Modeling Two-Charge State Helium Plasmas*

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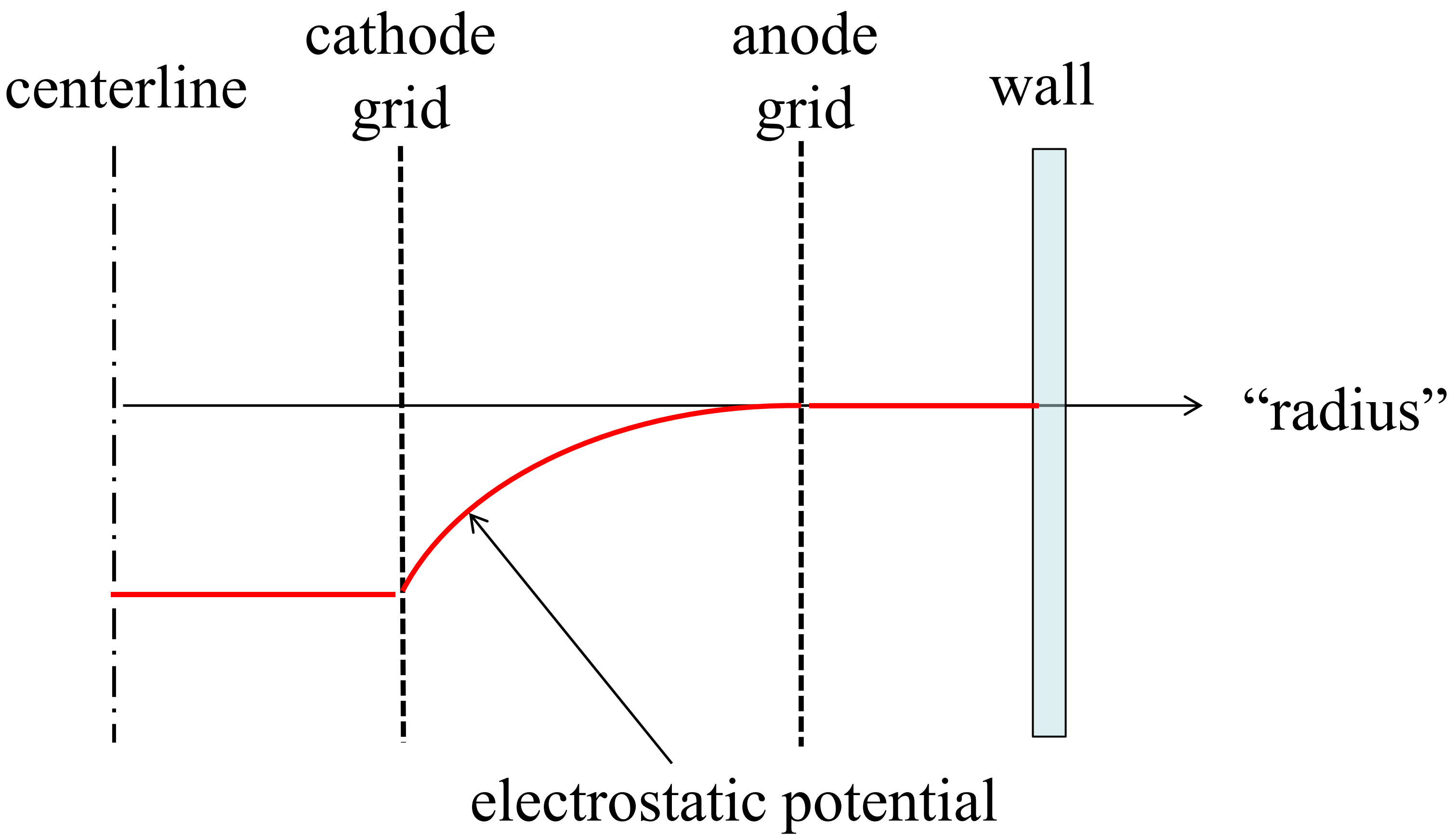
Why Model Helium?

