Electron Beam Ion Traps

# Principles

Components: e-gun, solenoidal magnets, axial electrostatic trap, e-collector

Primary Purpose: Charge Breeds Ions through electron impact ionization

Ions can be injected, or generated with ambient gas in vacuum vessel. *Breeding injected beams allows high charge states (thus greater energy beam after acceleration) for exotic ions (i.e. neutron rich species only made via collision into targets like beryllium or liquid lithium).*

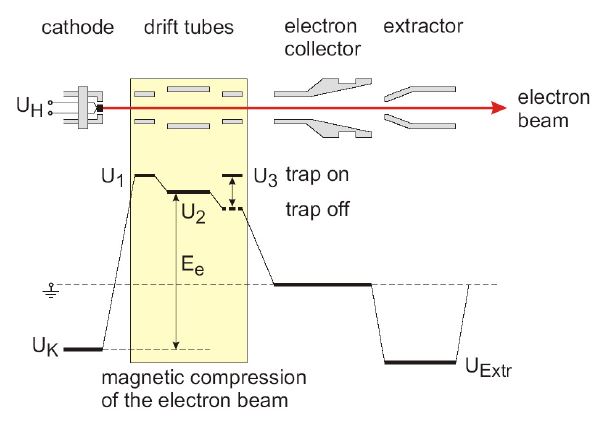
Radial confinement performed by the space-charge potential of the e-beam. *Note that the charge capacity of the trap is based on the negative charge of the electrons in the length of the trap, i.e. higher e-beam current means it can accept higher rates of injected ions. Higher current will also effect current density, therefore reducing charge breeding time and increase ability to reach higher charge states.*

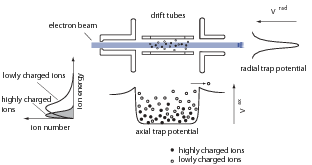
Electron beam is generated, compressed by B-field of solenoidal magnets through ion trapping region, and collected on the other side. *Compressing the beam will increase e-beam current density, allowing for generation of higher charge states and shorter breeding times. Note it also effectively lowers acceptance for injected ions.*

Cylindrical electrostatic plates centered on axis provide axial confinement. *The uniformity and depth of the electrostatic well within the trap can also be adjusted. Note that higher charge state ions are more strongly trapped, lower charged or lighter ions have an increased chance of leaking out over the barrier.*

Keep in mind that in order to accelerate the beam, the whole source, and all of its components must be kept on a voltage platform.

Keeping it all at 4K helps reduce pressure and contamination levels. It also allows for feasible (SC) magnet design for a longer trapping region.





# Key Parameters (based on ReA EBIT at NSCL/FRIB)

Magnetic Field: ~4T

E-Beam Current: <1.4A, but typically ran around 300mA for stable operation

…child-langmuir law:  (V anode, d dist cathode->anode) And perveance of our source ~0.85\*10-6 A/V^3/2

Current density: (@300mA) ~170A/cm^2

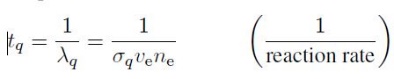
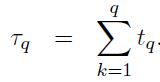
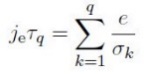
E-Beam energy: < 30 keV (e.g., Ne-like U82+) …Ee = e(U2 - UK + Ue);

Length of Trapping Region: ~0.64m

# Ion Production

Rates q=1: dno/dt = -λ\_1 n\_0, and to q: dnq/dt = λ\_q n\_(q-1) – λ\_(q+1) n\_q

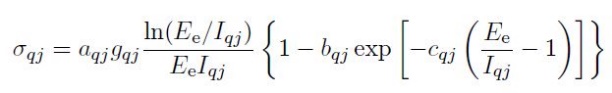
Reaction rate: σq = σqvene (reaction rate) [s^-1] …w/ σ ionization cross-section, electron velocity, & electron density

