Adopted Levels, Gammas

\( Q(\beta^-) = 1.656 \times 10^4 \) I0; S(n) = 580 90; S(p) = 2.667 \times 10^4 23; \( Q(\alpha) = -1.984 \times 10^4 \) I9 2017Wa10

The mass excess adopted by (2012Wa38) is 32.41 MeV I0. See also 1986Vi09, 1987Gi05, 1988Wo09, 1991Or01.

**Halo nucleus:**
The \( ^{19}\text{C} \) nucleus has been suggested as a 1-neutron halo nucleus based on measurements of various reaction cross sections and momentum distributions of breakup products. See discussions in:
1989Sa10: E(\( ^{19}\text{C} \)) = 45.12 MeV/nucleon, Cu target, \( \sigma_{\text{reaction}} = 2.7 \) b 15.
1995Ba28: E(\( ^{19}\text{C} \)) = 77.2 MeV/nucleon, Be target, FWHM(\( ^{18}\text{C} \) parallel momentum dist) = 44 MeV/c 6.
1996Ma25: E(\( ^{19}\text{C} \)) = 30.3 MeV/nucleon, Ta target, \( \sigma_{\text{in}} = 2.5 \) b 4, \( \sigma_{\text{charge changing}} = 0.595 \) b 10, FWHM(n angular momentum dist) = 42 MeV/c.
1998Ba28: E(\( ^{19}\text{C} \)) = 88 MeV/nucleon, Be and Ta targets, \( \sigma(\text{Be})_{\text{in}} = 105 \) mb 17 and FWHM(\( ^{18}\text{C} \) parallel momentum dist) = 42 MeV/c 4, \( \sigma(\text{Ta})_{\text{in}} = 1.1 \) b 4 and FWHM(\( ^{18}\text{C} \) parallel momentum dist) = 41 MeV/c 3.
1998Ba87: E(\( ^{19}\text{C} \)) = 910 MeV/nucleon, carbon target, FWHM(\( ^{18}\text{C} \) parallel momentum dist) = 69 MeV/c 3. See (1999Sm01) who suggest the momentum distributions at different energies are affected by the low-lying excited state.
2001Co06: E(\( ^{19}\text{C} \)) = 910 MeV/nucleon, C and Pb targets, \( \sigma(\text{C})_{\text{in}} = 235 \) mb 51 and \( \sigma(\text{Pb})_{\text{in}} = 1967 \) mb 334. Evaluated relationship between \( S_{\text{1n}} \) and the \( S_{\text{1n}} \) separation energy. See also (2000Co31).
2001Oz03: E(\( ^{19}\text{C} \)) = 960 MeV/nucleon, carbon target, \( \sigma_{\text{interaction}} = 1231 \) mb 28, analyzed relation of \( \sigma_{\text{1}} \) to effective matter radius.
2009Na39: E(\( ^{19}\text{C} \)) = 240 MeV/nucleon, carbon and lead targets, \( \sigma(\text{C})_{\text{in}} = 132 \) mb 4 and \( \sigma(\text{Pb})_{\text{in}} = 969 \) mb 34. Deduced \( \sigma_{\text{in}}(\text{Coulomb}) = 690 \) mb 70.
2016Do10: E = 307 MeV/nucleon, carbon target, \( \sigma_{\text{interaction}} = 1.125 \pm 0.025(\text{stat}) \pm 0.013(\text{syst}) \) b; find \( R_{\text{mater}} = 3.10^{\pm 0.05}_{-0.03} \) fm.
2001Ma08, 2001Ma21: E(\( ^{19}\text{C} \)) = 50 MeV/nucleon, \( ^{9}\text{Be} \) target surrounded by 11 NaI detectors, \( \sigma_{\text{in}} = 264 \) mb 80 on \( ^{9}\text{Be} \), \( \sigma_{\text{1n}} = 1.35 \) b 18 on Au. Deduced (56 9%) of 1n-removal events populate \( ^{18}\text{C} \), and measured a narrow \( ^{18}\text{C} \) parallel momentum distribution by gating on events not in coincidence with \( \gamma \) rays. By considering the relationship between the parallel momentum distribution width and \( S_{\text{1n}} \) they deduce \( S_{\text{1n}} = 650 \) keV 150. Their analysis is found consistent only if \( J\pi(19\text{C}) = 1/2^+ \).
2010Ta04: E(\( ^{19}\text{C} \)) = 40 MeV/nucleon, \( ^{1}\text{H} \) liquid hydrogen target, \( \sigma_{\text{R}} = 754 \) mb 22, using the transmission method.

**Theoretical analysis:**

**19C Levels**

**Cross Reference (XREF) Flags**

<table>
<thead>
<tr>
<th>E(level)</th>
<th>J(^\pi)</th>
<th>T(_{1/2})</th>
<th>XREF</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>(1/2(^+))</td>
<td>46.3 ms 40</td>
<td>ABCDEFGHIJK MNOPQR</td>
<td>%(\beta^- = 100); %(\beta^- = 47;\text{3}); %(\beta^- = 7;\text{3})</td>
</tr>
</tbody>
</table>

T\(_{1/2}\): from the weighted average of 49 ms 4 (1988Du09); see also preliminary value 30 ms 10 in 1988Du2ZT, 45.5 ms 40 (1995Oz02) and 44,1 ms 42 (Reeder et al., Int. Conf. on Nucl. Data for Science and Technology, May 9-13, 1994, Galimburg, Tennessee: see also 44

Continued on next page (footnotes at end of table)
### 19C Levels (continued)