- Greg Piefer used an IEC device to study ^3He-^3He fusion reactions.

- Studying Helium is a stepping stone on the way to modeling D-^3He IEC plasmas.

Geometry



geometry can be planar, cylindrical, or spherical

Basic Assumptions

- Background He gas
- Planar, cylindrical, or spherical symmetry
- Prescribed electrostatic potential profile
  - Child-Langmuir or vacuum potential in intergrid region
  - Flat in the cathode and source regions
- He^+ and He^{2+} Helium ions ions enter from the source region
- He^+ and He^{2+} are created in the intergrid and cathode regions by ion impact ionization, charge exchange, and stripping of fast ions colliding with the background He gas
- Interactions occur without momentum transfer between nuclei; daughter products travel at the same speed as parent
- Collisionless ion motion between interactions

Reactions between He^+ and He Atoms

- Single electron capture by He^+

  $He^+ + He \rightarrow He + He^+$

- Single ionization by He^+

  $He^+ + He \rightarrow He^+ + He^+ + e^-$

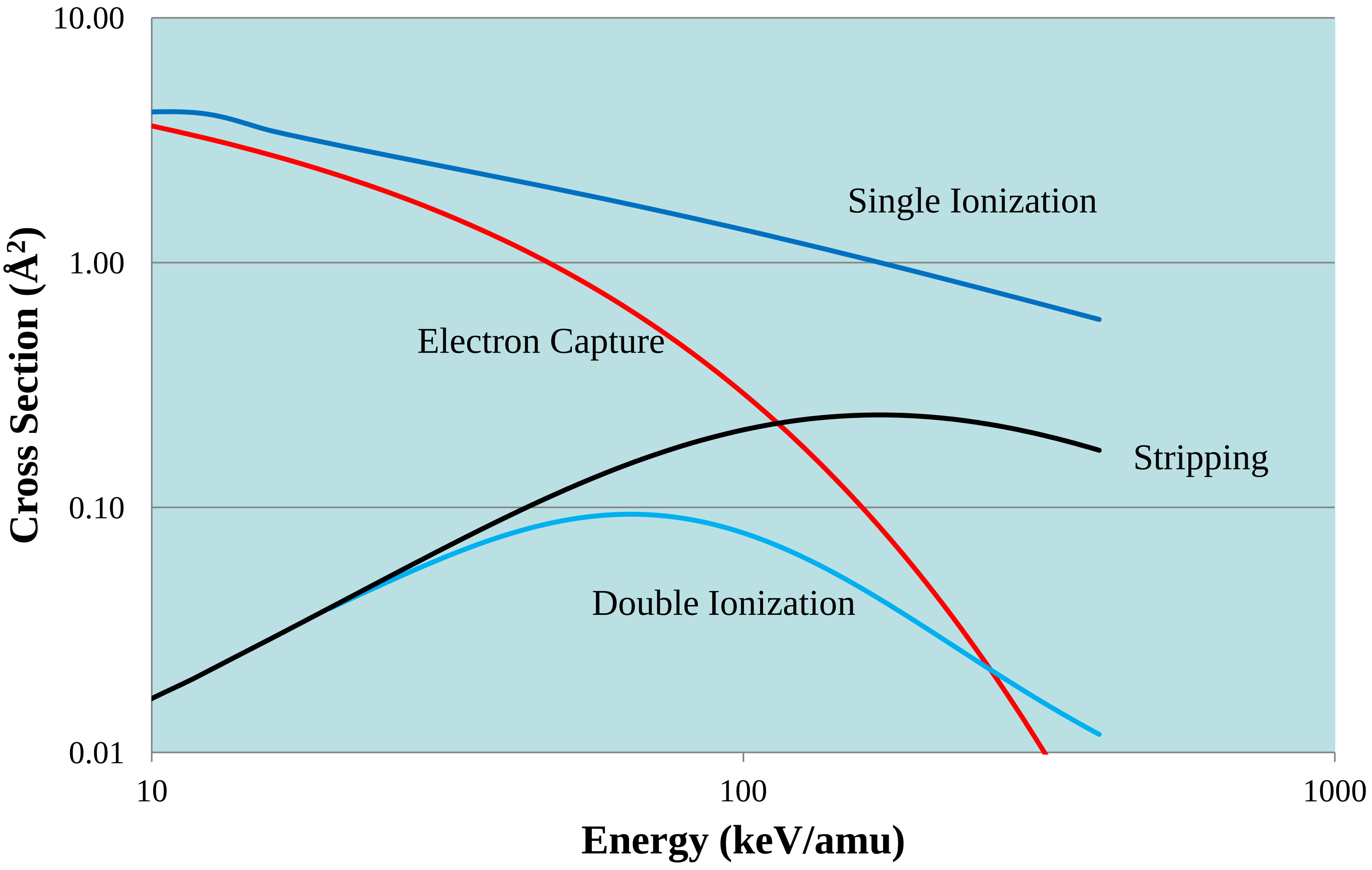
- Double ionization by He^+

  $He^+ + He \rightarrow He^+ + He^{2+} + 2e^-$

- Stripping of He^+

  $He^+ + He \rightarrow He^{2+} + He + e^-$

He^+ Cross Sections



Reactions between He^{2+} and He Atoms

- Single electron capture by He^{2+}

  $He^{2+} + He \rightarrow He^{+} + He^{+}$

- Double electron capture by He^{2+}

  $He^{2+} + He \rightarrow He + He^{2+}$

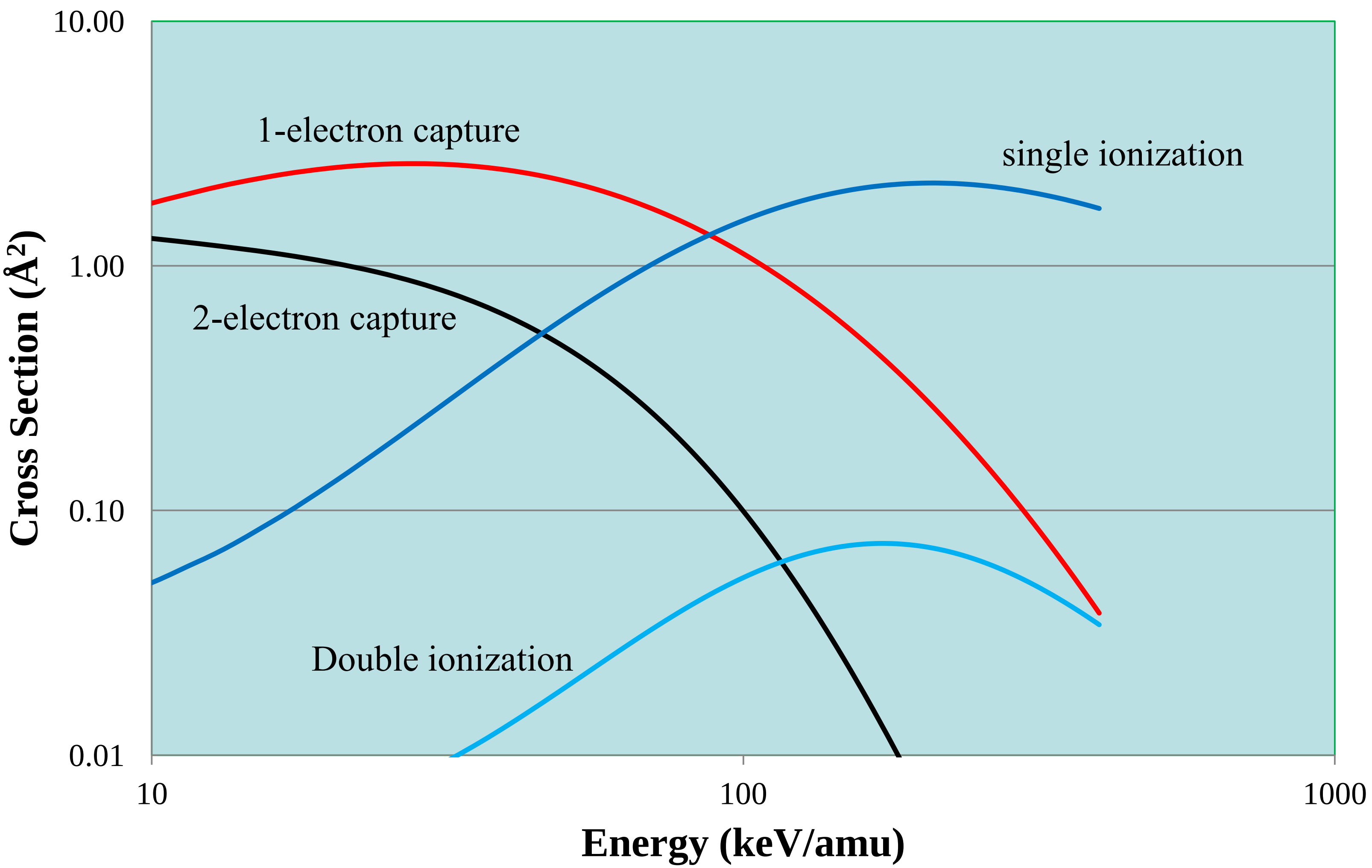
- Single ionization of He by He^{2+}

  $He^{2+} + He \rightarrow He^{2+} + He^{+} + e^{-}$

- Double ionization of He by He^{2+}

  $He^{2+} + He \rightarrow He^{2+} + He^{2+} + 2e^{-}$

