Charge Exchange Processes for Highly Charged Ion - Atom, Molecule Collisions

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Charge Exchange Processes

- Highly charged ions (HCI's) exist as an impurity ion in high temperature plasma.
- Charge exchange cross sections of HCI's are very large ($\sim 10^{-14} cm^2$)
- Charge Exchange Processes of HCI's are very important for understanding the edge plasma behavior in thermonuclear plasma
- Charge Exchange Spectroscopy (CXS) is one of the most important plasma diagnostic in LHD

Collision Processes

$$A^{q+} + B \Rightarrow AB^{q+} \Rightarrow A^{(q-j)+**---} + B^{j+}$$

quasi-molecule

$$\Rightarrow A^{(q-i)+} + (j-i)e^{-} + n(h\ )$$

A^{q+}: Highly Charged Ion, B: Target Atom, e^{-}: Ejected Electron,

i-electron capture after j-electron transfer

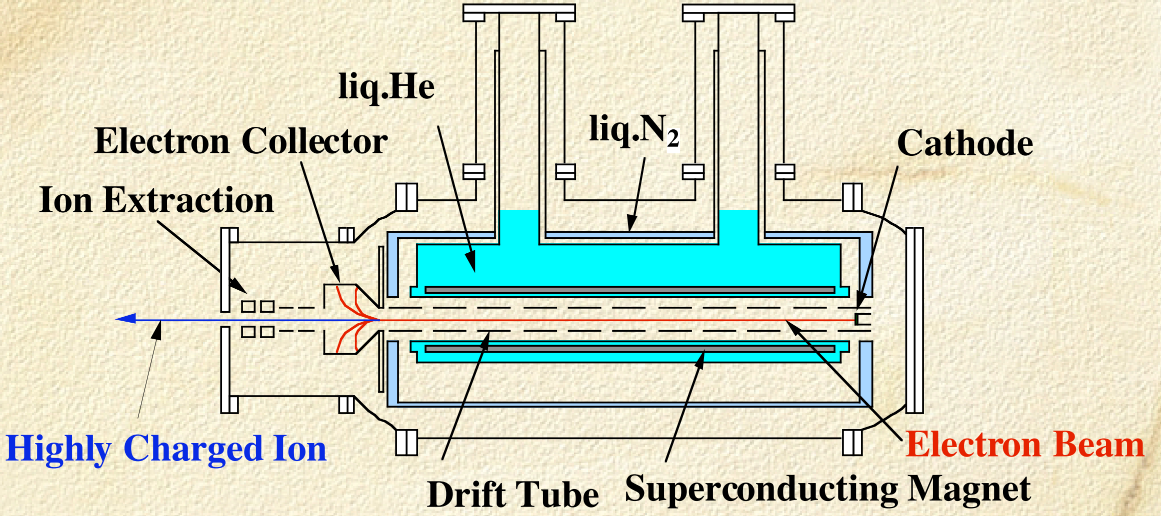
This collision process and decay process are greatly concerned with the cooling of the plasma. We paid attention to the following thing, and did research by using the superconductivity Electron Beam Ion Source (EBIS).

- How is an electron transfered?
- How large is transfer cross section?
- How is the charge dependence of the transfer cross section?

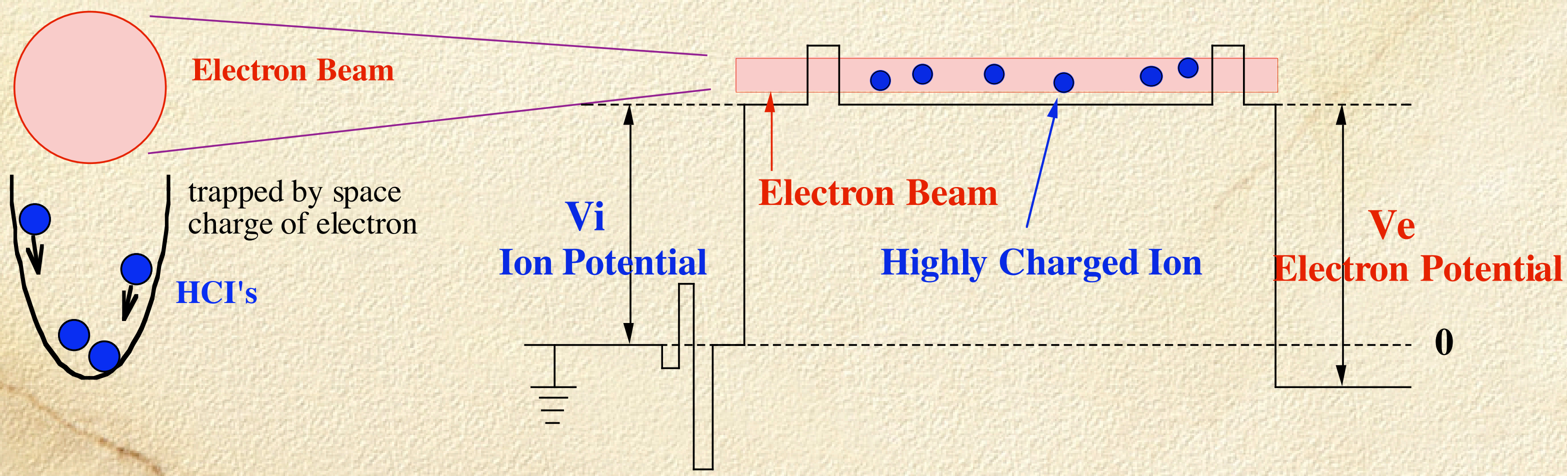
Highly Charged Ion Source

EBIS

Electron energy : ~5keV
Ion energy : 1.5keV
Magnetic field : 2T
Electron current : ~10mA



