Transfer reactions induced with $^{56}\text{Ni}$: pairing and N=28 shell closure

Anastasia Georgiadou
Supervised by Marlène Assié
Nuclear Reactions

- Fission
- Fusion

Compound Nucleus Reactions

- Elastic Scattering
- Inelastic Scattering
- Break-up Reactions
- Knock out Reactions
- Transfer Reactions

Direct Reactions

Proton
Neutron
One of the best tools to probe single particle states due to the information extracted by the angular distribution for the orbital angular momentum corresponding to the single particle state populated by the reaction.

N=28 shell closure by transfer reaction
Transfer Reactions

Single Particle Transfer Reaction

\[ { }^{56}\text{Ni} \rightarrow { }^{55}\text{Ni} \]

\[ { }^{56}\text{Ni} \rightarrow { }^{55}\text{Ni} \]

Two Particle Transfer Reaction

\[ { }^{56}\text{Ni} \rightarrow { }^{54}\text{Co} \]

\[ { }^{56}\text{Ni} \rightarrow { }^{4}\text{He} \]

Transfer is proportional to the number of neutron-proton pairs. The number of \( np \) pairs decreases very quickly as the neutron-proton imbalance grows, and therefore the transfer of a deuteron-like pair from an even-even to an odd-odd nucleus, stands out as the best tool to investigate \( np \) correlations.

One of the best tools to probe single particle states due to the information extracted by the angular distribution for the orbital angular momentum corresponding to the single particle state populated by the reaction.

N=28 shell closure by transfer reaction

T=0 np pairing by transfer reaction
Two different physical aspects

Energy level sequence calculated for several potentials.

When several energy levels lie close together they form a nuclear shell. The gaps between these shells are labelled with the corresponding magic numbers.
Two different physical aspects

- Adding a neutron (d,p): provides information about the structure of the shells above the gap
- Removing a neutron (d,t): provides information about the structure of the shells below the gap

Study of N=28 shell closure
To probe the gap of $N=28$, we study the spectroscopy of the $N=29$ and $N=27$ isotones by the $(d,t)$ and $(d,p)$ one nucleon transfer reactions on $^{56}\text{Ni}$ and extract information on the single-particle configuration around the fermi surface.
Two different physical aspects

While $T=1$ np pairing should be similar to nn and pp pairing due to charge independence, the characteristics of $T=0$ pairing are largely unknown.

In the $T=0$ channel the interaction is stronger than in the $T=1$ channel, the proof is the existence of the bound $A=2$ nucleus (deuteron).

$n$ and $p$ in nuclei may couple, to form nuclear pairs having a significant role in the nuclear medium properties.

From Theory: $n$-$p$ pairing may be important in $N=Z$ nuclei with high $J$ valence.
The experiment was performed at GANIL, CAEN at Spring 2014.

Primary beam: $^{58}\text{Ni}$ at 74.5 A MeV

Rotating target (CLIM): $^{12}\text{C}$ (1 mm)

Secondary beams: $^{56}\text{Ni}$ at 30 A MeV,
$^{52}\text{Fe}$ at 31.2 A MeV

*The experiment was performed at GANIL, CAEN at Spring 2014.*
Kinematics
Kinematics

\[ E_{\text{lab}} \text{ (MeV)} \]

\[ \theta_{\text{lab}} \text{ (deg)} \]

- \( ^{56}\text{Ni}(d,\alpha)^{54}\text{Co} \)
- \( ^{56}\text{Ni}(d,t)^{55}\text{Co} \)
- (1st excited state)
Experimental Set-up

2-CATS

TIARA

4-EXOGAM

CLOVERS

MUST2

CHARISSA

*Illustration by Emmanuel Rindel

Beam $^{56}$Ni

Alphas

Protons

Target: CD$_2$
Simulation of the (d,t) with
Experimental Set-up

*Illustration by Emmanuel Rindel

Beam $^{56}\text{Ni}$
- Alphas
- Protons

Target: $\text{CD}_2$
Data Analysis

Particle ID

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<th>hIDT</th>
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<tr>
<td>Mean y</td>
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<td>3.355</td>
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<tr>
<td>RMS y</td>
<td>2.059</td>
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- Proton
- Deuteron
- Triton or $^3$He
- $\alpha$-particle
56Ni (d,t) 55Ni

$^{56}$Ni(d,t)$^{55}$Co

Data

$E_{\text{lab}}$ (MeV) vs. $\theta_{\text{lab}}$ (deg) plots for different telescope numbers (h1, h2, h3, h4) with entries, mean x, mean y, RMS x, and RMS y values.

IPN
INSTITUT DE PHYSIQUE NUCLEAIRE
ORSAY
56Ni (d,t) 55Ni

Data

Counts

Excitation Energy (MeV)

-2 0 2 4 6

g.s.

1st Ex. State

Entries 44343
Mean -1.659
RMS 3.952
**56Ni (d,t) 55Ni**

Counts

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<tr>
<td>RMS    3.952</td>
<td>RMS    3.952</td>
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1st Ex. State

Excitation Energy (MeV)
Future Plans

• Angular distribution of the (d,t) to compare with the (p,d).

• Use γ-α coincidences as to identify the populated state of $^{54}\text{Co}$.

• Extract the angular distribution of the (d,α) transfer reaction to the first excited state (T=0) of $^{54}\text{Co}$.

• Farther future plans: analysis of the $^{56}\text{Ni}(d,p)^{57}\text{Ni}$ reaction
  - Calibration of Tiara (Hyball and Barrel)
  - Extract physical observables
THANK YOU FOR YOUR ATTENTION

ANASTASIA GEORGIADOU

NESTER GROUP
Motivation

T=0 pairing by transfer reaction

- transfer is proportional to the number of pairs (the number decreases quickly as the n and p imbalance grows)
- \( \sigma (0+)/\sigma (1+) \) gives the relative strength of T=0/T=1 pairing

<table>
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<th>sd Shell</th>
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<tr>
<td>n,p transfer</td>
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<td>J=0(^{+}),T=0</td>
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<tr>
<td>(Z,N=Z)</td>
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</table>

sd Shell

- Experimental data
- Single particle estimate
- Isovector superfluid limit
- Parabolic shape
Motivation for \((d,\alpha)\)

**f Shell Generic Level Scheme**

- \(\text{n,p transfer} \)
- \(\text{d transfer \((d,\alpha)\)} \)

<table>
<thead>
<tr>
<th>(\text{56Ni} )</th>
<th>(\text{54Co} )</th>
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<tbody>
<tr>
<td>(0^+, T=1)</td>
<td></td>
</tr>
<tr>
<td>(197\text{keV} )</td>
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<tr>
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<tr>
<td>(2^+, T=1)</td>
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<tr>
<td>(\text{0^+, T=1} )</td>
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</table>

\(56\text{Ni} \) \((p,^3\text{He})\) \(54\text{Co}, \Delta T=0,1 \) *

\(56\text{Ni} \) \((d,^4\text{He})\) \(54\text{Co}, \Delta T=0\)

*Analysis Performed by Dr. Le Crom*
For the time calibration purposes a time calibrator module has been used. It generates a start and stop signal for each strip of the detector.
The stop signal is delayed comparing to the start signal by a fixed number of different periods in order to cover the whole spectra range.

A second order calibration was applied by taking the time periods as reference.

Due to time asynchronism the different telescopes are not necessarily aligned even after the calibration. For that reason we study each telescope separately.

Typical Spectra: Time calibrator peak for telescope 2. The period between two peaks is 10ns.