A. Odahara  
Department of Physics, Osaka University

1. isomer spectroscopy using secondary beam line at RCNP, Osaka Univ.
   (1) introduction  
   (2) results  
   (3) future plan of Osaka group

2. decay spectroscopy using BigRIPS + EURICA at RIKEN
   (1) introduction  
   (2) future plan of Osaka group
1. isomer spectroscopy using RI beam line at RCNP, Osaka Univ.

   (1) introduction
   (2) results
   (3) future plan of Osaka group

2. decay spectroscopy using BigRIPS + EURICA at RIKEN

   (1) introduction
   (2) future plan of Osaka group
1. isomer spectroscopy using RI beam line at RCNP, Osaka Univ.

(1) introduction
EN beam line

RI beam with beam energy from low (~ MeV/u) to high (~several tens MeV/u) can be delivered.

Maximum rigidity \( 3.2 \) Tm
Energy acceptance \( \Delta E/E = 16 \% \)
Angular acceptance \( \Delta \theta = 40 \) mrad \( \Delta \phi = 28 \) mrad
Path length \( 16.8 \) m

T. Shimoda et al., NIM B70 (1992) 320.
Study for change of nuclear structure using isomers

Isomers are good probe to obtain information of change of nuclear structure.

ex. shape isomer:
caused by the sudden shape change

EN beam line has been used as spectrometer.
* prompt- and delayed-$\gamma\gamma$ coincidence method using primary beam and secondary beam
* recoil-catcher method
and so on ...
1. isomer spectroscopy using RI beam line at RCNP, Osaka Univ.
   
   (1) introduction
   (2) results
   
   (3) future plan of Osaka group

2. decay spectroscopy using BigRIPS + EURICA at RIKEN
   
   (1) introduction
   (2) future plan of Osaka group
1. **isomer spectroscopy using RI beam line at RCNP, Osaka Univ.**

(2) results

---

**1. high-spin shape isomers in $N=83$ isotones**

(1) prompt- and delayed-$\gamma\gamma$ coincidence

$^{151}\text{Er}$

$^{116}\text{Sn}(^{40}\text{Ar}, 5n)^{151}\text{Er}$

4.9 MeV/u, 3 pnA

(2) $^{17}\text{N}$ RI beam fusion reaction

$^{142}\text{Pr}$

primary reaction: $^{9}\text{Be}(^{18}\text{O},^{17}\text{N})^{10}\text{B}$

9.2 MeV/u, 0.8 pµA

secondary reaction: $^{130}\text{Te} + ^{17}\text{N}$

5.0 MeV/u, ~10$^5$ pps

---

**2. spin-gap isomers in nuclei with $N\sim51$, $Z\sim40$**

(3) recoil catcher method

$^{86}\text{Kr}$ beam + $^{13}\text{C}$ target

7.4 MeV/u, 7 pnA

---

**3. high-spin states in transitional nuclei with $Z\sim57$ and $A\sim130$**

(4) $^{17}\text{N}$ RI beam fusion reaction

$^{135}\text{La}$, $^{136}\text{La}$

primary reaction: $^{9}\text{Be}(^{18}\text{O},^{17}\text{N})^{10}\text{B}$

9.3 MeV/u, 1.5 pµA

secondary reaction: $^{124}\text{Sn} + ^{17}\text{N}$

5.5 MeV/u, 1.2x10$^5$ pps, around 60%
High-spin shape isomers in $N=83$ isotones

$^{152}$Er: $[\nu(f_7/2 h_9/2 i_{13/2})\pi(h_{11/2}^4)]_{61/2}^+$

$^{151}$Ho: $[\nu(f_7/2 h_9/2 i_{13/2})\pi(h_{11/2}^3)]_{28}^-$

Odd

$[\nu(f_7/2 h_9/2 i_{13/2})\pi h_{11/2}^2]_{49/2}^+$

Odd-odd

$[\nu(f_7/2 h_9/2 i_{13/2})\pi(h_{11/2}^2d_{5/2})]_{27}^+$

Oblate

$\beta \sim -0.19$

$^{152}$Er:

$[\nu(f_7/2 h_9/2 i_{13/2})\pi(h_{11/2}^4)]_{61/2}^+$

$49/2^+$

$420\text{ns}$

$[61/2^+, 65/2^-]$

$10.288$

$spherical$

$^{151}$Ho:

$[\nu(f_7/2 h_9/2 i_{13/2})\pi(h_{11/2}^3)]_{28}^-$

$27/2^+$

$35\text{ns}$

$[61/2^+, 65/2^-]$

$8.989$

$oblate$

$^{152}$Er:

$[\nu(f_7/2 h_9/2 i_{13/2})\pi(h_{11/2}^4)]_{61/2}^+$

$49/2^+$

$8.597$

$8.786$

$spherical$

$oblate$

$^{151}$Ho:

