Separation of Transfer and Fusion Products

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• Results from SHIP experiments
• Kinematics and cross-sections
• Separation criteria
• Separator concept
• High-resolution final stage
Kinematics of heavy transfer products

Angular and energy distributions of n–rich heavy transfer products
→ calculations (G. Adamian and N. Antonenko, Dubna)

$^{48}$Ca + $^{248}$Cm, $E_{cm} = 209$ MeV

isotropic angular distributions in the cm-system
(deep-inelastic transfer)
Excitation functions

*Calculated excitation functions for Lr-264 and Sg-271*

(G. Adamian and N. Antonenko, Dubna)

$$\sigma_{\text{max}}(\text{Lr-264}) = 600 \text{ pb}$$

$$\sigma_{\text{max}}(\text{Sg-271}) = 62.5 \text{ pb}$$
Velocity filter – Performance for transfer products

- **Starting point:** SHIP

  present acceptance: 10 msr

  expected counting rates with present setup:

  \[
  Lr-264 \rightarrow \epsilon = 0.04
  \]
  \[
  \sigma_{\text{max}}(Lr-264) = 600 \text{ pb for } E_{\text{cm}} = 202 \text{ MeV}
  \]
  \[
  N(Lr-264) = 9 / \text{ day} \text{ (with } 25 \mu\text{A } ^{48}\text{Ca}^{10+}, 460 \mu\text{g/cm}^2 ^{248}\text{Cm })
  \]

  \[
  Sg-271 \rightarrow \epsilon = 0.05
  \]
  \[
  \sigma_{\text{max}}(Sg-271) = 62.5 \text{ pb for } E_{\text{cm}} = 205 \text{ MeV}
  \]
  \[
  N(Sg-271) = 1 / \text{ day}
  \]
Experimental results from SHIP
Transfer in $^{48}$Ca + $^{248}$Cm reactions at SHIP

- Transfer products with $Z < Z_{\text{Cm}}$ → Identification via $(\text{Re} - \alpha)$ correlations

\[ \frac{d\sigma}{d\Omega} \approx 100 - 500 \text{ nb/sr} \]
Fission events from short-living isotopes

- Identification of short-living fission events via (Re–SF) - correlations

\[
\text{d}\sigma/d\Omega (^{242m}\text{Am}) = 100 \text{ pb/sr} \\
\text{d}\sigma/d\Omega (^{244m}\text{Am}) = 700 \text{ pb/sr}
\]
Transfer in $^{48}$Ca + $^{248}$Cm reactions

<table>
<thead>
<tr>
<th>Z</th>
<th>Transfer Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>95</td>
<td>No 250 (0.25 ms)</td>
</tr>
<tr>
<td>96</td>
<td>No 252 (2.30 s)</td>
</tr>
<tr>
<td>97</td>
<td>No 258 (1.2 ms)</td>
</tr>
<tr>
<td>98</td>
<td>No 260 (106 ms)</td>
</tr>
<tr>
<td>99</td>
<td>No 262 (5 ms)</td>
</tr>
<tr>
<td>100</td>
<td>Md 247 (1.12 s)</td>
</tr>
<tr>
<td>101</td>
<td>Fm 256 (2.63 h)</td>
</tr>
<tr>
<td>102</td>
<td>Cf 254 (60.5 d)</td>
</tr>
</tbody>
</table>

transfer products with $Z > Z_{Cm}$
Separation criteria I

$^{48}\text{Ca} + ^{248}\text{Cm}, E_{\text{cm}} = 209 \text{ MeV}$

ion charge states at zero degree

ion ranges in 1 bar He gas

$^{48}\text{Ca}$

$^{271}\text{Sg}$

$^{257}\text{Fm}$

$^{248}\text{Cm}$, $E_{\text{cm}} = 209 \text{ MeV}$

$\bar{q}$

gas filled separator

range separation
Separation criteria II

Ion velocities and magnetic rigidities in vacuum

Velocities

Bp values

Velocity filter

Magnetic separation
Separation of Transfer- and Fusion Products

Goals: Primary Beam $I_{\text{max}} = 10^{(14-15)}/s$
$\sigma=0.1\text{pb}$, $T_{1/2} < 10\text{ ms}$

Target

- Beam Swinger
- Change of Incident Beam Angle
- Separation of Primary Beam Reaction Products
- I. Separation Stage
- II. Separation Stage
- Coarse Separation of Reaction Products
- Ion-Catcher RFQ MR-ToF
- High-Resolution Separation of Reaction Products

G. Münzenberg, H. Geissel, S. Heinz, H. Weick, M. Winkler
How to collect a large transverse phase space?

At the Entrance:

Superconducting Quadrupole Triplet

Beam Dump

Superconducting Solenoid

Beam Dump is 40 times more efficient

Emittance: Primary Beam = 5 \( \pi \) mm mr  Reaction Products = 500 \( \pi \) mm mr
Ion-Catcher -- RFQ – MR-ToF

Cryogenic helium gas filled stopping cell

Extraction RFQ

RFQ mass filter

Cooler RFQ

Ion gate

Detector

P. Dendooven, T. Dickel, W. Plass
Setup of the MR-TOF-MS

- Device including electronics mounted in one frame
- Easily transportable
- Variable entrance potential (~2kV)

→ Suitable to be employed at different facilities

T. Dickel, W. Plass
RFQ System for SHIPTRAP

Solution: Matched combination of cooling, mass separation and bunching from Stopping cell to Penning traps

E. Haettner
m/Δm: up to 600000 have been achieved

More than 10,000 ions/cycle

Repetition rate:
100 Hz

More than 10^6 ions/s can be processed
Summary and Conclusion

- Calculated transfer reactions open a new field
- First results from SHIP experiments are promising
- Separation criteria:
  - velocity- and range selection: superior
  - mean-charge state: very difficult
  - brho: not appropriate
- Separator concept for high-intensity primary and small x-sections: Multi-stage separator
- A solenoid is a high-acceptance device for a coarse separation for the primary beam
- High-resolution final stage: of great importance