Third Order Design of the q/m Separator for REX-ISOLDE

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The ion optics of a mass spectrometer for the REX-ISOLDE project were studied by taking into account aberrations up to third order with the COSY INFINITY code [1]. The main task of the design was to obtain a mass resolving power high enough in order to separate all isotopes (neutron rich Na, Mg, Ca or K) of interest from the residual gas ions with similar q/m, which are also produced in the ion source.

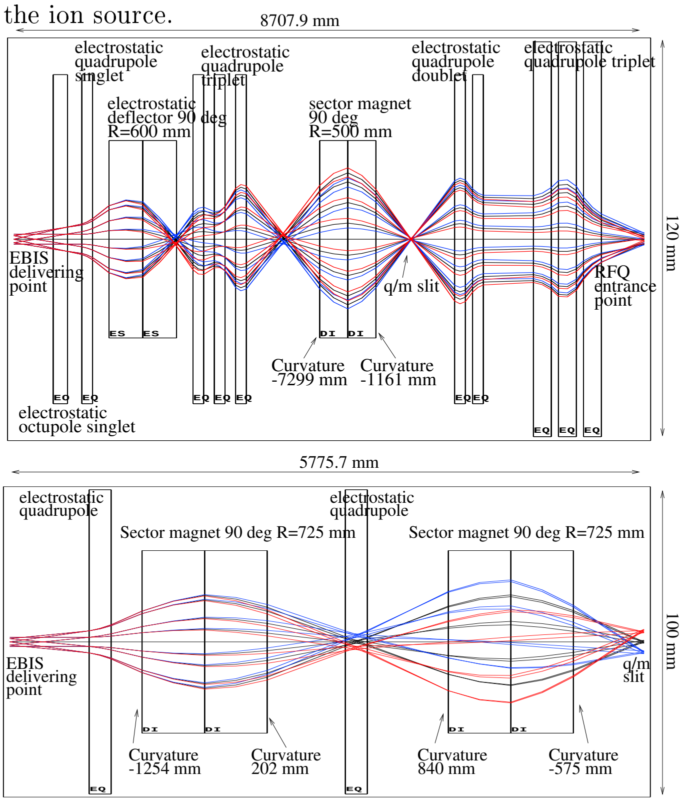

Fig. 1: *Upper figure*: Straight optical axis representation of the achromatic system. The entrance parameters are $x = 1.5\ mm$, $x' = 5\ mrad$, $\delta_M = 1/400$ and $\delta_E = 2.5 \times 10^{-3}$. With this values a δ_M of 1/645 can be resolved (third order). Note that for this system the energy dispersion is negligible up to $\delta_E = 0.01$. *Lower figure*: Representation of the pure magnetic system. The parameters are $x = 1.5\ mm$, $x' = 5\ mrad$, $\delta_M = 1/400$ and $\delta_E = 0$. Here a δ_M of 1/1350 can be resolved. Note that for this system the energy and mass dispersions are identical.

The online mass separator ISOLDE delivers radioactive singly charged ions which are cooled in a Penning trap. The ions are injected into an electron beam ion source (EBIS) where high charge states are breeded. Finally the highly charged ions are accelerated in a new combination of LINAC elements to energies up to 2.2 MeV/u.

As the number of delivered isotopes amounts to 10^4 and the number of residual gas ions coming out from the EBIS is approximately 100 times higher, an accurate q/m selection is necessary. The required resolving power was calculated by comparing the charge states of the residual gas ions $^\diamond$ and of the radioactive isotopes reached within 10-20 ms of stepwise ionization inside the EBIS. As EBIS parameters an electron beam energy, current and current density of 5 keV, 0.5 A and 250 A/cm^2 were used, respectively. Allowing q/m values between 0.20 and 0.34, all radioactive isotopes, except of ^{40}K, can be separated from the residual gas ions with a resolving power of 150.

The resolving power of a mass separator system is

$$R = \frac{< x|\delta_M >}{2x_f}\ , \tag{1}$$

where $< x|\delta_M >$ is the first order mass dispersion matrix element, δ_M the mass deviation, and $2x_f$ the final beam spot at the mass slit in the dispersive plane. The formula given above is only an approximation, since for higher order calculations the dispersion matrix element cannot be replaced by a combination of higher order matrix elements. To obtain a more realistic value the resolving power was redifined to be

$$R = \frac{f}{\delta_M} \qquad f = \frac{x_d}{2x_f}\ , \tag{2}$$

where x_d is the total mass dispersion. If $f < 1$ then δ_M cannot be resolved. In case of $f = 0$ the separation is possible and for $f > 1$ also smaller δ_M values are resolvable. With the third order transport matrix calculated by the COSY INFINITY code, the values for x_f and x_d can be calculated using the MONTECARLO method. The total aberration x_f is calculated as proposed in [3] as the sum of all aberrations. The total mass dispersion x_d is the sum of all δ_M dependend aberrations.

Using these rules series of calculations were done for an achromatic system. The result was that the resolving power of the mass separator system depends strongly on the ion beam emittance coming out of the EBIS. A resolving power of 150 could be ensured for emittances up to 40 π mm mrad and an energy spread of a few percent $^\diamond$. These are statistical rms values with 4 standard deviations. This criterion is necessary to ensure that an overlap between isotopes and residual gas of only 0.01% at the mass slit will occur, since the 4-σ rms value contains 99.99% of the particles. The usually used 2-σ rms emittance (95% of the beam) would be then 10 π mm mrad.

In case of higher EBIS emittances a pure magnetic system was designed, which has still the required resolving power for emittances 2.5 times higher than mentioned above. But in this case the energy spread δ_E may not exceed 0.2%, which could be achieved by the spill over ion extraction mode from the EBIS [4].

References

[1] M. Berz, Nucl. Instr. Meth. **A298** (1990) 473

[2] D. Habs *et al.*, Nucl. Instr. Meth. **B126** (1997) 218

[3] H. Matsuda, Nucl. Instr. Meth. **A258** (1987) 310

[4] M. Stockli, Accelerator-based atomic physics: techniques and applications, eds. S.M. Shafroth and J.C. Austin, 1997, chap 3

$^\diamond$As the solenoid of the EBIS has a warm bore O, N, C and Ar are the main part of the residual gas. For the calculation of the required resolving power all rare isotopes of these elements must be taken into account.

$^\diamond$The highest expected energy spread from the EBIS corresponds to the potential depression produced by the space charge of the electron beam and amounts to 0.5%.