$[\nu(f_7/2 h_9/2 i_{13/2})\pi(h_{11/2}^3)]_{28}^-$

$27/2^+$

$8.649$

$8.588$

$spherical$

$oblate$

$^{152}$Er:

$[\nu(f_7/2 h_9/2 i_{13/2})\pi(h_{11/2}^4)]_{61/2}^+$

$49/2^+$

$510\text{ns}$

$spherical$

$oblate$

$^{151}$Ho:

$[\nu(f_7/2 h_9/2 i_{13/2})\pi(h_{11/2}^3)]_{28}^-$

$27/2^+$

$1.310\mu s$

$spherical$

$oblate$

$^{152}$Er:

$[\nu(f_7/2 h_9/2 i_{13/2})\pi(h_{11/2}^4)]_{61/2}^+$

$49/2^+$

$28\text{ns}$

$spherical$

$oblate$

$^{151}$Ho:

$[\nu(f_7/2 h_9/2 i_{13/2})\pi(h_{11/2}^3)]_{28}^-$

$27/2^+$

$787\text{ns}$

$spherical$

$oblate$
Results by the systematic study of high-spin shape isomers in $N=83$ isotones

1. shape isomer with high-spin

![Graph showing properties of 13/2$^+$, 27/2$^-$, and 49/2$^+$ isomers.]


2. change of the $Z=64$ sub-shell gap energy

- 1h$_{11/2}$
- 2d$_{5/2}$

![Graph showing the change in the Z=64 sub-shell gap energy.]


3. experimental pairing interaction in high-spin states

\[ \Delta(Z) = \frac{\pi Z}{2} \left[ B(Z-1) + E(Z-1) \right] \]
\[ + \left[ B(Z+1) + E(Z+1) - 2\{B(Z) + E(Z)\} \right] \]


![Graph showing odd-even mass difference in high-spin states.]


Deformed independent particle model (DIPM) by H. Sagawa

3. high-spin states in transitional nuclei with $Z \sim 57$ and $A \sim 130$

(4) $^{17}$N RI beam fusion reaction $^{135}$La, $^{136}$La

primary reaction : $^{9}$Be($^{18}$O,$^{17}$N)$^{10}$B

9.3 MeV/u, 1.5 pµA

secondary reaction : $^{124}$Sn +$^{17}$N

5.5 MeV/u, 1.2x10$^5$ pps, around 60%
Study of high-spin states of nuclei in transitional mass region with Z~57 and A~130

primary reaction : \( ^9\text{Be}(^{18}\text{O},^{17}\text{N})^{10}\text{B} \)
9.3 MeV/u, 1.5 \( p\mu A \)

secondary reaction : \( ^{124}\text{Sn} +^{17}\text{N} \rightarrow ^{135}\text{La} (6n), ^{136}\text{La} (5n) \)
5.5 MeV/u, 1.2\( \times 10^5 \) pps, around 60%

Ge detector array
12 tapered Ge + 8 BGOACS (co-axial Ge det. used in EUROBALL) from gamma pool

total efficiency : around 3 % at 1.3 MeV

collaboration with French group (CNSMS, Orsay & Universite Paris Sud XI)

Si-ball
170 \( \mu m \) \( \Delta E \) type
by Kyushu Univ. & CNS, U. of Tokyo
Development of direct low-energy $^{17}$N RI beam

-$^{17}$N RI beam purity around 60%
-intensity $1.2 \times 10^5$ cps
-spot size 90% in $\phi_{22}$

Si detector
$\Delta E$ 72.3$\mu$m – $E$ 250$\mu$m

PPAC

$^{18}$O$^7+$
$^{18}$O$^6+$
$^{12}$C$^5+$
$^{15}$C$^6+$
$^{17}$N$^7+$

traced size of $^{17}$N RI beam at target

$^{17}$N RI beam
-purity around 60%
-intensity $1.2 \times 10^5$ cps
-spot size 90% in $\phi_{22}$
(1) Improvement of S/N in $\gamma$-ray spectrum

Gamma rays correlated to the RI beam were selected by using information of time difference between PPAC and Ge detectors.

- $\gamma$-ray singles spectrum
- Prompt $\gamma$-ray spectrum
- $\gamma-\gamma$ projection
- $\gamma-\gamma$ projection gated by $\gamma$-rays in $^{136}$La

S/N

- Low
- High

Post-prompt
Prompt
Pre-prompt

delayed $\gamma$-ray
accidental $\gamma$-ray

spectrum of time difference between PPAC & Ge detectors by H. Nishibata
(2) preliminary result: revised level scheme of $^{135}$La

Level scheme has been revised.

Spins and parities are also re-assigned.

