Dresden. Deduced $E_{c.m.}$=426.1 keV *4*, Γ_p=35.6 keV *2* and Γ_γ=0.48 eV *3* from an R-matrix analysis.
2023Cs01: ^{12}C(p,γ) E≈460 keV and 1.69 MeV; measured $\sigma(E,\theta(\gamma))$ for θ=0°, 90° and 112° at Atomki in Hungary. Analyzed excitation with a Breit-Wigner shape and deduced resonances at E_p=459.8 keV *8* and 1685.1 keV *7* with Γ_{lab}=38.2 keV *5* and 57.6 keV *8*, respectively.
2023Ke11: ^{12}C(p,γ). Measured $\sigma(E,\theta(\gamma))$ for E=1-2.5 and θ=0° to ≈130° at Notre Dame using a thin-target approach and measured σ(E) using thick-target activation methods. At Bochum they measured $\sigma(E,\theta(\gamma))$ around the E_p≈460 keV resonance. The analysis is a continuation of (2010Az01), where (p,γ) data (1974Ro29,1963VoZZ) and (pol. p,p) data of (1976Me22) were reanalyzed using the AZURE R-matrix code; in (2023Ke11) additional (p,γ) data from (1992Hi14,1963Yo06,2008Bu19) have been added along with the new (2023Ke11) data. The data of (1974Ro29) were not considered. A global R-matrix analysis using AZURE found resonance parameters of E_p=460.3 keV *5* with $J^\pi=1/2^+$, Γ=34.0 keV *2* and Γ_γ=0.48 eV *3*, E_p=1688.8 keV *8* with $J^\pi=3/2^-$, Γ=55.2 keV *3*, Γ_γ(M1)=0.49 eV *3* and Γ_γ(E2)=7.2×10-4 *11*, and E_p=1735.5 keV *5* with $J^\pi=5/2^+$, and Γ=49.0 keV *5*.
2023Gy02: ^{12}C(p,γ) E=0.3-1.9 MeV; measured σ(E) using activation techniques at ATOMKI. Discussed astrophysical rate.

Theoretical analysis:
1977Ba29: ^{12}C(p,γ) E=low. Theoretical analysis of direct capture to ^{13}N*(2366).
1980Ba54: ^{12}C(p,γ). Shell model analysis of E=100-800 keV capture.
1982Ph01: ^{12}C(p,γ). Single-particle model of capture to continuum states.
1984Se16: ^{12}C(vec p,$\gamma_{0,3}$); analyzed $\sigma(\theta)$, A_y and b_2 coefficients to determine *j* sensitivity.
1990Lo20: ^{12}C(p,γ) E=40 MeV; calculated $A_y(\theta)$.
1992Lo01: Theory: E=40 MeV; analyzed angular distributions.
1993Ho06: Theory: Analyzed giant resonance region.
1997Du09: Theory: GCM analysis of cluster effects in the ^{12}C+p system.