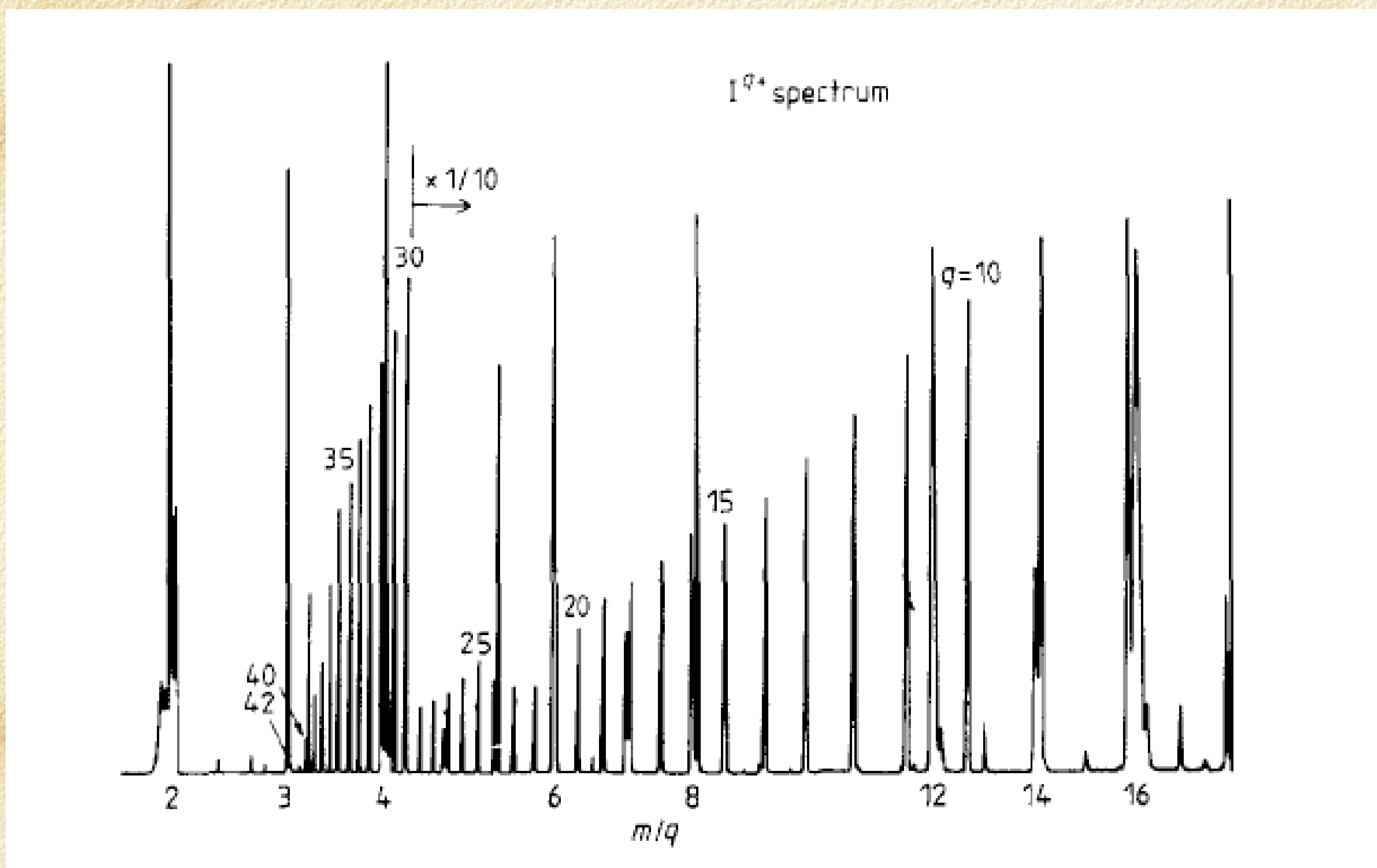
Electron Beam Ion Source (EBIS)



Electric potential in ion source

Mass Spectrum of EBIS

$_{53}I^{127}$



Experiments and Results

1.Energy Gain Spectroscopy $\longrightarrow$ Energy level of electron transfer

We measure the kinematic energy Ei+ΔQ(eV)
by energy analysis of the scattered ion.

e.g. one-electron transfer processes

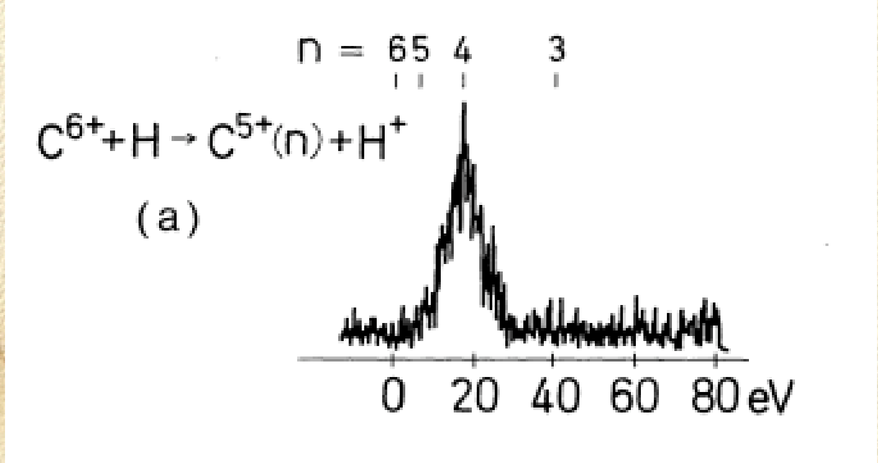
$$C^{6+} + H \longrightarrow C^{5+*}(nl) + H^{+}$$

