Nucleon transfer reactions induced by $A < 50$ projectiles

A. Türler

*Paul Scherrer Institute and Bern University*
Why nucleon transfer reactions?

- Quasi-elastic transfer
- Deeply inelastic transfer
- Quasi-fission

New, neutron-rich below target
New, neutron-rich above target

Target
Transfer reactions with $A < 50$ projectiles and $^{248}\text{Cm}$ as a target

Studied systems:

- $^{16}\text{O} + ^{248}\text{Cm} \rightarrow$ above target yields up to $^{256}\text{Md}$
- $^{18}\text{O} + ^{248}\text{Cm} \rightarrow$ above target yields up to $^{259}\text{No}$, below target to Pu
- $^{20}\text{Ne} + ^{248}\text{Cm} \rightarrow$ above target yields up to $^{256}\text{Md}$,
- $^{22}\text{Ne} + ^{248}\text{Cm} \rightarrow$ above target yields up to $^{256}\text{Fm}$
- $^{31}\text{P} + ^{248}\text{Cm} \rightarrow$ above target yields up to $^{256}\text{Fm}$, excitation functions
- $^{40}\text{Ar} + ^{248}\text{Cm} \rightarrow$ above target yields up to $^{256}\text{Fm}$, excitation functions
- $^{40}\text{Ca} + ^{248}\text{Cm} \rightarrow$ above target yields up to $^{256}\text{Fm}$, below target to Th, excit. functions
- $^{44}\text{Ca} + ^{248}\text{Cm} \rightarrow$ above target yields up to $^{256}\text{Fm}$, below target to Th, excit. functions
- $^{48}\text{Ca} + ^{248}\text{Cm} \rightarrow$ above target yields up to $^{256}\text{Fm}$, below target to Rn, excit. functions
Common features

- Yields are highest for transfers of 1 and 2 protons from projectile to target

- FWHM of Gaussian distributions are 2.5 to 3 amu for above target yields ⇒ quasi elastic reactions!

- FWHM of Gaussian distributions are 5 to 5.5 amu for below target yields ⇒ deeply inelastic reactions!

- Pronounced even-odd staggering of above target yields

- Orders of magnitude different cross sections for below target yields

Elemental yields $^{40,44,48}\text{Ca} + ^{248}\text{Cm}$

Production of Fm-isotopes in various HI transfer reactions

(Additional data is available for $^{22}\text{Ne}$, $^{31}\text{P}$, $^{40}\text{Ar}$, $^{40,44}\text{Ca}$ projectiles)

FIG. 8. Production of fermium isotopes from several heavy ion reactions with $^{248}\text{Cm}$ at energies near the nominal Coulomb barrier. The data are plotted against the difference of the nuclide mass number and the mass expected for a $Z=100$ species arising from a uniform charge density intermediate. The $^{254}\text{Fm}$ data points are filled in.

Analysis of the production of $^{256}$Fm

- $^{238}$U
- $^{40}$Ar
- $^{44}$Ca
- $^{48}$Ca
- $^{18}$O
- $^{22}$Ne
- $^{31}$P

Cross section (µb) vs. Projectile Z

- neutron deficient
- beta stable
- neutron-rich
A qualitative interpretation of the results with the aid of potential Energy Surfaces

\[ \text{PES} = V_{\text{Prod}} - V_{\text{React}} - Q_{gg} \]

\[ V_{\text{Prod}} (Z,N) - M_{\text{TL}} - M_{\text{PL}} = V_{\text{Coul}} + V_{\text{Nucl}} + V_{\text{Cent}} \]

- \( M_{\text{TL}} \): mass target-like fragment
- \( M_{\text{PL}} \): mass projectile-like fragment
- \( V_{\text{Coul}} \): Coulomb potential at \( R_{\text{int}} \)
- \( V_{\text{Nucl}} \): nuclear potential at \( R_{\text{int}} \)
- \( V_{\text{Cent}} \): centrifugal potential at \( R_{\text{int}} \)
PES for the system $^{40,44,48}\text{Ca} + ^{248}\text{Cm}$

Above target yields have unfavorable Q-values!
Below target yields have favorable Q-values!
Centroids of the distributions closely follow the valley of the PES

PES in detail: $^{48}\text{Ca} + ^{248}\text{Cm}$

Above target yields have unfavorable Q-values! Below target yields have favorable Q-values! Centroids of the distributions closely follow the valley of the PES.


FIG. 8. Excitation functions for Es and Fm isotopes produced in the bombardment of $^{248}\text{Cm}$ with $^{48}\text{Ca}$. 
Above target yields have favorable Q-values! Below target yields have less favorable Q-values!

Centroids of the distributions approach the valley of the PES

PES in detail:

\[ ^{248}\text{Cm} + ^{40}\text{Ca} \rightarrow \text{Am, Pu, U, Th} \]

Above target yields have unfavorable Q-values! Below target yields have very unfavorable Q-values! Centroids of the distributions do not reach the valley of the PES.

Summary and Outlook

- There is quite a large body of data that needs to be analyzed with new quantitative models (we need a „HIVAP“ for transfer reactions)
- Transfer of pairs is obviously enhanced!
- Most neutron-rich does not mean highest production of neutron-rich target-like fragments, the PE is important!

Proposal: Are there Q-value effects in transfer reactions (i.e. as with $^{48}\text{Ca}$ in fusion)?

- Let us investigate reactions where the projectile-like fragment is magic or doubly magic (investigated was i.e. $^{40}\text{Ar}(-2p,-2n)^{36}\text{S}$,
- i.e. $^{50}\text{Ti}(-2p)^{48}\text{Ca}, ^{54}\text{Cr}(-4p,-2n)^{48}\text{Ca}, ^{58}\text{Fe}(-6p,-4n)^{48}\text{Ca}$, …