<table>
<thead>
<tr>
<th>E(level)</th>
<th>J(^{\pi})</th>
<th>T(_{1/2})</th>
<th>XREF</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>209 2</td>
<td>(3/2(^{+}))</td>
<td>1.34 ns 10</td>
<td>A DE K</td>
<td>ms 4 in the unpublished private communications of (2008ReZZ)/(1995ReZZ) and 45.5 ms 40 (1994RaZW). Also see 46.2 ms 40 in (2015Bi05). J(^{\pi}): from analysis of breakup fragment momentum distributions in 2001Ma08. Decay: Studies of the (\beta)-delayed neutron emission have been carried out in (1991Re02: (\beta^{-})=(\beta_{1n}+2(\beta_{2n})+3(\beta_{3n})=(53.26%)), (1995ReZZ/2008ReZZ: (\beta^{-})=(66.9%)), and (1988Du09: (\beta_{1n}=(47.3%)) and (\beta_{2n}=(7.3%)). Analysis of (\beta-\gamma) coincidences indicate the (\beta_{1n}) decay populates (^{19}\text{N}^<em>(6400,6508,7025)), which subsequently neutron decay to (^{18}\text{B}^</em>(115,587)) see (1995Oz02). There is evidence for additional branches that (\beta-2n) decay to (^{17}\text{B}) with (\beta^{-}=2n=(7.3%)) (1988Du09).</td>
</tr>
<tr>
<td>282? 5</td>
<td></td>
<td></td>
<td>A</td>
<td>E(level): from (2015Wh02). See also 2005El07: 197 keV 6, 2015Va09: 198 keV 10, and 2008St18: 201 keV 15. T(<em>{1/2}): Analysis of the spectra using lineshape and recoil-distance techniques indicate T(</em>{\text{mean}})=198 ns 10 and 190 ns 10 values, respectively (2015Wh02). Additional systematic uncertainties give final uncertainties of T(<em>{\text{mean}})=198 ns 12 and 190 ns 13 for the two methods, respectively. The authors give a recommended value T(</em>{\text{mean}})=194 ns 15. J(^{\pi}): from 2015Wh02, based on the B(M1) value; E2 components are excluded and neglected. The J(\pi) of this state had initially been suggested as 5/2(^{+}) based on expectations from shell model analysis. In this case (\beta_{2}=0.29); deduced from integrated experimental cross section for this state from 0(^{\circ})-1.7(^{\circ}) and distorted wave analysis (2005El07). However, subsequent observations and discussion in (2011Oz01, 2012Ko38, 2013Th06) support the notion that the first J(\pi)=5/2(^{+}) state must be unbound. Cross section: 4.2 mb 5 in (p,p(^{\prime})).</td>
</tr>
<tr>
<td>653 95</td>
<td>(5/2(^{+}))</td>
<td>&lt;100 keV</td>
<td>F</td>
<td>E(level): deduced from E((^{18}\text{C}+n))=76 keV 14 and S(n)=577 keV 94. %(_{n}^{\approx}100).</td>
</tr>
<tr>
<td>1.46\times10(^{3}) 10</td>
<td>5/2(^{+})</td>
<td>0.29 MeV 2</td>
<td>B</td>
<td>E(level): deduced from E((^{18}\text{C}+n))=880 keV 10 and S(n)=577 keV 94. %(_{n}^{\approx}100).</td>
</tr>
</tbody>
</table>

### \(\gamma\)(\(^{19}\text{C}\))

<table>
<thead>
<tr>
<th>E((\text{level}))</th>
<th>J(^{\pi})</th>
<th>E(_{\gamma})</th>
<th>I(_{\gamma})</th>
<th>E(_{f})</th>
<th>J(^{\pi})</th>
<th>Mult.</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>209 2</td>
<td>(3/2(^{+}))</td>
<td>209 2</td>
<td>100</td>
<td>0</td>
<td>(1/2(^{+}))</td>
<td>M1</td>
<td>Br(M1)=0.00321 25 (2015Wh02); B(M1)(W.u.)=0.00179 14 (2015Wh02)</td>
</tr>
<tr>
<td>282?</td>
<td>72 4</td>
<td>100</td>
<td>209</td>
<td>(3/2(^{+}))</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Adopted Levels, Gammas

Level Scheme

Intensities: Relative photon branching from each level
Beam=\(^{19}\)C, target=liquid H\(_2\).

2005El07: A beam of 49.4 MeV/nucleon \(^{19}\)C ions, produced in fragmentation of a 110 MeV/nucleon \(^{22}\)Ne beam on a \(^{9}\)Be target at the RIKEN/RIPS facility, was momentum and mass analyzed before impinging in a 3 cm diameter cryogenic hydrogen target that had an areal density of 190 mg/cm\(^2\).

The scattered \(^{19}\)C particles were detected in a \(\Delta E\)-\(\Delta E\)-\(\Delta E\)-E telescope that covered \(\theta\textless 1.7^\circ\), while \(\gamma\)-rays were detected using the DALI2 array of 158 NaI(Tl) scintillators. \(E_\gamma\), \(I_\gamma\), \(\gamma\gamma\), particle-\(\gamma\) coinc were measured.

2005Ka26: The authors searched for evidence of an isomeric state with \(E_x\textless 300\) keV and \(T_{1/2}\textless 500\) ns, as predicted by shell model calculations.

A cocktail beam, including \(^{19}\)C and \(^{17}\)B, was produced by fragmenting a \(^{22}\)Ne beam on a \(^{9}\)Be target at RIKEN. Beam particles were identified from analysis of \(\Delta E\), time-of-flight and beam rigidity. The beam impinged on a liquid hydrogen target that was surrounded by NaI \(\gamma\)-ray detectors; results for prompt transitions are reported in (2005El07). After the target, the beam was stopped in a \(\Delta E\)-\(\Delta E\)-\(\Delta E\)-E telescope that was surrounded by thin plastic scintillators (for identification of \(\beta\) decay events) and an array of segmented HPGe clover detectors that were intended to observed delayed de-excitations from isomeric states populated in the reaction. Several transitions related to \(\beta\)-decay of daughters and granddaughters were identified. No definitive evidence in support of an isomeric state was found.

The authors commented on the level of confidence for non-observation over various transition energy ranges, and over various lifetime ranges. Finally, various combinations of \(J\pi\) values were considered for the ground state and a supposed isomeric state. See also analysis in (2008Ka39).

