Modeling for charge transfer of highly charged Xe ions produced by laser produced plasma

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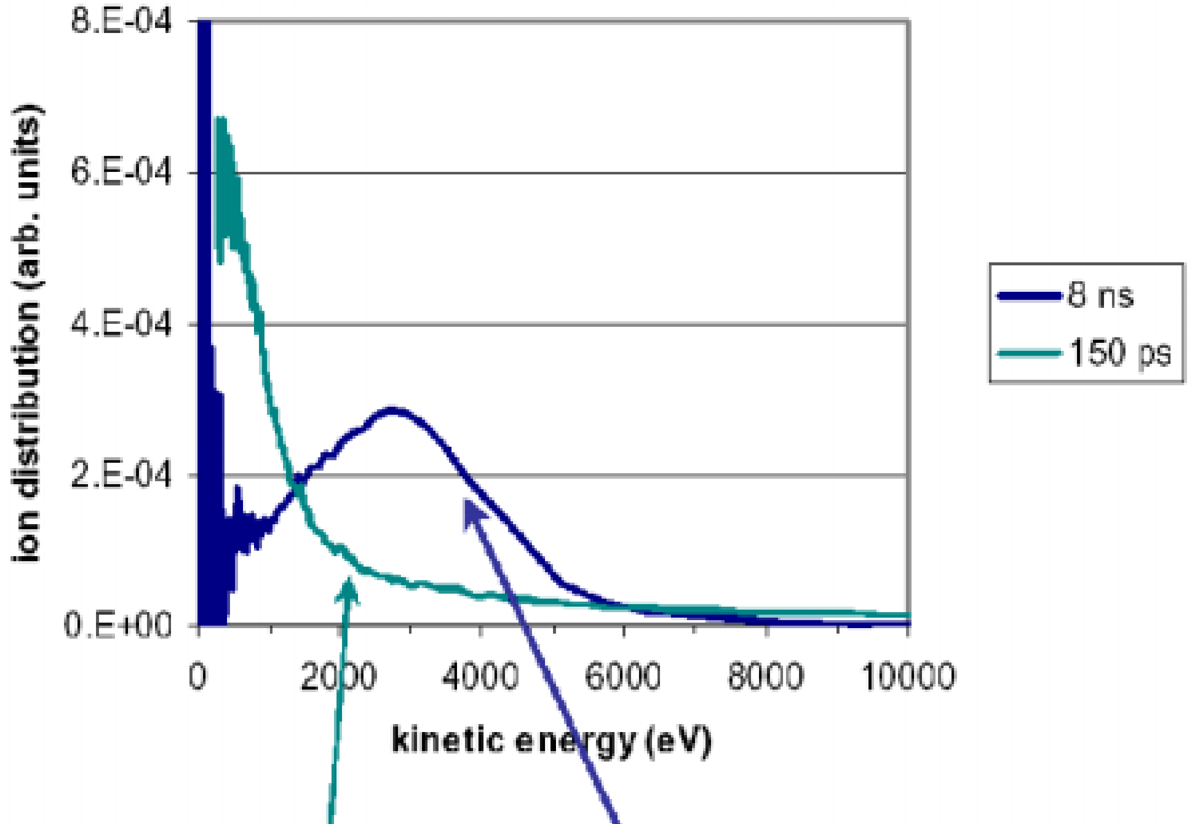
Abstract

Condenser erosion, caused by high energy ions, is one of the current issues EUV source. The charge and energy distribution of Xe ions was measured by EUVA and keV-order energetic ions were found to be formed in Xe laser produced plasma. The charge distribution shows a peak for doubly charged ions, and the population of highly charged ions monotonically decreases. Since highly charge ions around Xe^{10+} should be formed in the EUV optimized plasma, observed charge distribution strongly suggests that a charge transfer reaction occurs in the Xe LPP chamber. If that is true high energy neutrals are formed through charge transfer reactions. Rate equations for each charge transfer reaction were solved using a numerical calculations and the change of charge state distribution was calculated. Initial charge distribution, which have a peak at 10+, was assumed based on the plasma modeling. Dependence of charge transfer cross section was treated n^b, where n is charge number and b was set near unit based on the theoretical model. Finally, calculated charge distribution agreed well with the experimental data. Based on these calculations, fast neutrals of which amount is same order or larger with charged ions should be formed through the charge transfer reaction.
This work was supported by the New Energy and Industrial Technology Development Organization (NEDO), Japan.

