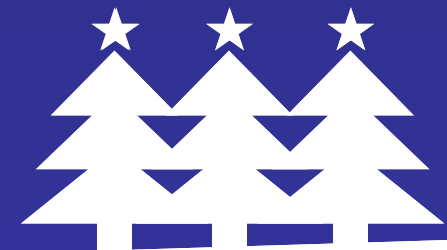


Charge Exchange Cross Sections for W^+ and W^{2+} Ions

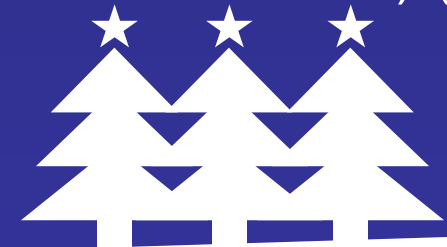
Makoto IMAI (as Alex IMAI)

Department of Nuclear Engineering, Kyoto University



Research Field of mine

- A+M collisions in gas phase (Kyoto)
 - A+M collisions in solid targets (JAEA)
-
- Cross section measurements
 - Charge exchange cross sections for fusion-related A+M collisions
 - Data compilation (and evaluations) (JAEA, NIFS)
 - Charge exchange cross sections derived experimentally
 - (1983–2008, JAEA)
 - For the NIFS database CHART (Charge Transfer and Ionization by Heavy Particle Collisions) (NIFS)



