Towards an order of magnitude improvement in high-precision atomic mass measurements

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Single Ion Mass Spectrometry

Strong magnetic field

Cyclotron motion
\[ \omega_c = \frac{qB}{m} \]

\[ \frac{\omega_{c1}}{\omega_{c2}} = \frac{q_1}{q_2} \frac{m_2}{m_1} \]

Harmonic Axial motion
\[ \frac{\omega_z}{2\pi} \approx 200 \text{ kHz} \]

Use mode coupling techniques to measure
\[ \omega_c / 2\pi \approx 5 \text{ MHz} \]

Slow Magnetron motion
(usually ignore)
\[ \frac{\omega_m}{2\pi} \approx 5 \text{ kHz} \]
Single Ion data

- 5 - 30 minutes to isolate a new single ion
- Precision of $10^{-10}$ for a full run (4 hours)

MIT Mass Table

<table>
<thead>
<tr>
<th>Element</th>
<th>$\Delta m/ m$ (x $10^{-10}$)</th>
<th>Factor of improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>5.0</td>
<td>24</td>
</tr>
<tr>
<td>$^2$H</td>
<td>2.5</td>
<td>48</td>
</tr>
<tr>
<td>$^{13}$C</td>
<td>0.8</td>
<td>17</td>
</tr>
<tr>
<td>$^{14}$N</td>
<td>0.9</td>
<td>22</td>
</tr>
<tr>
<td>$^{15}$N</td>
<td>0.7</td>
<td>36</td>
</tr>
<tr>
<td>$^{16}$O</td>
<td>1.3</td>
<td>24</td>
</tr>
<tr>
<td>$^{20}$Ne</td>
<td>1.2</td>
<td>957</td>
</tr>
</tbody>
</table>

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<thead>
<tr>
<th>Element</th>
<th>$\Delta m/ m$ (x $10^{-10}$)</th>
<th>Factor of improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{23}$Na</td>
<td>1.2</td>
<td>93</td>
</tr>
<tr>
<td>$^{28}$Si</td>
<td>0.7</td>
<td>350</td>
</tr>
<tr>
<td>$^{40}$Ar</td>
<td>0.8</td>
<td>424</td>
</tr>
<tr>
<td>$^{85}$Rb</td>
<td>1.6</td>
<td>193</td>
</tr>
<tr>
<td>$^{87}$Rb</td>
<td>1.7</td>
<td>187</td>
</tr>
<tr>
<td>$^{133}$Cs</td>
<td>2.0</td>
<td>111</td>
</tr>
</tbody>
</table>
Main Limitation of Single Ion Technique:

Magnetic Field Noise

Want to make SIMULTANEOUS measurements
Two Ions in One Trap

1 mm
Two Ions in One Trap

\[ m_1 \approx m_2 \]

New normal modes:
- center-of-mass
- difference

- \( \rho_s \) is constant
- \( \rho_s \approx 0.5 - 1 \) mm

perturbation \(< 2 \times 10^{-12}\) on mass ratio

Want \( \rho_{\text{com}} \approx 0 \) for the two ions to sample the same average magnetic field.
Simultaneous Measurements on Two Ions

Axial Frequency - 212 982 Hz

Power Density (Arb Units)

- $\text{N}_2^+$
- $\text{CO}^+$
- 4 K Thermal Noise

magnetron
1 mm
5 kHz

cyclotron
200 µm
5 MHz
Preliminary Two Ions Data

Measurement Time (on 1/29/2001)

Precision of $10^{-10}$ in 4 minutes (during the day)!!

Cyc Phase of CO (deg)

Cyc Phase of $\text{N}_2$ (deg)
Current and Future Work

Big jumps in cyclotron frequency difference:
- ions decouple?
- change in separation distance?

Tools to observe and control trajectories of 2 ions:
- Anharmonicities $\Rightarrow \omega_z(\rho)$
- Transfer a little bit of $\rho_{mag}$ into axial motion, to measure the ion’s radial position.
  - diagnostic
  - fine-tune orbits
  - study possible systematic errors
Simultaneous Measurements on Two Ions

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