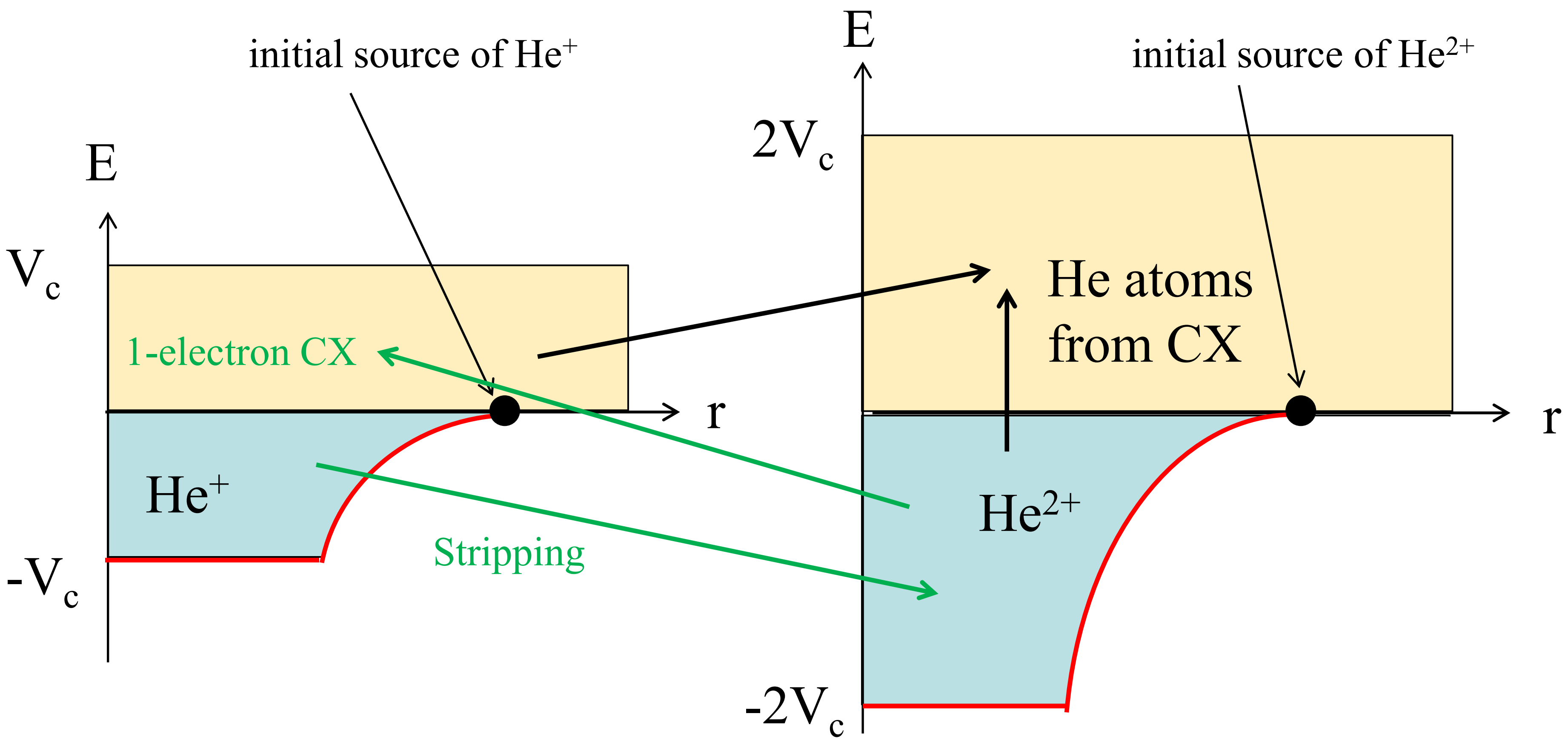
He^{2+} Cross Sections



Radius-Total Energy Phase Space Processes

He^{+} phase space

He^{2+}, He phase space



Definitions of Energy Spectra and Sources

$F_{zd}(r, E)\ \Delta E$ = current of species with charge z traveling in the "d" direction (inward, outward) at r and with total energy between E and $E+\Delta E$.

$S_{zd}(r, E)\ \Delta E\ \Delta r$ = number of ions created with charge z traveling in the "d" direction between r and $r+\Delta r$ and with total energy between E and $E+\Delta E$.

E = Total Energy = Kinetic + Potential Energy

Kinetic Equations to Solve

$$\frac{\partial F_{zd}\left(r,E\right)}{\partial r} = -n_g \sigma_z^{dest} F_{zd}\left(r,E\right) + S_{zd}\left(r,E\right)$$

$$S_{zd}\left(r,E'\right) = n_g \sum_w \sigma_{zw}\left(T\right) F_{wd}\left(r,E\right)$$

$E =$ total energy of the parent ion

$T = E - e\phi\left(r\right) =$ kinetic energy of parent ion

$E' =$ total energy of the daughter ion

Kinetic Equation to Solve - 2

- The equations are solved numerically using the integrating factor to put the solution in the form

$$F_{zd}\left(r,E\right)=F_{zd}\left(s,E\right)\exp\left(-\int_{s}^{r}n_{g}\sigma_{z}^{dest}dr'\right)+\int_{s}^{r}S_{zd}\left(r',E\right)\exp\left(-\int_{r'}^{r}n_{g}\sigma_{z}^{dest}dr''\right)dr'$$

Solution Technique

Since the sources depend on the F's, which you get by integrating over the sources, an iterative solution is necessary. We start with a delta function source at the anode streaming in with zero total energy; these represent ions produced in the filament-assisted discharge in the source region.

