Adopted Levels

S(n)=17770 *10*; S(p)=1512 *10*; Q(α)=−8220 *10* 2021Wa16
S_{2n}=40770 *60*; S_{2p}=2112 *10*; Q(εp)=15826 *10* (2021Wa16).

Theoretical studies:
Level properties and model analyses:
1978Gu10, 1987Sa15, 2001Sa06, 2001Su10, 2002Sa12, 2008Sh16, 2010Ti04, 2011Sh21, 2013Ti05, 2013Ma60, 2016Pa05, 2017Br02, 2020So01, 2022Zo01, 2023Me02.

Charge symmetry in mirror nuclei:
1971Bl12, 1973Sa25, 1974Ch46, 1999Ba21, 2021Ca23, 2023Se01.

Magnetic moments:
1999Ba21, 2003Su04, 2003Su28, 2013De06, 2016Me17, 2021Ca23.

Analyzed β-decay, β-p decay data.
1973Ha77, 1977Ce05, 1977Ri08, 1993Ch06.

Solar and cosmogenic production rates:
2006Li57, 2018Ge07, 2019Zh29.

In the early studies of (1984Se15, 1993Wa07) using $^{13}C(\pi^+,\pi^-)$, the levels observed in the excitation spectrum appeared as broad groups with excitation energies around E_x=3, 4.5, 6 and 8.7 MeV. In the later work of (2007GuZW), using $^{16}O(^3He,^6He)$, more structures are observed revealing a collection of narrower states. Finally, in the seminal work of (2021Ch45), analysis of the decay mechanism further resolved the groups observed by (2007GuZW) into narrower states that dominantly proton decay to different ^{12}N states.

^{13}O Levels

Cross Reference (XREF) Flags

A	$^1H(^{12}N,p)$:res	F	$^9Be(^{16}O,^{13}O)$	K	$^{14}N(p,2n)$
B	$^1H(^{14}O,d)$	G	$^{12}C(p,\pi^-)$	L	$^{14}N(^{12}N,^{13}O)$
C	$^2H(^{12}N,^{13}O)$	H	$^{12}C(^{15}O,^{13}O)$	M	$^{16}O(^3He,^6He)$
D	$^2H(^{14}O,t)$	I	$^{13}C(\pi^+,\pi^-)$	N	$^{28}Si(^{13}O,X)$
E	$^9Be(^{13}O,^{13}O),(^{13}O,p^{12}N)$	J	$^{13}C(^{11}B,^{11}Li)$	O	$^{208}Pb(^{13}O,^{13}O)$

E(level)	J^π	$T_{1/2}$ or Γ	XREF	Comments
0.0	3/2⁻	8.58 ms *5*	BCD FGHIJKLMNO	%ε+%$β^+$=100; %$β^+$p=11.3 *23* (2005Kn02) T=3/2 μ=1.3891 *3* (1996Ma38,2019StZV) Q=0.0111 *8* (2016St14,2021StZZ) Q: From reanalysis of (1999Ma46). J^π: Allowed *ft* values to ^{13}N J^π=1/2⁻, 3/2⁻, 5/2⁻ states (1970Es03). $T_{1/2}$: From weighted average of 8.7 ms *4* (1965Mc09), 8.95 ms *20* (1970Es03) and 8.55 ms *5* (1990As01).
2428[a] *18*	1/2+[e]	358 keV *19*	AB E G M	%p=100 XREF: A(2.69E3)B(2.8E3)G(2.82E3)M(2650) E(level),J^π,Γ: From (2021Ch45) $^9Be(^{13}O,^{13}O)$. See also E_x=2400 keV *50* (1991Go13,1991GoZR) $^{16}O(^3He,^6He)$, E_x=2690 keV *50* (2007Sk02) $^1H(^{12}N,p)$, and E_x=2690 keV *50* from the

Continued on next page (footnotes at end of table)

Adopted Levels (continued)

^{13}O Levels (continued)

