Towards $^{78}\text{Ni}$: In-beam $\gamma$-ray spectroscopy of the exotic nuclei close to $N=50$

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Physics case: Study of shell structure above $^{78}$Ni

- Is $^{78}$Ni a good core? Persistence of Z=28 and N=50, pair promotions from the lower shells
- What is the nature of valence space which opens up just above? single particle sequence

Known part of the valence space

Unknown part of the valence space

Neutron single particles

Proton single particles

Residual interaction
Is $^{78}$Ni good core?

- Probably yes...


  from binding energies of the states blow and above $Z=28$ and $N=50$

  \[ N=50 \text{ gap extrapolation} \rightarrow ^{78}\text{Ni} = 3.0(5) \text{ MeV} \]

- maybe not...

  « No direct evidence is found for an enhanced $Z=28$ core polarization, but the larger proton effective charge needed in the SMI calculations to describe $N=50$ isotones with $Z < 40$ indicate a larger proton core polarization for these isotopes. No evidence is found for breaking of the $N=50$ shell gap. »

- from $B(E2)$ measurement in $^{80}\text{Zn}$ (REX-ISOLDE)
  J. Van de Walle et al. PRC 79, 014309 (2009)
  « No direct evidence is found for an enhanced $Z=28$ core polarization, but the larger proton effective charge needed in the SMI calculations to describe $N=50$ isotones with $Z < 40$ indicate a larger proton core polarization for these isotopes. No evidence is found for breaking of the $N=50$ shell gap. »

- from Yrast structure studies from DIC experiments (Legnaro) down to $^{82}\text{Ge}$
  Y. H. Zhang et al. PRC 70, 024301 (2004) and subsequent studies E. Sahin et al.
  « The generally good agreement obtained between calculated and measured level energies in all the cases considered is taken as an argument for the proper description of such semi magic nuclei within the shell-model framework and therefore of the persistence of the $N=50$ closed shell down to $Z=32$. »

- from $\beta$-decay studies down to $^{81}\text{Ga}$ (Orsay)
  D. Verney et al. PRC 76, 054312 (2007)

- from mass measurements down to $^{80}\text{Zn}$ (IGISOL Jyvaskyla)
  J. Hakala et al. PRL 101, 052502 (2008)
  « The data indicates the persistence of this gap towards Ni ($Z=28$) with an observed minimum at $Z=32$. »

- from binding energies of the states blow and above $Z=28$ and $N=50$

  \[ N=50 \text{ gap extrapolation} \rightarrow ^{78}\text{Ni} = 2.5 \text{ MeV} \]
N=50 shell gap has local minimum at Ge

Two neutron separation energy
\[ \Delta = S_{2n}(52) - S_{2n}(50) \]
\[
\downarrow
\]
N=50 shell gap

Local minimum at Ge (Z=32)

FIG. 4. Evolution of the N = 50 shell gap and comparison to theoretical models.

J. Hakala et al. PRL 101, 052502 (2008)
Increasing collectivity toward N=50 in Ge isotope

Ge isotopes

HFB D1S Gogny + GCM: O. Perru, J. Libert and D. Girod

Prolate vibration

Spherical vibration

“γ-soft” nucleus

Triaxial rotation
What is the nature of valence space above $^{78}\text{Ni}$?

Neutron single particles

- $d_{5/2}$
- $s_{1/2}$
- $g_{7/2}$
- $d_{3/2}$
- $h_{11/2}$

$^{82}\text{Sr}$

E (MeV)

- 0.00
- 1.00
- 2.45
- 3.04


Duflo Zuker
PRC 59, R2347 (1999)

Shell model calc. with $^{78}\text{Ni}$ core
K. Sieja et al. PRC 79, 064310 (2009)
N=51 isotone systematic

Excitation energy [keV]

- $7/2^+$
- $3/2^-$
- $1/2^+$
- $5/2^+$
- $2^+ \otimes d_{3/2}$ or $g_{7/2}$?
- $5/2^+$