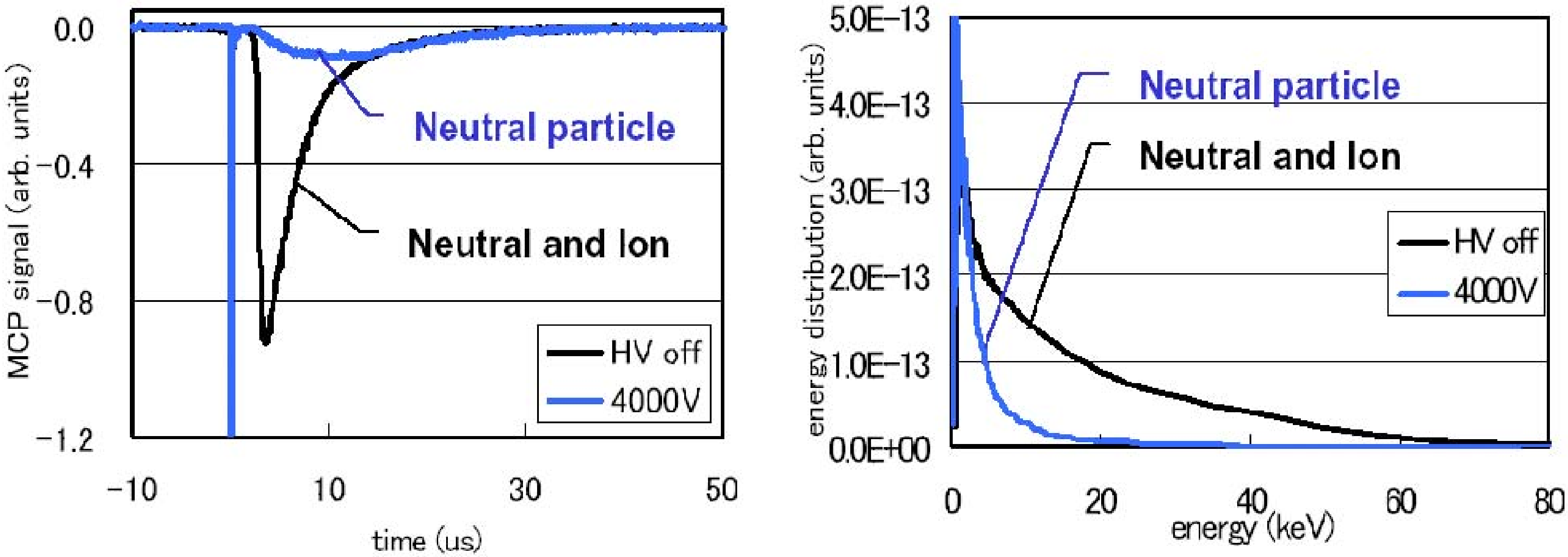
TOF measurement of Xe plasma



Xenon Ion Energy : **0.5 keV peak.** **3 keV peak.**
7 keV mean **3 keV mean**

Laser Energy=200mJ,
Pulse Duration= **150 ps (fwhm)** **8 ns (fwhm)**
Intensity = **4x 10^{13} W/cm^2** **7.5x10^{11} W/cm^2**