\(^{19}\)C Levels

\begin{tabular}{cccc}
E(level)\‡ & \(J^\pi\) & Comments \\
0.0 & 1/2\textsuperscript{+} & Configuration=d\(_5^4\) \(\otimes\) s\(_{1/2}\) (2001Ma08).
197? 6 & (3/2\textsuperscript{+}) & Configuration of state suggested as mixture of d\(_5^5\) \(\otimes\) s\(_{1/2}\)\(_{1/2}\) and d\(_5^4\) \(\otimes\) s\(_{1/2}\) configurations (2001Ma08).
269? 8 & (5/2\textsuperscript{+}) & \(\beta_2\textless 0.29\) \(J\); deduced from integrated experimental cross section for this state from 0\(^\circ\) to 1.7\(^\circ\) and distorted wave analysis (2005El07).
& & Cross section: 4.2 mb in (p,p\').
\end{tabular}

\(\gamma\)(\(^{19}\)C)

Neither of the observed transitions in \(^{19}\)C from 2005El07 corresponds to a 5/2\textrightarrow 1/2 \(\gamma\) ray as it would imply a long lifetime for each level and would make the observation of the transitions impossible with the setup described above.

\begin{tabular}{cccccc}
E\(_\gamma\)\†\‡ & \(I_\gamma\)\‡ & E\(_f\)(level) & \(J^F\)\(_f\) & \(E_f\) & \(J^F\)\(_f\) & Comments \\
72 4 & 100 13 & 269? & (5/2\textsuperscript{+}) & 197? & (3/2\textsuperscript{+}) & \(E_\gamma\): Assignment to (1/2\textsuperscript{+}) state based upon retarded feature of the 3/2\textrightarrow 1/2 transition and the prompt nature of the observed \(\gamma\) rays. (2005El07).
197 6 & 89 12 & 197? & (3/2\textsuperscript{+}) & 0.0 & 1/2\textsuperscript{+} &
\end{tabular}

\(\dagger\) Tentative assignments to excited states based upon systematics of transition strengths combined with considerations of g.s. configuration and half-lives of the excited states.

\‡ From 2005El07.

\(\gamma\)(\(^{19}\)C)

Neither of the observed transitions in \(^{19}\)C from 2005El07 corresponds to a 5/2\textrightarrow 1/2 \(\gamma\) ray as it would imply a long lifetime for each level and would make the observation of the transitions impossible with the setup described above.

\begin{tabular}{cccccc}
E\(_\gamma\)\†\‡ & \(I_\gamma\)\‡ & E\(_f\)(level) & \(J^F\)\(_f\) & \(E_f\) & \(J^F\)\(_f\) & Comments \\
72 4 & 100 13 & 269? & (5/2\textsuperscript{+}) & 197? & (3/2\textsuperscript{+}) & \(E_\gamma\): Assignment to (1/2\textsuperscript{+}) state based upon retarded feature of the 3/2\textrightarrow 1/2 transition and the prompt nature of the observed \(\gamma\) rays. (2005El07).
197 6 & 89 12 & 197? & (3/2\textsuperscript{+}) & 0.0 & 1/2\textsuperscript{+} &
\end{tabular}

\(\dagger\) Quoted uncertainties are from statistical error and Doppler correction.

\‡ From 2005El07.
\[ ^{1}H(^{19}C_{6}\gamma) \] 2005El07

**Level Scheme**

Intensities: Relative \( I_{\gamma} \)

\[ \begin{align*}
\text{(5/2\( ^{-}\))} & \quad \text{[\( \gamma \) 710]} \\
\text{(3/2\( ^{-}\))} & \quad \text{[\( \gamma \) 197]}
\end{align*} \]

Legend

- \( I_{\gamma} < 2\% \times I_{\gamma}^{\text{max}} \)
- \( I_{\gamma} < 10\% \times I_{\gamma}^{\text{max}} \)
- \( I_{\gamma} > 10\% \times I_{\gamma}^{\text{max}} \)
2008Sa03:
Beam=\(^{19}\)C, target=liquid hydrogen.
A E=70 MeV/nucleon \(^{19}\)C beam was produced at the RIKEN/RIPS facility by fragmenting a 110 MeV/nucleon \(^{22}\)Ne in a thick target. The beam impinged on a 3 cm diameter cryogenic hydrogen target with 120 mg/cm\(^2\) areal density. The \(\gamma\)-rays from reactions in the target were detected using 48 NaI(Tl) scintillators while charged particles were detected with a plastic counter hodoscope. Neutrons, from \(^{19}\)C breakup, were detected using a neutron hodoscope consisting of two walls of plastic scintillator array.
The inclusive \(^{18}\)C+n and exclusive \(^{18}\)C+n+\(\gamma\)\(^{18}\)C*\(2^+\)=1.58 MeV] spectra were analyzed. A resonance at E(rel)=0.88 MeV \(J^p\) with \(\Gamma=290\) keV \(2^+\) was observed in the inclusive spectrum, but absent in the exclusive \(\gamma\)-ray coincidence events; evidence the state decays to \(^{18}\)C\(_{g.s.}\). In addition, the angular distribution of the resonance was analyzed and compared with DWBA calculations. See analysis in (2016La20), which suggests strong dynamic excitation of the \(^{18}\)C core is required to find agreement in \(\sigma\) magnitude for the \(J^\pi=5/2^+\) (\(E_x=1.46\) MeV) state. See also (2011Cr02).

