Limits on the molecular resonance strengths in the $^{12}\text{C}+^{12}\text{C}$ fusion reaction

Xiao Fang

Department of Physics
University of Notre Dame
Carbon burning in stars

Gamow peak energy for $^{12}\text{C}+^{12}\text{C}$:
$E \approx 1.5\text{MeV}$

T: 0.2 - 1.2GK
$E_{\text{cm}}$: 1 – 3 MeV

Cauldrons in the Cosmos, C.E. Rolfs et al.
Molecular resonances in the $^{12}\text{C}+^{12}\text{C}$ fusion reaction measured by Almqvist et al., in 1960

Most recent $S(E)^*$ factor (Modified $S(E)$ factor) of the fusion process $^{12}\text{C}+^{12}\text{C}$ measured by Spillane et al., in 2007

50 years later….
Compare the $^{12}\text{C}+^{12}\text{C}$ reaction with carbon isotope fusion reactions, $^{12}\text{C}+^{13}\text{C}$ and $^{13}\text{C}+^{13}\text{C}$. Because of their similarities in mass, charge, and nuclear structure, comparing the cross sections of the $^{12}\text{C}+^{12}\text{C}$ with these other two carbon isotope fusion reactions may help us better understand the resonances in the $^{12}\text{C}+^{12}\text{C}$ fusion reaction.

To remove the Coulomb barrier penetration effect in the fusion process, we have introduced the cross section factor:

$$S(E)=\sigma(E) E \exp(87.21/E^{1/2})$$

<table>
<thead>
<tr>
<th></th>
<th>Reduced mass</th>
<th>Radius (fm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{12}\text{C}+^{12}\text{C}$</td>
<td>6</td>
<td>5.77</td>
</tr>
<tr>
<td>$^{12}\text{C}+^{13}\text{C}$</td>
<td>6.33</td>
<td>5.85</td>
</tr>
<tr>
<td>$^{13}\text{C}+^{13}\text{C}$</td>
<td>6.5</td>
<td>5.93</td>
</tr>
</tbody>
</table>
Fusion reactions of carbon isotopes

Before correction

$^{12}\text{C}+^{12}\text{C}$ (red, Becker et al., 1981)
$^{12}\text{C}+^{13}\text{C}$ (blue, Notani et al., 2009)
$^{13}\text{C}+^{13}\text{C}$ (purple, Trentalange 1982)
Isotope effect

<table>
<thead>
<tr>
<th></th>
<th>Reduced mass</th>
<th>Radius (fm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12C+12C</td>
<td>6</td>
<td>5.77</td>
</tr>
<tr>
<td>12C+13C</td>
<td>6.33</td>
<td>5.85</td>
</tr>
<tr>
<td>13C+13C</td>
<td>6.5</td>
<td>5.93</td>
</tr>
</tbody>
</table>

Difference in mass and radius → Difference in cross section (using CCFULL)

Elastic transfer enhancement in 12C+13C
After correcting the isotope effect (difference in mass and radius)
After correcting the isotope and couple channel effect to the $^{12}\text{C}(2^+,4.44\text{ MeV})$. 

Fusion reactions of carbon isotopes
The predictions are compared with:
1) the resonance (Ecm=2.1 MeV) found by Spillane et al.;
2) the resonance (Ecm=1.5 MeV) suggested by Cooper et al..
Both resonance peaks are well above the upper limits, therefore additional measurements are needed for verification.
Push measurement towards lower energies

High current accelerator (>40 p\(\mu\)A) + highly efficient Si/Ge array

A 5 MV Pelletron with ECR source in terminal.
We’d like to extend special thanks to all of those involved in this project. Especially Henning Esbensen and Cheng-lie Jiang in Argonne National Lab, And Cheng-jian Lin in China Institute of Atomic Energy.