2000Li06: ^{12}C(p,γ) E=98, 176 MeV; calculated $\sigma(\theta)$, analyzed reaction mechanism.
2010Hu11: ^{12}C(p,γ). Theoretical analysis of reaction mechanism.
2015Ti03: ^{12}C(p,γ). Shell model analysis of ^{13}N*(3.5: 3/2$^-$) proton resonance.
2018Ti06: Potential model analysis of direct capture reaction.
2020Br14: R-matrix analysis of ^{12}C(p,γ).
Astrophysically relevant:
1937Be10, 1939Be01: Early review of energy production in stars.
1979Ro12: Analyzed astrophysical reaction rates.
1980Ba27: ^{12}C(p,γ) 100-800 keV; calculated σ(E).
1984Ma36: ^{12}C(p,γ) E≤1 MeV; analyzed data from (1974Ro29) with input from (1980Ba54) and obtained spectroscopic factor $S_{g.s.}$=0.88 *11*. Analysed astrophysical reaction rates.
1985La06: ^{12}C(p,γ) E=90-600 keV; calculated σ(E).
1994Ka02: Theory: Analyzed vacuum polarization corrections in solar fusion rates.
1996Gi11: ^{1}H(^{12}C,γ), E(^{12}C)=11 MeV; measured $\sigma(\theta)$, nonresonant capture.
1998Ad12: Review of solar-fusion cross sections; includes analysis of the ^{12}C(p,γ) reaction at astrophysical energies.
1999An35: ^{12}C(p,γ) E≈100 keV-2.5 MeV; analyzed astrophysical S-factor.
2000Ic01: ^{12}C(p,γ). Calculated electron screening effects.
2001Ge10: ^{12}C(p,γ). Analysis of CNO rates in dense stellar plasma.
2000Li13: Calculated screening effects for astrophysical energies.
2001Ne15: ^{12}C(p,γ) E≤160 keV; analyzed S-factor shape.
2004Ue05: Calcluated astrophysical reaction rate.
2008Bu19: ^{12}C(p,γ) E=354, 390, 460, 463, 565, 750, 1061 keV; measured E_γ, I_γ, σ, $\sigma(\theta)$. Deduced astrophysical S-factors, Analyzed Γ_p and Γ_γ for various resonances. Deduced Γ_p=35.0 keV *10* and Γ_γ=0.65 eV *7* for $E_{c.m.}$=421 keV; Γ_p=62 keV for $E_{c.m.}$=1.7 MeV. To fit their data, the tail of the $E_{c.m.}$=8.2 MeV state was included in their R-matrix analysis; using Γ_p=280 keV from (1973Me12); they suggest Γ_γ=6 keV, but it is important that the E_p≈9 MeV region is not included in their measurement.
2010Az01: ^{12}C(p,γ). AZURE R-matrix analysis of astrophysically relevant data.
2011Ad03: ^{12}C(p,γ). Broad analysis of CNO reactions.