2011Oz01: The cross section for 1-n removal from 40 MeV/nucleon \(^{19}\)C on protons in a liquid hydrogen target (204 mg/cm\(^2\)) was measured at the RIKEN/RIPS facility along with the parallel momentum distribution of \(^{18}\)C fragments. In addition, the 160 NaI(Tl) element DALI2 array surrounded the reaction target and measured deexcitation \(\gamma\)-rays correlated with breakup fragments. The cross section \(\sigma_{1\text{n}}=101\) mb \(1\pi\) is measured along with a \(^{18}\)C fragment parallel momentum distribution width of FWHM=83 MeV/c.

\[^{19}\text{C Levels}\]

<table>
<thead>
<tr>
<th>E(level)(^\dagger)</th>
<th>(J^\pi)</th>
<th>(\Gamma) (MeV)</th>
<th>(\sigma) (mb)(^#)</th>
<th>Comments</th>
</tr>
</thead>
</table>
| 0                 | 1/2\(^+\) | 0.29 MeV        | 8.6 4          | Resonance energy(c.m.)=880 keV \(1\pi\) (g.s. in \(^{18}\)C).
| 1.46\times10\(^3\) | 5/2\(^+\) | 0.29 MeV        | 8.6 4          | \(J^\pi\): from DWBA analysis of angular distribution. |

\(^\dagger\) Excitation energy=resonance energy+\(S(n)\)+excitation energy of the daughter nucleus \(^{18}\)C.
\(^\dagger\) From comparison of \(\sigma(\theta)\) distributions with DWBA calculations for \(^{19}\)C(p,p\(^\prime\)) reaction.
\(^\#\) Experimental cross-sections.
Charge changing cross sections and total reaction cross sections for 40 MeV/nucleon $^{19}\text{C}+^{1}\text{H}$ reactions were measured at the RIKEN/RIPS facility. The $\sigma_R=754$ mb was measured, along with various cross sections to specific elements.

$^{19}\text{C}$ Levels

| E(level) | 0 |
2015Va09: The authors studied the low-lying structure of $^{19}$C using the $^1$H($^{20}$C,$^{19}$C$\gamma$) reaction to populate levels that de-excited via $\gamma$-ray transitions. A single transition was observed and compared with theoretical estimates suggesting decay from a $J\pi=3/2^+$ state to the $1/2^+$ ground state.

A cocktail beam that included a $^{20}$C component was produced by fragmenting a $^{40}$Ar beam=63 MeV/nucleon beam in a 0.2 mm thick $^{181}$Ta target. The beam was purified in the RIKEN/RIPS fragment separator and transported to a 190 mg/cm$^2$ liquid hydrogen target. The beam, which was identified via time-of-flight (ToF) using a thin plastic scintillator that was near the target, had an energy of around 50 MeV/nucleon at the center of the target. The heavy ejectiles within $\theta_{lab}<6.5^\circ$ were identified using $\Delta E$ vs. E and $\Delta E$ vs ToF analysis. De-excitation $\gamma$-rays in coincidence with $^{19}$C ejectiles were detected using the 160 DALLI2 NaI scintillators arranged in a ball-like configuration that covered angles between $\theta_{lab}=15^\circ−160^\circ$. A GEANT4 simulation indicated 54% efficiency at 200 keV.

The Doppler corrected spectrum indicated a transition corresponding to $E_\gamma=198$ keV, which agrees with prior observations. The cross section $\sigma=4.54$ mb was deduced. This cross section is in line with expectations from direct feeding of a $J\pi=3/2^+$ state in the one-neutron removal reaction, but it is not in agreement with expectations if the reaction would feed a bound $J\pi=5/2^+$ state that cascades through the $3/2^+$ state (yielding an order of magnitude higher predicted cross section).

Further discussion focuses on the high degree of certainty for excluding a higher-lying bound $J\pi=5/2^+$ state in $^{19}$C.

### $^{19}$C Levels

<table>
<thead>
<tr>
<th>E(level)</th>
<th>$J^\pi$</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1/2$^+$</td>
<td>$J^\pi$: from 2001Ma08.</td>
</tr>
<tr>
<td>198</td>
<td>3/2$^+$</td>
<td></td>
</tr>
</tbody>
</table>

### $\gamma(^{19}$C)

<table>
<thead>
<tr>
<th>$E_\gamma$(level)</th>
<th>$J^\pi$</th>
<th>$E_\gamma$</th>
<th>$I_\gamma$</th>
<th>$E_f$</th>
<th>$J^\pi_f$</th>
</tr>
</thead>
<tbody>
<tr>
<td>198</td>
<td>3/2$^+$</td>
<td>198</td>
<td>100</td>
<td>0</td>
<td>1/2$^+$</td>
</tr>
</tbody>
</table>

### $^{1}$H($^{20}$C,$^{19}$C$\gamma$) 2015Va09

#### Level Scheme

Intensities: % photon branching from each level

```
\begin{tikzpicture}
  \node at (0,0) {$^{19}$C} ;
  \draw[->] (0,0) -- (1,0) node [midway, left] {3/2$^+$} ;
  \draw[->] (1,0) -- (2,0) node [midway, left] {198} ;
  \draw[->] (2,0) -- (3,0) node [midway, left] {1/2$^+$} ;
  \draw[->] (3,0) -- (4,0) node [midway, left] {0} ;
\end{tikzpicture}
```
2015Wh02: The authors studied the magnetic response of the halo nucleus ${}^{19}\text{C}$ by measuring the lifetime of the first excited state and deducing the $B(\text{M}1)$ transition strength.

A beam of $E(\text{N}) = 74 \text{ MeV/nucleon}$ ions ($\Delta p/p \approx 2\%$), produced by fragmentation of $^{22}\text{Ne}$ in a thick $^9\text{Be}$ target at the NSCL, impinged on a 370 mg/cm$^2$ $^9\text{Be}$ target that sometimes induced single proton knock-out reactions populating $^{19}\text{C}^+(209)$. The heavy $^{19}\text{C}$ recoil was detected using the S800 focal plane detectors, while de-excitation $\gamma$-rays were detected using seven elements of the GRETINA array. The Doppler-shift of the de-excitation $\gamma$-rays was measured in two configurations: first with only the $^9\text{Be}$ reaction target ($v/c = 0.36$) located 13 cm upstream with respect to the center of the array and second with the reaction target at 15.5 cm upstream with respect to the center of the array and a 1527 mg/cm$^2$ thick Ta degrader located 5 cm downstream from the reaction target ($v/c = 0.32$). In this arrangement, the GRETINA detectors were located at $\theta_{\text{lab}} = 40^\circ$ and $\theta_{\text{lab}} = 65^\circ$.

