The Spectrometer System at RCNP and Combination with Gamma-Ray Detectors

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Outline

• The Spectrometer System at RCNP
  High-Resolution Beam Line: WS
  High-Resolution Spectrometer: Grand Raiden
  Large Acceptance Spectrometer: LAS

• Experimental Possibilities with Gamma-Ray Detectors
RCNP Cyclotron Facility

Double arm spectrometer (Grand Raiden & LAS)

K400 ring cyclotron

p: 400MeV
HI: 100MeV/u

K140 AVF cyclotron
p ~ Xe
Pol. p & d
Double Arm Spectrometer

Grand Raiden

LAS
Double-Arm Spectrometer
Grand Riaden and LAS

D1 : 第1段双極電磁石
D2 : 第2段双極電磁石
Q1 : 第1段4重極電磁石
Q2 : 第2段4重極電磁石
SX : 6重極電磁石
MP : 多重極電磁石
DSR : スピン回転用双極電磁石
FP : 焦点面
FPP : 焦点面ボラリメータ

T : 標的
Q : 4重極電磁石
D : 双極電磁石
FP : 焦点面
High-Resolution Spectrometer “Grand Raiden”

M. Fujiwara et al., NIMA422,494(1999)

- Resolving Power: 37,000
- Bending Radius: 3 m
- Bending Angle: 162 deg
- Bending Power: 5.4 Tm
- Dispersion: 15.4 m
- Solid Angle: ~4 msr
- Momentum Acceptance: 5 %
- Horizontal Magnification: -0.42
- Vertical Magnification: 6.0
- Angle: 0-70 deg

Two Multi-Wire Drift Chambers
Plastic Scintillators
Focal Plane Polarimeter (for protons)
Resolving Power: 5,000  
Bending Radius: 1.75 m  
Bending Angle: 70 deg  
Bending Power: 3.22Tm  
Dispersion: 2 m  
Solid Angle: ~20 msr  
Momentum Acceptance: 30 %  
Horizontal Magnification: -0.40  
Vertical Magnification: -7.3  
Angle: 0-130 deg  

Two Multi-Wire Drift Chambers  
Plastic Scintillators
## Double-Arm Spectrometer
### Grand Riaden and LAS

<table>
<thead>
<tr>
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<th>LAS</th>
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 Beam Intensity
max: 1 µA ($10^{13}$/sec)
(limitation by radiation safety)
high-quality beam: 1-20 nA ($10^{10-11}$/sec)

Energy
low-energy beam from AVF
upto highest energy beam from RING.
e.g. 10-400 MeV for protons

Dispersion Matching

ΔE=60-100 keV

ΔE=20-30 keV
Unique Features of the Cyclotrons and Spectrometers

Accelerator Complex

• high-quality beams (1-20 nA)
  stable, high-resolution, low-background (no beam halo)
• high-intensity beams (up to 1 μA)
• low to Intermediate (100-400 MeV/A) Energy (10-400 MeV for p)
• polarized p and d beams
• variety of ion species from H to Xe

Spectrometer System

• high-Resolution
• large magnetic rigidity (triton 150 MeV/A)
• realization of 0-deg measurements including inelastic scattering
• focal plane proton polarimeter
• coincidence measurements with two spectrometers
• coincidence measurements with decay counters (SSD, neutron, (gamma))
High-Quality Beams

High-Quality beams
e.g. the case for a proton beam at 295 MeV

In achromatic mode

beam energy spread: 60-100 keV
beam spot size: < 0.3 mm

In dispersion matching mode

energy resolution: 20-30 keV
beam spot size: 3-5 mm^H, 0.3 mm^V

Halo free beam

High-quality beam is essential to realize 0-deg inelastic scattering measurements.
Also for measurements with gamma detectors.
Unique Features of the Cyclotrons and Spectrometers

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$^{48}\text{Ca}(p,p')$ at $E_p=295$ MeV