Ei Ei+ΔQ

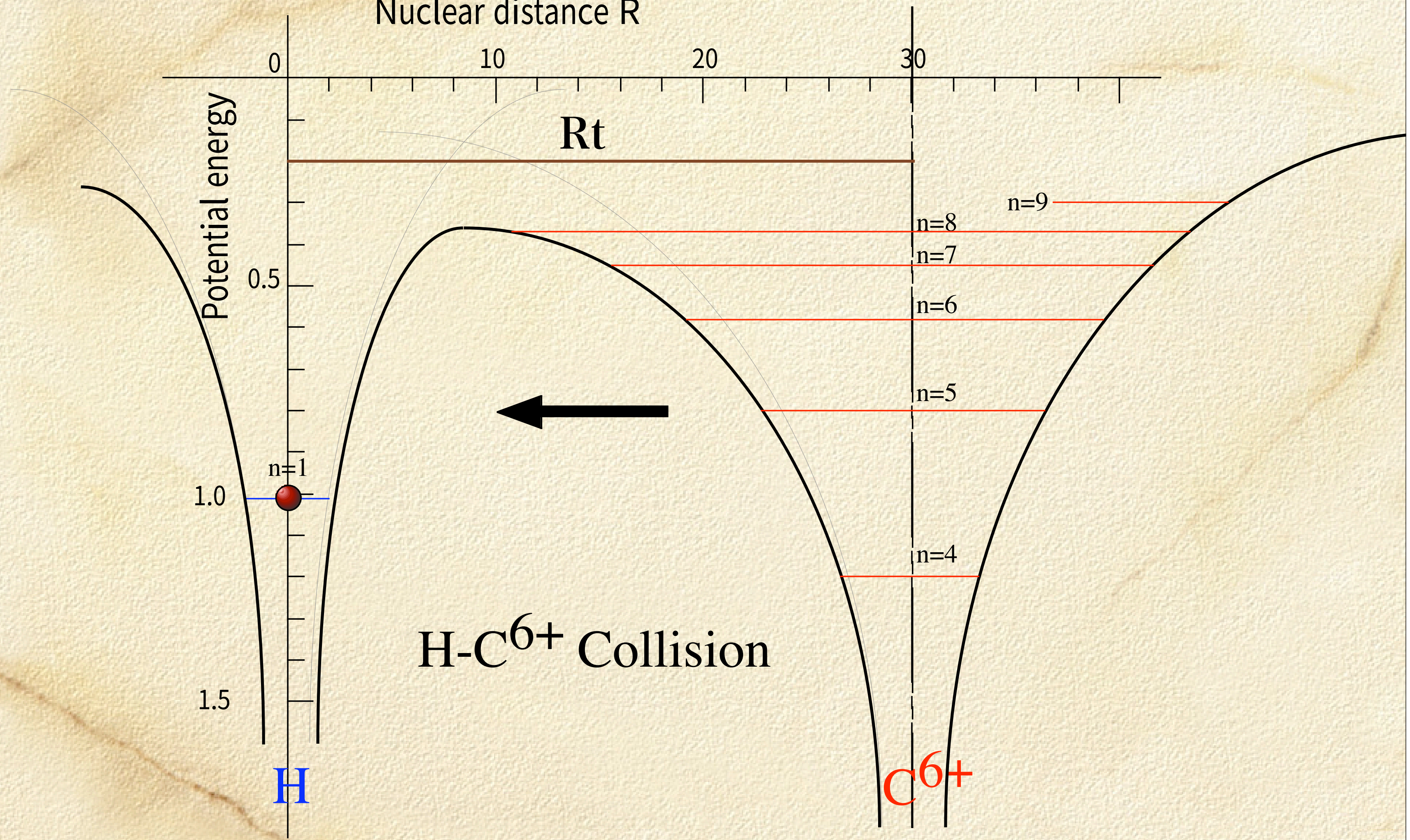
Ei: incidence energy

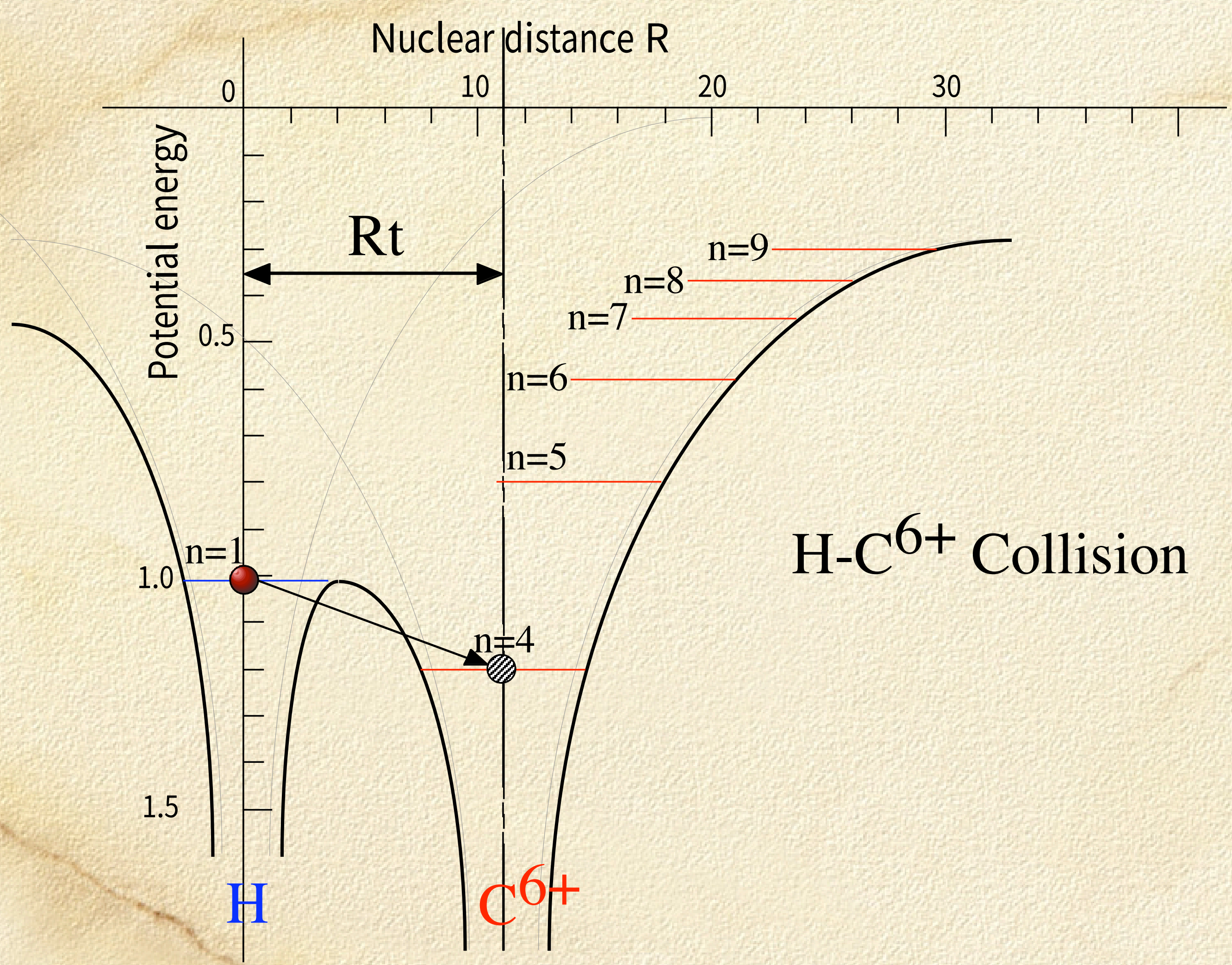
ΔQ:Energy Gain

n: principal quantum number



Classical over barrier model




Nuclear distance R
0
10
20
30
Potential energy
0.5
1.0
1.5
Rt
n=9
n=8
n=7
n=6
n=5
n=1
n=4
H
C6+
H-C6+ Collision

