High Resolution Spectroscopy with Primary Beams at 0
Spectroscopy at 0 "

- "Gamow-Teller strength studied via"
  - 
  - "(3He,t)"
  - "(12C,12N)"
  - "(12C,12B)"
  - "Advantage: L=0 dominant at 0 "
  - "Spin-Flip (GT) dominant"
  - "Smallest distortion effects ~300 MeV/u covered by RIBF"
- "High resolution spectroscopy"
  - "Measure GT states observed with β-decays (100-200 keV resolution is required for heavy nuclei)"
  - "Give GT unit cross sections"

- "Astro-physics interest"
  - "rp-process"
- "Only Ex and Γ are needed"
  - "Can be measured at 0 "
- "100-200 keV resolution is required to measure E_x and Γ"
H-CNO Cycle

- At $T_9=0.2$, CNO cycle only
- At $T_9=0.4$, start bypass cycle through $^{14}\text{O}(\alpha,p)^{17}\text{F}$
- At $T_9=0.5$, breakout from CNO cycle through $^{15}\text{O}(\alpha,p)^{19}\text{N}$
- At $T_9=0.8$, breakout from CNO cycle through $^{18}\text{Ne}(\alpha,p)^{21}\text{Na}$
Level scheme of $^{22}\text{Mg}$

- The level scheme of $^{22}\text{Mg}$ is determined by the $^{21}\text{Na}+p$ reaction (Inverse kinematics).
- Levels at $E_x=8-10.6$ MeV are unknown.
- If there are some levels, breakout of the CNO cycle is accelerated through $^{18}\text{Ne}(\alpha,p)^{21}\text{Na}$ at $T_9=0.8$.

The diagram shows the energy levels and transitions in the $^{22}\text{Mg}$ nucleus, with specific energies and quantum numbers indicated.
Breakout from CNO Cycle

- At $T_9 = 0.60$
  - Breakout from CNO cycle is mainly via $^{18}\text{Ne}(\alpha,p)^{21}\text{Na}$

- At $T_9 = 0.8$
  - If there are some levels in low energy region ($E_x > 8 \text{ MeV}$)
    - Breakout from CNO cycle is accelerated through $^{18}\text{Ne}^+\alpha^+\rightarrow^{22}\text{Mg}\ast\rightarrow^{21}\text{Na}+p$

- $T_9 = 0.60$
  - $\rho = 100 \text{ g/cm}^3$
Requirement for High-Resolution Spectroscopy

- Reaction cross section
  \[ \sigma = \frac{1}{(E - E_R)^2 + (\Gamma/2)^2} \]
  \( E_R \): Resonance energy
  \( \Gamma \): Resonance Width

- Luminosity
  \( \text{Boltzmann distribution with stellar temperature} \)

- Reaction rate is sensitive to resonance energy.
  \( \Gamma \) should be determined experimentally with high accuracy (high resolution).

- Experimentally determined reaction energy \( E_R \) is significantly different with theoretical one.

- Reaction Rate for \(^{23}\text{Al} + p\)

\[
\sigma = \frac{\Gamma^2}{(E - E_R)^2 + (\Gamma/2)^2}
\]

- Shell Model

- Reaction Rate for \(^{23}\text{Al} + p\)

- Reaction Rate (cm\(^3\)/s/mol)

- Resonance Energy (keV)
Resonance states in $^{22}\text{Mg}$ studied via the $^{24}\text{Mg}(\alpha,6\text{He})^{22}\text{Mg}$ reaction

**Experimental conditions**
- $^{22}\text{Mg}$: 1.8 mg/cm$^2$
- $\alpha$-beam: 205 MeV, 80enA
- Beam resolution: >150 keV
- Final resolution after dispersion matching: 98 keV (determined by target multiformity)

**Peak assignment (ERand $\Gamma$)** is now in progress
WS Beam Line at RCNP

- Constructed in 1999-2000
- Experiments with WS after April 2000
- Complete matching with GR
- Double achromatic mode is also available

West Experimental Hall at RCNP
Specifications of WS

- Total length: 65.46m
- Total bending angle: 270°
- Five double-focus points (Two for BLP)
- Dispersive mode
  - Dispersion: 37.1 m
  - Angular dispersion: 20.0 rad
  - Compete matching with GR
- Achromatic mode
  - Lateral dispersion: 0 m
  - Angular dispersion: 0 rad
  - Double achromatic beam
Typical Spectrum of $^{168}$Er(p,p') after Employing Dispersion Matching