Isomer might be caused by shape change. (ex. spherical, triaxial, prolate ...)

by H. Nishibata et al. to be submitted
### Search for high-spin states in transitional nuclei with Z~57 and A~130

<table>
<thead>
<tr>
<th>Institution</th>
<th>Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Univ. of Paris Sud, France</td>
<td>R. Leguillon, C. Petrache (CSNSM Orsay)</td>
</tr>
<tr>
<td>CNS, Univ. of Tokyo</td>
<td>R. Yokoyama</td>
</tr>
<tr>
<td>RCNP, Osaka Univ.</td>
<td>E. Ideguchi, N. Hamatani, T. Suzuki</td>
</tr>
<tr>
<td>RIKEN</td>
<td>H. Watanabe, Y. Wakabayashi, S. Nishimura, Y. Gono</td>
</tr>
<tr>
<td>Tokyo Univ. of Sci.</td>
<td>K. Yoshinaga</td>
</tr>
<tr>
<td>IPN Orsay, France</td>
<td>D. Beaumel</td>
</tr>
<tr>
<td>IPN Lyon, France</td>
<td>G. Lehaut, D. Guinet</td>
</tr>
<tr>
<td>CSNSM Orsay, France</td>
<td>P. Desesquettes</td>
</tr>
<tr>
<td>IPHC Strasbourg, France</td>
<td>D. Curien</td>
</tr>
</tbody>
</table>
1. isomer spectroscopy using RI beam line at RCNP, Osaka Univ.
   (1) introduction
   (2) results
   (3) future plan of Osaka group

2. decay spectroscopy using BigRIPS + EURICA at RIKEN
   (1) introduction
   (2) future plan of Osaka group
1. Isomer spectroscopy using RI beam line at RCNP, Osaka Univ.
(3) Future plan of Osaka group

Development of isomer beam

Isomer beam
RI beam with high spin
(+ high-excitation energy)

What advantage?

Nuclear structure
Study of nuclear structure of high-spin states which cannot be produced by the ground-state beam

Nuclear reaction
Study of nuclear reaction for initial state with high spin
1. Study of high-spin states
   (1) search for limit of high-spin state
       search for hyper deformation ?
   (2) study of high-spin non-yrast states
       search for exotic deformation and its motion
       (precession mode, oblate super deformation,
        nuclear tidal wave, tetrahedral, octahedral …..)

2. Nuclear reaction at high-spin states
   transfer reaction from / to high-spin states

3. Nuclear structure of high-spin and high-excited states
   giant resonance built on high-spin isomer

example of study using isomer beam
(ex. 1) Fusion reaction using high-spin isomer beam

High-spin states close to yrast state can be populated.

(ex. 2) Coulomb excitation of isomer beam

Non-yrast high-spin states can be studied.

extracted B(E2) Q, sign of Q

* precession mode
* oblate super deformation
* nuclear tidal wave, ...., etc
Nuclear reaction mechanism can be understood between high-spin and low-spin states.

(ex,3) transfer reaction from / to isomeric state

(ex, 4) giant resonance built on isomer

GT GR can be effective to spin and configuration of isomer.
1. isomer spectroscopy using RI beam line at RCNP, Osaka Univ.
   (1) introduction
   (2) results
   (3) future plan of Osaka group

2. decay spectroscopy using BigRIPS + EURICA at RIKEN
   (1) introduction
   (2) future plan of Osaka group
EURICA (EUroball-RIKEN Cluster Array) project

at RIKEN, RIBF
using BigRIPS and Zero-degree separators

decay spectroscopy
β-decay and isomer decay
of nuclei far from stability line
Radioactive Isotope Beam Facility (RIBF) at RIKEN

New Generation Radioactive Isotope Beam Facility

$^{238}\text{U} \quad \ldots \quad 345 \text{ MeV/u}$
Detectors used in EURICA project

EURICA
12 EUROBALL Cluster Ge detectors
+ 3 NaI detectors

WAS3ABi (Wide-range Active Silicon Strip Stopper Array for Beta and Ion detection)

