In-trap decay and trap-assisted decay spectroscopy at ISOLTRAP

ISOLTRAP experimental setup
In-trap decay:
  principle
  application for mass measurements
Trap-assisted decay spectroscopy:
  principle and purpose
  proposed setup
  1st physics cases
Summary and outlook

Magdalena Kowalska, CERN PH-Dept., ISOLDE

**The funding and support:**
BMBF, GSI, CERN, ISOLDE, EU networks EUROTRAPS, EXOTRAPS, NIPNET
**EU Marie Curie EIF programme**
ISOLTRAP experimental setup

ISOLDE beam (DC)

HV platform

RFQ structure

MCP 1

MCP 3

MCP 5

stable alkali ion reference source

2.8-keV ion bunches

laser beam

MCP 3

MCP 1

85\text{Rb}

\omega_c = \frac{q}{m} \cdot B

Time of flight \[\mu s\]

Excitation frequency [Hz]

1071195 1071200 1071205 1071210 1071215 1071220 1071225

200 220 240 260 280 300 320 340

200 220 240 260 280 300 320 340

2 m

preparation Penning trap

determination of cyclotron frequency

removal of contaminant ions

RFQ structure

ion beam cooler and buncher

ISOLTRAP at ISOLDE/CERN

measurement

Theoretical Fit

\nu

\nu

\omega_c = \frac{q}{m} \cdot B

\text{excitation frequency} [\text{Hz}]

\omega_c = \frac{q}{m} \cdot B

\text{measurement}

\text{Theoretical Fit}

<table>
<thead>
<tr>
<th>\text{Excitation frequency [Hz]}</th>
<th>Time of flight [\mu s]</th>
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<tbody>
<tr>
<td>1071195</td>
<td>200</td>
</tr>
<tr>
<td>1071200</td>
<td>220</td>
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<tr>
<td>1071205</td>
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<td>1071220</td>
<td>300</td>
</tr>
<tr>
<td>1071225</td>
<td>320</td>
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</table>

\omega_c = \frac{q}{m} \cdot B

\text{excitation frequency} [\text{Hz}]

\text{measurement}

\text{Theoretical Fit}

\text{excitation frequency} [\text{Hz}]

\omega_c = \frac{q}{m} \cdot B

\text{measurement}

\text{Theoretical Fit}
In-trap decay

one of tasks of EURONS TRAPSPEC JRA

**Use:** nearly simultaneous $\omega_c$ measurement for mother and daughter nucleus:
- More precise determination of mass differences
- Measurements on isotopes of elements unavailable otherwise
- Different chemical elements reached without changing ion source or/and target

**Method:** Decay in the buffer-gas-filled preparation trap

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<table>
<thead>
<tr>
<th>Kinetic energy of recoiling ions:</th>
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<tbody>
<tr>
<td>$\beta$-decay $10^2$-10$^3$eV</td>
</tr>
<tr>
<td>$Q^2 / 2 - m_e Q$</td>
</tr>
<tr>
<td>$Q - m_e + m_{recoil}$</td>
</tr>
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</table>

**Charge state after decay**
(for singly-charged ions):

- $\beta^+:$ neutral, e- shake-off needed
- $\beta^-:$ doubly charged or more

**Important**

Half-life

Herlert et al.,
Mass measurements using in-trap decay

Evidence of shell effects at $N=40$

$^{61-63}\text{Mn} \rightarrow^{61-63}\text{Fe}$, $\beta^-$ decay

$^{37}\text{K} \rightarrow^{37}\text{Ar}$, $\beta^+$ decay

$^{37}\text{Cl}$, $813.87$ keV, $35.04$ d

$^{37}\text{K}$, $6147.46$ keV, $1.226$ s

Proof of principle
Mn and Fe results

Other possible cases:

112-113Xe -> 112-113I
32Ar -> 32Cl

Herlert et al., in preparation
Trap-assisted decay spectroscopy

**Motivation:**
decay spectroscopy on isomerically and/or isobarically pure beams
(purification in the preparation or precision Penning trap)