Separation of neutral particle from ion

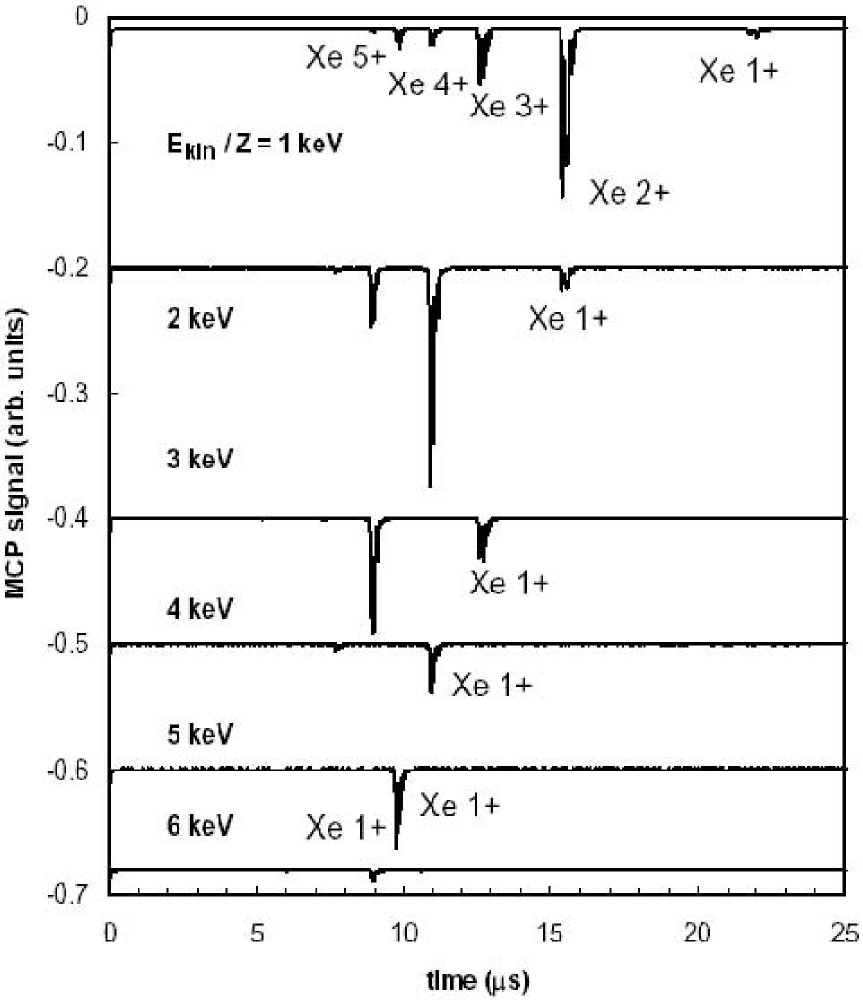


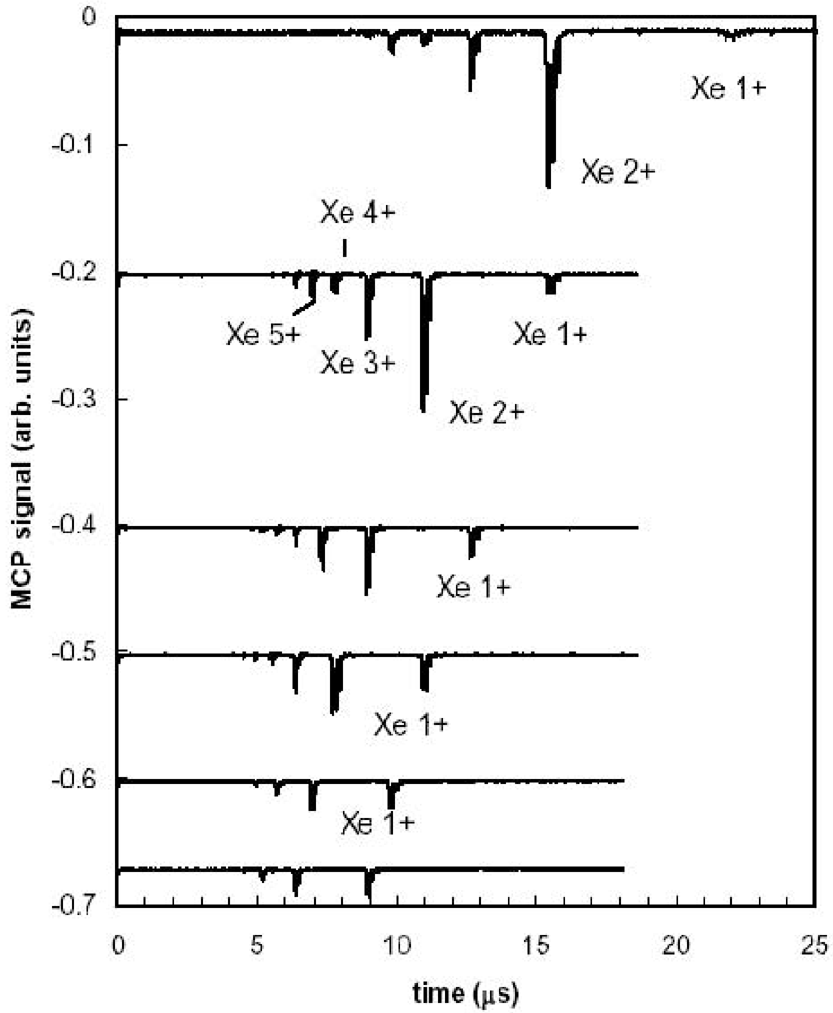
YAG Laser Energy=	**160 mJ**
Pulse Duration=	**150 ps (fwhm)**
Intensity =	**3×10^{13} W/cm^2**
Target =	**Liquid Xe Jet**

ESA TOF signal dependence on laser pulse duration

Laser energy: 100mJ

Pulse duration: 8 ns, Intensity: 3.8×10^{11} W/cm² 150 ps, 2×10^{13} W/cm²





Simulation model

1. To consider charge transfer reaction of fast Xe^{n+} ion with background Xe Gas

$$Xe^{n} + Xe \rightarrow Xe^{n-1} + Xe^{+*}$$

Reaction rate constant of multicharged ion is quite different from single charged ions.

