Investigating the nuclear molecule structure of states in $^{18}\text{O}^*$

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GALVESTON, TEXAS
Overview

- Aims and motivations
- Clustering models and rotational bands
- Experimental set-up
- Observed $^{18}$O states
- Catania plots
- Preliminary results
- Future work
Aims and Motivations

Aims:

➢ Determine branching ratios in high-energy excited states of $^{18}$O.

➢ Extract the structure of certain rotational bands through their partial $\alpha$-decay widths.

Motivations:

➢ A measurement performed by W. von Oertzen et. al identified 30 new states in $^{18}$O (Munich).

➢ $^{18}$O is an excellent contender for observing cluster structure.

➢ Nuclear clustering provides a good test of theoretical models.
<table>
<thead>
<tr>
<th>Isotope</th>
<th>Mass Number</th>
<th>Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{12}$Be</td>
<td>12.05</td>
<td>8.89</td>
</tr>
<tr>
<td>$^{11}$Be</td>
<td>8.34</td>
<td>1.57</td>
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<tr>
<td>$^{8}$Be</td>
<td>-0.090</td>
<td>7.27</td>
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<tr>
<td>$^{14}$C</td>
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<td>12.21</td>
</tr>
<tr>
<td>$^{16}$C</td>
<td>25.87</td>
<td>12.01</td>
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<td>$^{12}$C</td>
<td>30.78</td>
<td>14.44</td>
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<td>$^{13}$C</td>
<td>48.69</td>
<td>38.19</td>
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<td>$^{19}$O</td>
<td>57.61</td>
<td>47.42</td>
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<tr>
<td>$^{28}$Mg</td>
<td>60.28</td>
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<td>$^{30}$Mg</td>
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<td>50.41</td>
</tr>
<tr>
<td>$^{36}$Si</td>
<td>53.15</td>
<td>53.15</td>
</tr>
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</table>

Edited by C. Beck, (2016). JPCS Cluster16 - Recent Experimental Results on Nuclear Cluster Physics
<table>
<thead>
<tr>
<th></th>
<th>18C</th>
<th>22O</th>
<th>30Mg</th>
<th>38Ar</th>
<th>36Si</th>
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<tr>
<td>12Be</td>
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<td>30.78</td>
<td>57.61</td>
<td>60.28</td>
<td>53.15</td>
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<td>11Be</td>
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<td>39.73</td>
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<td>21.86</td>
<td>41.19</td>
<td>44.57</td>
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<tr>
<td>8Be</td>
<td>-0.090</td>
<td>12.01</td>
<td>11.49</td>
<td>15.89</td>
<td>32.55</td>
</tr>
</tbody>
</table>

- \( ^{12}\text{Be} \otimes ^{16}\text{C} \otimes ^{20}\text{O} \otimes ^{28}\text{Mg} \otimes ^{40}\text{Ar} \otimes ^{36}\text{Si} \)
- \( ^{11}\text{Be} \otimes ^{15}\text{C} \otimes ^{19}\text{O} \otimes ^{23}\text{Ne} \otimes ^{27}\text{Mg} \otimes ^{39}\text{Ar} \)
- \( ^{10}\text{Be} \otimes ^{14}\text{C} \otimes ^{18}\text{O} \otimes ^{22}\text{Ne} \otimes ^{26}\text{Mg} \otimes ^{38}\text{Ar} \)
- \( ^{9}\text{Be} \otimes ^{13}\text{C} \otimes ^{17}\text{O} \otimes ^{21}\text{Ne} \otimes ^{25}\text{Mg} \otimes ^{36}\text{Ar} \)
- \( ^{8}\text{Be} \otimes ^{12}\text{C} \otimes ^{16}\text{O} \otimes ^{20}\text{Ne} \otimes ^{24}\text{Mg} \otimes ^{36}\text{Ar} \)

Excitation energy (MeV):
- 6.23
- 19.35
- 26.63

Recent Experimental Results on Nuclear Cluster Physics

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$^{12}\text{C} \otimes 2n \otimes \alpha$

$K^{\pi} = 0_4^{+/-}$
Rotational bands

- The energy of an excited state in a nucleus can be related to its total angular momentum as follows:

\[ E_x(J) = \frac{\hbar^2}{2\Theta} [J(J + 1)] + E_0. \]

- Members of the same rotational band have an identical structure.

- Broken intrinsic reflection symmetry causes signature splitting.

- The rotational bands of interest (non-shell model) are the \( K^\Pi = 0_2^{+-} \) and \( K^\Pi = 0_4^{+-} \)

Experimental set-up

1: $31.0^\circ$, $+14.2^\circ$, 86 mm
2: $31.0^\circ$, $-13.5^\circ$, 80 mm
3: $71.0^\circ$, $+23.7^\circ$, 70 mm
4: $71.0^\circ$, $-16.1^\circ$, 64 mm

Total angular range: $\theta_x \rightarrow 14^\circ$ to $92^\circ$
$\theta_y \rightarrow -36^\circ$ to $40^\circ$

$^{12}\text{C}(^7\text{Li},p)^{18}\text{O}^*$

$^{12}\text{C}$ target
(110 $\mu$g/cm$^2$)