Production of Absolute Cross Sections for Charge Exchange Collisions

Till 1994

C ^{1, 2, 3+}

+

H₂, CO₂, CH₄, C₂H₆, C₃H₈

Energy = (0.5) 5 – 32 keV

1995 – 1997

Cr ^{1, 2+}

+

He, Ne, Ar, Kr, H₂, CO, CO₂, CH₄, C₂H₆, C₃H₈

Be ^{1, 2+}

+

He, Ne, Ar, Kr, H₂, CO, CO₂, CH₄, C₂H₆, C₃H₈

1998 – 2000

Ni ^{1, 2+}

+

He, Ne, Ar, Kr, H₂, CO, CO₂, N₂, CH₄, C₂H₆, C₃H₈

2001 – 2004

Fe⁺

+

He, Ne, Ar, Kr, H₂, CO, CO₂, N₂, CH₄, C₂H₆, C₃H₈

Be ^{1, 2+}

+

He, Ne, Ar, Kr, H₂, CO, CO₂

B ^{1, 2+}

+

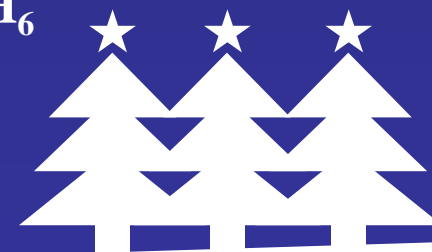
He, Ne, Ar, Kr, H₂, CO, CO₂

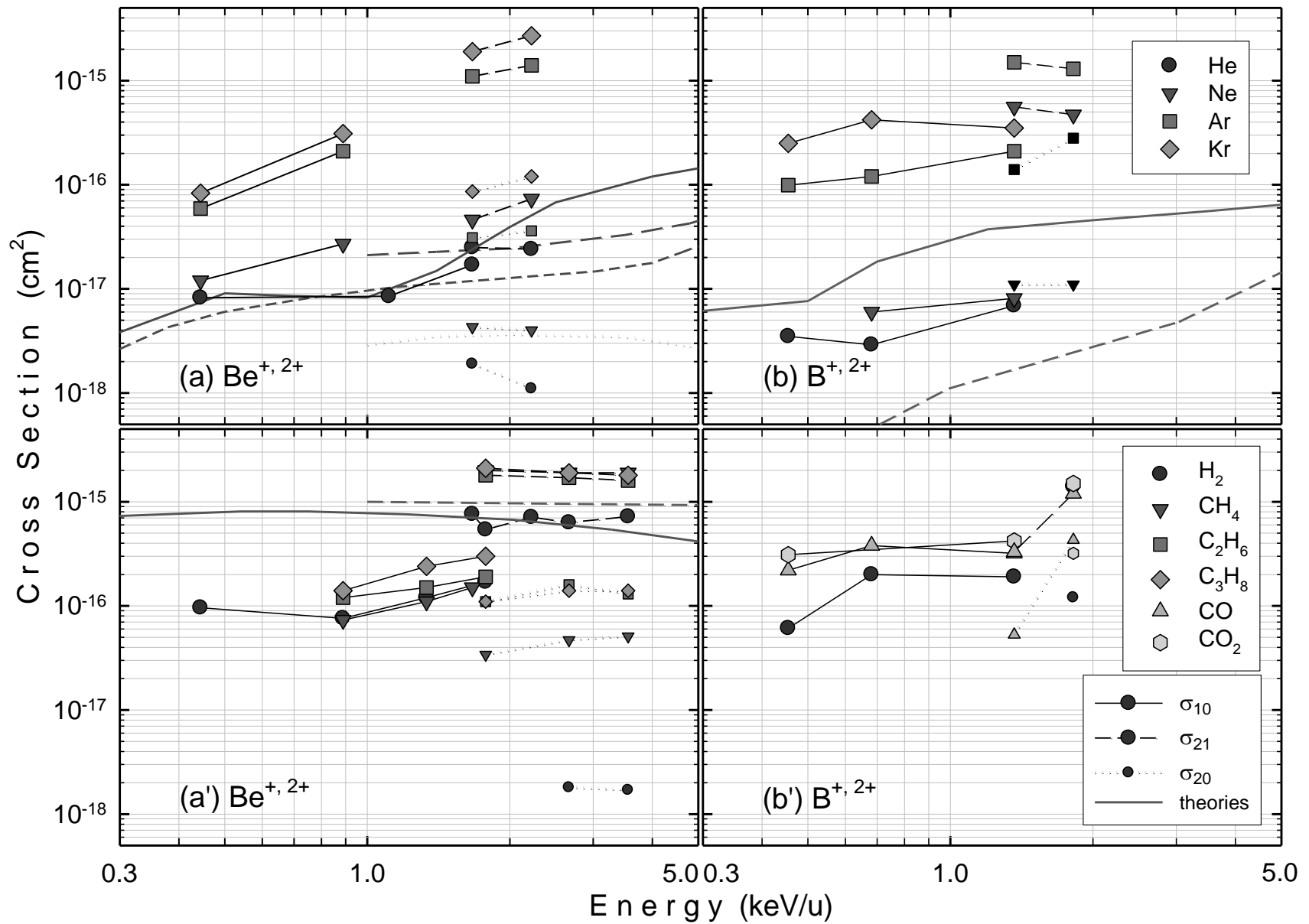
2005 – present

W ^{1, 2+}

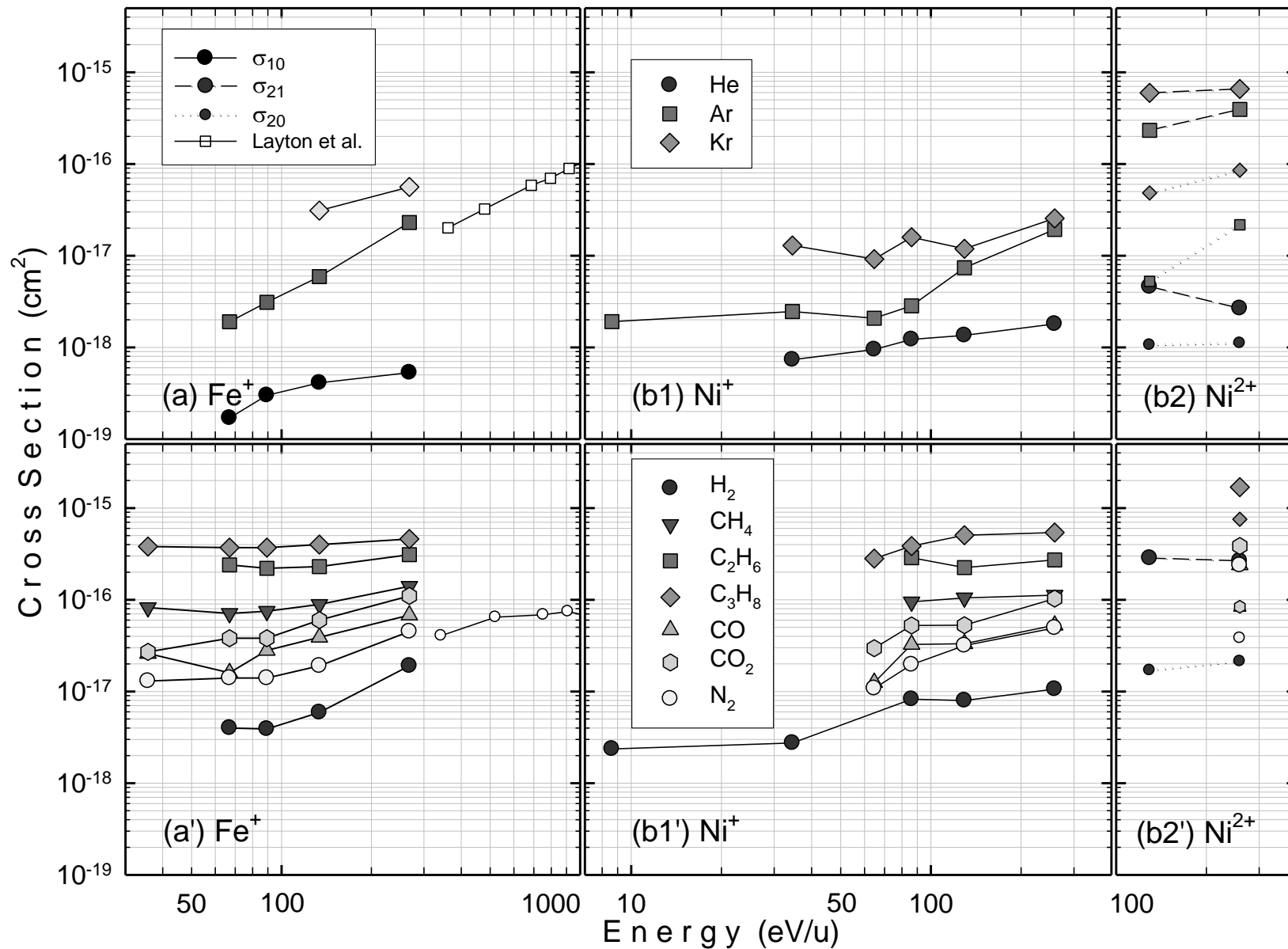
+

He, Ne, Ar, Kr, H₂, N₂, CH₄, C₂H₆





Single and double electron capture cross sections σ_{10} , σ_{21} and σ_{20} for Be and B ions.

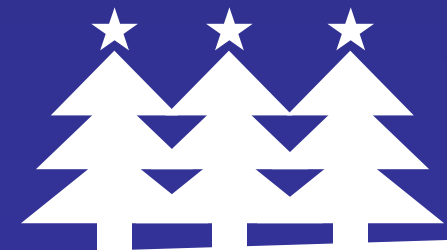


Single and double electron capture cross sections σ_{10} , σ_{21} and σ_{20} for Fe and Ni ions.

