Multinucleon transfer reactions and proton transfer channels

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Two-particle transfer processes are an ideal tool to study the dynamical aspects of pairing correlations.

**Heavy ion transfer reactions:**
- **Advantages:** simultaneous comparison of ±nn, ±pp and ±np pairs; transfer of “many” pairs.
- **Enhancement coefficients:** the ratio of the actual cross section to the prediction of models using uncorrelated states.
- **Drawbacks:** all existing studies involve inclusive cross sections at energies higher than the Coulomb barrier and at angles forward of the grazing collision.


J. Speer et al, PLB 259 (1991) 4
Reactions above the barrier

• many open channels - transfer process governed by:
  • optimum Q-value
  • nuclear structure properties

Change of population pattern from neutron-poor to neutron-rich projectiles

Open channels for stable projectiles:
• p stripping (-xp)
• n pick-up (+xn)

Open channels for n-rich projectiles:
• p pick-up (+xp)
• n stripping (-xn)

T. Mijatović et al., PRC 94 (2016) 064616
• heavy ions: presence of both QE and DIC components
• large TKEL more important for p transfer channels
• secondary processes may play a major role in the final mass distribution
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Heavy partner

- light partner: +p-n channels
- heavy partner: -p+n channels

see Poster No. 151

new opportunities with radioactive beams: $^{94}$Rb+$^{208}$Pb, 6.2 MeV/A

*Study of the neutron-rich region in the vicinity of $^{208}$Pb via multinucleon transfer reactions*

Petra Čolović (RBI, Zagreb, Croatia)
Heavy partner

- light partner: +p−n channels
- heavy partner: −p+n channels

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new opportunities with radioactive beams: $^{94}$Rb+$^{208}$Pb, 6.2 MeV/A

Study of the neutron-rich region in the vicinity of $^{208}$Pb via multinucleon transfer reactions

Petra Čolović (RBI, Zagreb, Croatia)
Other calculations

- **TDHF**: previous talk by **K. Sekizawa**

- **Langevin-type approach**: next talk by **V. Saiko**

- **quantum molecular dynamics model**
  Cheng Li, et al., PRC 99 (2019) 024602

- **experimentally important to disentangle different effects (DIC and evaporation) to be able to understand proton transfer channels**

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Advantages:
- reduced number of open channels
- very narrow Q-value distributions: no evaporation effects
- probe nucleon-nucleon correlations as close as possible to the ground to ground states

However, there are problems:
- cross sections very small for transfer channels
- angular distributions are backward peaked
- direct kinematics $\Rightarrow$ low kinetic energy $\Rightarrow$
difficult identification in $A$, $Z$ and $Q$-value
Reactions below the Coulomb barrier

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- probe nucleon-nucleon correlations as close as possible to the ground states

However, there are problems:
- cross sections very small for transfer channels
- angular distributions are backward peaked
- direct kinematics $\Rightarrow$ low kinetic energy $\Rightarrow$ difficult identification in A, Z and Q-value

Solution - inverse kinematic measurements:
- forward focused $\Rightarrow$ high detection efficiency
- high kinetic energy $\Rightarrow$ good energy and mass resolution

- background free spectra $\rightarrow$ ratio of transfer channel to elastic channel to $10^{-4}$
Proton channels below the barrier

- proton pair transfer studies so far performed above the Coulomb barrier
- experimental data very scarce - cross sections drop off rapidly
- large modification in the trajectories of entrance and exit channels due to the modification of the Coulomb field
- the single-particle level density less studied and the corresponding single-particle form factors less known
- theoretically very challenging to reproduce

\[ E_{\text{lab}} = 340 - 370 \text{ MeV} \]
\[ \theta_{\text{lab}} = 22^\circ \]
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$^{92}\text{Mo}^+{}^{54}\text{Fe}$
proton-rich system

$E_{\text{lab}} = 340 - 370 \text{ MeV}$
$\theta_{\text{lab}} = 22^\circ$
• mass distribution at different bombarding energies
• the yield of the 2p transfer channels are similar to those of the 2p+2n transfer channel
• the cross sections derived by integrating the whole TKEL distributions
• below the barrier TKEL gets more narrow and closer to the $Q_{gs}$

TKEL

- $^{52}\text{Cr} (-2p)$
- $^{51}\text{Cr} (-2p-1n)$
- $^{50}\text{Cr} (-2p-2n)$
- $^{56}\text{Ni} (+2p)$
- $^{57}\text{Ni} (+2p+1n)$
- $^{58}\text{Ni} (+2p+2n)$

Counts vs. TKEL [MeV]

- E = 370 MeV
- E = 362.8 MeV
- E = 354 MeV
New measurement: *Nucleon-nucleon correlations in $^{54}$Fe+$^{92}$Mo probed via $\gamma$-particle coincidences*

**PRISMA+LaBr$_3$ array**

$E_{\text{lab}} = 230$ MeV, $\theta_{\text{lab}} = 62^\circ$

will be used to extract the strength distribution for different isotopes

analysis ongoing
• Transfer reactions with heavy ions are a powerful tool to investigate reaction mechanism and structure properties of nuclei.
• Transfer of several nucleons at the same time - possibility to study relative role of transfer of one particle and pair.
• Better understanding of proton transfer channels crucial.
• Results need to be corroborated with population strength of excited states.
• New challenges: Pair transfer channels - radioactive beams with SPES
  • Nuclear properties of the very neutron rich regions, where shell evolution is an open question.
  • How pairing interaction is modified in the nuclear medium - inputs by measurements of nucleon transfer reactions to specific nuclear states.
Thank you!

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