E(level)	J$^{\pi}$	T$_{1/2}$ or Γ	XREF	Comments
				(2007GuZW: ΔE estimated by evaluator) ^{16}O(^{3}He,^{6}He) conference proceedings. Other values reported near this energy are E$_x$=2.82 MeV *24* (1978Co15) ^{12}C(p,π^-) and E$_x$=2.8 MeV *3* (2012Su21) ^{1}H(^{14}O,d). Γ: See also Γ=0.45 MeV *10* (2007Sk02), <300 keV (2012Su21) and <100 keV (2007GuZW: est.).
3006[a] *13*	3/2+[e]	55 keV *19*	E i	%p=100 XREF: i(2.75E3) E(level),J$^{\pi}$,Γ: From (2021Ch45) ^{9}Be(^{13}O,^{13}O). See also E$_x$=2956 keV *15* and Γ<50 keV (2013So11) ^{9}Be(^{13}O,^{13}O). Ambiguity exists in the level energies obtained from the ^{13}C(π^+,π^-) reaction. A narrow resonance is reported in (1984Se15) with E$_x$=2.75 MeV *4* and in (1993Wa07) with 3.10 MeV *7*; we associate these observations with either or both of the E$_x$=3006 keV and 3051 keV Adopted Levels of this evaluation.
3051[b] *16*	5/2+[e]	54 keV *19*	E i m	%p=100 XREF: i(2.75E3)m(3120) E(level),J$^{\pi}$,Γ: From (2021Ch45) ^{9}Be(^{13}O,^{13}O). See also E$_x$=3025 keV *16* and Γ<50 keV (2013So11) ^{9}Be(^{13}O,^{13}O) and E$_x$=3038 keV *9* (2019We11) ^{9}Be(^{13}O,^{13}O). Also see E$_x$=2750 keV *40* (1984Se15) and 3100 keV *70* (1993Wa07) both from ^{13}C(π^+,π^-), and 3120 keV *50* (2007GuZW:ΔE est.) ^{16}O(^{3}He,^{6}He). Γ: See also ≈0.43 MeV (2007GuZW:est.).
3290?[d] *50*	(1/2,3/2)$^-$	75 keV *30*	A m	XREF: m(3120) E(level),J$^{\pi}$,Γ: From R-matrix analysis in (2007Sk02) ^{1}H(^{12}N,p). See also E$_x$=3120 keV *50* and Γ=0.43 MeV *10* (2007GuZW:est.) ^{16}O(^{3}He,^{6}He). E(level): This level is listed because of the significant energy difference between 3290 and the nearest level at E$_x$=3051 keV and because of the broad width of the group reported in (2007GuZW) that may suggest both groups were populated in that study. But, its existence is rather uncertain.
3692[a] *13*	7/2+[e]	53 keV *21*	E m	%p=100 XREF: m(3800) E(level),J$^{\pi}$,Γ: From (2021Ch45) ^{9}Be(^{13}O,^{13}O). See also E$_x$=3669 keV *13* and Γ<50 keV (2013So11) ^{9}Be(^{13}O,^{13}O), E$_x$=3701 keV *10* (2019We11) ^{9}Be(^{13}O,^{13}O). Also see E$_x$=3800 keV *50* and Γ≈160 keV (2007GuZW: ΔE and Γ est.) ^{16}O(^{3}He,^{6}He) where the unresolved ^{13}O*(3692+3721) states may have been observed.
3721[c] *16*	(3/2+,5/2+,5/2$^-$)[e]	10 keV *+19−10*	E m	%p=100 XREF: m(3800) E(level),J$^{\pi}$,Γ: From (2021Ch45) ^{9}Be(^{13}O,^{13}O). See also E$_x$=3800 keV *50* and Γ≈160 keV (2007GuZW: ΔE and Γ est.) ^{16}O(^{3}He,^{6}He) where

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Adopted Levels (continued)

^{13}O Levels (continued)

E(level)	J^π	$T_{1/2}$ or Γ	XREF	Comments
				the unresolved $^{13}O^*$(3692+3721) states may have been observed.
4287[a] *13*	$(3/2^+,5/2^+)$[e]	170 keV *25*	B E I M	%p=100 XREF: I(4210)M(4410) E(level),J^π,Γ: From (2021Ch45) ^{9}Be(^{13}O,^{13}O). E(level): See also E_x=4.21 MeV (1984Se15) and 4500 keV *90* (1993Wa07) discrepant values reported in $^{13}C(\pi^+,\pi^-)$, 4.2 MeV *3* (2012Su21) ^{1}H(^{14}O,d) and 4410 keV *50* (2007GuZW: ΔE est.) ^{16}O(^{3}He,^{6}He). J^π: See also $(1/2^-,3/2,5/2^+)$ (2012Su21) and $(1/2^-)$ from (1993Wa07). Γ: See also Γ=0.6 MeV *4* (1993Wa07), <500 keV (2012Su21) and ≈0.43 MeV (2007GuZW: est.).
4866[b] *20*	$(1/2^+,1/2^-,3/2^-)$[e]	103 keV *37*	E	%p=100 E(level),J^π,Γ: From (2021Ch45) ^{9}Be(^{13}O,^{13}O).
4892[a] *25*	$7/2^+$[e]	323 keV *27*	E M	%p=100 E(level),J^π,Γ: From (2021Ch45) ^{9}Be(^{13}O,^{13}O). See also E_x=4.95 MeV *10* and Γ≈280 keV (2007GuZW: ΔE and Γ estimated by evaluator.) ^{16}O(^{3}He,^{6}He).
5483[c] *17*	$7/2^-$[e]	204 keV *41*	E	%p=100 E(level),J^π,Γ: From (2021Ch45) ^{9}Be(^{13}O,^{13}O).
5951[b] *18*	$(7/2^+,7/2^-)$[e]	875 keV *68*	E IJ M	%p=100 XREF: J(6E3) E(level),J^π,Γ: From (2021Ch45) ^{9}Be(^{13}O,^{13}O). E(level): (2021Ch45) suggests two states in this region: one at E_x=5951 keV *18* along with a questionable state at ≈6.2 MeV; both have broad widths of around 1 MeV. Other reactions have reported broad states near E_x≈6 MeV, but none have suggested or resolved two states. We associate all firm states reported in this region with the lower level reported in (2021Ch45), but highlight that the associations may be different if both states are found to exist. Other energies reported near E_x=6 MeV are 6020 keV *80* (1984Se15) and 6100 keV *90* (1993Wa07) both from $^{13}C(\pi^+,\pi^-)$, 6.00 MeV *10* (2007GuZW: ΔE est.) ^{16}O(^{3}He,^{6}He) and 6 MeV (2007TaZR) ^{13}C(^{11}B,^{11}Li). Γ: Other reported widths are Γ≈1.2 MeV (1984Se15) and Γ=0.6 MeV *4* (1993Wa07) from $^{13}C(\pi^+,\pi^-)$; (1984Se15) suggest the group may correspond to one or more unresolved states. See also Γ≈1.0 MeV (2007GuZW: est.).
≈6.2×10^3?[c]			E	%p=100 $T_{1/2}$ or Γ: Γ=BROAD. E(level),$T_{1/2}$ or Γ: From (2021Ch45) ^{9}Be(^{13}O,^{13}O).
6.90×10^3[d] *10*		≈160 keV	M	From (2007GuZW: ΔE and Γ est.) ^{16}O(^{3}He,^{6}He).
8.7×10^3[d] *2*		3.1 MeV *5*	IJ	E(level),Γ: From (1993Wa07) $^{13}C(\pi^+,\pi^-)$. See

