Investigation of α-Cluster Transfer in Peripheral Collisions of ^{40}Ca at 12.3 MeV/nucleon

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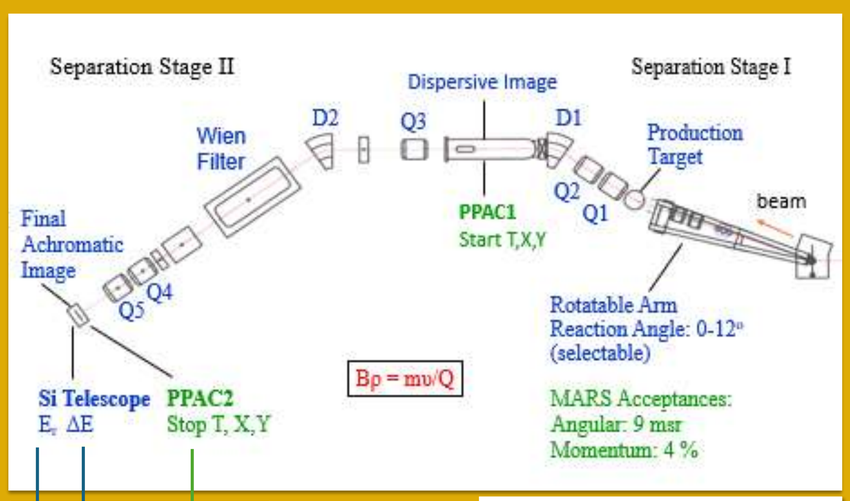
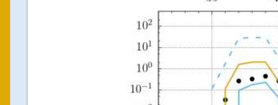
Overview

The investigation of α-clustering is pivotal for elucidating nuclear structure and reaction dynamics within light and medium-mass systems. We present a preliminary comparison of experimental data with theoretical calculations for the ^{40}Ca (12.3 MeV/nucleon) + ^{27}Al , ^{124}Sn reactions, conducted at the Cyclotron Institute of Texas A&M University using the MARS recoil separator. The primary objective is the identification of projectile-like fragments (PLFs) resulting from α-cluster transfer mechanisms, leveraging the cluster substructure of the ^{40}Ca beam. Event-by-event particle identification (Z, q, A) was achieved via a two-element silicon ΔE–E telescope at the MARS focal plane, combined with magnetic rigidity measurements. Experimental observables (isotopic yields, momentum p/A distributions, and excitation energy spectra) are compared with the Deep Inelastic Transfer (DIT) model calculations followed by the de-excitation code GEMINI. The heavier ^{124}Sn target enables a systematic examination of target mass and neutron-to-proton (N/Z) ratios on clustering dynamics. Collectively, this research provides insights into multinucleon dynamics during the transition from the Coulomb barrier to the Fermi energy regime.

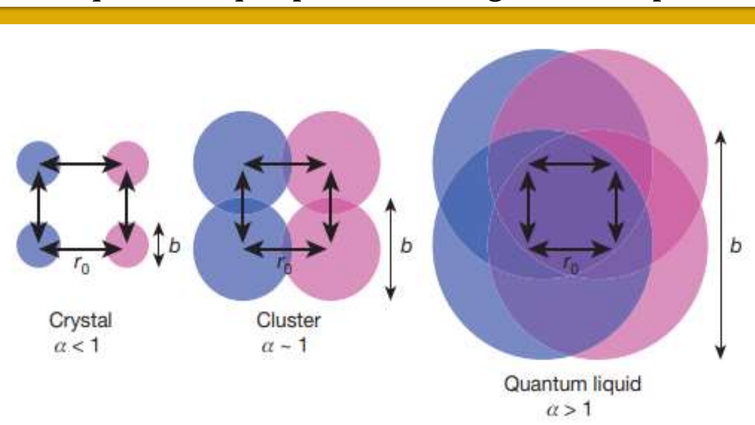
MARS Recoil Separator for Rare Isotope Studies: Cyclotron Institute, Texas A&M University*





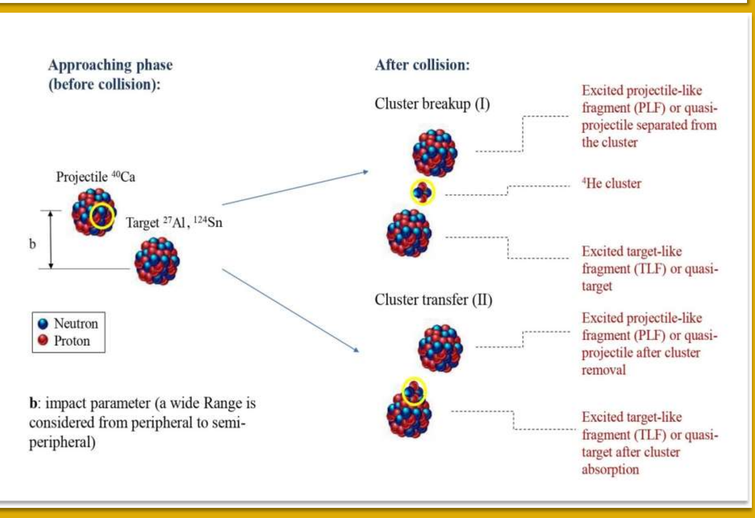
*G. A. Souliotis et al., Nucl. Instr. Methods B, 266, 4692 (2008) and references therein