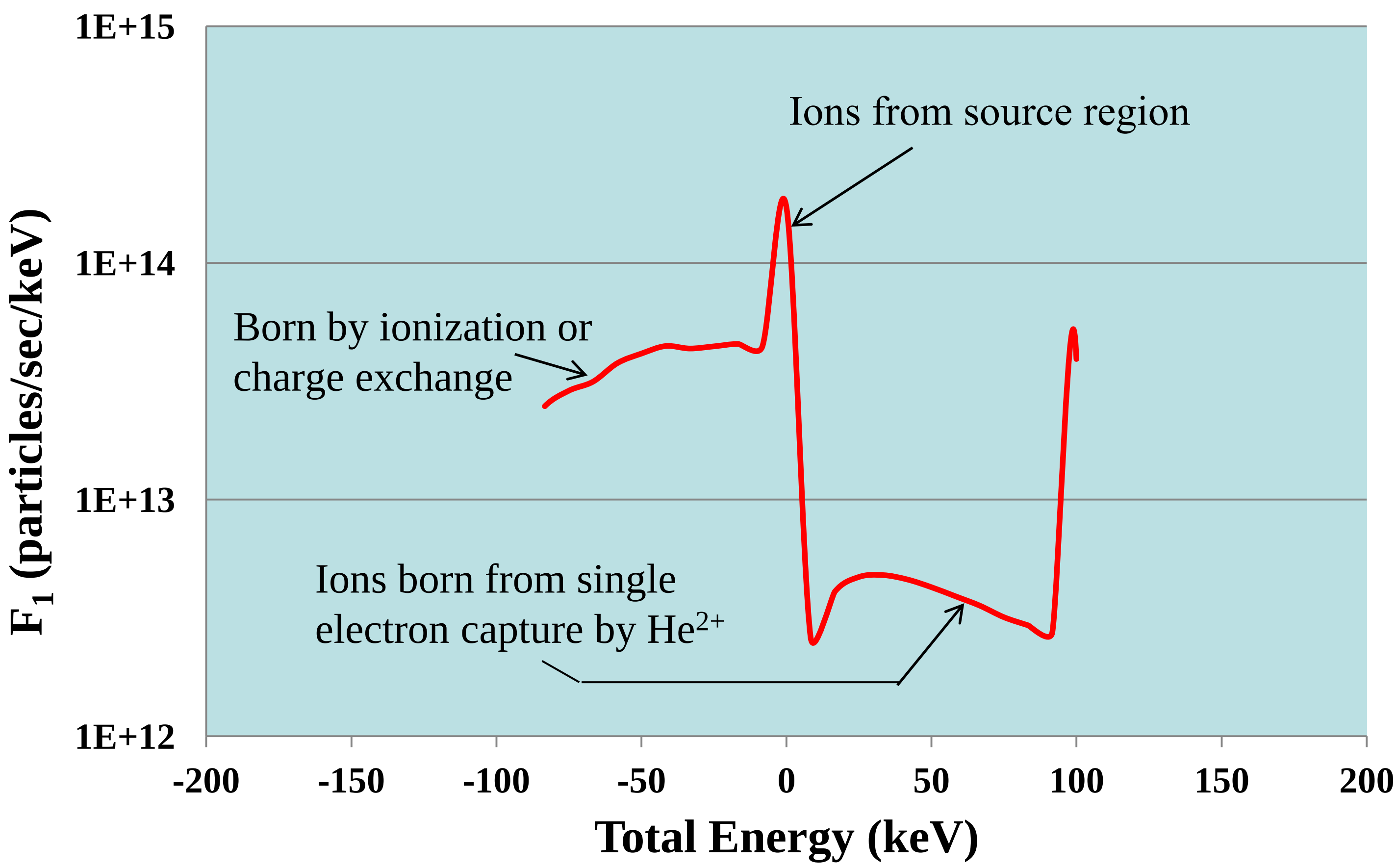
We then iterate until convergence of

$$\int \sum_{z,d} \sqrt{F_{zd}\left(r, E\right)}\, dr\, dE$$

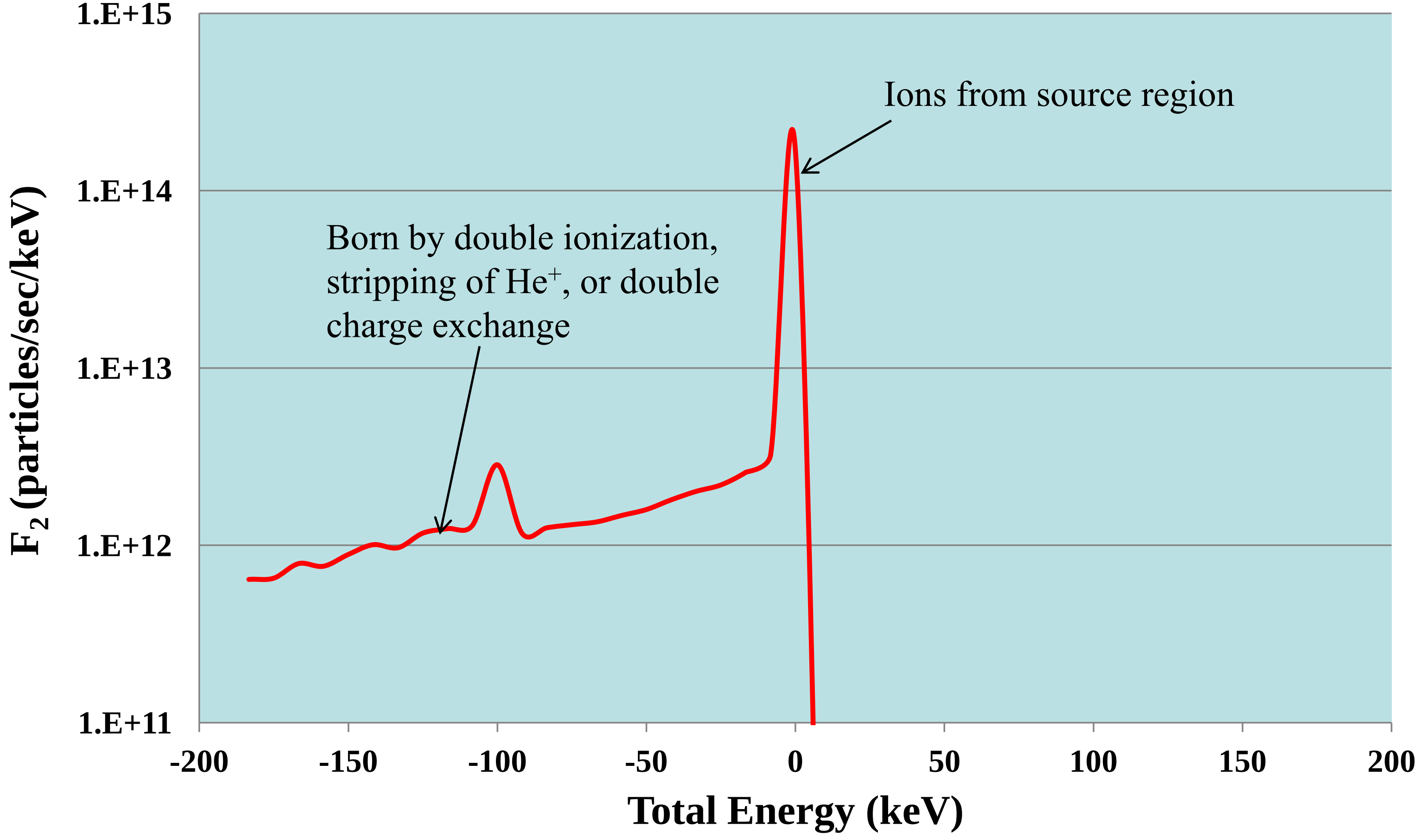
Sample Calculation

- Spherical geometry
- Cathode radius = 10 cm
- Anode radius = 20 cm
- Cathode potential = -100 kV
- ^{4}He gas at 3 mTorr
- Source region plasma = 50% He^{+}, 50% He^{2+}