### $^{19}\text{C}$ Levels

<table>
<thead>
<tr>
<th>$E(\text{level})$</th>
<th>$J^\pi$</th>
<th>$T_{1/2}$</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>$1/2^+$</td>
<td>1.34 ns 10</td>
<td>$J^\pi$: from 2001Ma08.</td>
</tr>
<tr>
<td>209</td>
<td>$(3/2^+)$</td>
<td>$100$</td>
<td>$T_{1/2}$: Analysis of the spectra using lineshape and recoil-distance techniques indicate $T_{\text{mean}} = 198$ ns 10 and 190 ns 10 values, respectively (2015Wh02). Additional systematic uncertainties give final uncertainties of $T_{\text{mean}} = 198$ ns 12 and 190 ns 13 for the two methods, respectively. The authors give a recommended value $T_{\text{mean}} = 194$ ns 15.</td>
</tr>
</tbody>
</table>

### $\gamma(^{19}\text{C})$

<table>
<thead>
<tr>
<th>$E(\text{level})$</th>
<th>$J^\pi_i$</th>
<th>$E_\gamma$</th>
<th>$I_\gamma$</th>
<th>$E_f$</th>
<th>$J^\pi_f$</th>
<th>Mult.</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>209</td>
<td>$(3/2^+)$</td>
<td>209</td>
<td>100</td>
<td>0</td>
<td>$1/2^+$</td>
<td>$M1$</td>
<td>$B(\text{M}1)\downarrow = 0.00321$ 25 (2015Wh02); $B(\text{M}1)(\text{W.u.}) = 0.00179$ 14 (2015Wh02)</td>
</tr>
</tbody>
</table>

### $^9\text{Be}(^{20}\text{N},^{19}\gamma)$ 2015Wh02

#### Level Scheme

Intensities: % photon branching from each level

```
(3/2^+)  209  1.34 ns 10

1/2^+     0

^{19}\text{C}_{13}
```

---

---
\(^{9}\text{Be}(^{22}\text{N},^{19}\text{C})\) \textbf{2013Th06}

\textbf{1995Oz02}: \(^{9}\text{Be}(^{22}\text{N},^{19}\text{C})\) was used to produce \(^{19}\text{C}\). The beam was implanted in a plastic scintillator and \(\beta\)-delayed neutrons were measured corresponding to three neutron decay transitions. Analysis of the decay rate gives the lifetime \(T_{1/2}=45.5\) ms \(40\). In total, eight neutron groups were observed in the neutron energy spectrum, three from \(^{19}\text{C}\) and five from \(^{19}\text{N}\) delayed neutrons and other beam contaminants. The total \(P_{\text{1n}}=(47\ 3)\%\). Shell model calculations used by the authors predict \(J^{\pi}=1^{+}/2^{+}\), but \(3/2^{+}\) and \(5/2^{+}\) states were predicted nearby and could not be ruled out.

\textbf{2013Th06}: Neutron decay spectroscopy was used to analyze the \(^{18}\text{C}+\text{n}\) pairs produced when a \(^{22}\text{N}\) beam was fragmented on a target.

A beam of 68 MeV/nucleon \(^{22}\text{N}\) ions, produced by fragmenting a \(^{48}\text{Ca}\) beam on a thick \(^{9}\text{Be}\) target at the NSCL, impinged on a 481 mg/cm\(^2\) \(^{9}\text{Be}\) reaction target. The resulting \(^{18}\text{C}+\text{n}\) products were momentum analyzed using both a large-gap superconducting dipole magnet and the MoNA array.

A single resonance is observed with \(E_{\text{rel}}=76\) keV \text{14} and \(\Gamma \leq 100\) keV; this corresponds to \(E_{x}=653\) keV \text{95}. The width was dominated by the \(\approx 100\) keV experimental resolution.

Significant discussion on the spin-parity of the state is given. Results from prior measurements are given as support for assuming \(J^{\pi}=5/2^{+}\) (\text{2011Oz01, 2012Ko38}), and for removing the previously suggested \(J^{\pi}=5/2^{+}\) assignment from the \(E_{x}=270\) keV resonance reported in (2005El07). Particular comments are given to explain the present lack of sensitivity to the \(E_{x}=1.46\) MeV, \(J^{\pi}=5/2\) state observed in 2008Sa03.

\begin{tabular}{|c|c|c|c|}
\hline
\text{E(level)} & \text{J}\textsuperscript{\pi} & \text{\Gamma} & \text{Comments} \\
\hline
0 & \((1/2^{+},3/2^{+})\) & 45.5 ms \text{40} & \text{J}\textsuperscript{\pi}: from shell model predictions (1995Oz02). \\
653 95 & \((5/2^{+})\) & \textless 100 keV & \text{E(level)}: deduced from \(E(18\text{C}+\text{n})=76\) keV \text{14} and \(S(\text{n})=577\) keV \text{94} (from http://amdc.in2p3.fr/mastables/Ame2003/rct2.mas03). Rounded value of \(S(\text{n})\) is 580 keV \text{90} in published 2012Wa38. \\
\hline
\end{tabular}
$^{9}\text{Be}(^{40}\text{Ar},^{19}\text{C})\quad 2000\text{Oz01}, 2012\text{Kw02}$

*2000Oz01:* Production yields for fragmentation of 1 GeV/nucleon $^{40}$Ar projectiles on a beryllium target were measured. Cross sections of roughly $1.00 \times 10^{-7}$ b were deduced.

*2012Kw02:* Production yields for fragmentation of 120 MeV/nucleon $^{40}$Ar projectiles on beryllium, nickel and tantalum targets were measured. Cross sections of roughly $2 \times 10^{-5}$ mb were deduced.

See also 2002Ji08.