Schematic illustration of the transition from a crystalline to a quantum liquid phase, including the cluster phase



The dimensionless parameter $\alpha = b/r_0$, where b is the dispersion of the fermion wavefunction and r_0 the typical inter-fermion distance, quantifies nuclear clustering.

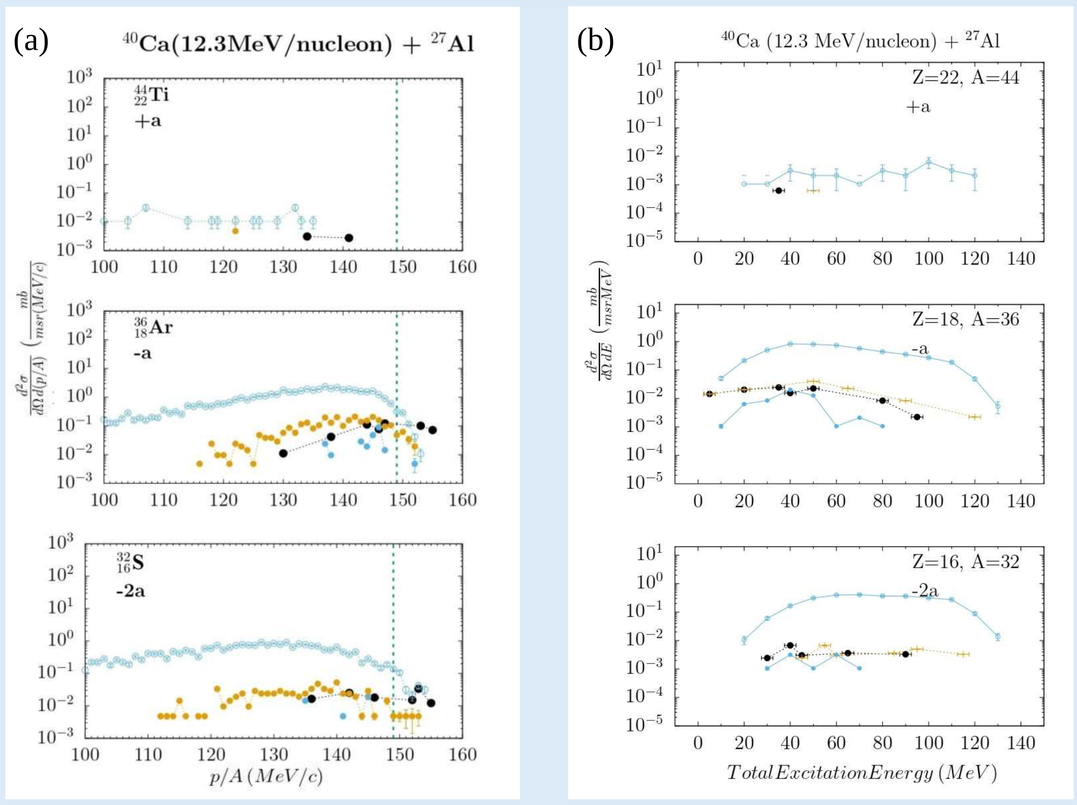
Production method: Cluster breakup (I) or cluster transfer (II) in peripheral collisions



Yield Distributions: Data & Calculations

Production cross sections (mass distributions) of elements with Z=15-22 from ^{40}Ca (12.3 MeV/nucleon) + ^{27}Al (left), ^{124}Sn (right). Experimental Data: Closed (black) circles. The calculations shown are DIT/GEMINI by a dashed (blue) line for total nuclide cross sections and by a solid (blue) line for nuclide cross sections filtered for the angular and magnetic rigidity acceptance. The yellow lines represent the DIT/GEMINI calculation filtered for the angular acceptance only. The green vertical dashed line indicates the starting point of neutron pickup.