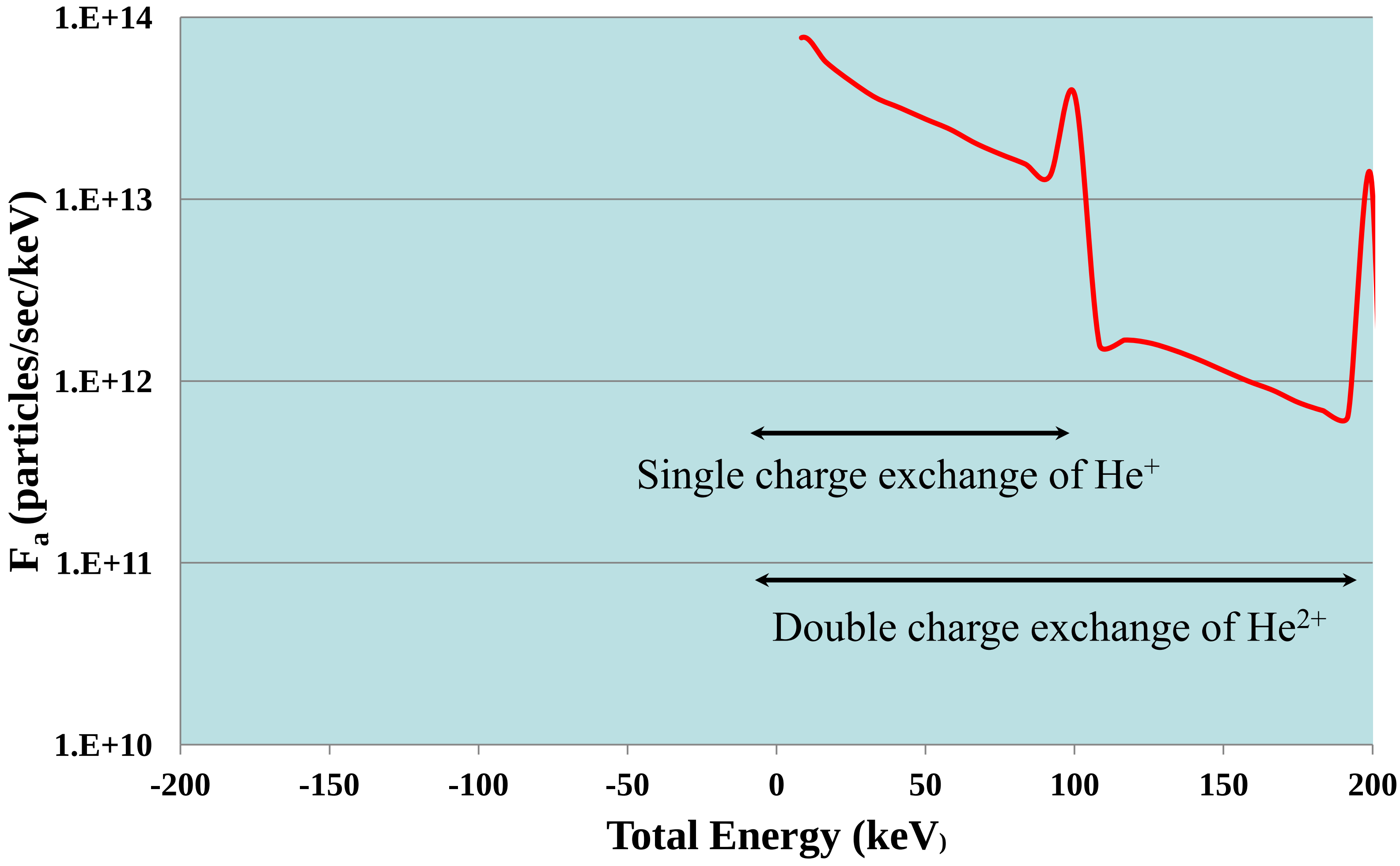
He^+ Energy Spectra at the Center



He^{2+} Energy Spectra at the Center



He Atom Energy Spectra at the Center



Summary and Conclusions

- A code to model Helium discharges is being developed.
- It is based on a radius-energy phase space.
- Both He^{+} and He^{2+} charge states are included.
- The following reactions are included:
  - Single electron capture by He^{+} and He^{2+}
  - Double electron capture by He^{2+}
  - Single ionization by He^{+} and He^{2+}
  - Double ionization by He^{+} and He^{2+}
  - Stripping of He^{+}

Future Work and Possible Extensions

- Use a hybrid approach – model slow daughter ions with a Volterra equation and fast daughter ions with the (r, E) phase space formalism. This may lead to faster convergence of the iterative procedure.
- Include fast neutral atom reactions with the background gas in the (r, E) formalism.
- The hybrid approach can also be used with molecular deuterium ions in VICTER.

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Thank you for your attention.