$^{19}$C Levels

<table>
<thead>
<tr>
<th>E(level)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
</tbody>
</table>
1981St23: Production yields for fragmentation of 213 GeV/nucleon $^{48}$Ca projectiles on a beryllium target were measured at the Bevalac using a 0° magnetic spectrometer. The neutron-rich fragments were focused on a stack of Lexan plastic track detectors; analysis of the tracks provided the range, charge and magnetic deflection of the produced isotopes. A charge resolution of 0.2 was obtained along with a mass resolution of approximately $\leq 0.2$ u.

The analysis showed clear indications of $^{18}$C, $^{19}$C, $^{20}$C. Ambiguous results on $^{21}$C are found. This work is credited with the discover of $^{20}$C and $^{27}$F. For $^{19}$C, the cross section of roughly 0.8 $\mu$b was deduced.

$^{19}$C Levels

<table>
<thead>
<tr>
<th>E(level)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
</tbody>
</table>
2012Ko38: The cross section for 1-n removal from 243 MeV/nucleon $^{19}$C on a carbon target was measured at the RIKEN/ZDS (zero degree spectrometer), along with the parallel momentum distribution of $^{18}$C fragments. The $\sigma = 163 \text{ mb}$ $J^2$ is deduced. The discussion analyzes the momentum distribution shape by assuming various $^{18}$C states are populated in the breakup, and is consistent with $J\pi = 1/2^+$ for the ground state.

$^{19}$C Levels

<table>
<thead>
<tr>
<th>E(level)</th>
<th>$J^\pi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>$1/2^+$</td>
</tr>
</tbody>
</table>
1988Du09: $^{19}$C was produced by fragmentation of a 60 MeV/n $^{22}$Ne beam impinging on either a tantalum or a carbon target and was selected using the LISE spectrometer. The $^{19}$C ions were implanted into a 7 mm thick plastic scintillator. Following the decay, $\beta$-particles were detected by a plastic scintillator while the delayed neutrons were detected through the Gd(n,$\gamma$) reaction in a $4\pi$ neutron ball that surrounded the implantation target. $T_{1/2}=49$ ms, $P_{0n}=0.46$, $P_{1n}=0.47$ and $P_{2n}=0.07$ were measured.

$^{19}$C Levels

<table>
<thead>
<tr>
<th>E(level)</th>
<th>$T_{1/2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>49 ms</td>
</tr>
</tbody>
</table>
2004St10,2004ST29,2008St18: The authors populated $^{19}\text{C}$ using a cocktail beam of neutron-rich nuclides [25$\text{Ne}$, 26$\text{Ne}$, 27$\text{Na}$, 28$\text{Na}$, 29$\text{Mg}$, and 30$\text{Mg}$] that were produced by fragmenting an initial 77.5 MeV/nucleon 36$\text{S}$ beam at the GANIL/SSI beamline. The cocktail beam was selected using the ALPHA spectrometer and focused on a carbon target that was coupled to a plastic scintillator. E$\gamma$, $\gamma\gamma$, $\gamma$(fragment) coincidences were measured using 74 BaF$_2$ detectors that surrounded the target with 4$\pi$ and the SPEG spectrometer. The $^{19}\text{C}$ were identified using time-of-flight, energy loss and focal-plane position information. A single $\gamma$-ray transition is observed. Results are compared with shell-model calculations for analysis of $J\pi$ values.

All data are from 2008St18.

### $^{19}\text{C}$ Levels

<table>
<thead>
<tr>
<th>E(level)</th>
<th>$J^\pi$</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>(1/2$^+$)</td>
<td>$J^\pi$: from Adopted Levels of $^{19}\text{C}$ in ENSDF database.</td>
</tr>
<tr>
<td>201</td>
<td>(3/2$^+$)</td>
<td>$J^\pi$: 3/2$^+$ or 5/2$^+$ from shell-model predictions; the latter would require 201$\gamma$ to be E2 and corresponding half-life $\approx$ 1 $\mu$s for 201 level.</td>
</tr>
</tbody>
</table>

#### $\gamma^{(19}\text{C)}$

<table>
<thead>
<tr>
<th>$E_\gamma$</th>
<th>$E_i$(level)</th>
<th>$J^\pi_i$</th>
<th>$E_f$</th>
<th>$J^\pi_f$</th>
</tr>
</thead>
<tbody>
<tr>
<td>201</td>
<td>201</td>
<td>(3/2$^+$)</td>
<td>0</td>
<td>(1/2$^+$)</td>
</tr>
</tbody>
</table>

### $^{12}\text{C}(^{25}\text{Ne},^{19}\text{C}\gamma)$ 2004St10,2008St18

#### Level Scheme

```
\[\begin{array}{c}
(3/2^+) \\
\gamma
\end{array}\]
```

```
\[\begin{array}{c}
(1/2^+) \\
0
\end{array}\]
```

$^{18}\text{C}_{13}$
\[ ^{19} \text{B} \beta^- \text{decay} \quad 1998\text{Yo06,2003Yo02} \]

Parent: \(^{19}\text{B} \): E=0; J\(^{\pi}\)=3/2\(^{-}\); T\(_{1/2}=2.92\) ms \(^{13}\text{C} \); Q(\(\beta^-\))=26.37\times10^{3} \text{ eV} \;
\%\beta^- \text{decay}=100.0

\(^{19}\text{B}-\text{T}_{1/2} \): from 2003Yo02.

\(^{19}\text{B}-\text{Q}(\beta^-) \): from 2012Wa38.