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Adopted Levels (continued)

^{13}O Levels (continued)

E(level)	J^π	$T_{1/2}$ or Γ	XREF	Comments
				also E_x=8.8 MeV *5* and Γ=3.0 MeV *6* (1991Mo02) and E_x=8.8 MeV (2007TaZR) $^{13}C(^{11}B,^{11}Li)$. E(level): Suggested GDR⊗IAS (GDR built on isobaric analog states) see (2007TaZR, 1984Se15).

[a] Decays to p+$^{12}N_{g.s.}$. See details in (2021Ch45) $^{9}Be(^{13}O,^{13}O)$.

[b] Decays to p+^{12}N(961 keV:2^+). See details in (2021Ch45) $^{9}Be(^{13}O,^{13}O)$.

[c] Decays to p+^{12}N(1.19 MeV:2^-). See details in (2021Ch45) $^{9}Be(^{13}O,^{13}O)$.

[d] Decay mode not specified.

[e] From (2021Ch45) analysis of the *m* sub-state distributions obtained by comparison of measured ^{12}N+p angular distributions with those expected for proton decay via the relevant *s*-, *p*- and *d*-wave components. Angular distributions are found that uniquely identify J^π values.

^{1}H(^{12}N,p):res 2007Sk02

2003Te09, 2003Te12: ^{1}H(^{12}N,p) E=3.9 MeV/nucleon; Used two parallel-plate avalanche counters to tag events by nuclide and to monitor angular spread. Si detectors measured recoil proton spectra. Deduced resonance at E_p≈4.5 MeV (E_x≈2.7 MeV).

2007Sk02: ^{1}H(^{12}N,p) produced the 46 MeV $^{12}N^{7+}$ beam via ^{10}B(^{3}He,n) reaction at E(^{10}B)=43 MeV. Used a CH_2 polyethylene target. At E(c.m.)=0.8-2.7 MeV, measured elastic scattering E_p excitation at θ=7.5°, 22.5° and 37.5° using three Si ΔE-E detectors. Deduced ^{13}O resonance energies, J^π and Γ using R-matrix analysis.

^{13}O Levels

E(level)[b]	Jπ[ab]	Γ[b]	L[a]	Comments
2.69×10^3 *5*	1/2$^+$	0.45 MeV *10*	0	Γ=Γ_p. See related discussion on ANCs and widths in (2015Mu08, 2017Mu06, 2022Mu07).
3290 *50*	[1/2$^-$,3/2$^-$]	75 keV *30*	1	E(level): Possible mirror of a shell model predicted (1/2$^-$,3/2$^-$) state in ^{13}B at E_x≈4 MeV.

[a] From shape of resonance and R-matrix analysis assuming a only a single-proton decay channel. The following three distant resonances were included in the R-matrix analysis to fit the background: 4550, 3/2$^-$, Γ=0.24 MeV; 5000, 3/2$^+$, Γ=0.78 MeV; 5700, 3/2$^+$, Γ=2.0 MeV.

[b] From 2007Sk02.

^{1}H(^{14}O,d) 2012Su21

2012Su21: XUNDL dataset compiled by TUNL, 2012.

The authors measured ^{14}O(p,d) at E(^{14}O)=51 MeV/nucleon using a hydrogen gas target mounted in the SPEG/GANIL target chamber and using position sensitive Si strip arrays to detect the deuteron recoils (MUST2 and RIKEN Si telescope). The energy and angular distributions of deuterons were measured in coincidence with ^{13}O and ^{12}N (from ^{13}O* –>^{12}N + p) recoils. A distorted wave analysis of the angular distributions is given as well as a discussion on the breakdown of Z=8 shell closure.

2023Po05: ^{1}H(^{14}O,^{13}O) E=94 MeV/nucleon at RIKEN/RIBF; they also studied ^{1}H(^{14}O,^{13}N). Measured the parallel momentum distributions and reaction cross sections. Analyzed quasifree knockout and other mechanisms. Deduced S=3.42 in DWIA analysis.

^{13}O Levels

E(level)[a]	Jπ[a]	$T_{1/2}$ or Γ[a]	L[a]	S	Comments
0.0	3/2$^-$	8.58 ms *5*	1	2.1 *4*	$T_{1/2}$: From Adopted Levels. E(level): Observed at E_x=−0.2 MeV *3*.
2.8×10^3 *3*	1/2$^+$,(1/2$^-$ to 5/2$^+$)	<0.3 MeV	0,(1,2)		J^π=1/2$^+$,(1/2$^-$,3/2$^-$,3/2$^+$,5/2$^+$). The authors suggest this state corresponds to the 2.7 MeV J^π=1/2$^+$ level of (2007Sk02), though participation of a second ΔL=1 or 2 state can not be ruled out. Discussion on the spectroscopic factors for the various doublet combination is given in Table 1.
4.2×10^3 *3*	(1/2$^-$,3/2,5/2$^+$)	<0.5 MeV	(1,2)		Discussion on the spectroscopic factors is given in Table 1.

[a] From (2021Su21). Note: systematic uncertainty of 0.2 MeV is included.

^{2}H(^{12}N,^{13}O) 2013Gu04

2013Gu04: XUNDL dataset compiled by TUNL, 2013.