^{12}C(p,γ) (continued)

2012Du10: ^{12}C(p,γ). Broad analysis of astrophysically relevant reactions.
2012Mi24: ^{12}C(p,γ). Broad analysis of astrophysically relevant reactions.
2017Mu06: Potential model analysis of ^{13}N*(2.37 MeV) radiative width and related ANC.
2018Ti06: Potential model analysis of capture reactions for E_p<1.2 MeV.
2021An01: Folding model analysis of ^{12}C(p,γ) at low energies.
2021An05: Mean-field analysis of ^{12}C(p,γ) and other astrophysical CNO cycle reactions.
2021An13: Potential model analysis of capture reactions for E_p<800 keV.
2022An15: Analyzed capture cross section for E≤600 keV.
2023Ch57: Discussed the role of ^{12}C(p,γ) on X-ray burst phenomena.
2023Sk04: Compared proton capture on ^{12,13}C and discussed stellar abundances.

^{13}N Levels

E(level)[†‡]	J^π	Γ	E_p(res.) (MeV)[@]	Comments
0	1/2$^-$[#]	598.02 s *61*		J^π: From Adopted Levels. $T_{1/2}$: $T_{1/2}$ from (1980An40). (1953Ch34): $T_{1/2}$=602.9 s *19*. (1957De22): $T_{1/2}$=10.02 min *10*. (1958Ar15): $T_{1/2}$= 597.6 s *18*. (1980An40): $T_{1/2}$=598.02 s *61* from τ_m=862.76 s *88*. (1974Ro29): C^2S=0.49 *15* L=1.
2367.6 *9*	1/2$^+$	34.7 keV *3*	459.7 *9*	$\Gamma_{\gamma0}$=0.51 eV *3* E(level): E_p=459.7 keV *9* from the average (external errors) of E_{res}=456.0 keV *20* (1949Fo18), E_p=456.8 keV *5* (1953Hu18) E_{res}=457 keV *1* (1974Ro29), $E_{c.m.}$=426.1 keV *4* (E_p=461.9 *4*) (2023Sk02) E_p=460.3 keV *5* (2023Cs01) and E_p=459.8 keV *8* (2023Ke11: includes global analysis of data). Γ: From weighted average (external errors) of Γ_{lab}=37.4 keV *10* (1953Hu18, 1973Cl04), $\Gamma_{c.m.}$=33.7 keV *20* (1968Bl17), Γ_{lab}=34 keV *1* (1968Ri16), $\Gamma_{c.m.}$=33.3 keV *18* (1974Bl06), $\Gamma_{(lab)}$=39 keV *2* (1974Ro29), $\Gamma_{c.m.}$=34.9 keV *2* (2023Sk02), Γ_{lab}=38.2 keV *5* (2023Cs01) and $\Gamma_{c.m.}$=34.0 keV *2* (2023Ke11: includes 2008Bu19). See also Γ_p=33.5 keV *10* obtained from a global analysis in (2022Ar03). Note: some inconsistencies exist in the literature related to assigning the values as lab or c.m. frame values. Table 1 of (1992Hi14) is helpful for resolving some issues. $\Gamma_{\gamma0}$: Weighted average (external errors) of Γ_γ=0.45 eV *5* (1968Ri16-c.m. value), Γ_γ=0.53 eV *5* (1992Hi14-c.m. value), Γ_γ=0.49 eV *3* (2023Sk02-c.m. value); Γ_γ=0.48 ev *2* (2023Ke11-c.m. value: includes 2008Bu19); see also $\Gamma_{\gamma0}$=0.63 eV (1949Fo18-lab value). As with Γ, there are some inconsistencies with determining the reference frame of the widths. J^π: From R-matrix analysis in (2023Ke11). C^2S=1.02 *15* (1974Ro29). (1949Fo18): Eres=456.0 keV *20*, Γ=35 keV and $\omega\gamma$=0.63 eV. (1951Se67,1952Se01): E_p=0.45 MeV, Γ_{lab}=35 keV and $\omega\gamma$=0.67 eV (implies $\Gamma_{\gamma0}$=0.67 eV). (1953Hu18): E_p=456.8 keV *5* and Γ_{lab}=39.5 keV *10* (analysis in (1973Cl04) deduced Γ_{lab}=37.4 keV *13* after correcting for target thickness effects). (1968Bl17): E_p=459 keV and $\Gamma_{c.m.}$=33.7 keV *20* (Uncertainty given in (1970Aj04) from (1968Bl18), see also (1973Cl04) where γ uncertainty of 2 keV is given). (1968Ri16): Γ_{lab}=34 keV *1*, τ=1.47 fs *15* and Γ_γ=0.45 eV *5*. A private communication in (1973Cl04) establishes this Γ is a lab

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^{12}C(p,γ) (continued)

^{13}N Levels (continued)