(p,p') at 0.0–0.5 deg

Counts/5 keV

Excitation Energy [MeV]
$^{48}\text{Ca}(p,p')$ at $E_p = 295$ MeV
$^{48}\text{Ca}(p,p')$ at $E_p=295$ MeV

Counts/5 keV

Excitation Energy [MeV]
Excitation Energy Spectra

$^{208}\text{Pb}(p,p')$ at $E_p=295$ MeV

$p,p'$ at 0.0–2.5 deg

$S_n$

PDR region

GDR
Excitation Energy Spectra

$^{208}\text{Pb}(p,p')$ at $E_p=295$ MeV

$p,p'$ at 0.0–2.5 deg

$S_n$
Excitation Energy Spectra

$^{208}\text{Pb}(p,p')$ at $E_p=295$ MeV

$(\gamma,\gamma')$  
Enders et al.  
Ryezayeva et al.

$(\gamma,\tilde{n})$  
Laszweski et al.

$d\sigma/d\Omega dE_x$ (mb/sr/sr/10keV)

Excitation Energy (MeV)
$^{58}\text{Ni}(p,p')$ at $E_p=295$ MeV

$^{64}\text{Ni}(p,p')$ at $E_p=295$ MeV

$\theta=0^\circ$, full acceptance
underfocus mode
with b.g. subtraction
4.7 mg/cm$^2$
$^{64}\text{Ni}(p,p')$ at $E_p=295$ MeV

$\theta=0^\circ$, full acceptance
underfocus mode
with b.g. subtraction
4.7 mg/cm$^2$
Level density, auto-correlation, wavelet analysis

Experimental limit due to resolution

Resolution: 25 keV

Level density can be extracted up to $\sim 10^4$/MeV
Gamow-Teller Resonance

\[ ^{58}\text{Ni}(p, n)^{58}\text{Cu} \]
\[ E_p = 160 \text{ MeV} \]

J. Rapaport et al.
NPA (‘83)

\[ ^{58}\text{Ni}(^{3}\text{He}, t)^{58}\text{Cu} \]
\[ E = 140 \text{ MeV/u} \]

Y. Fujita et al.,
EPJ A 13 (’02) 411.
H. Fujita et al.,
PRC 75 (’07) 034310

Counts

Excitation Energy (MeV)

→ Talk by Fujita
(p,t) Spectra and Stellar Rates

First observation of 20 states above $\alpha$-threshold

Determination of excited states and its energy with 1 keV resolution

$^{32}$S(p,t)$^{30}$S
Ep = 100 MeV

(p,t) Measurement

$^{29}$P(p,γ) Reaction Rate

$^{18}$Ne(α,p)$^{21}$Na

$^{28}$Si(α,p) Reaction Rate
(p,2p) Measurement

208Pb(p,2p)

Double Arm Spectrometer
Spectrometers in the 0-deg. experiment setup

Ion optics: Medium under-focus mode

Transport: Dispersive mode

Gamma-Ray Detectors With modification of the scattering chamber

Grand Raiden (GR)

0 deg. Beam Dump (GR = 0 deg.)

295MeV proton (un-polarized)

Feb. 14 2006 defense
Where to Stop the Beam
Inelastic Scattering at 0 deg
(3He, t) at 0 deg

scattered tritons

3He beam

Gamma-Ray Detectors
Scattered deuterons or tritons

(proton beam) at 0 deg

Gamma-Ray Detectors

Target
Proton Beam 295 MeV

No Slits

Q1-FC

SX

Q2

D1

D2

MWDC1,2

PS1,2

DSR
Measurement at angles larger than 25deg

To the beam dump in the wall

> 25 deg

Gamma-Ray Detectors
RCNP Cyclotron Facility

beam dump

Grand Raiden
Measurement at 5 deg (and 3-25 deg)

We need to modify this part to transport the beam to further down stream.