A beam of 72 MeV ^{12}N ions was produced via the ^{3}He(^{10}B,^{12}N) reaction at the RIKEN RI Beam facility. The trajectory of beam particles was tracked onto a 1.5 mg/cm^{2} deuterated polyethylene foil, where ^{2}H(^{12}N,^{13}O) reactions occurred. Interacting ^{12}N ions were identified by their time of flight relative to the cyclotron rf. The ^{13}O ejectiles were identified by ΔE-E in a telescope array.

The data are normalized by the ^{2}H(^{12}N,^{12}N) elastic scattering reaction. The code FRESCO was used to analyze the cross section angular distributions and to deduce the ANC′s. Values of $(C_{p1/2})^2$=3.4 fm^{-1} *13* and $(C_{p3/2})^2$=0.54 fm^{-1} *20* yield a total ANC of $(C_{tot})^2$=3.9 fm^{-1} *13*. An earlier measurement at RIKEN is mentioned in (2010LiZW).

Discussion is given on the astrophysical implications to the ^{1}H(^{12}N,^{13}O) reaction. See also (2022Du11).

^{13}O Levels

E(level)[a]	Jπ[a]
0.0	3/2⁻

[a] From Adopted Levels.

^{2}H(^{14}O,t) 2013Fl01

2013Fl01: XUNDL dataset compiled by TUNL, 2013.

A 18.1 MeV/nucleon ^{14}O beam was produced at the GANIL/SPIRAL facility. The beam impinged on a 1.5 mg/cm^2 CD_2 target (elastic scattering) or a 8.5 mg/cm^2 CD_2 target ((d,t)) and the light recoil nuclei were detected in one of six MUST2 array telescopes: four telescopes covered $\theta_{cm}\approx$15-70° for the nucleon transfer reactions while the other two were near $\theta_{lab}\approx$90° and were used to extend the elastic measurements.

The angular distributions were analyzed using the FRESCO code. Spectroscopic factors are deduced using both phenomenological and microscopic overlap functions and compared with literature results for ^{16}O(d,^{3}He), (d,t) and ^{18}O(d,^{3}He). See further analysis in (2018Fl03).

^{13}O Levels

E(level)	J^{π}[a]	Comments
0.0	3/2$^-$	C^2S(phenomenological)=1.69 *17* (experimental) *20* (analysis). C^2S(microscopic)=1.89 *19* (experimental) *22* (analysis).

[a] From FRESCO analysis of spectroscopic factors.

^{9}Be(^{13}O,^{13}O),(^{13}O,p^{12}N) 2013So11,1996Oz01

1996Oz01, 2001Oz04: ^{9}Be, C, ^{27}Al(^{13}O,^{13}O) E≈730 MeV. Measured interaction cross section. Deduced p, charge, neutron and matter r.m.s. radii of 2.56 fm *5*, 2.68 fm *5*, 2.48 fm *5* and 2.53 fm *5*, respectively.

2013So11: XUNDL data set compiled by TUNL, 2013.

A beam of E(^{13}O)=30.3 MeV/nucleon ions, produced via ^{1}H(^{14}N,^{13}O) reaction at the Texas A&M MARS facility, impinged on a 45.6 mg/cm^2 ^{9}Be target. Breakup particles were detected in a 10 cm× 10 cm segmented ΔE-E telescope located on the beam axis, 18 cm from the target.

Momentum analysis of the breakup particles permitted the kinematic reconstruction of the invariant mass and determination of excitation energies for ^{12}N* and ^{13}O* states involved in the reactions. The intrinsic width resolution was roughly 50 keV and there was a 10 keV systematic uncertainty in the invariant mass energy. The excitation spectra of p+^{12}N and 2p+^{11}C events were analyzed to deduce ^{13}O excited states.

A single state was observed at E_x=2956 keV *10* in the p+^{12}N relative energy spectrum, while two states at E_x=3025 keV *6* and 3669 keV *3* were found in the 2p+^{11}C spectrum (uncertainty is statistical only, systematic uncertainty is 10 keV). The widths of ^{13}O states were found consistent with the system resolution, hence narrow widths of Γ<50 keV are assumed.

Analysis of the Jacobi T and Y systems provides insight into the decay mechanism for the 3-body breakup systems; the decays are consistent with sequential decay mainly through E_x=0.96 and 1.18 MeV unbound states in ^{12}N.

2019We11: ^{9}Be(^{13}O,^{13}O), the authors of (2013So11) measured the excitation spectra of particle unbound nuclides produced in the breakup ^{13}O ions on a ^{9}Be target, the emphasis was on ^{11,12}N and ^{12}O, but some new information on ^{13}O was presented.

A beam of 69.5 MeV/nucleon ^{13}O ions, from the NSCL/A1900 fragment separator, was purified in the Radio Frequency Fragment Separator before impinging on a 1 mm thick ^{9}Be target. The reaction products were detected using the HiRA High-Resolution position sensitive ΔE-E telescope array, which covered the polar angles θ_{lab}=2.1° to 12.1°. Peaks corresponding to ^{13}O*(3038 *9*,3701 *10*) were reported. These values are consistent with (2013So11) but more precise. See related discussion in (2019Ka50).

2021Ch45: XUNDL dataset compiled by TUNL (2022).

The authors of (2013So11, 2019We11) reported new results on unbound ^{13}O states and analyzed the associated decay proton angular distributions to obtain information on the spin values.