Momentum and Excitation Energy Distributions for the ^{40}Ca + ^{27}Al reaction : Data & Calculations

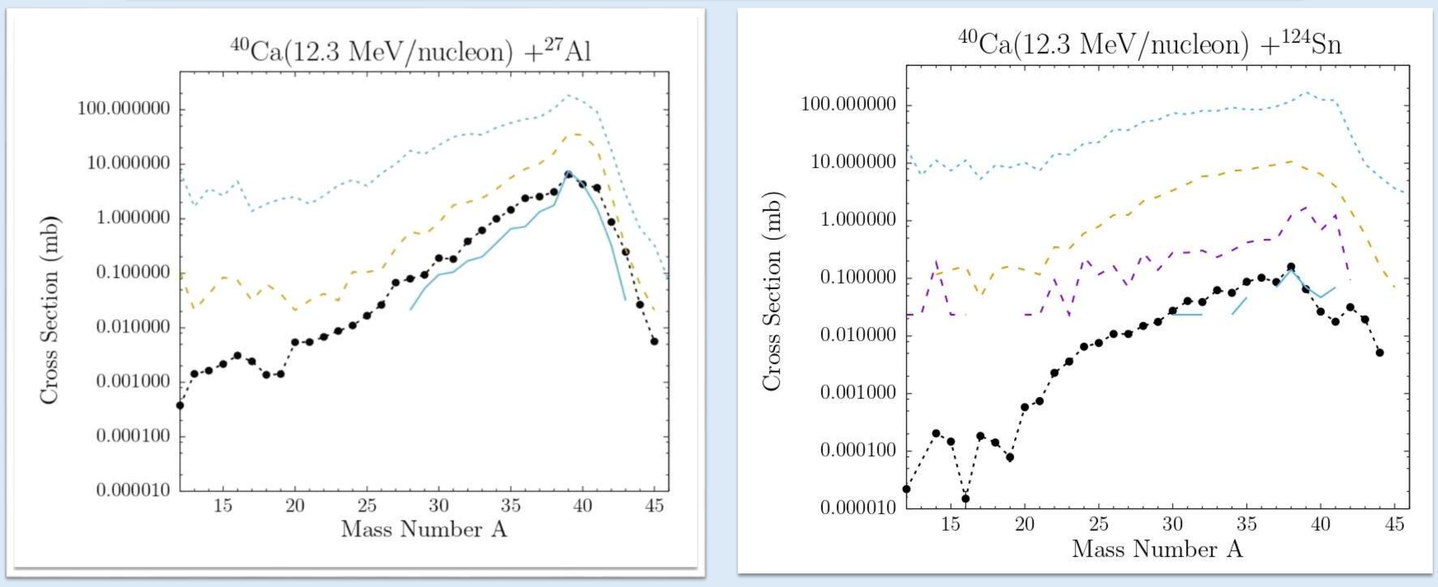


(a): Momentum per nucleon distributions of ejectiles from α-transfer channels of the reaction ^{40}Ca (12.3 MeV/nucleon) + ^{27}Al. Experimental Data: closed (black) circles. The calculations shown are DIT/GEMINI by open (blue) circles for total nuclide cross sections and by closed (blue) circles for nuclide cross sections filtered for the angular and magnetic rigidity acceptance. The closed (yellow) circles represent the DIT/GEMINI calculation filtered for the angular acceptance only. The green vertical dashed line shows the velocity of the projectile.
(b): Reconstructed excitation energy distributions of ejectiles for the same channels. Experimental Data: Neutron evaporation-only [closed (black) circles], no evaporation [(yellow) crosses]. The DIT/GEMINI calculation [closed (blue) circles] incorporate filtering for the angular acceptance and the magnetic rigidity coverage in the experiment. The open (blue) circles represent the total nuclide cross sections.

Next Steps:

- Further study of the ^{40}Ca (12.3 MeV/nucleon) + ^{124}Sn reaction (p/A and E* distributions)
- Primary analysis of new experimental data from the ^{40}Ca (12.3 MeV/nucleon) + ^{40}Ar reaction
- Systematic study of the contribution of the CoMD model by varying key parameters, such as:
  - the effect of the Pauli constraint
  - the compressibility of nuclear matter
- Optimization of CoMD parameter sets to improve agreement with experimental data, especially in the low-excitation (quasi-elastic) region where cluster formation is favored.
- Utilization of the microscopic hybrid a-cluster (HaC) model

Isobaric Mass Distributions: Data & Calculations



Isobaric mass distributions from ^{40}Ca (12.3 MeV/nucleon) + ^{27}Al (left), ^{124}Sn (right). Experimental Data: Closed (black) circles. The calculations shown are DIT/GEMINI by a dotted (blue) line for total nuclide cross sections and by a blue solid (left) and blue dashed (right) line for nuclide cross sections filtered for the angular and magnetic rigidity acceptance. The dashed (yellow) lines represent the DIT/GEMINI calculation filtered for the angular acceptance only, while the dashed (purple) line represents the DIT/GEMINI calculation filtered for the magnetic rigidity acceptance only.

References

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