Isospin effects in multi fragmentation

M.J. van Goethem

for

Wanpeng Tan, Bao-An Li, S. Souza, H.S. Xu,
W.G. Lynch, C. K. Gelbke, M.B. Tsang,
G. Verde, T.X Liu, X.D. Liu, A Wagner, R Donangelo.

Presented at

HIRMEC 2001
Overview

- The density dependent symmetry term of the EOS.
- Model calculations
- Secondary decay
- Isotopic Scaling
- Influence of excitation energy
- Conclusion
The isospin dependence of the EOS

The EOS of asymmetric nuclear matter is parameterized by:

\[ E(\rho, \beta) = E(\rho, 0) + S(\rho)\beta^2, \quad \beta = (\rho_n - \rho_p) / (\rho_n + \rho_p) \]

Symmetric part of EOS

\[ \text{Symmetry energy} = 13.4 \left( \frac{\rho}{\rho_0} \right)^{2/3} + \varepsilon_a F_i \left( \frac{\rho}{\rho_0} \right) \]

There are however many functional forms proposed for \( S(\rho) \)

Need experimental input to set limits on \( S(\rho) \)
Experimental observables

Need observables that are sensitive to the isospin asymmetry of the reaction
- Isotopic distributions
- Comparison of proton- to neutron-spectra
- Mirror isotope ratios
- Neck fragments
- ...

Here we will look at multifragmentation in central $^{112}$Sn+$^{112}$Sn and $^{124}$Sn+$^{124}$Sn reactions at $E/A=50$ MeV

Isotopic composition of fragments
→ sensitive to symmetry energy
# Model calculations

- (Pre-) equilibration residue → Fragmentation → Secondary decay

<table>
<thead>
<tr>
<th>Microscopic model</th>
<th>Fragmentation</th>
<th>Secondary Decay</th>
</tr>
</thead>
<tbody>
<tr>
<td>BUU model</td>
<td>MSU_SMM McGill_SMM</td>
<td>MSU-empirical decay Botvina model Simone</td>
</tr>
<tr>
<td>Boltzmann-Langevin model</td>
<td>AMD</td>
<td></td>
</tr>
</tbody>
</table>

Calculations using different assumptions for the isospin dependence of the EOS
Calculations from BUU/SMM

- Isospin-dependent BUU* defines the state of the equilibrium

<table>
<thead>
<tr>
<th>EOS</th>
<th>Residue N/Z</th>
<th>EOS</th>
<th>Residue N/Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>F_1 (asy-stiff)</td>
<td>85/67=1.27</td>
<td>F_1 (asy-stiff)</td>
<td>102/71=1.44</td>
</tr>
<tr>
<td>F_3 (asy-soft)</td>
<td>82/71=1.16</td>
<td>F_3 (asy-soft)</td>
<td>95/77=1.23</td>
</tr>
</tbody>
</table>

- The SMM model obtains primary distributions
  - The Statistical Multi fragmentation Model(SMM) describes the formation of hot fragments.
  - McGill-SMM gives similar results (S. Das Gupta et al)

F_1 emits relatively more pre-equilibrium protons than F_3

⇒ Primary fragments for F_1 are more neutron rich

* Bao An Li.
Boltzmann-Langevin Calculations

<table>
<thead>
<tr>
<th>EOS</th>
<th>$^{112}\text{Sn}+^{112}\text{Sn}$</th>
<th>$^{124}\text{Sn}+^{124}\text{Sn}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_1$</td>
<td>$&lt;N/Z&gt;_{\text{fragments}}$</td>
<td>$&lt;N/Z&gt;_{\text{fragments}}$</td>
</tr>
<tr>
<td>Asy-soft ($\sim F_3$)</td>
<td>1.31</td>
<td>1.46</td>
</tr>
<tr>
<td></td>
<td>1.24</td>
<td>1.36</td>
</tr>
</tbody>
</table>

$F_1$ also emits relatively more pre-equilibrium protons than $F_3$
Secondary decay

The primary fragments are highly excited, and will decay by evaporating particles.

Secondary decay dramatically changes the isotopic distributions

We need an observable that is less sensitive to secondary decay
Scaling

If one assumes that the grand canonical limit applies:

\[ Y(N, Z) \propto \rho_n^N \cdot \rho_p^Z \cdot e^{B(N, Z)/T} \cdot G_{N, Z}(T) \]

Assuming cancellation of secondary decays in \( ^{124}\text{Sn} + ^{124}\text{Sn} \) and \( ^{112}\text{Sn} + ^{112}\text{Sn} \):

\[ R_{21} = \frac{Y^{^{124}\text{Sn} + ^{124}\text{Sn}}(N, Z)}{Y^{^{112}\text{Sn} + ^{112}\text{Sn}}(N, Z)} \approx C \cdot \rho_n^N \cdot \rho_p^Z \]

The \( R_{21} \) observable is relatively insensitive to secondary decay.
Scaling in experimental data.

Plot the ratio of isotopic yields from $^{124}\text{Sn}+^{124}\text{Sn}/^{112}\text{Sn}+^{112}\text{Sn}$

Data show scaling → Grand canonical assumption seems valid

The slopes are:

$\alpha = 0.37$
$\beta = -0.405$
Scaling in BUU/SMM/MSU-e calculations

Scaling also observed in BUU/SMM (EOS: F_1)
Secondary decay has no effect

<table>
<thead>
<tr>
<th>EOS</th>
<th>$\alpha$-primary</th>
<th>$\alpha$-final</th>
</tr>
</thead>
<tbody>
<tr>
<td>F_1</td>
<td>0.385</td>
<td>0.399</td>
</tr>
<tr>
<td>F_3:</td>
<td>0.26</td>
<td>0.22</td>
</tr>
<tr>
<td>Data</td>
<td>-----</td>
<td>0.37</td>
</tr>
</tbody>
</table>

F_1 compares better to data
Scaling in BL/MSU-e calculations

- BNV also shows scaling (EOS F_1)

- But secondary decay changes scaling parameter dramatically from primary to final distribution.

Scaling parameter
\[ \alpha = 1.071 \text{ primary, } 0.286 \text{ final} \]
Scaling in BNV/MSU-e (2)

Plot of scaling parameter $\alpha$-final, where secondary decay used modified excitation energies of primary fragments.

(red EOS F_1, blue EOS asy_soft ~F_3)

Excitation energy of Fragments in BNV may be overestimated

Question: which EOS F_1 or F_3 ?

Need better understanding of fragmentation.

$<E^*> = 1.8$ AMeV as used in BUU/SMM  $<E^*> = 3$ AMeV
Conclusion

Scaling parameters are sensitive to the isospin dependence of the EOS

However:
BNV and BUU-SMM models show very different scaling behavior.
Secondary decay obscures differences between the models and data.
→ interpretation is ambiguous.

Need
- more direct probes to study the isospin dependence of the EOS.
- better understanding of multifragmentation