A beam of 69.5 MeV/nucleon ^{13}O ions from the NSCL/A1900 fragment separator was purified in the Radio Frequency Fragment Separator before impinging on a 1 mm thick ^{9}Be target. The reaction products were detected using the HiRA High-Resolution position sensitive ΔE-E telescope array, which covered the polar angles θ_{lab}=2.1° to 12.4°. The invariant-mass spectra were obtained for states decaying to p+$^{12}N_{g.s.}$ and 2p+^{11}C (resulting from p+^{12}N(1.19 MeV:2$^-$) and p+^{12}N(961 keV:2$^+$) events).

Events corresponding to low target excitations were selected, since these events are thought to possess a strong spin alignment in the ejectile that should be sensitive to the excited state′s spin value. Additionally, the breakup events having the decay protons emitted perpendicular to the beam axis were preferentially selected to enhance the excitation energy resolution. Five states were observed in the p+$^{12}N_{g.s.}$ spectrum, three states were observed in the p+^{12}N(961 keV:2$^+$) spectrum, two states were observed in the p+^{12}N(1.19 MeV:2$^-$) spectrum, and evidence for a third, difficult to interpret, broad state was also observed in the p+^{12}N(1.19 MeV:2$^-$) decay channel.

The decay proton angular distributions were analyzed and compared with a model based on DWBA calculations to gain insight into sensitivity for constraining spin values of the excited states. The model analyzed the *m*-state distribution dependence for small-angle, and all-angle scattering of the ^{13}O ejectiles. Using the *m*-state distributions, angular distributions were calculated for *s*-, *p*- and *d*-wave components that are expected in proton emission from ^{13}O. The angular distributions showed a differentiable dependence for J and π values, and they were compaired with the measured ^{13}O→^{12}N+p angular distributions to obtain J^π values given below.

The present results are found in reasonable agreement with prior reports. In a few instances, states at similar excitation energies are found in the different decay modes; these states are assigned to different close-lying levels with different J$^\pi$ values based on the analysis of the decay proton angular distributions. See discussion in text.

note: In the initial publication, Table 1 was found to have inconsistencies between the E* and $E_{c.m.}$ values given. These values were corrected in September 2022 following a private communication with R.J. Charity (June 14, 2022). However, inconsistencies persist in the published ΔE values; in the present analysis ΔE values are obtained beginning with the uncertainties on $E_{c.m.}$ values. Also, the discussion indicates J^π=7/2$^+$ for peak 3, the Table I contains a typographycal error.

^{9}Be(^{13}O,^{13}O),(^{13}O,p^{12}N) 2013So11,1996Oz01 (continued)

^{13}O Levels

E(level)	J$^\pi$[b]	Γ[a]	$E_{c.m.}$(p+^{12}N) (keV)[a]	Comments
2428[c] *18*	1/2$^+$	358 keV *19*	916 *14*	
3006[c] *13*	3/2$^+$	55 keV *19*	1494 *8*	E(level): See also 2956 keV *15* (2013So11).
3051[d] *16*	5/2$^+$	54 keV *19*	578 *11*	E(level): See also 3025 keV *16* (2013So11) and 3038 keV *9* (2019We11).
3692[c] *13*	7/2$^+$	53 keV *21*	2180 *8*	E(level): See also 3669 keV *13* (2013So11) and 3701 keV *10* (2019We11).
3721[e] *16*	(3/2$^+$,5/2$^+$,5/2$^-$)	10 keV *+19−10*	1019 *11*	
4287[c] *13*	(3/2$^+$,5/2$^+$)	170 keV *25*	2775 *9*	
4866[d] *20*	(1/2$^+$,1/2$^-$,3/2$^-$)	103 keV *37*	2393 *16*	
4892[c] *25*	7/2$^+$	323 keV *27*	3380 *23*	
5483[e] *17*	7/2$^-$	204 keV *41*	2781 *11*	
5951[d] *18*	(7/2$^+$,7/2$^-$)	875 keV *68*	3478 *14*	
≈6.2×10^3?[e]		1.2 MeV	≈3500	Γ: From (1984Se15).

[a] From (2021Ch45). An 8 keV systematic uncertainty is combined in quadrature to the $\Delta E_{c.m.}$ decay energy values of Table 1 (labled ΔE_p in that table).

[b] From (2021Ch45) analysis of the *m* sub-state distributions obtained by comparison of measured ^{12}N+p angular distributions with those expected for proton decay via the relevant *s*-, *p*- and *d*-wave components.

[c] E=S(p)+E_{cm}(p+$^{12}N_{g.s.}$)=1512 keV *10* + $E_{c.m.}$(p+^{12}N).

[d] E=S(p)+E_{cm}(p+^{12}N(961 keV:2$^+$))=1512 keV *10* + $E_{c.m.}$(p+^{12}N) + 961 keV *5*.

[e] E=S(p)+E_{cm}(p+^{12}N(1.19 MeV:2$^-$))=1512 keV *10* + $E_{c.m.}$(p+^{12}N) + 1190 keV *7*.

^{9}Be(^{16}O,^{13}O)

1996Ma38, 1999Ma46, 1999Sa75: ^{9}Be(^{16}O,^{13}O), studied β-NQR and β-NMR. Deduced ABS(μ(^{13}O))=1.3891 μ_N *3* (1996Ma38) and ABS(Q(^{13}O))=11.0 mb *13* (1999Ma46, 1999Sa75).

See preliminary and conference results in (1996MaZQ, 1998MaZK, 2002Ma43).

See theoretical analyses in (1999Ki27, 1999Ki28, 2003Sm02, 2003Su04, 2003Su28).