- Beam energy:
  - 295 MeV (April 2000)
  - 392 MeV (June 2000)
- Beam energy spread $\Delta E$: 150 keV (FWHM)
- Target: $^{168}$Er: 2 mg/cm²
- Energy resolution:
  - 13.0 keV for 295 MeV
  - 16.7 keV for 392 MeV
- Energy resolutions are consistent with the resolving power limit of Grand Raiden
Possibility for High Resolution Spectroscopy with Big-RIPS

- Beam analyzer for dispersion matching
- Particle analyzer
Requirements

- To achieve 100 keV resolution
  - $\Delta p = 1.5 \times 10^{-4}$
  - Resolution of spectrometer $> 7000$
    (if the object size of beam = 1mm)
  - Dispersion matching is required
    (the energy spread of beam $> 100$ keV)

- To perform experiments efficiently
  - Angular acceptance: $\Delta \theta = \pm 10$ mrad, $\Delta \phi = \pm 30$ mrad (1.2 msr)
    (cf. 5.6 msr for Grand Raiden)
  - Momentum acceptance: $\Delta p = \pm 1\%$
    (cf. $\Delta p = \pm 2.5\%$ for Grand Raiden)
Beam Envelopes of Beam Line (From F0 to F4)

- Divided into 3 sections
  - F0-F2: Dispersive
  - F2-F3: Matching
  - F3-F4: Achromatic

- Ion-optical properties
  - $M_x$: 0.76
  - $D$: 4.47 m
  - $M_y$: -0.70

- Double focused at the end of each section
- 2 groups of Q for F0-F2 and F3-F4: Unique (Envelope min. Focus point)
- 3 groups of Q for F2-F3
  - 2 groups: Double focus
  - 1 group: Disp. matching
Beam Envelopes of Beam Line (From F0 to F4)

- Beam Envelopes:
  - $\Delta x = \pm 1\text{mm}$, $\Delta y = \pm 1\text{mm}$
  - $\Delta \theta = \pm 5\text{mrad}$, $\Delta \phi = \pm 5\text{mrad}$
  - $\Delta p = \pm 0.1\%$
 Beam Envelopes of Spectrometer (From F4 to F7)

- F4-F4': Dispersive
- F4’-F5: Rotate dispersion
- F5-F7: Dispersive

- M_x: 0.55
- D: 4.47 m (R=8100 for 1mm)
- M_y: 19.1

- 2 groups of Q: Unique
  (Envelope min. □ Focus point)
Beam Envelopes of Spectrometer (From F4 to F7)

- **Horizontal**
  - $\Delta x = \pm 1\text{mm}$, $\Delta y = \pm 1\text{mm}$
  - $\Delta \theta = \pm 10\text{mrad}$, $\Delta \phi = \pm 10\text{mrad}$
  - $\Delta p = \pm 1\%$

- **Vertical**
  - $\Delta x = \pm 1\text{mm}$, $\Delta y = \pm 1\text{mm}$
  - $\Delta \theta = \pm 8\text{mrad}$, $\Delta \phi = \pm 30\text{mrad}$
  - $\Delta p = \pm 1\%$
Dispersion Matching between Beam Line and Spectrometer

- Ion-optical properties
  - $M_x: 0.42$
  - $D: 0 \text{ m}$
  - $M_y: 13.1$

- Beam Envelopes
  - $\Delta p = 0.1\%$
Summary

- Charge exchange \((^3\text{He},t)\), \((^{12}\text{C},^{12}\text{N})\), \((^{12}\text{C},^{12}\text{B})\) reactions
  - Deduce GT unit cross sections and GT strengths
- \((^4\text{He},^6\text{He})\), \((^4\text{He},^{8}\text{He})\) etc.
  - Information for rp-process
- High resolution spectroscopy

- R = 8000 (100 keV for 400 MeV)
- Acceptance = 1.0 msr \((\Delta\theta = 8\text{ msr}, \Delta\phi = 30\text{ msr})\)
- Momentum acceptance = 1%
- There will be much more appropriate usage of (part of) Big-RIPS for spectrometer (Large acceptance, high resolution etc.)
  (Just 1day calculations)

- Large dispersion of 10m will be possible with F0-F4 of Big-RIPS
  (Spectrometer part will be limit the total resolution)