Experiments and Results

2.Initial Growth-Rate Method

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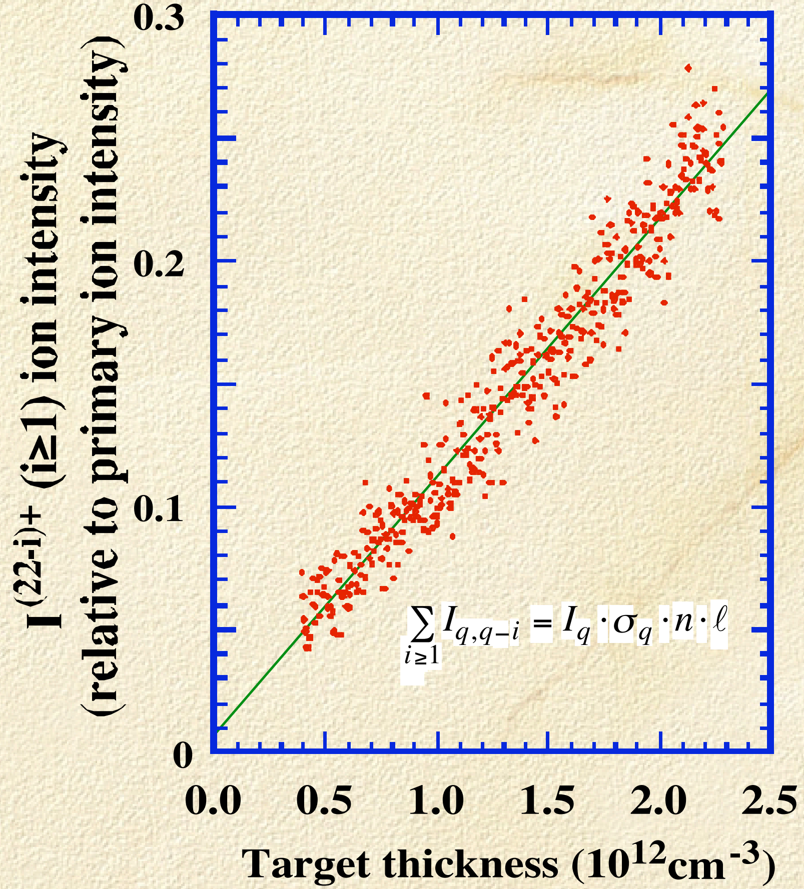
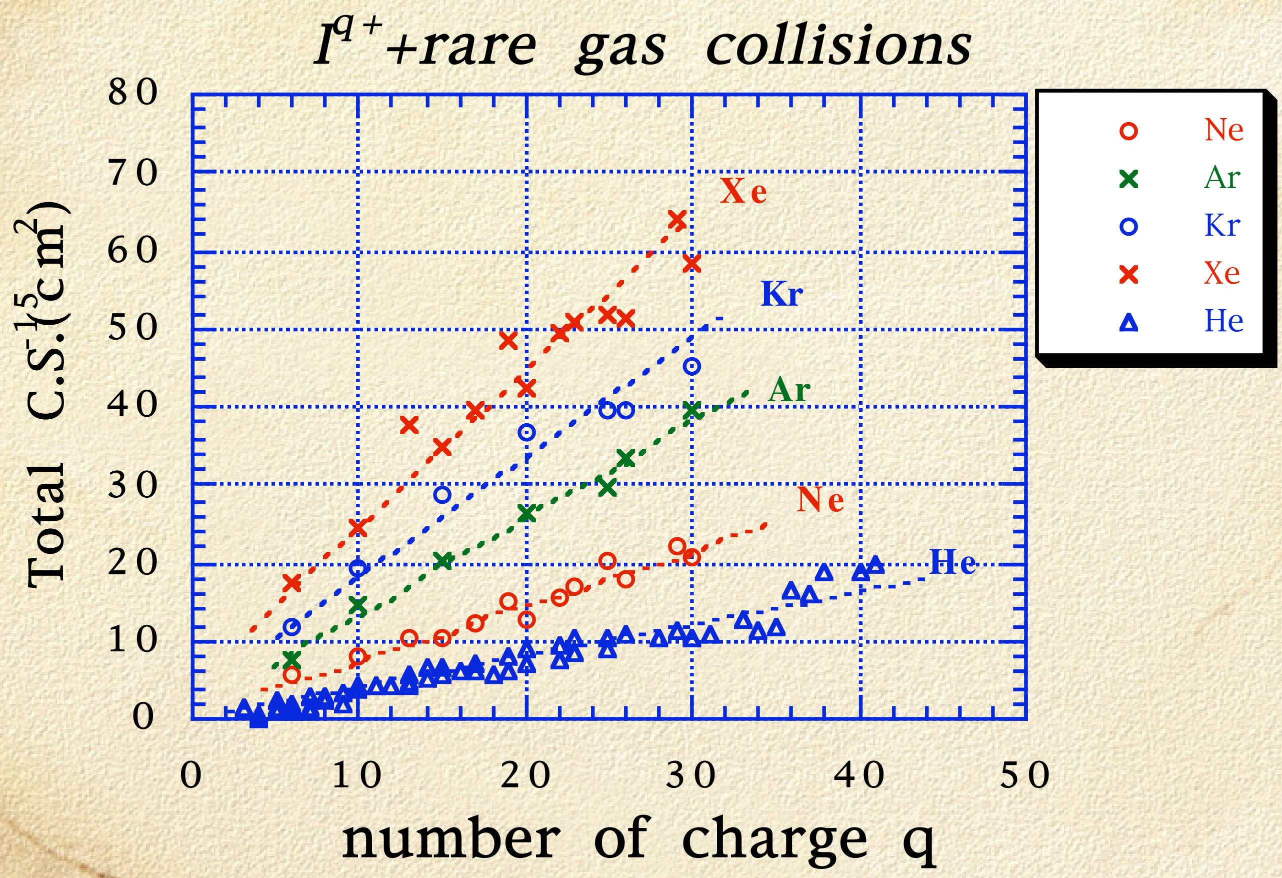
Electron transfer cross section