^{13}O Levels

E(level)
0

^{12}C(p,π^-) 1978Co15,1980Ho20

1978Co15: ^{12}C(p,π^-) E=613 MeV from the Saclay synchrotron Saturne; measured π yields using the SPES I high-resolution magnetic spectrometer at θ=5°, 15° 25°and 35°. Deduced level at E_x=2.82 MeV *24*, enhancement at ≈5.5 MeV (450 keV energy resolution). No Q dependence on angular distribution.

1980Ho20: ^{12}C(p,π^-) E=200 MeV from Indiana University Cyclotron Facility; measured $\sigma(\theta)$ for $^{13}O_{g.s.}$, deduced structure and reaction process interplay.

1982Ja05: ^{12}C(pol. p,π^-) E=205 MeV from the Indiana University Cyclotron Facility; measured $\sigma(E(\pi))$, $\sigma(\theta)$, and A_y vs θ from θ(c.m.)=31° to 153° using the quadrupole-quadrupole split-pole spectrometer. Analyzed $^{13}O_{g.s.}$.

1985Bi04: ^{12}C(p,π^-) E= 180, 201 MeV from the Orsay synchrocyclotron, measured $\sigma(\theta,E(\pi))$. Deduced σ_{total}.

1988Ab05: ^{12}C(p,π^-) E=997(5) MeV, measured $\sigma(\theta)$ vs. π momentum from 75-950 MeV/c at θ=0° and 57.8°. Used two magnetic spectrometers π1 and π2 with angular acceptance of 0.01 sr. Total RMS error for normalisation of the differential cross section was 6% and 11% for 0° and 57.8°, respectively.

1992Ho03: ^{12}C(p,π^-) E=186, 204 MeV, θ(c.m.)=155°−180°. Observed π's emitted in backward direction corresponding to $^{13}O_{g.s}$.

2002Ha02: ^{12}C(pol. p,π^-) E=250, 300, 350 MeV, proton polarization of about 0.7 from the atomic beam-type polarized ion source at the Research Center for Nuclear Physics in Osaka University. Measured $\sigma(\theta)$ and analyzing powers using spectrometer LAS. Focal plane detectors consisted of two vertical drift chambers and two ΔE trigger scintillators. 10% data acquistion deadtime. Most background was from μ produced from π-decay. Less than 5% overall systematic uncertainties. Comparison with DWBA.

See also (theory) (1981Bu18, 1984Gu27, 1985Co11, 1991Ku07, 1992Be37, 1992No01, 1998No08, 2018No02).

^{13}O Levels

E(level)[a]	J$^\pi$[b]
0	(3/2$^-$)
2.82×10^3 *24*	

[a] From 1978Co15.
[b] From 1980Ho20.

^{12}C(^{15}O,^{13}O) 2022Bo01

2022Bo01: ^{12}C(^{15}O,^{13}O) E=349 MeV/nucleon. Measured fragmentation yields for nuclei produced in the fragmentation of ^{15}O. In addition they measured the production yields of ^{12}C(^{13}O,X) at E=397 MeV/nucleon for X=^{7,9}Be, ^{8,10,11}B, ^{9,10,11,12}C and ^{12}N.

^{13}O Levels

E(level)
0

$^{13}C(\pi^+,\pi^-)$ 1993Wa07

1980Bu15: $^{13}C(\pi^+,\pi^-)$ E=180 MeV, θ=5°, measured $\sigma(\theta)$ and Q. Used the Energetic Pion Channel and EPICS spectrometer to separate pions.

1984Se15, 1985SeZY: $^{13}C(\pi^+,\pi^-)$ E=164, 292 MeV, measured $\sigma(E(\pi),\theta)$, missing mass spectrum. Used a 90% isotopic pure ^{13}C target. Normalized yields with $^{1}H(\pi^+,\pi^+)$ at 50° and compared with phase-shift anlaysis. Found ΔE≈0.9 and 0.5 MeV FWHM resolution of missing mass spectra for thick and thin targets. The pions were separated using the EPICS spectrometer. Deduced ^{13}O levels. Excited state peaks appear significantly narrower than the ground state peak, which is surprising. The energies of the observed peaks appear to be shifted lower by ≈300 keV when compared with (1993Wa07), while the g.s. seems to have a high-energy tail. The ground state and other levels are reported at E_x=2.75 MeV *4*, 4.21 MeV and 6.02 MeV *8*.

1989Mo09: $^{13}C(\pi^+,\pi^-)$ E=292 MeV, θ=5°, measured $\sigma(\theta)$. ^{13}O deduced GDR built on IAS.

1990Gl09: $^{13}C(\pi^+,\pi^-)$ E=132 MeV, compiled data.

1990Mo02: $^{13}C(\pi^+,\pi^-)$ E=292 MeV, θ=5°, measured $\sigma(\theta)$. ^{13}O deduced GDR built on IAS. 90% enriched ^{13}C target.

1991Mo02: $^{13}C(\pi^+,\pi^-)$ E=292 MeV,θ=18°, measured $\sigma(\theta(\pi),E(\pi))$. 90% isotopic pure ^{13}C target. ^{13}O deduced giant resonances, Γ, ISPIN.

1993Wa07: $^{13}C(\pi^+,\pi^-)$ E=140-295 MeV, measured $\sigma(\theta)$ vs E using EPICS at LAMPF. 90% isotopic pure ^{13}C target. Deduced levels, Γ, configurations from mising mass spectra. Analyzed level structures at E_{π^+}=140, 180, 220, 260, 295 MeV. The ground state and other levels are reported at E_x=3.10 MeV *7*, 4.50 MeV *9*, 6.10 MeV *9* and 8.7 MeV *2*. The ground state width is reported at Γ=0.40 MeV *6*, even thought the state is known to have Γ<<1 eV. Other widths for the excited states are reported as Γ=0.6 MeV *4*, 0.6 MeV *4*, 0.6 MeV *4* and 3.1 MeV *5*, respectively.

