MASS MEASUREMENTS OF RARE ISOTOPES WITH THE PENNING TRAP MASS SPECTROMETER SHIPTRAP

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GSI: Unique Combination for SHE Studies

ECR + UNILAC
Beam

Stable targets

Actinide targets

SHIP

SHIPTRAP

TASCA

TASISpec

Future: + Laser spectroscopy

Chemistry
Radiochem. labs

Chemical theory

courtesy Ch.E. Düllmann
Importance of Masses for Z > 92

- masses give access to nuclear binding energy
- masses allow studies of the shell structure evolution
- high-precision mass measurements can provide anchor points to fix decay chains
- benchmark nuclear models

\[ M(Z, N) = Z(m_e + m_p) + Nm_n - B(Z, N)/c^2 \]
Principle of Penning Traps

**PENNING trap**
- Strong homogeneous magnetic field
- Weak electric 3D quadrupole field

**Cyclotron frequency:**
\[ f_c = \frac{1}{2\pi} \cdot \frac{q}{m} \cdot B \]

Typical values: \( B = 7 \text{ T}, \ A = 133, \ f_c \approx 800 \text{ kHz} \)
SHIPTRAP Setup

\( \approx 50 \text{ MeV} \rightarrow \approx 1 \text{ eV} \rightarrow \approx 1 \text{ keV} \)

Gas Cell
- SHIP ion beam
- entrance window
- DC cage
- RF funnel
- Extraction RFQ

Buncher
- Surface ion source
- Quadrupole deflector
- Purification trap

Transfer
- Penning Trap

TRAPSPEC
- Silicon box
- Focussing tube
- Measurement trap
- Cluster- and Clover-type Ge detectors
SHIPTRAP Performance

Mass resolving power of $m/\delta m \approx 100,000$

in purification trap:

⇒ separation of isobars

Mass resolving power of $m/\delta m \approx 1,000,000$

in measurement trap:

⇒ separation of isomers
Requirements for Mass Measurements $Z > 100$

Typical production rates at present facilities:
- 1 atom/s @ $Z=102$ ($\sigma \approx 1 \mu b$)
- 1 atom/week @ $Z=112$ ($\sigma \approx pb$)

- energy matching of reaction products to trap's energy scale
- high efficiency to deal with very low production rates
- high cleanliness for low background
- stable and reliable operation over extended time

Present performance of Penning Traps for RIBs

- Half-life $> 10$ ms
- Rate of trapped ions $> 1 / h$
- Rel. uncertainty $\approx 10^{-8}$
Direct Mass Measurements of $^{252-254}$No

Gateway to Superheavies

- $^{252}$No
  - 102
  - 150
  - 2.44 s $^0$
  - M 83(57)
  - $\gamma=57\%$
  - SF=92.2 (6)%

- $^{253}$No
  - 102
  - 151
  - 31 us $^0$
  - M 140(19) (20)%
  - $\alpha=\ ?$
  - $\beta=29\%$

- $^{254}$No
  - 102
  - 152
  - 54 c $^0$
  - M 84(74) (19)
  - $\alpha=90\%$
  - $\beta=18\%$
Towards Mass Measurements of SHE
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Mean ToF / µs

Exc. Frequency + 843324.5 / Hz

255_{Li}^{2+}
Towards Mass Measurements of SHE

Exc. Frequency - 840025.3022 (Hz)

Time of flight (µs)
Towards Mass Measurements of SHE

- $^{256}\text{Lr}$ radionuclide with lowest yield ever measured in a Penning trap (2 ions/minute)
Direct Mass Measurements above Uranium

![Graph showing the island of stability and SHIPTRAP area in the proton-neutron chart.](image-url)
TRAPSPEC: Trap-assisted Spectroscopy

Idea: use Penning traps as high-resolution mass separator for isotope-selected decay spectroscopy

Benefits:

• clean spectra
• detailed nuclear structure information in one experiment
• great potential for studies of isomers
• future option for SHE identification
TRAPSPEC: Trap-assisted Spectroscopy

M. B.
D. Rudolph et al.
TRAPSPEC Commissioning

Counts per Channel

Gamma-ray Energy (keV)

X-rays

110 singles

213\textsuperscript{Ra} coincidence 110 keV

215

2% branch

F.P. Hessberger et al.
EPJA 30, 551 (2006)
Conceptual design of a cryogenic gas stopper

- Entrance window
- Exit nozzle
- Extracted ions
- RF funnel
- DC electrodes
- Ion beam
Summary and Outlook

- first direct mass measurements above uranium performed
- high-precision mass measurements of stopped rare isotopes with production rates of only 1 per minute demonstrated
- opened the door for novel experiments with heavy elements
- trap-assisted decay spectroscopy successfully established at SHIPTRAP
- technical developments and new techniques will pave the way towards heavier elements $Z > 104$

Thank you for your attention!