Charge Exchange Cross Sections for W in Literature

Only two Experimental papers available

- Single electron capture cross section for W^{q+} ($q = 4 - 15$) ions by Meyer *et al.* at 8.5, 11 MeV (46, 60 keV/u) in PRA19, 515 (1979).
- Single electron capture cross section for W^+ by Kheyrandish, Armour and Jones at 40 keV in Vacuum 34, 269 (1984).



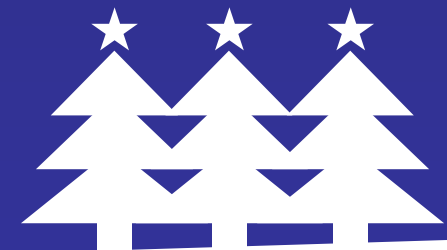
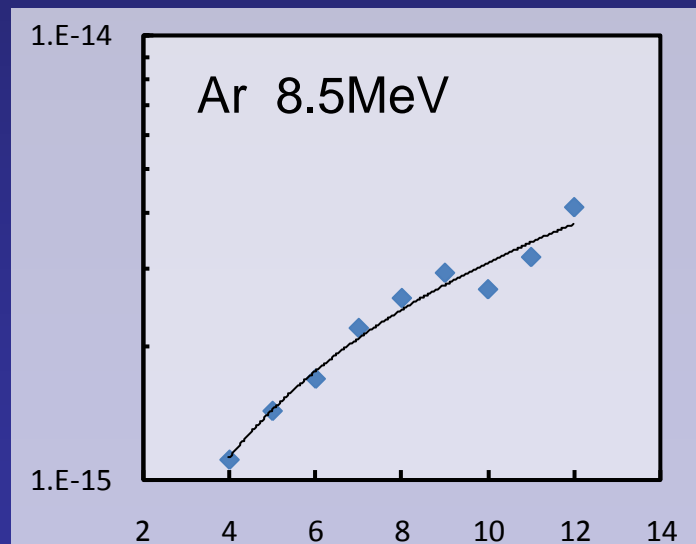
Charge Exchange Cross Sections for W in Literature