\(^{1998}\text{Yo06} \): A beam of \(^{19}\text{B} \) was produced by fragmentation of a 95 MeV/A \(^{40}\text{Ar} \) beam on a \(^{181}\text{Ta} \) target. \(^{19}\text{B} \) was selected using the RIKEN Projectile-fragment Separator (RIPS) and was implanted into a 12 mm thick plastic scintillator stopper. The \(\beta^-\) decays were observed during the 100 ms beam-off period. The active stopper detected \(\beta^-\)-rays and a neutron detector array, consisting of 14 liquid scintillation counters covering about 80% of 4\(\pi \) detected delayed neutrons. The efficiency of the neutron array was 30% by comparison of a measurement of \(\beta^-\)-delayed neutrons of \(^{15}\text{B} \), which has a known delayed neutron emission probability of 100%. A preliminary value of \(T_{1/2}=3.3\) ms was deduced from the least-squares fits to the data, and \(P_{n}=125\% \) was determined from the ratio of the number of detected neutrons to that of \(\beta^-\)-rays. \(P_{n}\) is more than 100% which implies the existence of significant multineutron emissions in the decay, reflecting its large \(Q(\beta^-) \) value (26.5 MeV) compared with the multineutron separation energies of daughter nucleus \(^{19}\text{C} \) (\(S_{1n}=160\) keV, \(S_{2n}=4.4\) MeV, \ldots ).

\(^{2003}\text{Yo02} \): The authors reevaluated the preliminary values \(T_{1/2}\) and \(P_{n} \) reported in 1998Yo06. The new experiment was performed using RIPS at RIKEN Accelerator Research Facility as was in 1998Yo06. A beam of \(^{19}\text{B} \) was produced by the projectile-fragmentation reaction of a 95 MeV/u \(^{40}\text{Ar} \) beam on a 670 mg/cm\(^{2}\) nat\(^{19}\text{Ta} \) target. The values of \(T_{1/2}\) and \(P_{n} \) were determined by fitting a set of decay curves altogether to remove possible complication and inconsistency. The method of maximum likelihood was applied for deducing \(T_{1/2}\) and \(P_{n} \). The neutron detection efficiencies were treated carefully, the total detection efficiencies of direct and scattered neutrons are 31.5 % and 4.7% \pm\) 2-6, respectively. The new values of \(T_{1/2}=2.92\) ms \(^{15}\text{B} \), \(P_{1n}=71.8\% \) \pm\) 83-91 and \(P_{2n}=16.0\% \) \pm\) 56-48 were determined with a better precision. \(P_{3n}\) was not determined because of the limited statistics. In the text it is unclear if the 1998Yo06 “preliminary” data are included in the 2003Yo02 analysis; we assume that it is and use the 2003Yo02 result to avoid possible data correlations.

1999Re16: A low statistics determination of \(T_{1/2}=4.5\) ms \(^{15}\text{B} \) was given.

In Summary, the decay to \(^{19}\text{C} \) levels is not measured. Only the \(P_{1n}=71.8\% \) \pm\) 83-91 to \(^{18}\text{C} \) and \(P_{2n}=16.0\% \) \pm\) 56-48 to \(^{17}\text{C} \) were determined.

\(^{19}\text{C} \) Levels

<table>
<thead>
<tr>
<th>E(level)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>581+x</td>
<td>E(level): group of neutron-decaying levels above S((n))((^{19}\text{C} ))=581 keV.</td>
</tr>
<tr>
<td>4763+y</td>
<td>E(level): group of 2 neutron-decaying levels above S(2(n))((^{19}\text{C} ))=4763 keV.</td>
</tr>
</tbody>
</table>

\(\beta^-\) radiations

<table>
<thead>
<tr>
<th>E(decay)</th>
<th>E(level)</th>
<th>(I\beta^-)</th>
<th>Log (ft)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1.1\times10^{4} \text{ eV}) \quad 11</td>
<td>4763+y</td>
<td>16.0 56</td>
<td>5.02 16</td>
<td>(I\beta^-): total (\beta^-) 2n decay branch (\beta^-_{2n}=16.0% ) \pm) 56-48.</td>
</tr>
<tr>
<td>(1.3\times10^{4} \text{ eV}) \quad 13</td>
<td>581+x</td>
<td>71.8 91</td>
<td>4.74 7</td>
<td>(I\beta^-): total (\beta^-) n decay branch (\beta^-_{1n}=71.8% ) \pm) 83-91.</td>
</tr>
</tbody>
</table>

\(^{1}\) Absolute intensity per 100 decays.
\(^{2}\) Estimated for a range of levels.
1991Or01: The authors measured the masses of several nuclides, produced in the fragmentation of 55 MeV/nucleon $^{48}$Ca ions on a 330 mg/cm$^2$ nat Ta target at GANIL, by measuring their time-of-flight over a roughly 80 meter flight path. The nuclides were detected and identified in the SPEG spectrometer focal plane. A mass resolution near $3 \times 10^{-4}$ was achieved. The mass excess $\Delta M = 33.07$ MeV was deduced.

$^{19}$C Levels

<table>
<thead>
<tr>
<th>E(level)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
</tbody>
</table>
1987Gi05: The authors measured the masses of several nuclides, produced in the fragmentation of 60 MeV/nucleon $^{40}$Ar ions on a 350 mg/cm$^2$ natTa target at GANIL, by measuring their time-of-flight over a roughly 80 meter flight path. The nuclides were detected and identified in the SPEG spectrometer focal plane. A mass resolution near $5 \times 10^{-4}$ was achieved. The mass excess $\Delta M=32.95$ MeV $^{42}$ was deduced.

19C Levels

<table>
<thead>
<tr>
<th>E(level)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
</tbody>
</table>
1999Na27: The Coulomb dissociation of 67 MeV/nucleon $^{19}$C on $^{208}$Pb was measured in a study of the low-lying E1 strength distribution at the RIKEN/RIPS facility. Complete kinematics of the $^{18}$C+n dissociation products were measured and analyzed. The Coulomb dissociation cross section 1.19 b was deduced after subtraction the nuclear component (obtained from a $^{12}$C target) from the total cross section obtained with the Pb target. This corresponds to an E1 strength of 0.71 e2fm2. Analysis of the $^{18}$C+n distributions indicates $S_n=530$ keV $^{130}$, and gives a clear indication of $J\pi=1/2^+$ for the ground state (compared to $5/2^+$ suggested in other analyses).