2. Produced Xe^{+*} ions are ignored since they cannot enter in detector

$$Xe^{n+1} \xrightarrow{k_{n+1}} Xe^{n} \xrightarrow{k_{n}} Xe^{n-1}$$

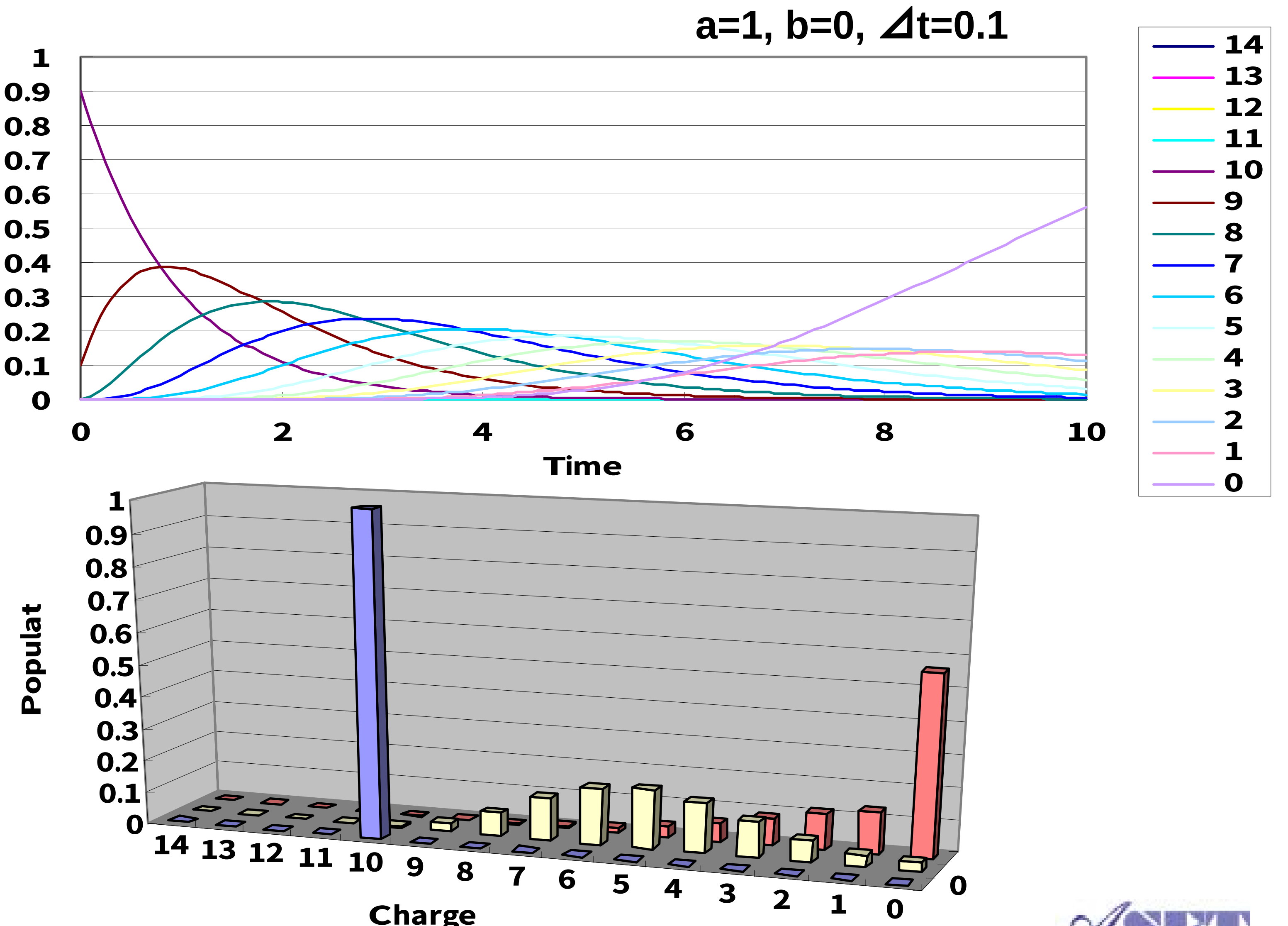
$$d[Xe^{n}]/dt \rightarrow k_{n+1}[Xe^{n+1}] - k_{n}[Xe^{n+1}]$$

3. Charge dependence of Rate constant was taken in following formula

$$k_n = a*n\text{^}b_n$$

Constant b_n is typically ～1 or little bit grater for n>2.