**Physics use:**
- Penning traps used only as purifiers: for beams valuable as isomerically and isobarically pure
- Decay spectroscopy used to assist mass measurements and distinguish between species

**Important:**
- Amount of contaminants
  - ISOLTRAP limit ratio: ca. $10^3$
- Mass difference
  - Determines purification time
  - ISOLTRAP limit: ca. 100keV
- Half-life
- Decay losses
- Collected counts

**Minimum excitation time (s)**
to resolve g.s. and isomer

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Decay spectroscopy – planned setup

Tape station above last ISOLTRAP Penning trap

Beta-, gamma-detection in the air
Differential pumping necessary

Technical design by Ulrike Hager
Decay spectroscopy – planned setup

Present status:
- Channeltron
- MCP
- Precision trap

To be exchanged by:
- Channeltron
- MCP
- Tape station entrance
Decay spectroscopy – planned setup

Ion path simulations

GSI Tape station

Detectors:
- Beta – plastic scintillators
- Gamma – ISOLDE Ge detectors
**Aim:** measurements in regions with large amounts of surface-ionised contaminants

**1st planned case:** excited states in neutron-rich Tl and Pb isotopes
Fr contamination
Proposal in preparation for INTC meeting in May

**Physics interest:** little data in this region
Proton hole – neutron interaction
Single-particle configurations
Possible isomers
Decay-spectroscopy – 1st physics case

207Tl: 81p, 126n

π h11/2

π s1/2
Decay-spectroscopy – other cases

Isomeric purification: g.s. and isomer not assigned unambiguously

![Graph showing known isomer yields, known g.s. yields, and known yields in this isotope chain.](image-url)
Summary

In-trap decay for mass measurements:
- Access to elements not produced at ISOLDE
- First measurements performed
- Plans for Qb measurements

Trap-assisted decay spectroscopy
- Decay spectroscopy on isobarically and isomerically pure beams
- Setup in preparation
- 1st physics cases found
- Measurements anticipated in 2008
In-trap decay

Figure 5. Relative abundance of $^{37}$Ar$^+$ as a function of the storage time in the preparation trap as calculated with equation (2) (data are taken from the cyclotron resonances in figure 4). The dashed line shows the increase in the relative abundance following $f(t) = 1 - \exp[-\ln(2)t / T_{1/2}]$ with the half-life $T_{1/2} = 1.225$ s of $^{37}$K.


Hg  Tl  Pb  Bi  Fr

stable

mass

half-live (s)

204  206  208  210  212  214  216  218  220
(evaluation in progress ...)
Mn and Fe masses

\textbf{in-trap decay}

Decay in the buffer-gas-filled preparation trap

produced at ISOLDE

\[ \frac{A}{Z} X \rightarrow \frac{A}{Z-1} Y + e^+ \]

not produced at ISOLDE

- Make more radioactive species available
- Nearly simultaneous measurement of mother and daughter nuclei

<table>
<thead>
<tr>
<th>Element</th>
<th>Ref.</th>
<th>Mass number</th>
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<tr>
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<td>8</td>
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<tr>
<td>Li</td>
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</tr>
<tr>
<td>Be</td>
<td>11</td>
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<tr>
<td>N</td>
<td>17</td>
<td>18 19</td>
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<tr>
<td>O</td>
<td>14</td>
<td></td>
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<tr>
<td>Ne</td>
<td>[11,12]</td>
<td>17   18 19</td>
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<tr>
<td>Mg</td>
<td>[13]</td>
<td>22</td>
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<tr>
<td>Al</td>
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<tr>
<td>K</td>
<td>[14]</td>
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<tr>
<td>Mn</td>
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<td>59 60 61 62 63 64 65 66</td>
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<td>Ni</td>
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<td>Ag</td>
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<tr>
<td>Cd</td>
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<td>[17]</td>
<td>131 132 133 134</td>
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<td>Tl</td>
<td>211 212 213 214 215 216</td>
<td></td>
</tr>
<tr>
<td>Pb</td>
<td>213 214 215 216 217</td>
<td></td>
</tr>
<tr>
<td>Bi</td>
<td>[18]</td>
<td>215 216 217 218</td>
</tr>
</tbody>
</table>