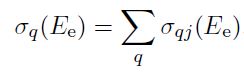
Characteristic time τ for ion production , , 

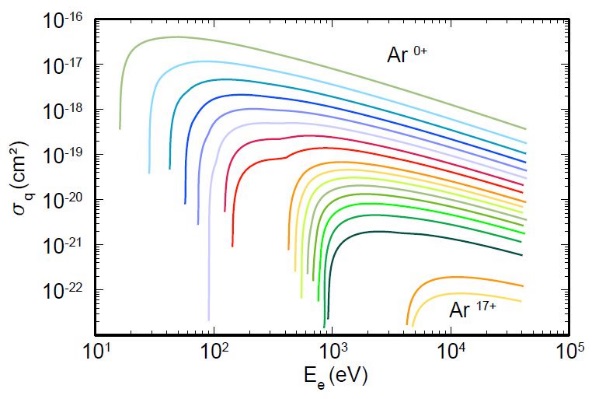
Require Ee > (2-3) x Ionization Potential of electron

And sufficiently high Ionization Factor

Impact Ionization

, with a = 4.5x10-14 cm^2 eV^2, and b=c=0 for highly charged ions

J index for subshell, I\_qj ionization potential, g\_qj occupation number.  (overall cross section for charge state).

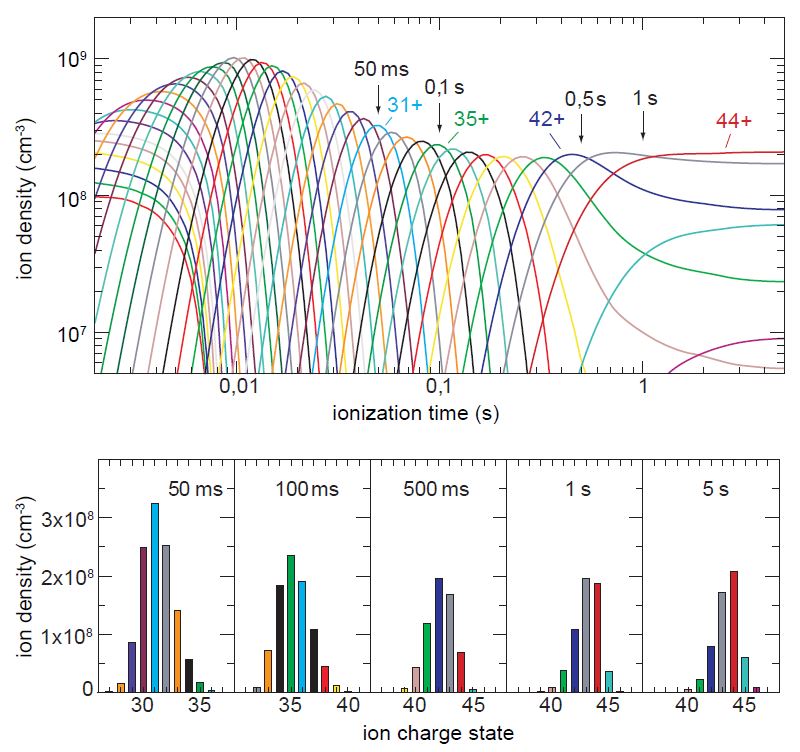


Charge Recombination

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Charge exchange is high, 10^-14-10^-15 [cm^-2] for exchange to neutrals. Cross section decreases with increasing ionization potential. Is dominant loss mechanism.

Example



# Mass Separator

Coordinate Transformation, emittance is conserved, energy and mass are transversely dispersed at focus locations for separating desired energy and mass.

Some numbers in ReA, 25% single charge state efficiency, 80% all charge states

(x,dE) = (x,dM) = 10 mm/%

**Resources**

Electron Beam Ion Soures, G. Zschornack, M.Schmidt and A.Thorn

First two years of on-line operation of the ReA EBIT charge breeder, A. Lapierre et.al.