Rate constant for n=1 is Larger than n>1.

Time dependence of charge distribution when only Xe^{10+} is assumed as initially produced ion (delta function)



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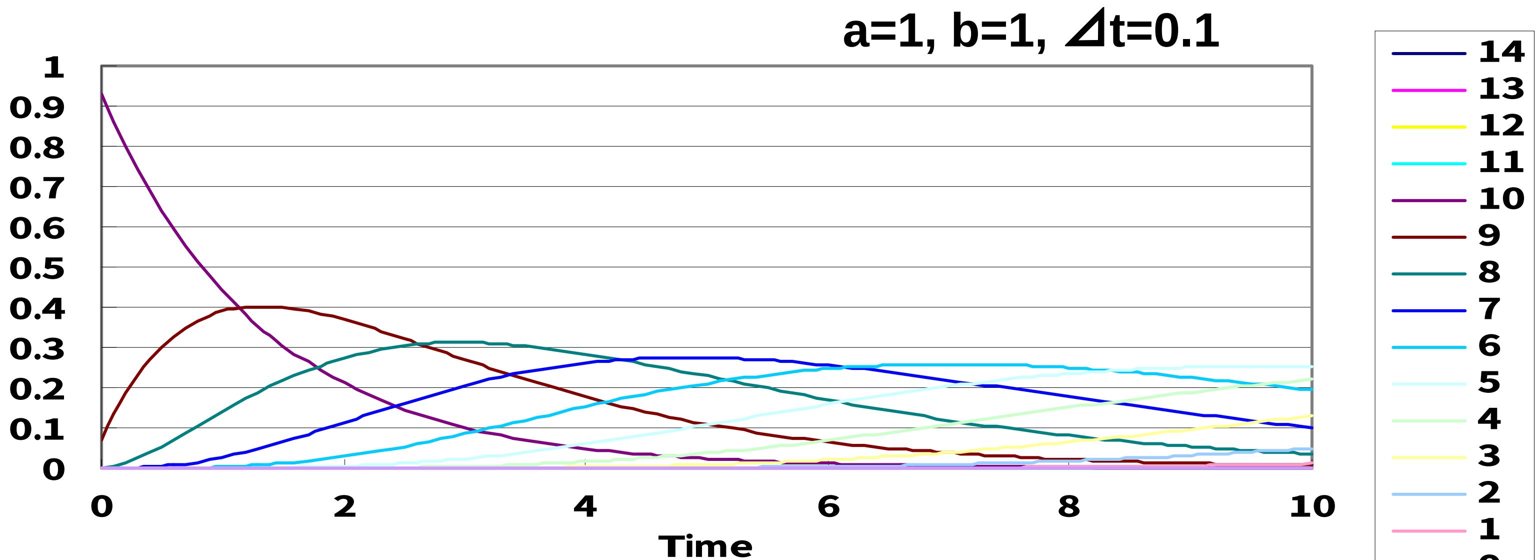
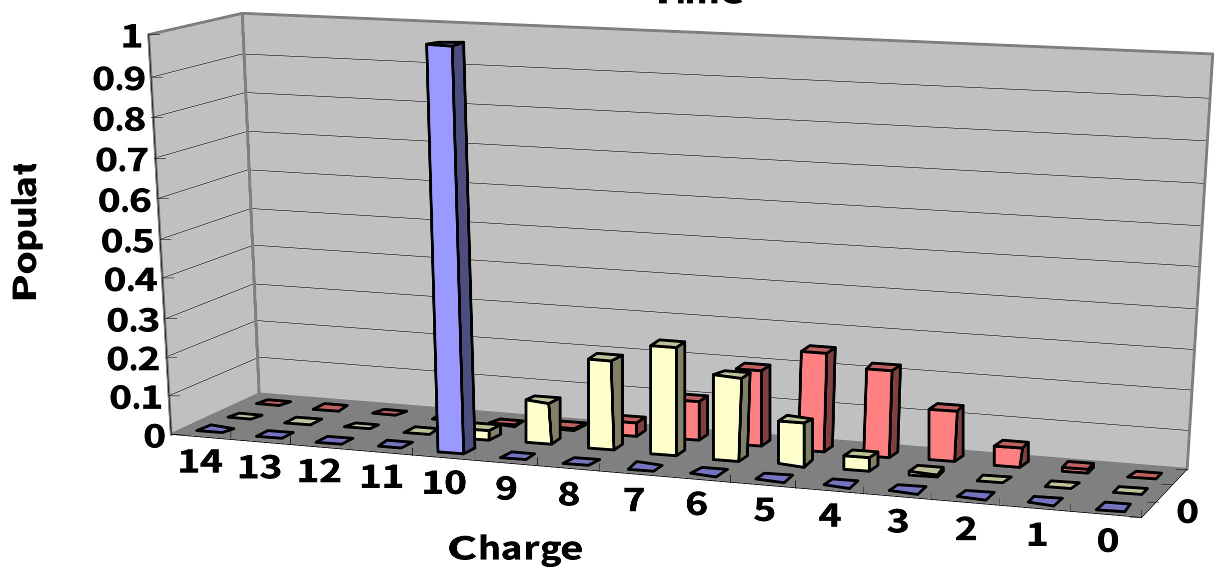
Time dependence of charge distribution when only Xe^{10+} is assumed as initially produced ion (delta function)