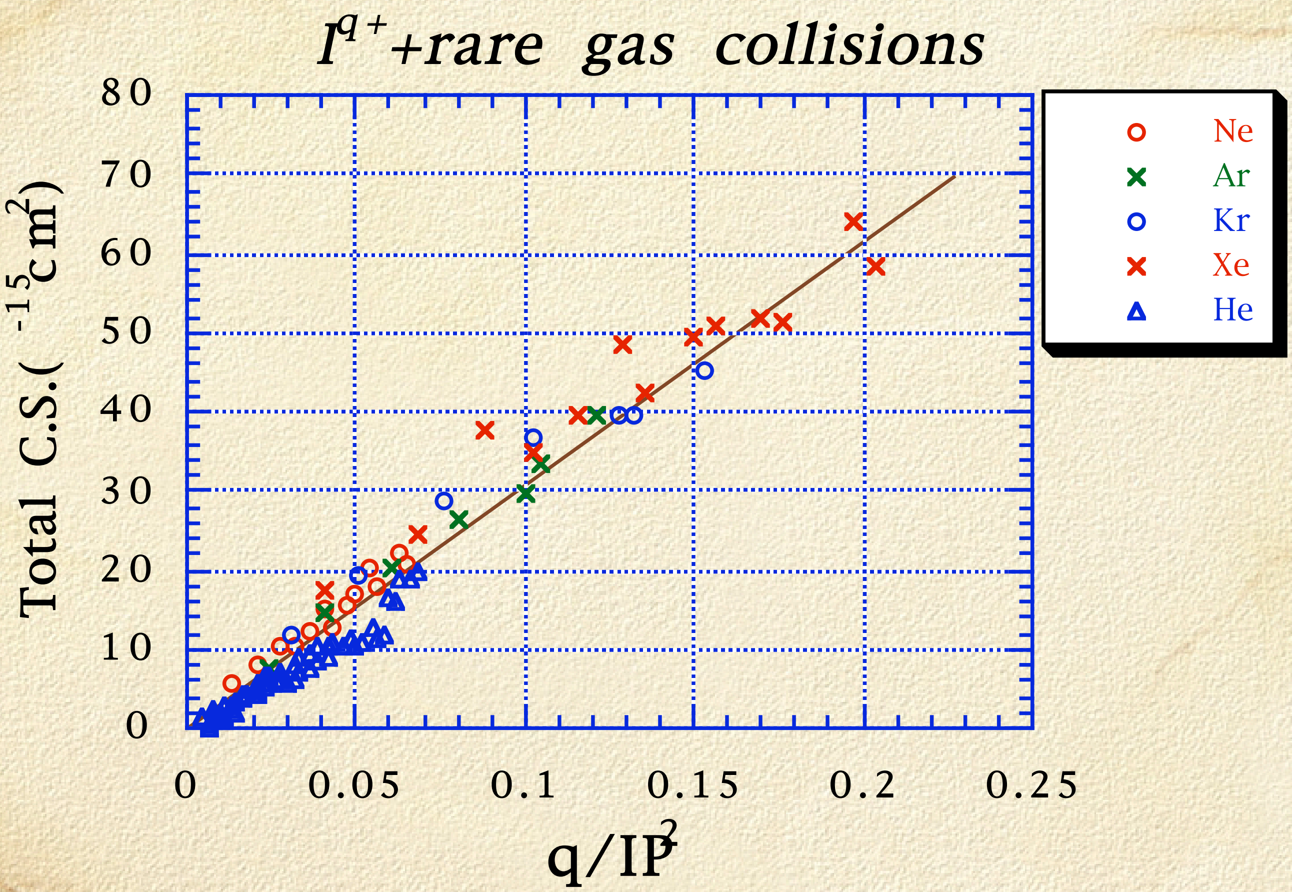
We can decide the total electron transfer cross sections from the gradient of that function of the scattered ion signal strength vs target density.



Experimental results

Charge Exchange Cross Section
(Electron Transfer)





I^{q+}+rare gas collisions
Total C.S.(10^{-15} cm^2)
q/IP^2
0
10
20
30
40
50
60
70
80
0
0.05
0.1
0.15
0.2
0.25
Ne
Ar
Kr
Xe
He