- **Green**: nuclide measured
- **Red**: no successful measurement (contaminants or broken target)
- **Light green**: requested but not scheduled
- **Yellow**: power cut
Principle of a Penning trap

Cyclotron frequency: \( v_c = \frac{1}{2\pi} \cdot \frac{q}{m} \cdot B \)

Superposition
- strong homogeneous magnetic field
- weak electrostatic quadrupole field

PENNING trap
Ion motion in the Penning trap

**Three harmonic eigenmotions**

1. **Axial oscillation**
   
   \[ \omega_z = \sqrt{\frac{qV_0}{md^2}} \]

2. **Magnetron motion** (slow):

   \[ \omega_- = \frac{\omega_c}{2} - \sqrt{\frac{\omega_c^2}{4} - \frac{\omega_z^2}{2}} \]

3. **Cyclotron motion** (fast):

   \[ \omega_+ = \frac{\omega_c}{2} + \sqrt{\frac{\omega_c^2}{4} - \frac{\omega_z^2}{2}} \]

\[ \omega_+ + \omega_- = \omega_c \]

A=100, B=6T
- \( v_+ \approx 1 \text{ MHz} \)
- \( v_- \approx 1 \text{ kHz} \)
- \( v_z \approx 44 \text{ kHz} \)
Mass measurement procedure

Scan QP-excitation freq. $\nu_{rf}$ about $\nu_c$

- Magnetron excitation

- Quadrupolar excitation $\nu_{rf}$

- radial $\Rightarrow$ axial energy

- Time-of-flight (TOF)

Determine atom mass from frequency ratio with a well known reference

$\omega_c = \frac{q}{m} \cdot B$

Remark: The time-of-flight cyclotron resonance detection has the

**Advantage:** very high resolving power (up to $10^8$)

**Disadvantage:** destructive! $\Rightarrow$ FT-ICR detection method
High-precision mass measurements of nickel, copper, and gallium isotopes and the purported shell closure at N=40,

A new Channeltron-detector setup for precision mass measurements at ISOLTRAP,
C. Yazidjian et al., Hyperfine Interact., accepted

High-accuracy mass measurements of neutron-rich krypton isotopes,

High-accuracy mass measurements on neutron deficient neon isotopes,

ISOLTRAP Mass Measurements for Weak-Interaction Studies,

Towards high-accuracy mass spectrometry of highly charged short-lived ions at ISOLTRAP,

Accurate mass measurements on neutron-deficient krypton isotopes,

Webpage: www.cern.ch/isoltrap
ISOLTRAP mass measurements in ‘04-05

Nuclides measured in 2004/2005

Highlights

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Half-life</th>
<th>Uncertainty</th>
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<tbody>
<tr>
<td>$^{17}$Ne</td>
<td>109 ms</td>
<td>530 eV</td>
</tr>
<tr>
<td>$^{22}$Mg</td>
<td>3.86 s</td>
<td>270 eV</td>
</tr>
<tr>
<td>$^{35}$K</td>
<td>178 ms</td>
<td>530 eV</td>
</tr>
<tr>
<td>$^{81}$Zn</td>
<td>290 ms</td>
<td>3.45 keV</td>
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</tbody>
</table>
Publications since last DPG-Tagung


Penning trap mass spectrometry for nuclear structure studies, K. Blaum, et al. Hyperfine Interact., accepted


A new Channeltron-detector setup for precision mass measurements at ISOLTRAP, C. Yazidjian et al., Hyperfine Interact., accepted


Webpage: www.cern.ch/isoltrap