Measurement of the Fusion Excitation Function for $^{19}$O + $^{12}$C at Near Barrier Energies

Indiana University, Bloomington

L. T. Baby, V. Tripathi, S. A. Kuvin, I. Wiedenhover
Florida State University

Outline
- Motivation
- Experimental Method
- Results
- Conclusions and Outlook
Motivation

- Neutron stars, remnant cores following supernova explosions, are interesting astrophysical environments.
- Some neutron stars that exist in a binary system with luminous stars (accreting neutron stars), provide a unique environment for nuclear reactions.
- Such neutron stars are identified as the origin of energetic X-ray superbursts.
  - X-ray superburst: \( \sim 10^{42} \text{ergs} \) (energy output of the sun in a decade)
- X-ray superbursts are thought to be fueled by \(^{12}\text{C} + ^{12}\text{C}\) fusion in the outer crust.
- However, the temperature of the outer crust is too low (~3x10^6 K) for \(^{12}\text{C}\) fusion.
- Fusion of neutron-rich light/mid mass nuclei is proposed as the potential “heat source”.

Haensel et al., Neutron Stars 1, (2007).
Fusion of Neutron-Rich Light Nuclei

- One heat source proposed is fusion of $^{24}\text{O} + ^{24}\text{O}$.

- If valence neutrons are loosely coupled to the core, then polarization can occur which can result in fusion enhancement.

- DC-TDHF calculations, which follow the collision dynamics, predict a fusion enhancement for a neutron-rich system.

Systematic fusion measurement for neutron-rich light and mid mass nuclei will help to understand:

1. Fusion cross-section enhancement
2. Fusion dynamics

The evaporated particles kick the evaporation residues away from zero degrees.

One can distinguish evaporation residues from scattered beam using particle energy and time-of-flight (TOF) information.
High Precision $^{18}$O + $^{12}$C Fusion Excitation Function

$$\sigma = \frac{N}{It}$$

$\sigma \rightarrow$ Fusion cross-section
$N \rightarrow$ No. of evaporation residues
$I \rightarrow$ No. of beam particles
$t \rightarrow$ Target thickness

- Fusion cross-section measured for $E_{c.m.}$ of 5.25 – 14 MeV.
- Measured fusion cross-section is in good agreement with the literature.
- Fusion cross-section is measured down to ~820 μb, which is 30 times lower than the previous measurements.

19O + 12C Using RESOLUT @ Florida State University

- 19O beam intensity ~ 1-2 x 10^4 pps
- Degrading Ion Chamber (CID) used to:
  - Change the beam energy
  - Provide event-by-event particle identification
- Time-of-flight is measured between US and TGT MCP detectors
- For evaporation residues and scattered beam:
  - Energy is measured in annular Si detector (T2, T3)
  - Time-of-flight is measured between TGT MCP and Si detectors

Beam Purity (19O): ~ 40 %

deSouza et al., Nucl. Inst. and Meth. A632, 133 (2011)
- T2 angular coverage $4.4^\circ \leq \theta_{\text{LAB}} \leq 11.7^\circ$
- T2 geometric efficiency: ~40%
- Energy range $E_{\text{c.m.}} = 7.4 - 18.0$ MeV

A clear separation is observed between evaporation residues and scattered beam.
This is the first fusion measurement for $^{19}\text{O} + ^{12}\text{C}$.

Simultaneous measurement of $^{18}\text{O} + ^{12}\text{C}$ is in good agreement with high precision measurement.

A substantial enhancement of the fusion cross-section is observed for $^{19}\text{O} + ^{12}\text{C}$ relative to $^{18}\text{O} + ^{12}\text{C}$.

One dimensional barrier penetration model fit parameters:

<table>
<thead>
<tr>
<th></th>
<th>$^{18}\text{O}$</th>
<th>$^{19}\text{O}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_c$ (fm)</td>
<td>$7.34 \pm 0.07$</td>
<td>$8.00 \pm 0.40$</td>
</tr>
<tr>
<td>$V$ (MeV)</td>
<td>$7.62 \pm 0.04$</td>
<td>$7.64 \pm 0.61$</td>
</tr>
<tr>
<td>$h\omega/2\pi$ (MeV)</td>
<td>$2.86 \pm 0.09$</td>
<td>$6.47 \pm 2.50$</td>
</tr>
</tbody>
</table>

[Graph showing fusion cross-section for $^{18}\text{O} + ^{12}\text{C}$ and $^{19}\text{O} + ^{12}\text{C}$ with Thinner Barrier indicated.]
Fusion Enhancement for $^{19}\text{O} + ^{12}\text{C}$

- Fusion enhancement is $\sim 20\%$ for energies well above the fusion barrier.
- Fusion enhancement increases rapidly near the fusion barrier.
We measured $^{18}$O + $^{12}$C fusion cross-section down to the $\sim$820 $\mu$b level (30 times lower than previous measurements).

For the first measurement of $^{19}$O + $^{12}$C, we measured the fusion cross-section down to the $\sim$150 mb level.

Addition of a single neutron, in $^{19}$O as compared to $^{18}$O, enhanced the fusion cross-section by a factor of 3 (at the fusion barrier).

**Outlook**

- Compare the observed experimental results with DC-TDHF calculations
- Measure fusion for other neutron-rich nuclei
  - MSU: $^{39,47}$K + $^{28}$Si (Experiment No. 15214 @ReA3)
  - Ganil: $^{20,21}$O + $^{12}$C
  - FSU: $^{18,19}$O + $^{18}$O