E(level)[†‡]	J^{π}	Γ	E_p(res.) (MeV)[@]	Comments
				value. (1974Bl06): $\Gamma_{c.m.}$=33.3 keV *18* (assumed lab in (1976Aj04)). (see for discussion on Γ variation in prior measurements). (1974Ro29): E_{res}=457 keV *1*, $\Gamma_{(lab)}$=39 keV *2*, L=0, C^2S=1.02 *15*, θ^2(l=0)≈0.81 A lab report (1975FoZD) indicates $\Gamma_{\gamma 0}$=0.64 eV *7*. (1992Hi14): E_p≈424, $\Gamma_{c.m.}$≈36.4 and Γ_{γ}=0.53 eV *5*. (2008Bu19): Γ_p=35.0 keV *10* and Γ_{γ}=0.65 eV *7* (assumed c.m.). (2023Sk02): $E_{c.m.}$=426.1 keV *4*, $\Gamma_{c.m.}$=34.9 keV *2* and Γ_{γ}=0.49 eV *3*. (2023Cs01): E_p=459.8 keV *8* and Γ_{lab}=38.2 keV *5*. (2023Ke11): E_p=460.3 keV *5*, Γ_p=34.0 keV *2* and Γ_{γ}=0.48 eV *3*. See additional discussion in (2017Mu06).
3500.4 *8*	3/2⁻	55.0 keV *3*	1.6878 *8*	$\Gamma_{\gamma 0}$=0.49 eV *3*; $\Gamma_{\gamma 1}$=0.043 eV E(level): From E_p=1687.8 keV *8* the weighted average of E_p=1687 keV *1* (1991Po18), E_p=1688.7 keV *7* (1989Ki21: thick target), E_p=1689 keV *2* (1989Ki21: thin target), E_p=1685.1 keV *7* (2023Cs01) and E_p=1688.8 keV *5* (2023Ke11). Γ: From $\Gamma_{c.m.}$=61.9 keV *40* (1968Bl17), Γ_{lab}=65 keV *3* (1974Ro29), Γ_{lab}=57.6 keV *8* (2023Cs01) and $\Gamma_{c.m.}$=55.2 keV *3* (2023Ke11). See also Γ=65.6 keV *18* (1989Ki21: thick target − taken as lab), see also Γ=74 keV *9* (1949Va03), Γ_{lab}=70 keV *10* (1951Se67,1952Se01) and Γ=62.2 keV *15* (1991Po18-reference frame is unclear). J^{π}: From phase-shift analysis in (1974Ro29). $\Gamma_{\gamma 0}$: From the R-matrix analysis in (2023Ke11) as detailed above. In (1991Aj01) the analysis of (1952Se01, 1963Yo06) cross sections given in (1980Ba54) was accepted; see discussion in (1991Aj01). See also $\Gamma_{\gamma 0}$=0.70 eV from $\omega\gamma$=1.39 eV (1951Se67,1952Se01) as quoted in (1954Wo09), and see $\omega\gamma$=1.06 and Γ_{γ}=0.53 eV in (1963Yo06). $\Gamma_{\gamma 1}$: From $\Gamma_{\gamma 0}$ and Iγ1=8% *1* from (1974Ro29). 1949Va03: E_{res}=1697 keV *12*, Γ=74 keV *9*, ratio of yield from E_{res}=1697 keV *12* and E_{res}=456 keV is R=1.3 *2*, which is used to deduce Γγ=1.3 eV *2* (this may be a typo). (1951Se67,1952Se01): E_p=1.698 MeV *5* and Γ_{lab}=70 keV *10* and $\omega\gamma$=1.39 eV (implies $\Gamma_{\gamma 0}$=0.70 eV). (1954Wo09): $\Gamma_{\gamma 1}$=0.04 eV. (1963Yo06): σ=37 μb, $\omega\gamma$=1.06 eV, Γ_{γ}=0.53 eV (no participation of $^{13}N^{*}$(3.56: 5/2⁺); σ≤0.16 μb ;$\omega\gamma$<0.006 eV); δ(M2/E1)=−0.092 from A_2/A_0=−0.65. (1968Bl17): E_p=1697 keV and $\Gamma_{c.m.}$=61.9 keV *40* (Uncertainty given in (1970Aj04) from (1968Bl18)). (1974Ro29): E_{res}=1699 keV *2*, Γ_{lab}=65 keV *3*, L=1, C^2S<0.5 and δ_R(M2/E1)=−0.09 *2* from *a2*=−0.64 *4*. (1989Ki21: thick target): E_p=1688.7 keV *7* and Γ=65.6 keV *18*. (1989Ki21: thin target):E_p=1689 keV *2*; in this work the energy shift is attributed to the thick target measurement methodology. (1991Po18: see important discussion): E_p=1687 keV *1*. Γ_{lab}=63.6 keV *16* and Γ_{lab}=62.2 keV *15* were deduced from separate configurations. (2008Bu19): Γ_p=62 keV (2008Bu19) (assumed c.m.). (2023Cs01): E_p=1685.1 keV *7* and Γ_{lab}=57.6 keV *8*. (2023Ke11): E_p=1688.8 keV *5*, $\Gamma_{c.m.}$=55.2 keV *3*, Γ_{γ}(M1)=0.49 eV *3* and Γ_{γ}(E2)=7.2E−4 eV *11*.

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^{12}C(p,γ) (continued)

^{13}N Levels (continued)