Scaling law for cross section

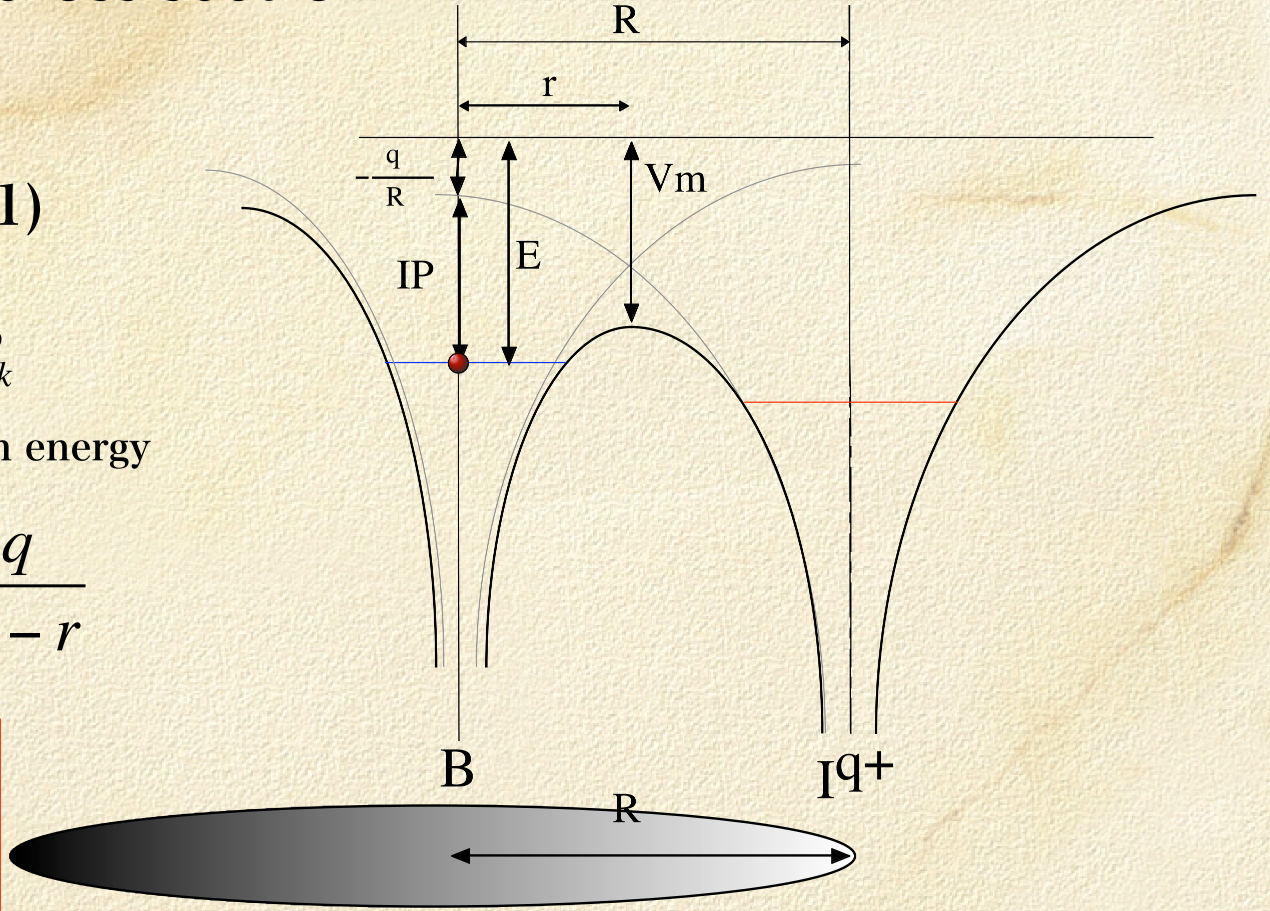
transfer condition

$$E = V_m \qquad (1)$$

$$E = -\frac{q}{R} - IP_k$$

IP:ionization energy

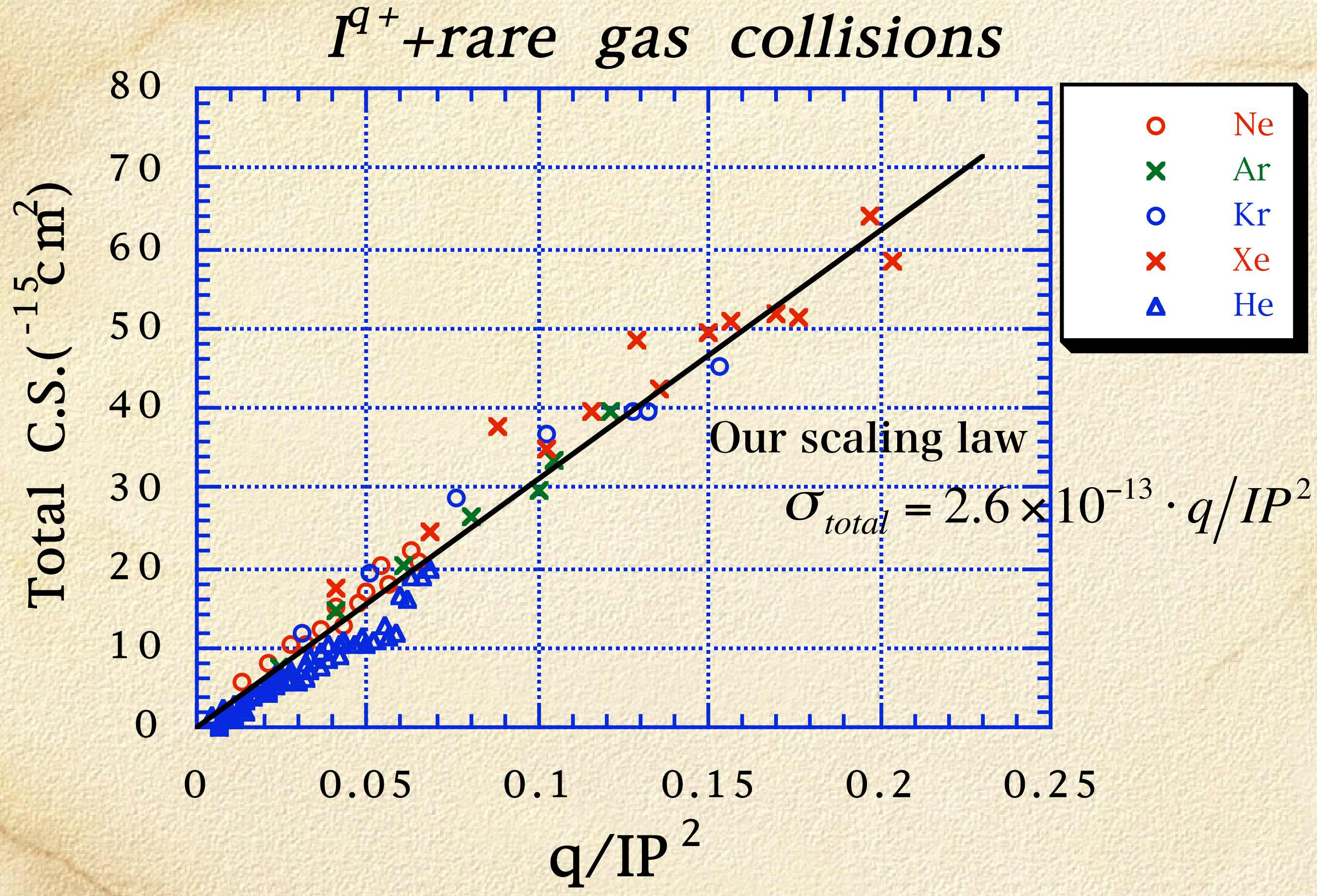
$$V_m = -\frac{k}{r} - \frac{q}{R-r}$$



$$R = 2 \cdot \sqrt{q} \cdot \frac{1}{IP}$$

$$\sigma_{total} = \pi R^2 = 4\pi \cdot q / IP^2 = 2.6 \times 10^{-13} \cdot q / IP^2$$

