Fusion excitation measurement for $^{20}\text{O} + ^{12}\text{C}$ at $E/A = 1\text{-}2 \text{ MeV}$

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Motivation

The crust of an accreting neutron star is a unique environment for nuclear reactions.

Fusion reactions in the outer crust result in X-ray bursts and superbursts.

Problem: At the temperature of the crust, the Coulomb barrier is too high for thermonuclear fusion of carbon – another heat source is needed.
Is fusion of neutron-rich light nuclei enhanced relative to $\beta$-stable nuclei?

Neutron transfer channels for N/Z asymmetric nuclei enhance the fusion cross-section at and below the barrier.

V. Oberacker, Th 5:30 pm Session 25
Fusion of neutron-rich radioactive beams with light targets

\[ ^{20}\text{O} + ^{12}\text{C} \rightarrow ^{32}\text{Si}^* \quad (E^* \sim 50 \text{ MeV}) \]

\[ ^{32}\text{Si}^* \rightarrow ^{29}\text{Si} + 3\text{n} \]
\[ ^{32}\text{Si}^* \rightarrow ^{29}\text{Al} + \text{p} + 2\text{n} \]
\[ ^{32}\text{Si}^* \rightarrow ^{26}\text{Mg} + \alpha + 2\text{n} \]

Energy and angular distributions predicted by Bass model + PACE2
Incident Beam: $^{20,16}\text{O} + ^{12}\text{C}$ @ 3 MeV/A

Intensity of $^{20}\text{O}$: 1-2x10$^4$ pps

Degrader ion chamber (CF$_4$) reduces energy to 1-2 MeV/A and identifies particle ($\Delta E$)

Target: 100 $\mu$g/cm$^2$ carbon foil

T2: $\theta_{\text{Lab}} = 3.5 - 10.8^\circ$; T3: $\theta_{\text{Lab}} = 11.3 - 21.8^\circ$

Time-of-Flight (TOF) between target-MCP and Si (T2, T3)
Experimental Setup: GANIL E575S (Summer 2010)

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- Intensity of $^{20}$O: 1-2x10$^4$ pps
- Degrader ion chamber (CF$_4$) reduces energy to 1-2 MeV/A and identifies particle ($\Delta E$)
- Target: 100 $\mu$g/cm$^2$ carbon foil
- T2: $\theta_{Lab} = 3.5 - 10.8^\circ$; T3: $\theta_{Lab} = 11.3 - 21.8^\circ$
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Experimental Details

Microchannel plate detector

- Inner hole 20 mm diameter
- 48 concentric rings; 16 “pies”
- Particle entry on ring (junction)
- Fast timing extracted from “pie” side
- Time resolution 425 ps (6 MeV alpha)

Advantages:
- compact
- Simple construction
- good time resolution (200 ps)

Disadvantages:
- Wire planes (4/det.) in path of beam

Silicon detectors

- R.T. deSouza et al., NIM. A632, 133 (2011)
Energy-TOF spectrum has many features

- Slit-scatter ridge extending from elastic peak to lower energies (expected)
- Incomplete charge collection ridge (same TOF as elastic); \(~20\%\) of elastic yield!
- “ghost” line in same region as residues but x-section \(~70\text{b}!\) (atomic process)

Require charged particle coincidence to eliminate atomic scattering background

select coincidence of charged particle \((p, \alpha)\) in T3 with a residue in T2

Fusion-evaporation model (evapOR)

1. Fusion stage: Bass model
2. Evaporation stage

Measured cross-section exceeds that predicted by fusion-evaporation model

- Is $\sigma_{\text{fusion}} > \sigma_{\text{Bass}}$?
- Does evapOR handle competition between CP and neutron only decay correctly?

Benchmark reaction: $^{16}\text{O} + ^{12}\text{C}$

- Measurement made in same expt. (E575S)
- Measurement subsequently at WMU
- Measured cross-section in both expts. is in good agreement with evapOR predictions

\[
^{16}\text{O} + ^{12}\text{C} \rightarrow ^{28}\text{Si}^* \rightarrow
\]

<table>
<thead>
<tr>
<th>Product</th>
<th>Reaction</th>
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</thead>
<tbody>
<tr>
<td>$^{27}\text{Si} + n$</td>
<td></td>
</tr>
<tr>
<td>$^{27}\text{Al} + p$</td>
<td></td>
</tr>
<tr>
<td>$^{26}\text{Al} + p + n$</td>
<td></td>
</tr>
<tr>
<td>$^{26}\text{Mg} + 2p$</td>
<td></td>
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<tr>
<td>$^{24}\text{Mg} + \alpha$</td>
<td></td>
</tr>
<tr>
<td>$^{23}\text{Na} + \alpha + p$</td>
<td></td>
</tr>
<tr>
<td>$^{20}\text{Ne} + 2\alpha$</td>
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</tbody>
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Origin of ghost line

“Ghost” line is due to electrons from carbon foil directly entering the MCP
The path forward: Decreased segmentation of the Si detector

- Si SBD fast rise time 3-4 ns
- MCP rise time < 2 ns
- Leading edge disc. of Si signal
- CFD disc. of MCP signal

\[\alpha \text{ source (}^{226}\text{Ra)}\]
The path forward: Development of a gridless MCP

Crossed E and B field design:


Time resolution for a single MCP $\sim 350$ ps
More than sufficient for measurement
Conclusions

- Extraction of fusion cross-section for $^{20}\text{O} + ^{12}\text{C}$ followed by charged particle emission
- Measured cross-section for these channels is larger than that predicted by evapOR. Two possibilities:
  - Increased overall cross-section as compared to Bass
  - Competition between charged particle emission and neutron only decay in de-excitation phase differs from evapOR prediction (which agrees for $^{16}\text{O} + ^{12}\text{C}$)
- Implementation of a gridless MCP reduces slit scattering
- Low segmentation silicon is needed to avoid incomplete charge collection

- Verify technique by re-measuring $\sigma_{\text{fusion}}$ for $^{16}\text{O} + ^{12}\text{C}$
- Measure fusion excitation functions for neutron-rich light nuclei