$^89\text{Sr}$ (Z=38)
$^87\text{Kr}$ (Z=36)
$^85\text{Se}$ (Z=34)
$^83\text{Ge}$ (Z=32)
$^81\text{Zn}$ (Z=30)
$^79\text{Ni}$ (Z=28)

$g_{7/2}$
$d_{3/2}$
$s_{1/2}$
$d_{5/2}$
$g_{9/2}$
$p_{1/2}$

$\text{Zr90}$
$\text{Zr91}$
$\text{Y89}$
$\text{Sr88}$
$\text{Sr89}$
$\text{Rb87}$
$\text{Kr86}$
$\text{Kr87}$
$\text{Br85}$
$\text{Se84}$
$\text{Se85}$
$\text{As83}$
$\text{As84}$
$\text{Ge82}$
$\text{Ge83}$
$\text{Ga81}$
$\text{Zn79}$
$\text{Zn80}$
$\text{Zn81}$
$\text{Cu79}$
$\text{Ni77}$
$\text{Ni78}$

50
N=49 isotone systematics

R.A. Meyer et al., PRC 25 (1982) 682
Valence space for proton in west part of $^{78}$Ni

T. Otsuka et al. PRL95, 232502 (2005)

K. Flanagan et al., PRL 103, 142501 (2009)
Valence space for proton in north part of $^{78}$Ni

The observed structure of the odd-proton $N=50$ isotones should only (and naturally) reflect the change of the Fermi level to be checked experimentally.

From Ji et Wildenthal
Proposed experimental setup

FRS + AGATA + LYCCA
secondary fragmentation reaction

\(^{86}\)Kr (550 MeV/u, 1.0 \times 10^{10} \text{ pps}) on \(^9\)Be target (4011 mg/cm\(^2\))

\(^{83}\)As (220 MeV/u, 2.5 \times 10^4 \text{ pps}) on \(^9\)Be target (2650 mg/cm\(^2\))
Yield estimation (preliminary)

- $^{83}\text{As}$ beam (220 MeV/u, $2.5\times10^4$ pps)
- Be target (2650 mg/cm$^2$)
- 15% efficiency for AGATA
- all products through 1st to g.s. transition

![Graph showing production rates for various elements]

- Production rate (pps)
  - 100 counts/week

- Elements: Ge, Ga, Zn, Cu, Ni, Co
- Production rates range from $1.0\times10^{-6}$ to $1.0\times10^2$ pps

- Key points:
  - $83\text{As}$ beam (220 MeV/u, $2.5\times10^4$ pps)
  - Be target (2650 mg/cm$^2$)
  - 15% efficiency for AGATA
  - All products through 1st to g.s. transition

- Graph showing production rates for various elements:
  - Ge, Ga, Zn, Cu, Ni, Co
  - Production rates range from $1.0\times10^{-6}$ to $1.0\times10^2$ pps

- Key points on graph:
  - 100 counts/week
Summary

We propose to perform the in-beam gamma-ray spectroscopy of very neutron-rich nuclei around N=50 towards $^{78}$Ni using the secondary fragmentation reaction of a $^{83}$As (Z=33, N=50) beam with FRS + AGATA + LYCCA.

Physics interest

- $^{78}$Ni can be considered as a good core for shell model?
  - increasing collectivity across N=50 (2$^+$, 4$^+$ sequence)
- shell structure, order of orbit, $\pi$-$\nu$ interaction
  - proton shell seems to be understood by tenser interaction (cf. Cu isotope)
  - inversion of g.s. spin from 5/2$^-$ to 3/2$^-$ between $^{85}$Ba and $^{83}$As
- decreasing single-particle energy space between vs$_{1/2}$ and vd$_{5/2}$
- mysterious of 1/2$^-$ state in N=49
Down sloping of $s_{1/2}$ states