(atomic unit) (cm^2)



I^{q+}+rare gas collisions
Total C.S.($^{-15}$cm^2)
0
10
20
30
40
50
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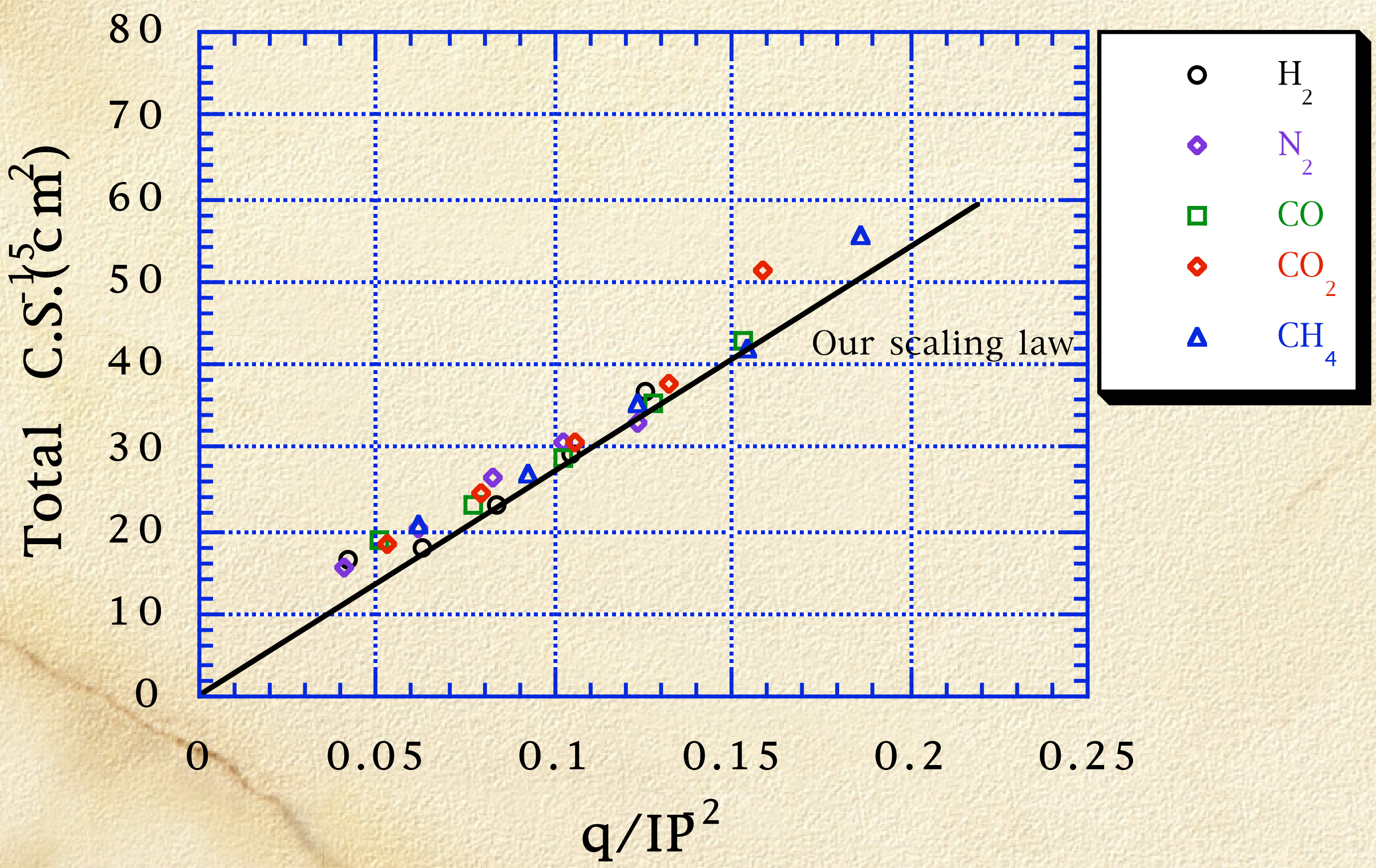
70
80
0
0.05
0.1
0.15
0.2
0.25
q/IP ^{2}
Ne
Ar
Kr
Xe
He
Our scaling law
$\sigma_{total} = 2.6\times10^{-13}\cdot q/IP^2$

Experimental results
molecule targets

IP(H_2) =15.4eV
IP(N_2) =15.6eV
IP(CO) =14.0eV
IP(CO_2) =13.8eV
IP(CH_4) =12.6eV

from Handbook of Chemistry and Physics

I^{q+} + mol. collisions



Summary

- The detail of electron transfer process by HCI's-Atom collision has been made clear.
- The absolute electron transfer cross sections were determined.
- We proposed the scaling law of the electron transfer cross section.
- We have found that this scaling law can also reproduce the experimental data for molecular targets.
- Most particles are in the excited states in the plasma. The charge exchange cross sections of excited targets-HCI's collision are very large.

e.g. IP{H*(2s)} : IP{H(1s)} = 3.4eV : 13.6eV

$$\sigma_{total} = 2.6 \times 10^{-13} \cdot q / IP^2$$

scaling law

σ_{total} H(2s) / σ_{total} H(1s) = 16

Thank you for your attentions.

감사합니다.

ありがとうございました。