Commissioning of the ECRIS Charge State Breeder at TRIUMF

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layout of the ISAC facility
Charge State breeding at ISAC

Requirements:

• $M/Q < 30$ with additional stripping after first acceleration stage (150 keV/u)
• $M/Q < (6)7$ without additional stripping
• ion velocity: 2 keV/u
• transversal emittance: $\leq 30\pi$ mm mrad

Incoming beam:

• singly charged ions continuous beam
• typical emittance $< 30\pi$ mm mrad @ 30 keV
• beam intensity: $1 \ldots > 10^9$ ions/sec
modified 14.5 GHz PHOENIX ECR ion source from Pantechnik
2 step deceleration for the injection of singly charged ions
2 step acceleration scheme + Einzel lens focusing
for the extraction of the highly charged ions
**Measurements with ions from standard ISAC ion sources at test stand**

<table>
<thead>
<tr>
<th>Element</th>
<th>Mass</th>
<th>Charge state with maximum efficiency (A/Q)</th>
<th>Efficiency (%)</th>
<th>rise time (90%) for charge state with maximum efficiency (ms)</th>
<th>1+ ion source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ar</td>
<td>40</td>
<td>8+ (5)</td>
<td>5.5</td>
<td>102</td>
<td>ECR</td>
</tr>
<tr>
<td>Kr</td>
<td>84</td>
<td>12+ (7)</td>
<td>6.3</td>
<td>401</td>
<td>ECR</td>
</tr>
<tr>
<td>Xe</td>
<td>129</td>
<td>17+ (7.6)</td>
<td>4.8</td>
<td>432</td>
<td>ECR</td>
</tr>
<tr>
<td>K</td>
<td>39</td>
<td>9+ (4.3)</td>
<td>2.1</td>
<td></td>
<td>surface</td>
</tr>
<tr>
<td>Rb</td>
<td>85/87</td>
<td>13+ (6.5)</td>
<td>3</td>
<td>230</td>
<td>surface</td>
</tr>
<tr>
<td>Cs</td>
<td>133</td>
<td>20+ (6.7)</td>
<td>3.5</td>
<td>300</td>
<td>surface + testsource</td>
</tr>
</tbody>
</table>

- emittance of Cs\(^{n+}\) measured < 20 \(\pi\) mm mrad @ 15q keV
Charge State Breeder in the ISAC mass separator room
Emittance = 32 pi mm-mrad
Energy spread = +- 0.4%
3 masses: dm/m = -1%, 0, +1%

ion optical simulation for mass resolution after charge state breeding
mass spectrum from ions out of the charge state breeder residual gas and plasma chamber material
charge breeding from test ion source

charge state distribution of stable Cs from test ion source

Efficiency for the production of Cs^{17+} as function of the potential difference between the singly charged ion source and the charge breeder
acceleration of radioactive charge bred ions

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measure $\gamma$ radiation of $^{80}\text{Rb}^{14+}$ after charge breeding
$\Rightarrow 1.1 \times 10^5$ ions per sec

radioactive beam is accompanied by $\sim 100$ nA $^{40}\text{Ar}^{7+}$

inject beam into RFQ, accelerate to 150 A keV, drift through DTL, analyze energy with magnet

transmission for $^{40}\text{Ar}^{7+}$ 33%

measure $\gamma$ radiation of $^{80}\text{Rb}^{14+}$ after acceleration
$\Rightarrow 3.5 \times 10^4$ ions per sec (32%)
## Radioactive Isotopes, Results

<table>
<thead>
<tr>
<th>isotope</th>
<th>q</th>
<th>A/q</th>
<th>efficiency [%]</th>
<th>I (in) [1/s]</th>
<th>background [pA]</th>
</tr>
</thead>
<tbody>
<tr>
<td>46K</td>
<td>9</td>
<td>5.11</td>
<td>0.5</td>
<td>4.0E4</td>
<td>340</td>
</tr>
<tr>
<td>64Ga</td>
<td>13</td>
<td>4.92</td>
<td>0.7</td>
<td>8.4E4</td>
<td>150</td>
</tr>
<tr>
<td>64Ga</td>
<td>14</td>
<td>4.57</td>
<td>0.75</td>
<td>8.4E4</td>
<td>210</td>
</tr>
<tr>
<td>74Br</td>
<td>14</td>
<td>5.28</td>
<td>3.1</td>
<td>3.2E7</td>
<td>10000</td>
</tr>
<tr>
<td>74Br</td>
<td>15</td>
<td>4.93</td>
<td>2.1</td>
<td>3.2E7</td>
<td>25</td>
</tr>
<tr>
<td>78Br</td>
<td>14</td>
<td>5.57</td>
<td>4.5</td>
<td>2.8E7 AlBr</td>
<td>20</td>
</tr>
<tr>
<td>74Kr</td>
<td>15</td>
<td>4.93</td>
<td>6.2</td>
<td>2.1E6</td>
<td>25</td>
</tr>
<tr>
<td>76Rb</td>
<td>15</td>
<td>5.07</td>
<td>1.68</td>
<td>3.8E6</td>
<td>15</td>
</tr>
<tr>
<td>80Rb</td>
<td>13</td>
<td>6.15</td>
<td>1.17</td>
<td>5.7E7</td>
<td>35</td>
</tr>
<tr>
<td>80Rb</td>
<td>14</td>
<td>5.71</td>
<td>1.1</td>
<td>5.7E7</td>
<td>70000</td>
</tr>
<tr>
<td>122Cs</td>
<td>19</td>
<td>6.42</td>
<td>1.1</td>
<td>3.1E5</td>
<td>6</td>
</tr>
<tr>
<td>124Cs</td>
<td>20</td>
<td>6.2</td>
<td>1.37</td>
<td>2.75E7</td>
<td>50</td>
</tr>
</tbody>
</table>
charge state distribution of $^{124}$Cs
$T_{1/2} = 30.8$ s
$2.75 \cdot 10^7$ $^{124}$Cs$^{1+}$ ions injected from Ta target with surface ion source

charge state distribution of $^{76}$Rb
$T_{1/2} = 36.8$ s
$3.8 \cdot 10^6$ $^{76}$Rb$^{1+}$ ions injected from Nb target with surface ion source
charge state distribution of $^{74}$Kr ($t_{1/2} = 690$ s) and $^{74}$Br ($t_{1/2} = 1524$ s) from a ZrC target and FEBIAD ion source. Both ions have been injected at the same time into the breeder.
$^{78}\text{Br}^{14+}$ (1E6 ion/s) A/q = 5.57 amu/e injected as AlBr from ZrC target accelerated to 5MeV/u measured at TIGRESS detector background ≈ 20 pA
• charge breeding of stable ions
  • efficiency \( \approx 3\% \) at test stand and on line, higher for noble gases
  • breeding time \( \times 100 \text{ ms} \)

• charge breeding of radioactive ions
  • 1.4% efficiency for \(^{124}\text{Cs}^{20+}\) \((A/q = 6.2)\), 1.7% efficiency for \(^{76}\text{Rb}^{15+}\) \(A/q=5.07\)
  • 6.2% for \(^{74}\text{Kr}^{15+}\)
  • injection of molecular ions \(\Rightarrow\) beam purification from isobars
  • acceleration of \(^{80}\text{Rb}^{14+}\) and \(^{78}\text{Br}^{14+}\)

• plans for the future
  • continue commissioning with radioactive ions, short half lives
  • further optimization of breeding and accelerator efficiency
  • background reduction, more gas purification, aluminum plasma chamber
  • charge breeding tests with EBIT
Thank you!

Merci!