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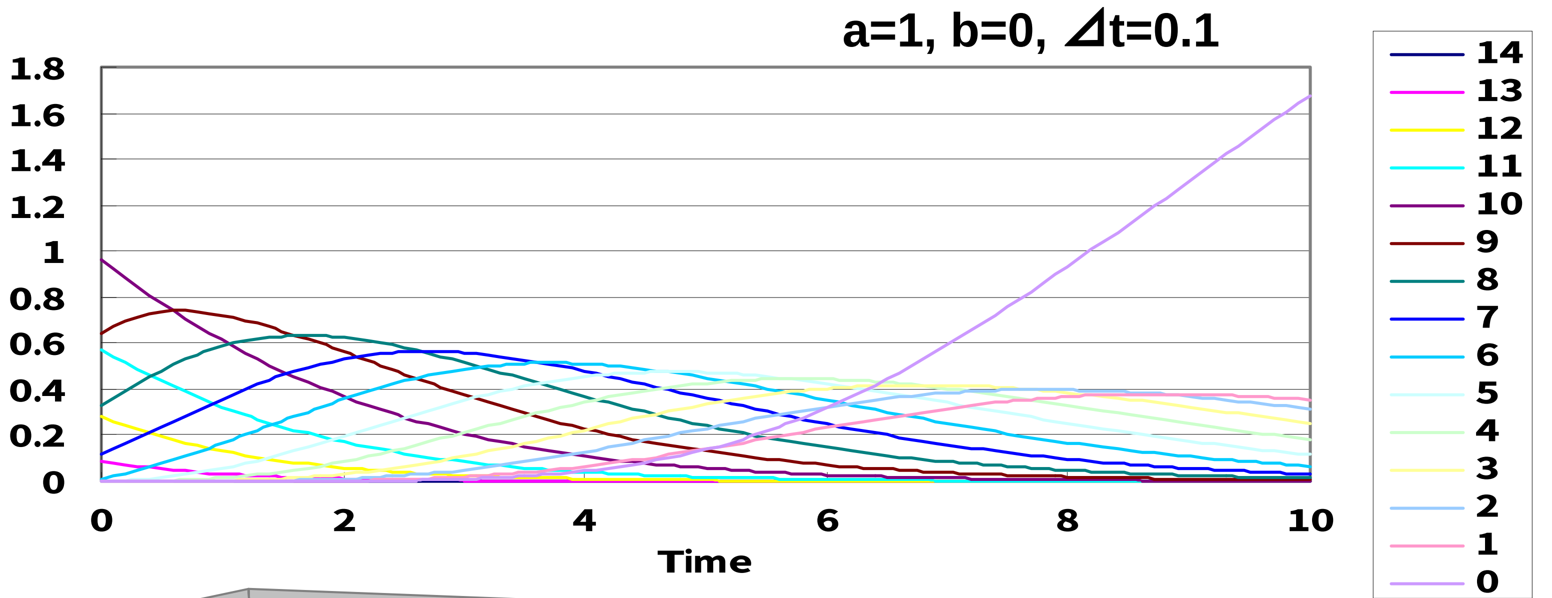
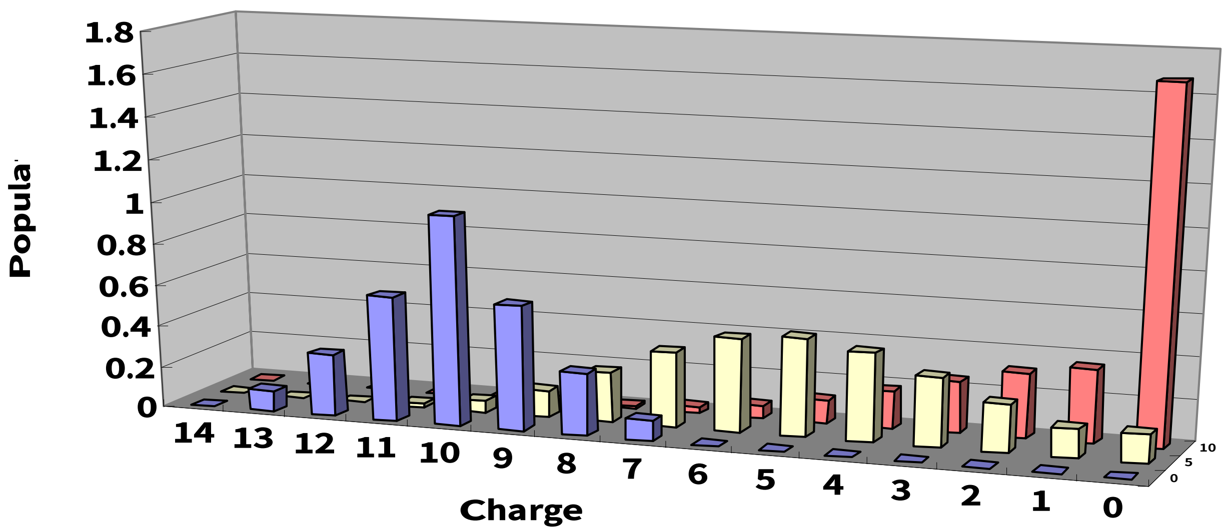
Time dependence of charge distribution when charge distribution was assumed