1994Mo04, 1994Mo44: $^{13}C(\pi^+,\pi^-)$ E=295 MeV, compiled, reviewed $\sigma(\theta)$. Deduced GDR excitation.

1996Mo03: $^{13}C(\pi^+,\pi^-)$ E=140-295 MeV, θ=18° measured $\sigma(\theta)$. Analyzed various results.

See theoretical analysis in (1991Ku07).

Discussion: The level structures observed in $^{13}C(\pi^+,\pi^-)$ are best resolved in (1984Se15), though they did not report uncertainties for some of their results. On the other hand, (1993Wa07) also utilized EPICS at LANSCE for their measurement, and they did report experimental uncertainties, but they reported rather unreliable width values such as $\Gamma_{g.s}$=400 keV *60*. A further complication is that the reported excitation energies of (1984Se15) are systematically lower than those in (1993Wa07) suggesting the data sets should not simply be averaged. We select the excitation energies and widths of (1984Se15) for the lower-lying states since they appear better resolved, and we note that (1993Wa07) was focused on the E_x=8.7 MeV GDR⊗IAS resonance.

^{13}O Levels

E(level)[a]	J$^\pi$	Γ[a]	Comments
0	(3/2⁻)		E(level): Q(g.s)=−18.9 MeV *1* (1993Wa07,1991Mo02). Γ: The value Γ=400 keV *60* is reported in (1993Wa07), but this would imply a particle unbound level.
2.75×10³ *4*			Γ: NARROW. E(level): From E_x=2.75 MeV *4* in (1984Se15). See also E_x=3.10 MeV *9* from Q=−22.0 MeV *6* (1993Wa07). Γ: In (1984Se15) a peak with a narrower width than the g.s. is observed; subsequent results from (2021Ch45) $^{9}Be(^{13}O,^{13}O)$ support the existence of narrow states (≈50 keV) in this region. The other width reported for this state is Γ=0.60 MeV *40* (1993Wa07).
4210	(1/2⁻)		E(level): From (1984Se15). See also E_x=4500 keV *90* from Q=−23.4 MeV (1993Wa07). J$^\pi$: Based on similarities with $^{12}C(\pi^+,\pi^-)^{12}O$(g.s.) and $^{14}C(\pi^+,\pi^-)^{17}O$(5.9 MeV) (1984Se15). Γ: In (1984Se15) a peak with a similar width to the g.s. is observed. The only width reported for this state in $^{13}C(\pi^+,\pi^-)$ is Γ=0.60 MeV *40* in (1993Wa07).
6020 *80*		≈1.2 MeV	E(level): From (1984Se15). See also E_x=6.10 MeV *9* from Q=−25.0 MeV *8* (1993Wa07) and see also 5.1 MeV from Q=−24.0 MeV *5* in (1991Mo02). Γ: From (1984Se15). The other width reported for this state is Γ=0.60 MeV *40* (1993Wa07).
8.7×10³ *2*		3.1 MeV *5*	E(level),Γ: From Q=−27.6 MeV *2* (1993Wa07). See also Q=−27.7 MeV *5* and Γ=3.0

Continued on next page (footnotes at end of table)

$^{13}C(\pi^+,\pi^-)$ 1993Wa07 (continued)

^{13}O Levels (continued)

E(level)[a]	J^π	Γ[a]	Comments
			MeV *6* (1991Mo02), and Q=−27.4 MeV *5* and Γ=2 MeV *1* (1989Mo09). Suggested GDR⊗IAS resonance.

[a] From (1984Se15).

^{13}C(^{11}B,^{11}Li)

2007TaZR: ^{13}C(^{11}B,^{11}Li) E=758 MeV, measured ^{13}O excitation spectrum at RCNP Grand Raiden spectrometer. Peaks are suggested in the spectrum, and results are compared with the ^{13}C(π^+,π^-) spectrum. The ground state is observed and there may be some evidence of levels at E_x=25.0 and 27.5 MeV. Comments on the GDR⊗IAS (GDR built on isobaric analog states) are given.

^{13}O Levels

E(level)	Comments
0	
6×10^3?	
8.8×10^3?	E(level): Possibly the GDR⊗IAS.

^{14}N(p,2n)

1963Ba63: Study of residual decays from a ^{14}N(p,2n) study at the McGill synchrocyclotron. The ^{13}O nucleus was discovered based on observed β-p branches. See also (2012Th01).

1965Mc09: ^{14}N(p,2n) E=50 MeV; deduced ^{13}O β-p branches with E_p=6.06 and 6.65 MeV. $T_{1/2}$=8.7 ms *4*.

1970Es03, 1971EsZR: ^{14}N(p,2n) E=43 MeV; measured nine ^{13}O β-p branches and $T_{1/2}$=8.95 ms *20*.

1983AsZZ, 1984MiZR, 1990As01: ^{14}N(p,2n) E=45 MeV; studied ^{13}O decay. Reported $T_{1/2}$=8.50 ms *10* (1984MiZR); $T_{1/2}$=8.55 ms *5* (1984MiZR, 1990As01).

2005Kn02,2014Te01: ^{14}N(p,2n) deduced ^{13}O β-p branches.

^{13}O Levels

E(level)	$T_{1/2}$	Comments
0	8.55 ms *5*	$T_{1/2}$: From (1990As01).