44 MeV $^7\text{Li}$ beam from Tandem accelerator

To Q3D spectrometer

DSSD array
Q3D spectrometer

- Angular acceptances of ±3° (x) and ±2° (y) when slits fully open.
- Position of particle detection at focal plane detector determines energy of incident particle.
Q3D spectrometer
$^{12}$C$(^7\text{Li},p)^{18}$O

44 MeV, 30°

Counts

Excitation energy (keV)

1.980, 2^+

g.s., 0^+

Catania plots

\[
\begin{align*}
{^{12}}C({^{7}}Li,p)^{4}\text{He} + {^{14}}C
\end{align*}
\]
Catania plots

The Q-value equation for the $^{12}\text{C}(^{7}\text{Li},p)^{4}\text{He}+^{14}\text{C}$ reaction is as follows:

$$Q = 2.173 \text{ MeV} = E_{14c} + E_{\alpha} + E_{p} - E_{\text{beam}}.$$
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Also, $E_{\alpha} = \frac{p_{\alpha}^2}{2m_{\alpha}}$. 
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\[
Q = 2.173 \text{ MeV} = E_{14c} + E_{\alpha} + E_p - E_{\text{beam}}.
\]

Also, \( E_{\alpha} = \frac{p_{\alpha}^2}{2m_{\alpha}} \).

Through rearranging we see that

\[
E_{\text{beam}} - E_{14c} - E_p = \frac{1}{m_{\alpha}} \frac{p_{\alpha}^2}{2} - Q.
\]
The Q-value equation for the $^{12}\text{C}(^7\text{Li},p)^4\text{He}+^{14}\text{C}$ reaction is as follows:

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Through rearranging we see that

$$E_{\text{beam}} - E_{14c} - E_p = \frac{1}{m_\alpha} \frac{p_\alpha^2}{2} - Q.$$
Catania plots

Catania plot (simulated data)
Detected particle = C14
Gradient = $\frac{1}{4} = \frac{1}{m_\gamma}$

Reconstructed E via E (MeV)

Reconstructed E via p (MeV*A)

y-intercept = -2.173 MeV = -Q

Excitation energy (keV)

Counts/20 keV

9.721, 5^-
10.297, 4^+
10.580
10.918
11.422
11.702, 6^+
11.855
11.117
10.580
10.918
11.117
11.422
11.702, 6^+
Gradient = 1/4
y-intercept = -2.173
Gradient = 1/14
y-intercept = -2.173
Gradient = 1/1
$\gamma$-intercept = -0.355

Catania plot (real data)
Detected particle = O17

Catania plot (simulated data)
Detected particle = O17
Efficiency corrections (Monte Carlo)

Cartesian view of detector array
Real data (10500 keV)

Cartesian view of detector array
Monte Carlo data (10500 keV)
Total excitation spectrum

Counts/20 keV
Excitation energy (keV)

9.721
10.297
10.580
10.918
11.012
11.117
11.422
11.702
11.855
Total excitation spectrum

Detected $^{14}$C gate
Total excitation spectrum

Detected $^{14}$C gate

Detected $\alpha$ gate
Detected $^{17}$O gate

Detected $^{14}$C gate

Detected $^{14}$C gate

Detected $^{17}$O gate
But what about other decay paths?

- Photon decay is possible, especially for states close to or below threshold for appropriate decay paths.
- How do we know whether or not we are observing photon decay?

**Excitation Energy (keV)**

- Neutron threshold: 8.045 MeV
- Alpha threshold: 6.227 MeV
- 7.112, 4⁺
- 7.855, 5⁻
- 8.214, 2⁺
- 7.969
- 9.046
Catania plot (data)

Detected particle = C14

Reconstructed E via p (MeV*A) vs. Reconstructed E via E (MeV)
Catania plot (data zoomed)
Detected particle = C14

Catania plot (data)
Detected particle = C14
Catania plot (data zoomed)
Detected particle = C14

Catania plot (simulated zoomed)
Detected particle = C14
Catania plot (data)
Detected particle = C14

Catania plot (photons removed)
7500 keV
Catania plot (data)
Detected particle = C14

Catania plot (photons removed)
7500 keV

Reconstructed E via E (MeV)

Reconstructed E via p (MeV*A)
Preliminary branching ratios

<table>
<thead>
<tr>
<th>Energy (MeV)</th>
<th>$\alpha$ B.R.</th>
<th>n B.R.</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.115</td>
<td>45(2)%</td>
<td>-</td>
</tr>
<tr>
<td>7.617</td>
<td>&gt;80%</td>
<td>-</td>
</tr>
<tr>
<td>7.858</td>
<td>78(3)%</td>
<td>-</td>
</tr>
<tr>
<td>8.129</td>
<td>79(9)%</td>
<td>&gt;1%</td>
</tr>
<tr>
<td>8.216</td>
<td>74(3)%</td>
<td>8(1)%</td>
</tr>
<tr>
<td>8.414</td>
<td>12(2)%</td>
<td>50(4)%</td>
</tr>
</tbody>
</table>
Future work

- Correct efficiencies and angular distributions from simulation.
- Analyse higher excitation ranges (with more decay paths).
- Establish branching ratios for all measured states.
- Calculate partial $\alpha$-decay widths to infer tendency towards cluster structure.
References


W. von Oertzen, M. Freer and Y. Kanada-En’yo, 2006 Physics Reports 432, 43


C. Beck, (2016). JPCS Cluster16 - Recent Experimental Results on Nuclear Cluster Physics


Collaborators


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