Isoscaling Behavior in Projectile Fragmentation

Deqing Fang

Shanghai Institute of Applied Physics, Chinese Academy of Sciences

CCAST Workshop on Isospin Physics and Liquid Gas Phase Transition

Beijing, August 19~21, 2005
Outline

- Introduction
- Statistical Abrasion-Ablation model
- Isospin effect and its disappearance in projectile fragmentation
- Isoscaling effect in projectile fragmentation
- Summary
Introduction

Nuclear Landscape

known nuclei

less than 300 stable

terra incognita

CCAST Workshop on Isospin Physics and Liquid Gas Phase Transition
Beijing, August 19~21, 2005
Radioactive Ion Beam Facilities in the World

- Operating IF, and Upgrades (completion dates)
- Operating ISOL
- Under-construction ISOL (completion date)
- ISOL Development/Proposal

CCAST Workshop on Isospin Physics and Liquid Gas Phase Transition
Beijing, August 19~21, 2005
Projectile Fragmentation (PF) is one of the most effective methods for the production of RIB.
Statistical Abrasion-Ablation Model

Schematic view of two nuclei collision in straight-line geometry.
a) Side view of a peripheral collision via collisions of tube pairs;
b) Seen in beam direction, the vectors s and b are defined in the plane perpendicular to the beam.

Transmission probability for an incident nucleon (k=n for neutron, k=p for proton)

$$ t_{j,k} = \exp \left( -\frac{1}{F}(N_j \sigma_{nk} + Z_j \sigma_{pk}) \right) $$

Average number of nucleons removed in a collision of tube pairs

$$ < \Delta A_i > = N_i(1 - t_{j,n}) + Z_i(1 - t_{j,p}) = < \Delta N_i > + < \Delta Z_i > $$

Binomial distributions are assumed for $< \Delta N_i >$ and $< \Delta Z_i >$. 
Modifications for the Model


\[ t_n = t_0^n + \frac{\hbar}{\sqrt{2Nm\varepsilon}} \]

where \( N \) and \( m \) are the neutron number and neutron mass respectively, \( \hbar \) is the Plank constant. \( \varepsilon \) (MeV) is the separation energy of the last neutron, \( t_0^n = 2.4 \text{fm} \) is given by the droplet model.


- Improved the numerical method in the code to calculate the very small production cross section for fragments close to the dripline.
Statistical Abrasion-Ablation Model

Isotopic Distributions for $^{40}\text{Ar}$

$^{40}\text{Ar} + ^{9}\text{Be}$ at 1 GeV

$^{40}\text{Ar} + ^{12}\text{C}$ at 213 MeV/Nucleon

CCAST Workshop on Isospin Physics and Liquid Gas Phase Transition
Beijing, August 19~21, 2005
Statistical Abrasion-Ablation Model

Isotopic Distributions

$^{129}\text{Xe} + ^{27}\text{Al}$ at 790 A*MeV

$^{86}\text{Kr} + ^{27}\text{Al}$ at 44 MeV/u

$^{129}\text{Xe} + ^{90}\text{Zr}$

CCAST Workshop on Isospin Physics and Liquid Gas Phase Transition
Beijing, August 19~21, 2005
Isospin Effect and its Disappearance in Projectile Fragmentation at Intermediate Energies

CCAST Workshop on Isospin Physics and Liquid Gas Phase Transition

Beijing, August 19~21, 2005
Isospin Effect and its Disappearance in Projectile Fragmentation

CCAST Workshop on Isospin Physics and Liquid Gas Phase Transition

Beijing, August 19~21, 2005
Isospin Effect and its Disappearance in Projectile Fragmentation

Experimental Isotopic Distributions for $^{36,40}\text{Ar} + ^9\text{Be}$

CCAST Workshop on Isospin Physics and Liquid Gas Phase Transition
Beijing, August 19～21, 2005
Isospin Effect and its Disappearance in Projectile Fragmentation
Isoscaling Effect in Projectile Fragmentation

Measured Isotopic yields

Shapes are similar
More n-rich isotopes from more n-rich system
Is Sequential decay effect isospin independent?
Isotopic effects are small how to quantify them?
Isoscaling from Relative Isotope Ratios

\[ R_{21} = \frac{Y_2}{Y_1} \propto e^{N\Delta \mu_n + Z\Delta \mu_p} \propto \left( \rho_n \right)^N \left( \rho_p \right)^Z \]

Factorization of yields into $p$ & $n$ densities

Cancellation of effects from sequential feedings

Robust observables to study isospin effects
Compact representation of isoscaling

Central Collisions
Sn+Sn
E/A=50 MeV

\[ \frac{Y_{124}(N,Z)}{Y_{112}(N,Z)} = \exp(0.37N - 0.41Z) \]

\[ S = R_{21} \exp(0.41Z) \]
Isoscaling observed in many reactions

\[ \frac{Y_2}{Y_1} \propto e^{(N\Delta \mu_n + Z\Delta \mu_p)/T} \]

PRL, 86, 5023 (2001)
Origin of isoscaling

- Isoscaling disappears when the symmetry energy is set to zero
- Provides an observable to study symmetry energy
Isoscaling Effect in Projectile Fragmentation for $^{40}\text{Ar}/^{36}\text{Ar}+^{9}\text{Be}$
Isoscaling Effect in Projectile Fragmentation

CCAST Workshop on Isospin Physics and Liquid Gas Phase Transition
Beijing, August 19∼21, 2005
Isoscaling Effect in Projectile Fragmentation

CCAST Workshop on Isospin Physics and Liquid Gas Phase Transition
Beijing, August 19~21, 2005
The modified SAA model can be used to describe the projectile fragmentation of different nuclei at both high and low energies and calculate the very small production cross sections for fragments close to the dripline.

Strong isospin effect and its disappearance are found in the isotopic distributions produced in projectile fragmentation.

The disappearance of the isospin effect is resulted from the geometry effect in abrasion stage and the sequential evaporation process, but the evaporation effect plays the most important role.

The model can describe the isoscaling effect in projectile fragmentation. An increase of $\alpha(\beta)$ with increase $Z(N)$ is observed. Strong effect of the evaporation process on the isoscaling parameters are found.
Thank You!

D. Q. Fang
dqfang@sinap.ac.cn