Meyer *et al.* at 8.5, 11 MeV (46, 60 keV/u) (1979)



$$\sigma_{H_2} = 1.6 \times 10^{-16} q^{1.3} \text{ (cm}^2\text{)}$$

$$\sigma_{Ar} = 2.4 \times 10^{-16} q^{1.1} \text{ (cm}^2\text{)}$$



Charge Exchange Cross Sections for W in Literature

Kheyrandish , Armour and Jones at 40 keV (210 eV/u) (1984)



Volume 34/numbers 1-2/pages 269 to 273/1984
Printed in Great Britain

0042-207X/84\$3.00+.00
Pergamon Press Ltd

The measurement of charge transfer cross-sections for a variety of ions on air and argon

H Kheyrandish and D G Armour, *Department of Electronic and Electrical Engineering, University of Salford, Salford M5 4WT, UK*

and

E J Jones, *Chemistry Division, AERE Harwell, Harwell, Oxfordshire OX11 0RA, UK*

A brief review of the importance of charge exchange collisions and their significance in particle accelerators is presented and an apparatus designed to study such collisions is described. This apparatus has been used to measure the charge exchange cross-sections for a number of projectiles of technological interest in air and argon in the energy range 10–40 keV. $\sigma_{1,0}$ cross-sections for Sb^+ , As^+ , In^+ , P^+ , N_2^+ , O_2^+ , N^+ , O^+ , Ge^+ , Cr^+ , Fe^+ are reported. The significance of the cross-section values and their dependence on energy from the point of view of optimum transportation of ion beams and on the accuracy of dose measurements in ion implantation is discussed.

Charge Exchange Cross Sections for W in Literature

Kheyrandish , Armour and Jones at 40 keV (210 eV/u) (1984)

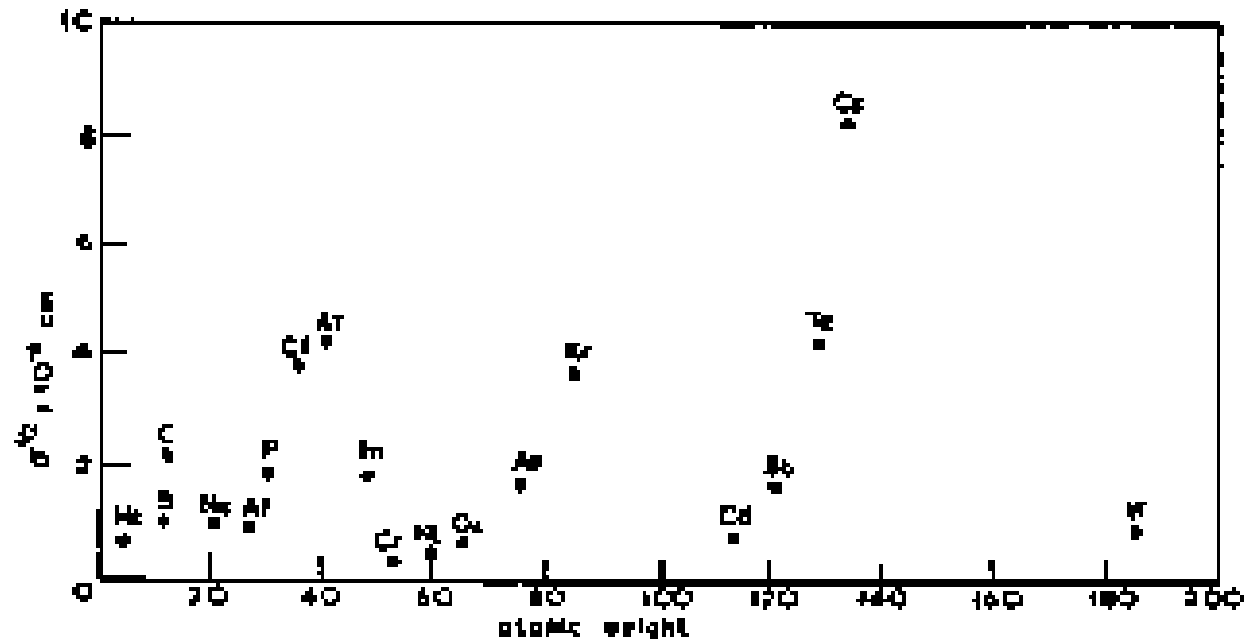


Figure 3. Variation of $\sigma_{10} \times 10^{12}$ with atomic weight for an incident velocity of $2 \times 10^7 \text{ cm s}^{-1}$ on argon.

