Neutron-Proton equilibration in dynamically-deformed nuclear systems
(at 35 MeV/nucleon)

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Systems studied: $^{70}\text{Zn}^{+}$$^{70}\text{Zn}$, $^{64}\text{Ni}^{+}$$^{64}\text{Ni}$, $^{64}\text{Zn}^{+}$$^{64}\text{Zn}$, and $^{64}\text{Zn}^{+}$$^{64}\text{Ni}$ at 35 MeV per nucleon using NIMROD.
Velocity gradient and surface tension amplifies instabilities
Composition of HF and LF vs rotation angle
= direct observation of the time dependence of NZ equilibration
Angular (\(\alpha\)) distributions:

- Lifetime of PLF* correlated with rotation angle:
  \[\alpha = \text{acos}(\frac{\vec{v}_{cm} \cdot \vec{v}_{rel}}{||\vec{v}_{cm}|| \cdot ||\vec{v}_{rel}||})\]

- Angular distribution peaked for most aligned configuration. Decreases in yield with decreasing alignment.

- Excess yield largest and most strongly aligned for most asymmetric splits.

- Less aligned decays represent longer decay times.

\[Y_T = Y_d + Y_s\]

- Dynamical yield dominates at small angles and decreases as \(\alpha\) increases.
As angle of rotation increases, $\Delta_{HF}$ ($\Delta_{LF}$) start off very n-poor (n-rich), then evolve towards each other.

- Exponential fit: $a + b \ e^{-c(\alpha)}$
  - $a$ = equilibrium value
  - $c$ = rate constant for equilibration
- First-order kinetics.

$\Delta_{Observable} = f_s\Delta_S + f_d\Delta_d$
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  - $a =$ equilibrium value
  - $c =$ rate constant for equilibration
- First-order kinetics.

- Dynamical composition generally follows the same trend as the overall composition (more extreme).
- Rate of change of the composition unaffected by correction

$$\Delta_{\text{Observable}} = f_s \Delta S + f_d \Delta d$$
Composition vs decay alignment: for different systems

- $\Delta/\alpha (^{70}\text{Zn}, ^{64}\text{Ni})$ correlations essentially the same.

- $\Delta/\alpha (^{64}\text{Zn})$ correlation shifted to lower values (i.e. lower equilibrium composition). Same rate constants and change from initial to final value.

Comparing the symmetric and the asymmetric systems:

- $\Delta/\alpha$ correlations for the symmetric system are systematically lower → target effects.
Equilibrium composition

\[ <\Delta> = a + b \cdot e^{-c(\alpha)} \]

• \( Z_L, Z_H \) values fairly clustered \( \rightarrow \) equilibrium value for LF (HF) depends on \( Z_L (Z_H) \) but not on \( Z_H (Z_L) \).

• Comparing \(^{70}\text{Zn} (\square)\) and \(^{64}\text{Ni} (\star)\) systems (similar n-rich system composition): 
  \~ same equilibrium composition.

• \(^{64}\text{Zn} (\bullet)\): consistently less n-rich equilibrium compositions

• The asymmetric \(^{64}\text{Zn} + ^{64}\text{Ni}\) system (\(\triangle\)): 
  slightly + n-rich daughters than the n-poor syst. 
  slightly - n-rich daughters than the n-rich syst.

\( \rightarrow \) target effect
Rate constant for equilibration:

\[
<\Delta> = a + b \, e^{-c(\alpha)}
\]

- Exponential slope

- Average rate constant \(zs^{-1}\):
  - LF \(4 \pm 1\)
  - HF \(4 \pm 2\)

- Relevant parameter to calculate the equilibration times.

- Describes how fast the equilibration occurs within the PLF\(^*\).

- Agreement of rates → force driving the equilibration is independent of the size of both partners only depends on the difference in asymmetry
Summary:

• Study the time-dependence of **n-p equilibration** in dynamically deformed nuclear systems by examining the composition of fragments produced by a system out of equilibrium.

• Method to measure the equilibration's time evolution by studying the fragments emitted from the PLF* as a function of the breakup alignment angle.

• The alignment angle serves efficiently as an effective **clock for equilibration**.

• The variation of the composition as a function of the alignment angle shows an exponential behavior for both LF and HF, suggesting **first-order kinetics**, for all the systems studied.

• The yield and measured composition are used to extract an estimate for the purely dynamical component.

• Small systematic effect in the composition for reactions of a relatively n-poor projectile with a n-rich **target**.

• **No significant differences in the rate constants** between systems of different initial composition.
Thank you!

SJY group and collaborators:  

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