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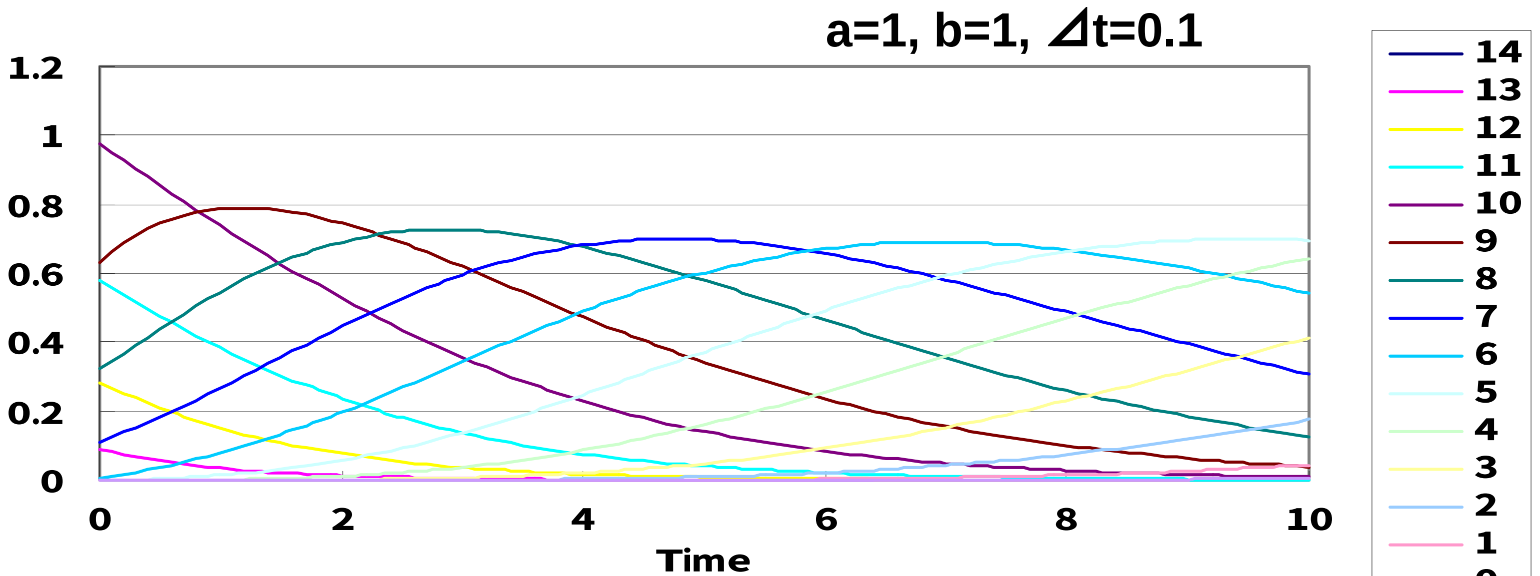
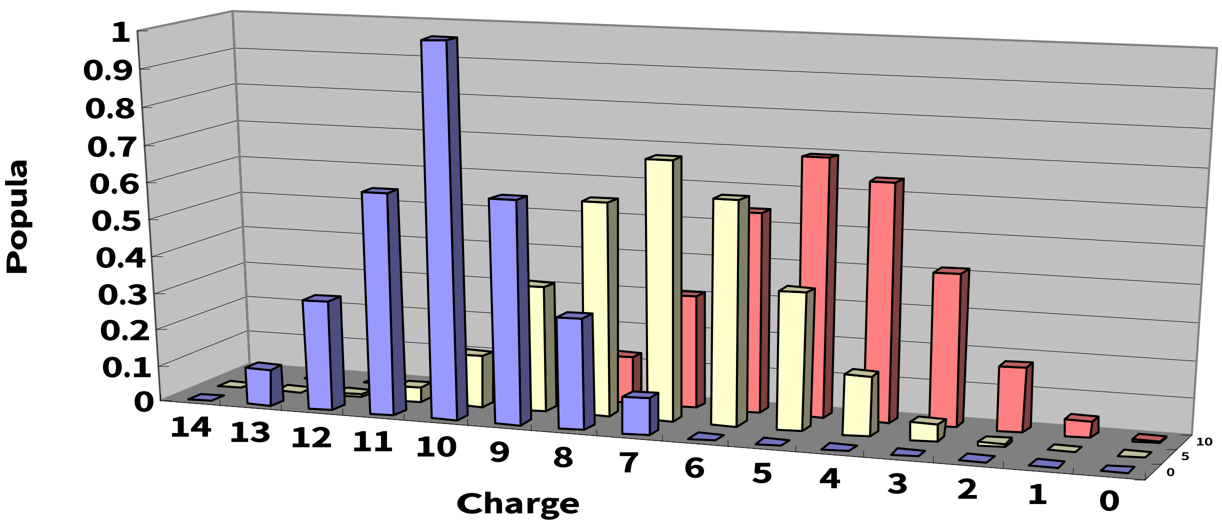
Time dependence of charge distribution when charge distribution was assumed