Our Efforts for Cross Sections for W Ions

- Measurement of electron capture cross sections in Kyoto



- Calculation of single ionization cross section
by V. P. Shevelko (P. N. Lebedev Physical Institute, Russia)



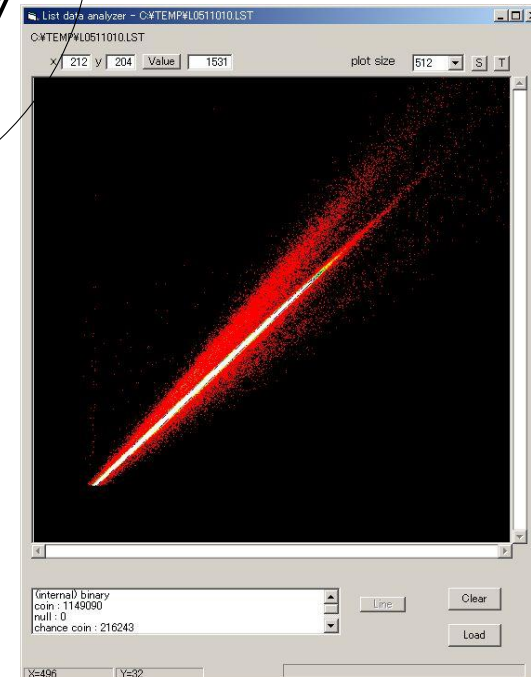
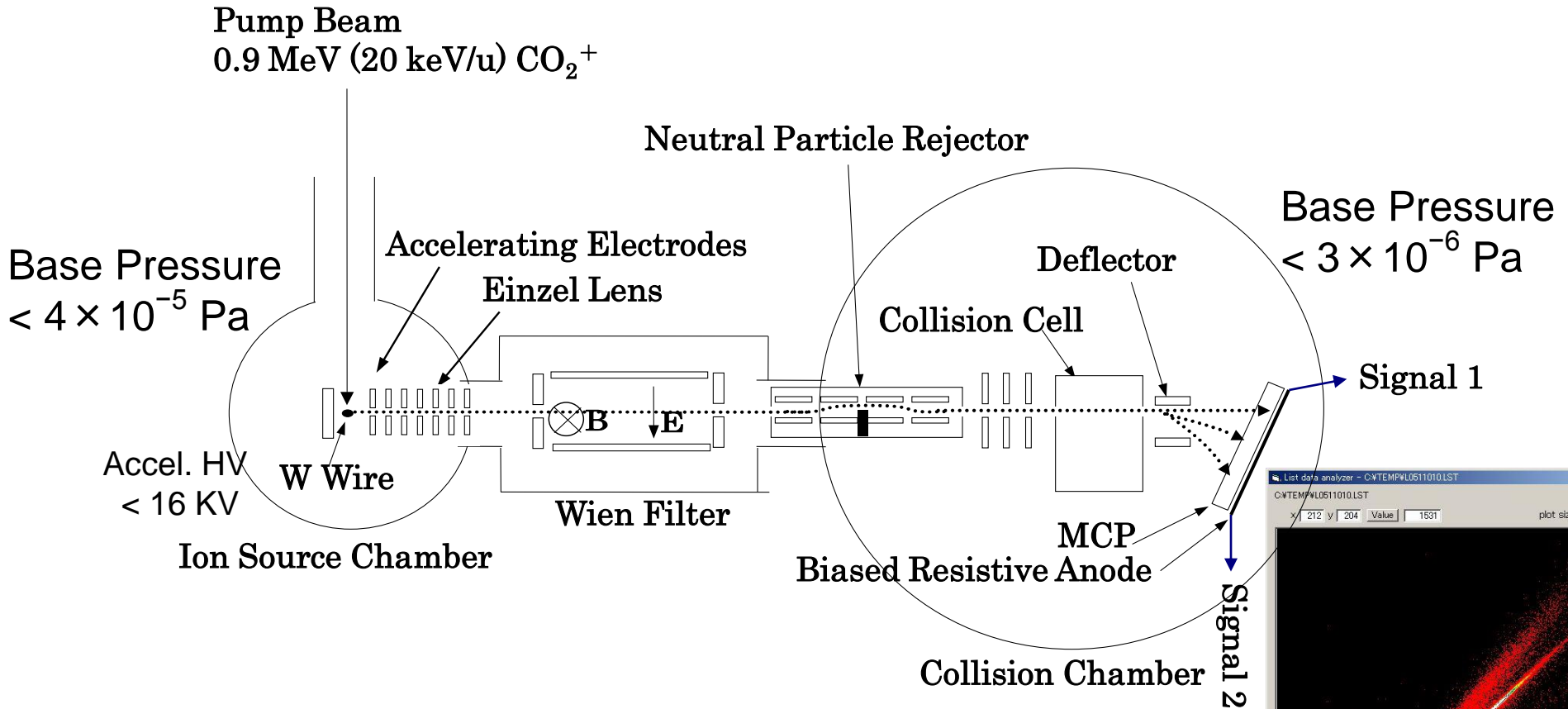
- Theoretical study of electron capture
by R. J. Buenker *et al.* (Universität Wuppertal, Germany)