E(level)[†‡]	J$^\pi$	Γ	Comments
10.26×10^3 *14*	(1/2$^+$,3/2$^+$)	0.26 MeV *9*	$\Gamma_{\gamma0}$>0.6 eV E(level): E_{res}=9.01 MeV *15* from E_{res}=9.01 MeV *15* (1972Ha32,1973Me12) and E_p=9.01 MeV *15* (1976Be28). Γ: From Γ_{lab}=0.28 MeV *10* (1972Ha32,1973Me12). $\Gamma_{\gamma0}$: From (1973Me12); see other discussion in (2008Bu19). (1972Ha32,1973Me12): E_{res}=9.01 MeV *15*, Γ_{lab}=0.28 MeV *10*, detector θ=90° gives π=+, J^π=(1/2$^+$,3/2$^+$) and $\Gamma_{p0}\Gamma_{\gamma0}$=0.17 keV^2 *9*. (1973Me12): $\Gamma_{\gamma0}\geq$0.6 eV. (1976Be28): E_p=9.01 MeV *15* and Γ≈300 keV. (2008Bu19): $E_{c.m.}$=8.371 MeV accounting for the tail of this resonance in the $E_p\leq$2 MeV region suggests Γ_γ=6 keV (assumed lab).
11.74×10^3 *11*	3/2$^+$	202 keV *46*	$\Gamma_{\gamma0}\approx$4.2 eV E(level),Γ: From (1972Ha32,1973Me12). $\Gamma_{\gamma0}$: From (1973Me12). (1972Ha32,1973Me12): E_{res}=10.62 MeV *12*, Γ_{lab}=220 keV *50*, J^π=3/2$^+$ and $\Gamma_{p0}\Gamma_{\gamma0}$=0.28 keV^2 *10*. (1973Me12): $\Gamma_{\gamma0}\approx$4.2 eV. (1976Be28): See discussion on J^π assignments of ^{13}N*(11.74, 14.05) and other nearby levels.
13.5×10^3 *2*	(3/2$^+$)	6500 keV	$\Gamma_{\gamma0}$>1.1 keV E(level),Γ: From (1973Me12). J$^\pi$: From (1973Me12) ^{12}C(p,γ_0); L=0,2, strong interference with J^π=3/2$^+$ states at ^{13}N*(11.74, 14.04), assumed component of GDR. $\Gamma_{\gamma0}$: From (1973Me12). (1973Me12): E_p=12.5 MeV *2*, Γ=7 MeV, $\Gamma_{\gamma0}\geq$ 1.1 keV. (1963Fi07): E_x=13 MeV. (1991Co07): E_x=14.0 MeV, Γ=12 MeV ^{12}C(p,γ_0).
14.05×10^3 *8*	3/2$^+$	157 keV *18*	$\Gamma_{\gamma0}$=3.7 eV *10* E(level),Γ: From (1972Ha32,1973Me12). $\Gamma_{\gamma0}$: From (1973Me12). (1972Ha32,1973Me12): E_{res}=13.12 MeV *9*, Γ_{lab}=170 keV *20* J^π=3/2$^+$ and $\Gamma_{p0}\Gamma_{\gamma0}$=0.47 keV^2 *12*. (1973Me12): $\Gamma_{\gamma0}$=3.7 eV *10*; associated with the J^π=3/2$^+$ state from (1969Le18) (p,p) phase-shift analysis. (1976Be28): See discussion on J^π assignments of ^{13}N*(11.74, 14.05) and other nearby levels.
15.07×10^3	3/2$^-$		T=3/2 (1968Di04): $\Gamma_p\Gamma\gamma/\Gamma$=5.5 eV *8*, J^π=3/2$^-$ from $\gamma(\theta)$, T=3/2 I(E2/M1)=−0.095 *7*, $\Gamma_{\gamma1}/\Gamma_{\gamma0}$<0.14, ($\Gamma_{\gamma2}$+$\Gamma_{\gamma3}$)/$\Gamma_{\gamma0}$=0.84 *8*. (1975Ma21,1977Ma16) $\Gamma_p\Gamma\gamma/\Gamma$=5.79 eV *20*, I(E2/M1)=0.013 *5*. Using Γ_{p0}/Γ=0.236 *12* from (1973Ad02) they deduced $\Gamma_{\gamma0}$(M1)=24.2 eV *15*, $\Gamma_{\gamma0}$(E2)=0.32 eV *12*, B(M1)W=0.342 *21* and B(E2)W=0.28 *11* for the ground state transition. They also measured ^{11}B(^{3}He,nγ) and determined relative transition strengths for γ_0, γ_1 and γ_2.
15.3×10^3 *2*	(3/2$^+$)	0.35 MeV *14*	$\Gamma_{\gamma0}$>0.5 eV E(level),J$^\pi$,Γ: From (1972Ha32,1973Me12). $\Gamma_{\gamma0}$: From (1973Me12). (1972Ha32,1973Me12): E_{res}=14.5 MeV *2*, Γ_{lab}=0.38 MeV *15*, $\Gamma_{p0}\Gamma_{\gamma0}$=0.21 keV^2 *8*. Possible doublet. (1973Me12): $\Gamma_{\gamma0}\geq$0.5 eV.
18.1×10^3		≈1 MeV	E(level),Γ: From (1976Be28). (1976Be28): $E_p\approx$17.5 MeV and Γ≈1 MeV.
20.5×10^3		≈3.7 MeV	E(level): From average of measured values listed below.