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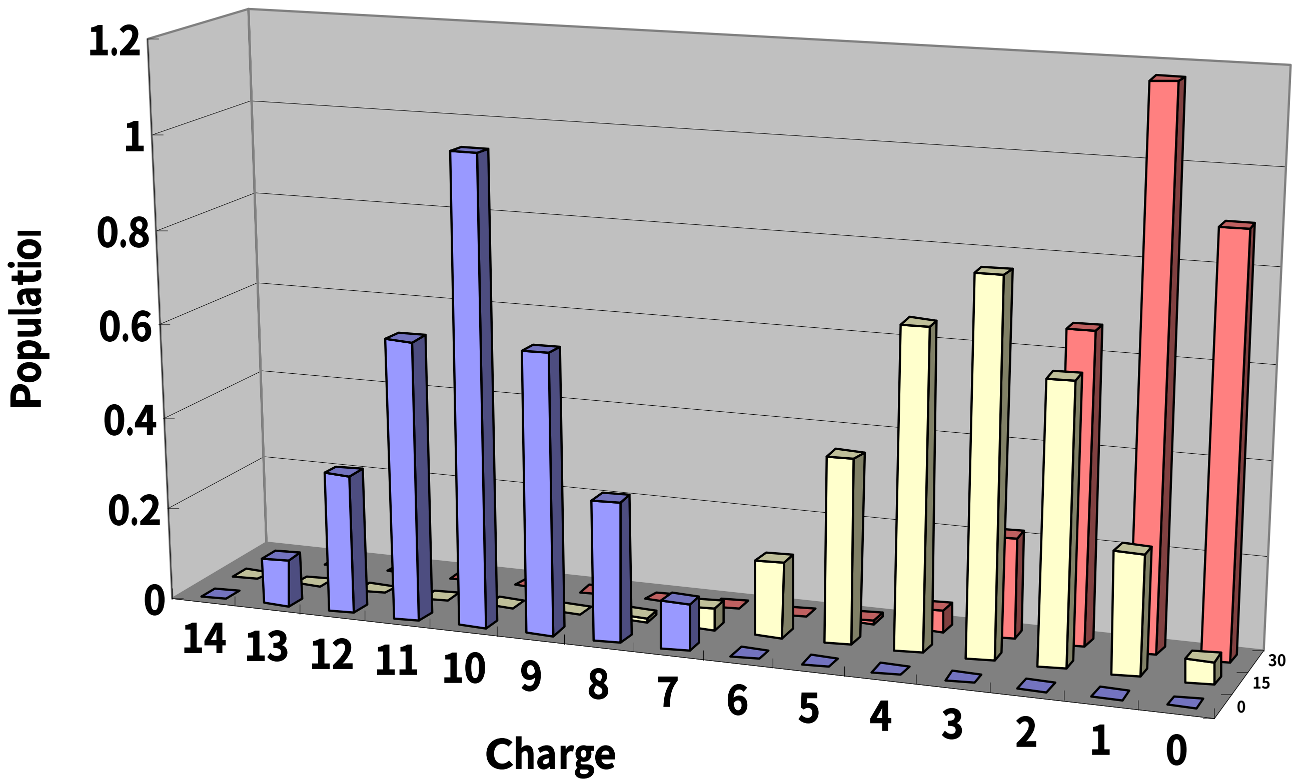
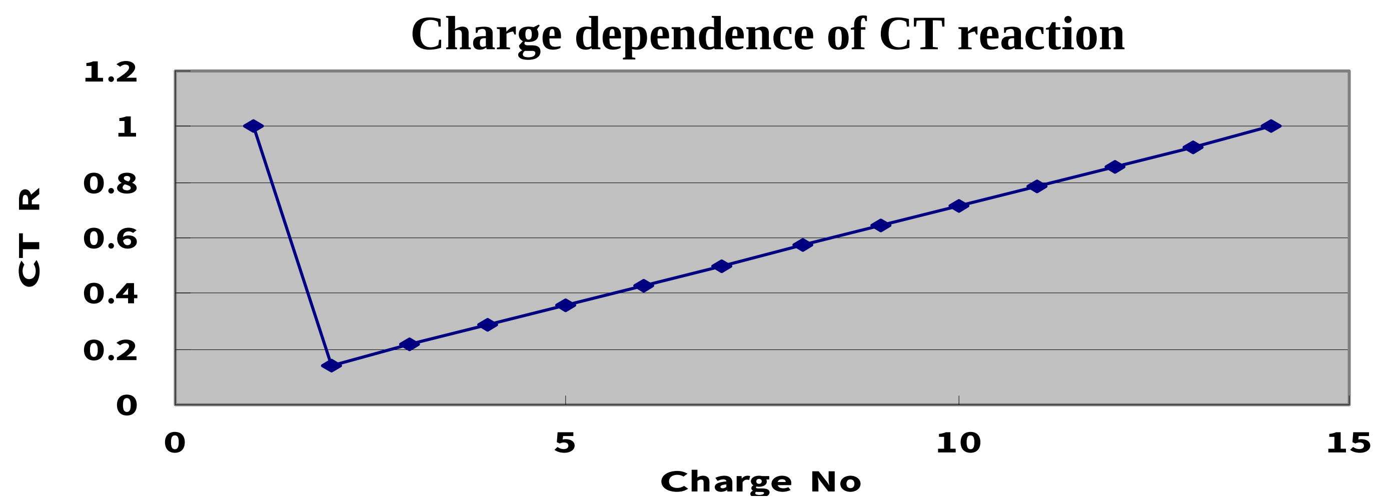
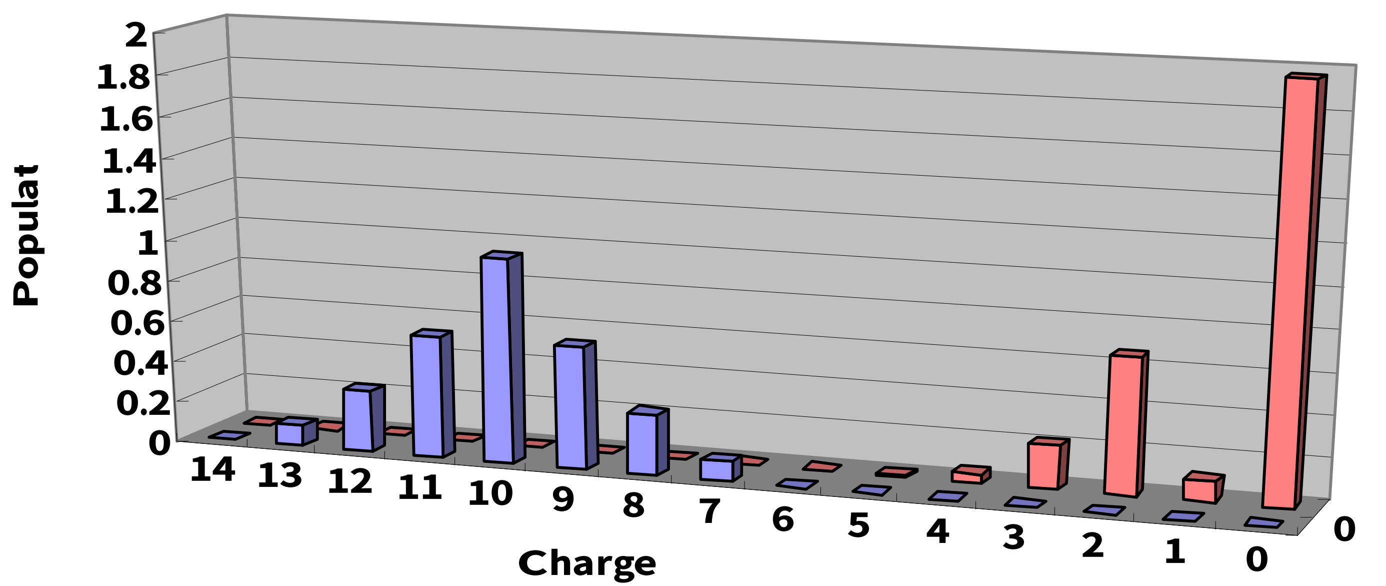
Experimentally observed charge distribution cannot be explained when singular distribution for 1⁺ ion is not considered

a=1, b=1, ⊿t=0.3



Experimentally observed charge distribution can be explained when resonance CT is considered for n=1





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Summary

- Experimentally observed charge distribution can be explained by considering the CT reaction of multicharged ions with background Xe gas based on the following models
  - Resonant reaction rate for single charged ion (n=1) is larger than non-resonant reaction rate for multicharged ions (n>1)
  - CT reaction rate for multicharged ions is proportional to the charge number
- Based on this modeling, large number of neutral species are suggested to be generated through CT reaction with background Xe gas.