$^{19}$C Levels

<table>
<thead>
<tr>
<th>E(level)</th>
<th>$J^\pi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>$1/2^+$</td>
</tr>
</tbody>
</table>

19
1986Vi09, 1988Wo09: Mass measurements of several neutron-rich light nuclei were carried out using an improved fitting technique for deducing nuclear mass values from measurements of time-of-flight (ToF) through the LANL/TOFI spectrometer; the ToF through the spectrometer depends on the mass-to-charge ratio and is independent of ion velocity. The rare isotope species were produced by proton spallation reactions on a Th target. Typical flight times of 500 ns, with timing uncertainties near 180 ps yielded typical mass-to-charge resolutions of $3.6 \times 10^{-4}$ from analysis of multiple runs that involved multiple charge states. A mass excess of 32.77 MeV $^{12}$ was deduced in (1988Wo09), which compares with 32.30 MeV $^{24}$ which was previously deduced in (1986Vi09).

1991Re02, 1991ReZZ, 2008ReZZ: Spallation products from 800 MeV proton bombardment of a $^{232}$Th target were captured by a transport line with a mass-to-charge filter and transferred to the TOFI spectrometer at LAMPF. The beamline was separately tuned to transport a number of different nuclides. The ions were implanted in a Si detector, and identification by standard techniques was implemented. The $\beta$-delayed neutrons were detected in a polyethylene moderated $^3$He counter; half-lifes and $\beta$-delayed neutron probabilities were deduced from analysis of the number of implanted ions (per beam pulse) and the rate of $\beta$-delayed neutrons detected in the zero-threshold counter. The $\beta$-delayed neutron probabilities $=\beta^-_n = \beta_1 + 2(\beta_2) + 3(\beta_3) = ...$ were deduced. Lifetimes of $T_{1/2}=44.1$ ms $^{42}$ (Reeder et al., Int. Conf. on Nucl. Data for Science and Technology, May 9-13, 1994, Gatlinburg, Tennessee: and 44 ms $^{4}$ in the unpublished private communications of (2008ReZZ)/(1995ReZZ) were deduced.

<table>
<thead>
<tr>
<th>$^{19}$C Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E$(level)</td>
</tr>
<tr>
<td>0</td>
</tr>
</tbody>
</table>
U(p,${}^{19}\text{C}$) 1974Bo05

1974Bo05: Spallation yield cross sections, on a uranium target, were measured at the Bevatron using 4.8 GeV protons. Reaction products were identified using $\Delta E$, $E$ and time-of-flight determinations. A production cross section of $\approx 5 \mu$b was measured. This result confirmed a the earlier first observation of $^{19}\text{C}$ by Raisbeck et al. that had been published only as a conference proceedings.

$^{19}\text{C}$ Levels

<table>
<thead>
<tr>
<th>E(level)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
</tbody>
</table>
$^{241}$Pu(n,F) $E=\text{thermal}$ 1999Ko26

1999Ko26: Light fission products, including $^{11}$Li, $^{14}$Be and $^{19}$C, were identified and characterized in neutron induced fission events on $^{241}$Pu.

$^{19}$C Levels

<table>
<thead>
<tr>
<th>E(level)</th>
<th>$\sigma$(yield)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.0014</td>
</tr>
</tbody>
</table>
REFERENCES FOR A=19


REFERENCES FOR A=19


Electromagnetic moments and electric dipole transitions in carbon isotopes.
REFERENCES FOR A=19 (CONTINUED)

Systematic analysis of neutron-rich carbon isotopes.

β-decay half-lives and β-delayed neutron multiplicities of the neutron drip-line nuclei $^{19}$B, $^{22}$C, and $^{23}$N.

Relativistic Hartree-Bogoliubov description of deformed light nuclei.

Application of the quasicalssical approximation for the analysis of properties of light atomic nuclei with high excess of neutrons.

β-decay half-lives and β-delayed neutron multiplicities of the neutron drip-line nuclei $^{19}$B, $^{22}$C, and $^{23}$N.

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Application of the quasicalssical approximation for the analysis of properties of light atomic nuclei with high excess of neutrons.
_Resonant breakup of $^{19}$C on a proton target._

_New calculations of matter radii for neutron-rich C nuclei._

_One- and two-neutron removal reactions from $^{19,20}$C with a proton target._

_Nuclear reactions of $^{19,20}$C on a liquid hydrogen target measured with the superconducting TOF spectrometer._

_One- and two-neutron removal reactions from the most neutron-rich carbon isotopes._

_Systematic studies of light neutron-rich nuclei produced via the fragmentation of $^{40}$Ar._

_The AME2012 atomic mass evaluation (II). Tables, graphs and references._

_Shell-model study of boron, carbon, nitrogen, and oxygen isotopes with a monopole-based universal interaction._

_Description of carbon isotopes within relativistic Hartree-Fock-Bogoliubov theory._

_Nuclear reaction cross-section for drip-line nuclei in the framework of Glauber model using relativistic and nonrelativistic densities._

_Nuclear reaction cross sections from a simple effective density using Glauber model._

_Observation of a low-lying neutron-unbound state in $^{19}$C._

_Ab Initio Coupled-Cluster Effective Interactions for the Shell Model: Application to Neutron-Rich Oxygen and Carbon Isotopes._

_Semi-microscopic folding model for the description of two-body halo nuclei._

_Evaluation of Beta-Delayed Neutron Emission Probabilities and Half-Lives for Z = 2-28._

_The effect of halo nuclear density on reaction cross-section for light ion collision._

_Nuclear structure study of some bubble nuclei in the light mass region using mean field formalism._

_γ-ray spectroscopy of $^{19}$C via the single-neutron knock-out reaction._

_Magnetic response of the halo nucleus $^{19}$C studied via lifetime measurement._

_Evidence of strong dynamic core excitation in $^{19}$C resonant break-up._

_Interaction cross section study of the two-neutron halo nucleus $^{22}$C._

_Proposal of a directly measurable parameter quantifying the halo nature of one-neutron nuclei._

_The AME2016 atomic mass evaluation (II). Tables, graphs and references._