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^{12}C(p,γ) (continued)

^{13}N Levels (continued)

E(level)†‡	Γ	Comments
		E(level): In (1981Aj01) an additional level at E_p≈20 MeV was deduced based a peak seen in Figure 11 of (1976Be28). However, those authors indicated, "at lower energies the γ_{2+3} pulses are completely submerged in the sea of inelastic γ rays"; therefore there seems to be evidence for only one level in this region. (1963Fi07): E_x=20 MeV ^{12}C(p,γ_0). (1976Fe11): E_p=20 MeV ^{12}C(p,$\gamma_{0,2+3}$). (1976Be28): E_x≈20.8 MeV and Γ≈4 MeV. (1988Ha04): E_x≈20.40 MeV and Γ≈3.5 MeV (GDR). (1991Co07): E_x=20.6 MeV with Γ=1.2 MeV.
22.0×10^3		E(level): From (1976Be28). (1976Be28): E_p=21.8 MeV ^{12}C(p,γ_1).
23.2×10^3	≈1 MeV	E(level),Γ: From (1976Be28). (1976Be28): E_p≈23 MeV and Γ≈1 MeV (1976Be28).
24.5×10^3	3.5 MeV	E(level): From (1963Fi07, 1991Co07). Γ: From (1991Co07). (1963Fi07): E_x=24.5 MeV (γ_2) and uncertain E_x=24 MeV (γ_0). (1991Co07): E_x=24.5 MeV with Γ=3.5 MeV ^{12}C(p,γ_{2+3}).
31.9×10^3		Γ: Γ=broad. E(level): From average (1963Fi07, 1976Fe11). (1963Fi07): E_x=32.5 MeV ^{12}C(p,γ_0). (1976Fe11): E_p=32 MeV ^{12}C(p,$\gamma_{0,2+3}$). (1991Co07): E_x=32.0 MeV, Γ=10 MeV ^{12}C(p,γ_0) and E_x=35.0 MeV, Γ=14 MeV ^{12}C(p,γ_{2+3}).

† Level energies are deduced using E_p(res) and ^{12}C, p and ^{13}C masses from (2021Wa16: AME-2020). E_x=S_p+$E_{c.m.}$(relativistic).

‡ In (1994Zu05), the continuum region was populated and capture γ rays to ^{13}N states at E_x=0, 2.37. 3.50+3.55, 6.36, 7.38, 7.90, 9.0, 10.36 MeV were observed. See also (1979Ko05).

From Adopted Levels.

@ Authors symbols are used in the discussion; for reference E_p=E_{res}=laboratory proton energy; $E_{c.m.}$=center of mass energy and E_x=$E_{c.m.}$+S_p.

γ(^{13}N)

E_i(level)	J^π_i	E_γ†	I_γ	E_f	J^π_f	Mult.	δ	Comments
2367.6	1/2$^+$	2367.4	100	0	1/2$^-$	E1		
3500.4	3/2$^-$	1135	8	2367.6	1/2$^+$	E1		E_γ: From (1987Po09). I_γ: From (1974Ro29). Mult.: From angular distributions measured in (1974Ro29).
		3498 *2*	92	0	1/2$^-$	M1+E2	−0.09 *2*	Mult.: From angular distributions and a_2=−0.64 measured in (1974Ro29). I_γ: In (1954Wo09), the partial widths $\Gamma_{\gamma1}$=0.04 eV and $\Gamma_{\gamma0}$=0.7 eV are given (5%:95%); $\Gamma_{\gamma0}$=0.7 eV is from $\omega\gamma$=1.39 eV in (1952Se01). Later, (1963Yo06) claim agreement and show Iγ=5% and 95%, respectively. In (1974Ro29) uncertainties of 1% are added to the branching ratios of (1954Wo09); however (1974Ro29) reported Iγ=8% *1* for γ_1. In (1991Aj01) $\Gamma_{\gamma1}$=0.06 eV and $\Gamma_{\gamma0}$=0.64 eV (8.5%:91.5%) were adopted based on an analysis of (1952Se01,1963Yo06) given in