^{14}N(^{12}N,^{13}O)

2009Ba09: ^{14}N(^{12}N,^{13}O) E=12 MeV/nucleon; measured particle spectra, angular distributions at TAMU/MARS spectrometer. DWBA analysis of elastic scattering channel to obtain ^{12}N(p,γ) ANC. Analyzed astrophysical reaction rate.

^{13}O Levels

E(level)
0

$^{16}O(^3He,^6He)$ 1991Go13,2007GuZW

1966Ce02: $^{16}O(^3He,^6He)$ E=65.3, θ=10-20°; deduced mass excess of 23.11 MeV *7*.
1970Me11: $^{16}O(^3He,^6He)$ E=65-75 MeV; measured M=23.107 MeV *15* at the 88-inch using ΔE-E telescopes. Compared IMME.
1970Tr05, 1970TrZX, 1971Tr03: $^{16}O(^3He,^6He)$ E=68-70 MeV, measured Q=−30.506 MeV *13* and ΔM=23.103 MeV *14*. Identification of particles using a position-sensitive Si surface-barrier detector in Enge spectrometer. Compared IMME.
1991Go13, 1991GoZR: $^{16}O(^3He,^6He)$ E=76.6 MeV. Used a gas target, solid SiO_2, and W_2O_5 targets to increase reliability. Collected spectra at θ=5° on a cooled semiconductor detector. Deduced levels. The article shows a spectrum with levels indicated and the text gives energy uncertainties around 50 keV, but the levels are not well resolved from other features. The peak fits appear drawn by hand via χ-by-eye technique. States at E_x=2.4 MeV *5* and 2.9 MeV *5* are deduced.
2007GuZW: $^{16}O(^3He,^6He)$ E=79.90 MeV; measured excitation spectra for θ=7° to 24° with ΔE≈250 keV (FWHM). Only one figure is shown for θ=12° where several peaks are observed with widths that are typically 2-3 times broader than the ground state width. The data were collected along with $^{20}Ne(^3He,^6He)$ data that were published in (1998Gu10); the $^{16}O(^3He,^6He)$ data appear only in (2007GuZW). By comparison with (1998Gu10) the peak energy resolution is estimated below by the evaluator.
The measured angular distributions disagreed with DWBA calculations which may indicate higher order effects, sequential transfer and core excitations should be considered.

^{13}O Levels

E(level)[a]	J^{π}[d]	Γ[e]	Comments
0			
2650[b]	(5/2$^+$)	<100 keV	E(level): See also E_x=2.40 MeV *5* (1991Go13,1991GoZR). Γ: The ≈250 keV width observed in the spectrum suggests Γ<100 keV.
3120[b]	(1/2$^-$)	≈0.43 MeV	E(level): See also E_x=2.90 MeV *5* (1991Go13,1991GoZR). Γ: ≈500 keV observed width.
3800[b]		≈160 keV	Γ: ≈300 keV observed width.
4410[b]		≈0.43 MeV	Γ: ≈500 keV observed width.
4.95×10^3[c]		≈280 keV	Γ: ≈375 keV observed width.
6.00×10^3[c]		≈1.0 MeV	Γ: ≈1 MeV observed width.
6.90×10^3[c]		≈160 keV	Γ: ≈300 keV observed width.

[a] From (2007GuZW). As the evaluation progressed it became clear that these level parameters would be more reliable if data from all nine angles had been analyzed and reported in a journal article. The weight given to these data and their uncertainties (deduced by the evaluator) is somewhat dismissed.
[b] ΔE≈50 keV is estimated by the evaluator.
[c] ΔE≈100 keV is estimated by the evaluator.
[d] Listed in (1991Go13,1991GoZR).
[e] The Γ values are estimated by the evaluator by subtracting the FWHM=250 keV resolution from the width observed in the Figure 2 spectrum of (2007GuZW).

^{28}Si(^{13}O,X)

2006Wa18: ^{28}Si(^{13}O,X) E=22.5-46.8 MeV; measured total σ_{reaction} and σ_{1p}, Glauber model analysis. Deduced proton, neutron and matter radii of 2.81, 2.47 and 2.69 fm, respectively. Deduced spectroscopic factors.

See other estimates of the ^{13}O nuclear density in (2005Ji04, 2017Ah08).

^{13}O Levels

E(level)
0

^{208}Pb(^{13}O,^{13}O) 2022Wa16

2022Wa16: XUNDL dataset compiled at TUNL (2022).

The authors measured elastic scattering of the ^{13}O and ^{13}B mirror nuclei on ^{208}Pb and analyzed the nuclear densities obtained from optical model analyses.

A beam of 413 MeV ^{13}O ions from the HIRFL in Lanzhou impinged on a 12.24 mg/cm^2 thick ^{208}Pb target. Scattered ^{13}O ions were momentum analyzed using an array of four position sensitive ΔE-E Si-detector telescopes that covered $\theta\approx3°$ to 27°. Differential cross sections were analyzed for θ_{lab}=4° to 15°. Only the ground state is bound in ^{13}O, and participation of any ^{208}Pb excited states was unresolved.

The data were analysed using two optical model approaches: first, using the double-folding Sao Paulo potential-2 (2021Ch70), and second using the single-folding Xu and Pang potential model (2013Xu06). The data are reasonably fit using standard global parameterization inputs. The discussion gives details on an approach for obtaining the proton, neutron and matter rms radii. A comparison of the results may suggest a thin proton skin for ^{13}O.

^{13}O Levels

E(level)	Comments
0	$<r_p^2>^{1/2}$=3.095 fm, $<r_n^2>^{1/2}$=2.670 fm, $<r_m^2>^{1/2}$=2.939 rm.

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