8 DSSSD
40x60x1 mm (40x60 strips)
for the detection of RI beam and β ray
EURICA Collaboration


1. University of Valencia, Spain
2. RCNP, Japan
3. RIKEN, Wako, Japan
4. Royal Institute of Technology, Stockholm, Sweden
5. INFN, Milano, Italy
6. University of Istanbul, Turkey
7. University of Milano, Italy
8. GANIL, Caen, France
9. VINCA, Belgrade, Yugoslavia
10. Tokyo University of Science, Japan
11. LNL, Legnaro, Italy
12. University of Padova, Italy
13. IPN Orsay, France
14. IPHC, Strasbourg, France
15. LRI - University of Salamanca, Spain
16. University of Akdeniz, Antalya, Turkey
17. TRIUMF, Vancouver, Canada
18. University of Surrey, Guildford, UK
19. GSI, Darmstadt, Germany
20. TU München, Germany
21. CLNS, University of Tokyo, Japan
22. CENBG Bordeaux, France
23. JAERI, Tokai, Japan
24. KEK, Tokai, Japan
25. Peking University, China
26. CSIC, Madrid, Spain
27. University of Tsukuba, Japan
28. CNNSM, Orsay, France
29. Hoseo University, Chun-Nam, Korea
30. ICU, Tokyo, Japan
31. Tokyo Institute of Technology, Japan
32. Osaka University, Japan
33. Uppsala University, Sweden
34. LPSC Grenoble, France
35. Kyoto University, Japan
36. University of Tokyo, Hong Kong, Japan
37. TU Darmstadt, Germany
38. Tohoku University, Japan
39. MPI, Heidelberg, Germany
40. ATOMKI, Debrecen, Hungary
41. CIAE, Peking, China
42. IMP, Lanzhou, China
43. University of Edinburgh, UK
44. University of Brighton, UK
45. Yale University, USA
46. Vietnam Academy for Science and Technology, Hanoi, Vietnam
EURICA Collaboration

Origin of Collaboration Members

- Bulgaria: 30.9%
- Canada: 16.0%
- China: 12.6%
- France: 8.0%
- Germany: 8.6%
- Hungary: 6.3%
- Italy: 2.3%
- Japan: 2.3%
- Korea: 1.1%
- Spain: 0.6%
- Sweden: 0.5%
- Turkey: 0.3%
- UK: 0.2%
- USA: 0.1%
- Vietnam: 1.0%

Total: 100%
Shell-structure evolution around doubly-magic nuclei around $^{78}\text{Ni}$, $^{100}\text{Sn}$, $^{132}\text{Sn}$

- Shape evolution from spherical to deformed shape
- Proton drip-line nuclei
- Isospin symmetry, np pairing etc.
- Nuclear astrophysics

Approved experiments and physics motivation in EURICA project
1. isomer spectroscopy using RI beam line at RCNP, Osaka Univ.
   (1) introduction
   (2) results
   (3) future plan of Osaka group

2. decay spectroscopy using BigRIPS + EURICA at RIKEN
   (1) introduction
   (2) future plan of Osaka group
Shape evolution in neutron-rich $A \sim 140$ nuclei beyond the doubly-magic nucleus $^{132}\text{Sn}$

EURICA campaign: $\beta$-$\gamma$ spectroscopy, isomer spectroscopy

Spokespersons:
- Atsuko Odahara, Department of Physics, Osaka University, Japan
- Radomira Lozeva, IPHC, Strasbourg, CNRS/IN2P3, France
- Changbum Moon, Hoseo University, Korea

$doubly-magic$ nucleus $^{132}\text{Sn}$ ($Z=50$, $N=82$)
Collaborators

Dep. of phys., Osaka Univ., Japan
T. Shimoda, H. Nishibata, J. Takatsu

Chung-Ang Univ., Korea
Y.-K. Kown

IPHC, CNRS/IN2P3, France
G. Duchene, D. Curien

CEA, France
J.-M. Daugas, R. Chevrier

CSNSM, CNRS/IN2P3, France
G. Georgiev

RIKEN, Japan
S. Nishimura, P. Doornenbal, H. Watanabe,
Z. Li, G. Lorusso, T. Nakao, T. Isobe,
H. Baba, Y. Gono, D. Kameda, N. Fukuda,
H. Takeda, H. Suzuki, Y. Shimizu, H. Sato,
N. Inabe, T. Kubo

Tokyo Univ. of Sci., Japan
T. Sumikama, K. Yoshinaga

Univ. of Tokyo
Z. Xu

JAEA
Y. Wakabayashi

RCNP, Osaka Univ., Japan
T. Suzuki

IPN, Orsay, France
M. Niikura
summary

1. isomer spectroscopy using secondary beam line at RCNP, Osaka Univ.

(1) the latest results
High-spin states in transitional nuclei with Z~57 and A~130 have been studied. Level schemes of transitional nuclei $^{135}$La and $^{136}$La have been re-constructed and new isomer has found in $^{136}$La.

(2) future plan.
We have a plan to develop high-spin isomer beam.
Isomer beam will open the study in new high-spin region.

2. stopped beam experiments using BigRIPS + EURICA at RIKEN

(1) EURICA project is to study by the decay spectroscopy for the very neutron-rich and proton-rich nuclei.
   EURICA --- 12 Euroball Cluster detectors
   WAS3ABi --- 8 DSSSD

(2) We hope that our experiment of ‘shape evolution in neutron-rich A~140 nuclei beyond the doubly-magic nucleus 132Sn’ will be able to performed next spring.