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^{12}C(p,γ) (continued)

γ(^{13}N) (continued)

E_i(level)	J^π_i	E_γ†	E_f	J^π_f	Mult.	δ	Comments
							(1980Ba54) and using the $I_{\gamma1}$=8% *1*, which is the only related value that is reported with an uncertainty. We accept the branching ratio given in (1974Ro29); however we accept the partial $\Gamma_{\gamma0}$ width from the R-matrix analysis in (2023Ke11) as detailed above where $\Gamma_{\gamma0}$=0.49 eV *3* (δ=0.038 *6*: $\Gamma_{\gamma0}$(M1)=0.49 eV *3* and $\Gamma_{\gamma0}$(E2)=0.49 eV *3*). See also δ(E2/M1)=−0.09 *2* (1974Ro29) from *a2*=−0.64 4 compared with δ(E2/M1)=−0.092 from *a2*=−0.65 reported in (1963Yo06). E_γ: From (1987Po09); see also 3501.5 keV (1989Ki21).
10.26×10^3	(1/2$^+$,3/2$^+$)	10.25×10^3	0	1/2$^-$			$\Gamma_{\gamma0}$≈6 eV
11.74×10^3	3/2$^+$	11.74×10^3	0	1/2$^-$			$\Gamma_{\gamma0}$≈4.2 eV (1973Me12)
13.5×10^3	(3/2$^+$)	13.5×10^3	0	1/2$^-$			
14.05×10^3	3/2$^+$	14.0×10^3	0	1/2$^-$			$\Gamma_{\gamma0}$=3.7 eV *10* (1973Me12)
15.07×10^3	3/2$^-$	11.5×10^3	3500.4	3/2$^-$			(1968Di04):$\Gamma_{\gamma(3.5+3.56)}$=23 eV *5*.
		12.71×10^3	2367.6	1/2$^+$			Γ_γ<4.5 eV (1968Di04)
		15.07×10^3	0	1/2$^-$	E2+M1	−0.115 *21*	Mult.: From angular distributions measured in (1975Ma21). (1968Di04): $\Gamma_{p0}\Gamma_{\gamma0}/\Gamma$=5.5 eV *8*, I(E2/M1)=−0.095 *7*. Then, $\Gamma_{\gamma0}$=27 eV *5* assuming Γ_{p0}/Γ=0.200 eV *25* (1967AdZY). (1975Ma21, 1977Ma16): $\Gamma_p\Gamma_\gamma/\Gamma$=5.79 eV *20*, I(E2/M1)=−0.013 *5* and $\Gamma_{\gamma0}/\Gamma_{p0}$=0.121 *11*. Assuming Γ_{p0}/Γ=0.236 *12* from (1973Ad02) gives Γ_γ(M1)=24.2 eV *15*, Γ_γ(E2)=0.32 eV *12*, and B(M1)W=0.342 *21* and B(E2)W=0.28 *11*; I(E2/M1)=0.013 5. See discussion in (1975Ku21). Also see (1975Ma21, 1977Ma16) where ^{11}B(^{3}He,nγ) data are used to deduce γ-ray partial widths $\Gamma_{\gamma(2+3)}$=19.6 eV *14*, $\Gamma_{\gamma1}$≤2.82 eV *30*, $\Gamma_{\gamma0(M1)}$=24.2 eV *15*, $\Gamma_{\gamma0(E2)}$=0.32 eV *12*, and Γ=0.86 keV *12*.
15.3×10^3	(3/2$^+$)	15.3×10^3	0	1/2$^-$			$\Gamma_{\gamma0}$≥0.5 eV (1973Me12)
18.1×10^3		18.1×10^3	0	1/2$^-$			
20.5×10^3		20.5×10^3	0	1/2$^-$			
22.0×10^3		19.6×10^3	2367.6	1/2$^+$			
23.2×10^3		23.2×10^3	0	1/2$^-$			
24.5×10^3		21.0×10^3	3500.4	3/2$^-$			
31.9×10^3		28.36×10^3	3500.4	3/2$^-$			
		31.9×10^3	0	1/2$^-$			

† From level-energy difference, except where noted.

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

Level Scheme

Intensities: % photon branching from each level