Usually a beam is stopped by Q1-FC for 3-5 deg or by SC-FC for 7-25 deg. They produce large background for gamma-ray detectors.
Gamma-Ray Support System

Gamma-Ray Detectors should be able to be pulled away from the beam line possibly with shielding for making beam tuning.
Research opportunities
Combination of Spectrometer and Gamma-Ray Detectors
(not exclusively by HPGe detectors)

Categories of physics and experimental opportunities

• Study of decay properties of excited states
• Tagging specific excited states by gamma-ray detectors
• Gamma-ray detection as a part of probe for spin-isospin excitations
• Detection of rare gamma-decay
• Higher energy resolution
• Background reduction by coincidence (detection of rare events)
• Spin-parity determination of excited states
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Tagging specific excited states by gamma-ray detectors

Study of the Transition Density of the Low-Lying Dipole Strength:

- q-dependence, surface nature, and neutron nature

→ Talk by Hashimoto

**(p,p′γ) measurement:**

- γ detection by HPGe for tagging each E1 excitation.
  
- Measure angular distribution of the (p,p′) excitation at angles where the nuclear excitation contributes. (~100 MeV/U? single step dominant, but lower Coulomb Ex.)

**(^3He,^3He′γ) measurement:**

- Same as above.

  ^3He is more sensitive to the surface transition.

**(t,t′γ) ⇔ (^3He,^3He′g) comparison**

- Same as above.

Neutron nature of the surface transition density can be studied by the difference.
D. Savran, PRL97, 172502(2006)

$\left(\alpha, \alpha'\gamma\right)$ at KVI

←ΔT=0 Excitation

Study of PDR Isospin Structure

←ΔT=0,1 Excitation

D. Savran, PRL100, 232501(2008)  $\left(\gamma, \gamma'\right)$
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Excitation of high-spin states with gamma-ray tagging

Direct reaction usually doesn’t favor many-particle many-hole excitations, but still it might have sizable cross section.

- Spin parity assignment of low-lying states. (excitation and decay)
- Isospin determination
- Excited states above the yrast line
- Transition strength from the ground state

also
- Life-time measurement with Doppler shift attenuation?

$\alpha$ at 100 MeV/U (or p or HI)

$q=1700$ MeV/c, $\beta=0.05$ at 60 deg
$q=2800$ MeV/c, $\beta=0.08$ at 120 deg

$qR = 34$ h-bar

Target spin is fully aligned in the normal direction of the scattering plane.
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Gamma-ray detection as a part of probe for spin-isospin excitations

\begin{align*}
(6\text{Li},6\text{Li}'\gamma) & \text{ measurement:} \\
\text{Probing Isovector Spin-Flip Inelastic Excitations} & \\
6\text{Li}(0^+,T=1; 3.563 \text{ MeV}) & \\
\text{SDR for neutrino process} & \\
\end{align*}

\begin{align*}
(14\text{C},14\text{C}'\gamma) & \text{ measurement:} \\
\text{Parity Transfer Inelastic Reaction } & 14\text{C}(0^-; 6.903 \text{ MeV}) \\
0^- & \text{ state search} \\
\text{unnatural parity states} & \\
\text{cf. } (7\text{Li},7\text{Be}\gamma) & \text{ with GSO detector, Nakayama et al.,} \\
\text{Isovector spin-flip/spin-non-flip excitations} & \\
7\text{Li}(1/2^-; 477 \text{ keV}) & \\
\end{align*}
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  detection of rare gamma decay events
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Detection of rare gamma-decay

e.g.
Gamma-decay branching ratio of giant resonances

Fundamental properties of the giant resonances
Fine structure
Background process in the Kamiokande/Kamland neutrino detector

Gamma decay of $^{12}\text{C}$ excited states (→ talk by Hashimoto)
Carbon synthesis in supernovae
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Level density, auto-correlation, wavelet analysis

Experimental limit due to resolution

Resolution: 25 keV

Higher resolution for extracting higher level density!

Research opportunities
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Decay property

R. Schwengner et al., PRC78, 064314(2008)

Bremsstrahlung Gamma ray

Only (single) gamma ray is measured

Correction of cascade decay is necessary for reconstructing the B(E1) distribution. (TALYS)

Also for gamma-strength function study at Oslo
Thank you