- Calculation of single electron capture cross sections
by I. Tolstikhina (P. N. Lebedev Physical Institute, Russia)



The Experimental Apparatus



How to Derive Cross Sections

Rate equation for W^{i+} intensity

$$\frac{dF_i(\pi)}{d\pi} = \sum_{j \neq i} [F_j(\pi)\sigma_{ji} - F_i(\pi)\sigma_{ij}],$$
$$\sum_i F_i(\pi) = 1,$$

where

$F_i(\pi)$: Relative Intensity of W^{i+} ion

π : Target Thickness (= Density \times Length in $/\text{cm}^2$)

σ_{ji} : Charge Transfer Cross Section (cm^2) $W^{j+} \rightarrow W^{i+}$

Under the single collision condition, this simultaneous equation

reduces to

$$\frac{I_0}{I_2 + I_1 + I_0} = \sigma_{10}\pi, \quad \frac{I_2}{I_2 + I_1 + I_0} = \sigma_{12}\pi,$$

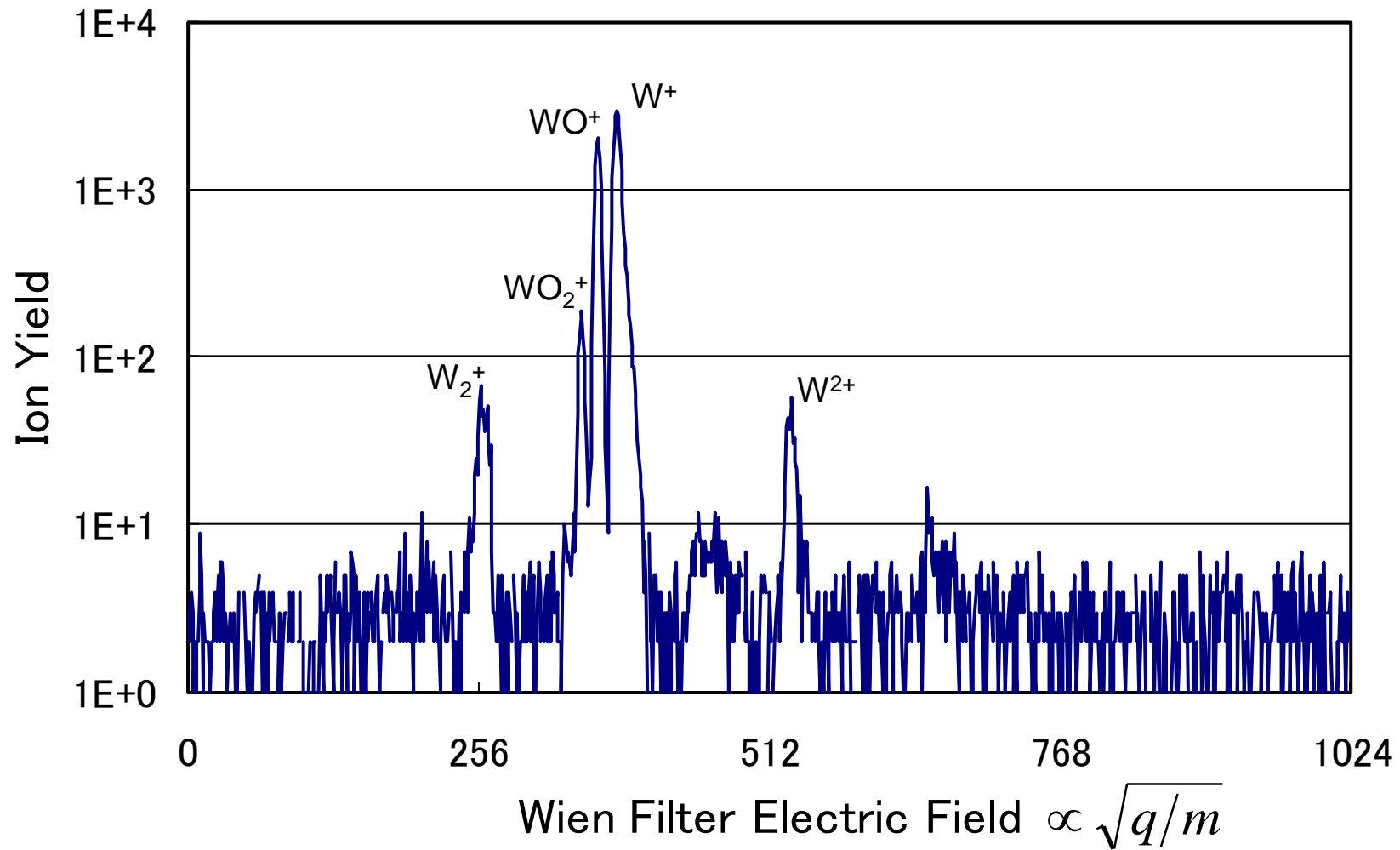
where

I_2, I_1, I_0 : Intensity of W^{2+}, W^+ and W^0 ions, respectively.



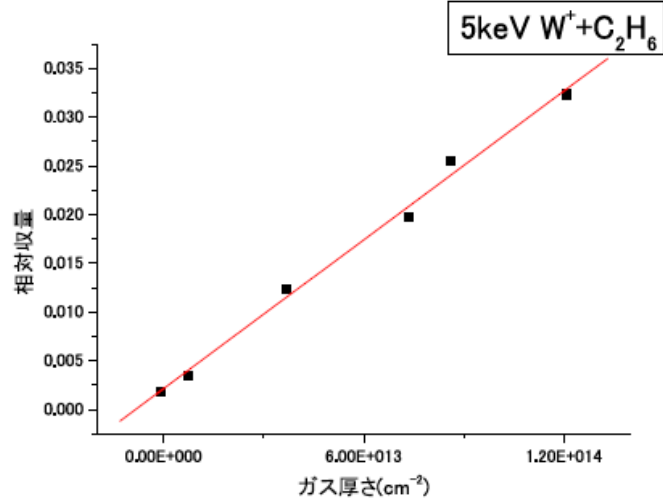
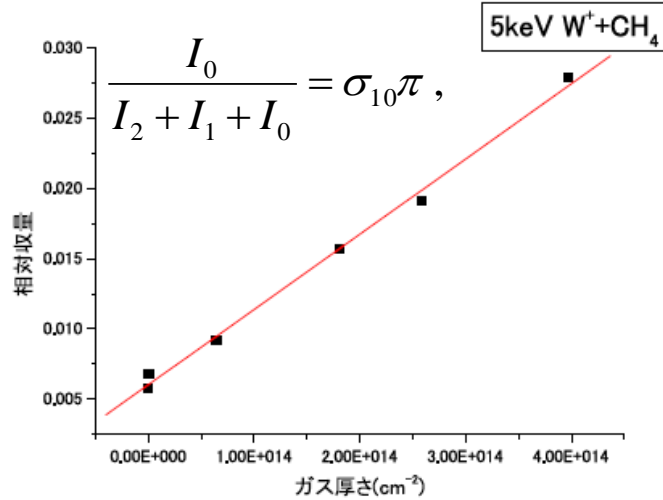
Projectile W Ion Selection

7.5 keV W⁺ Extraction

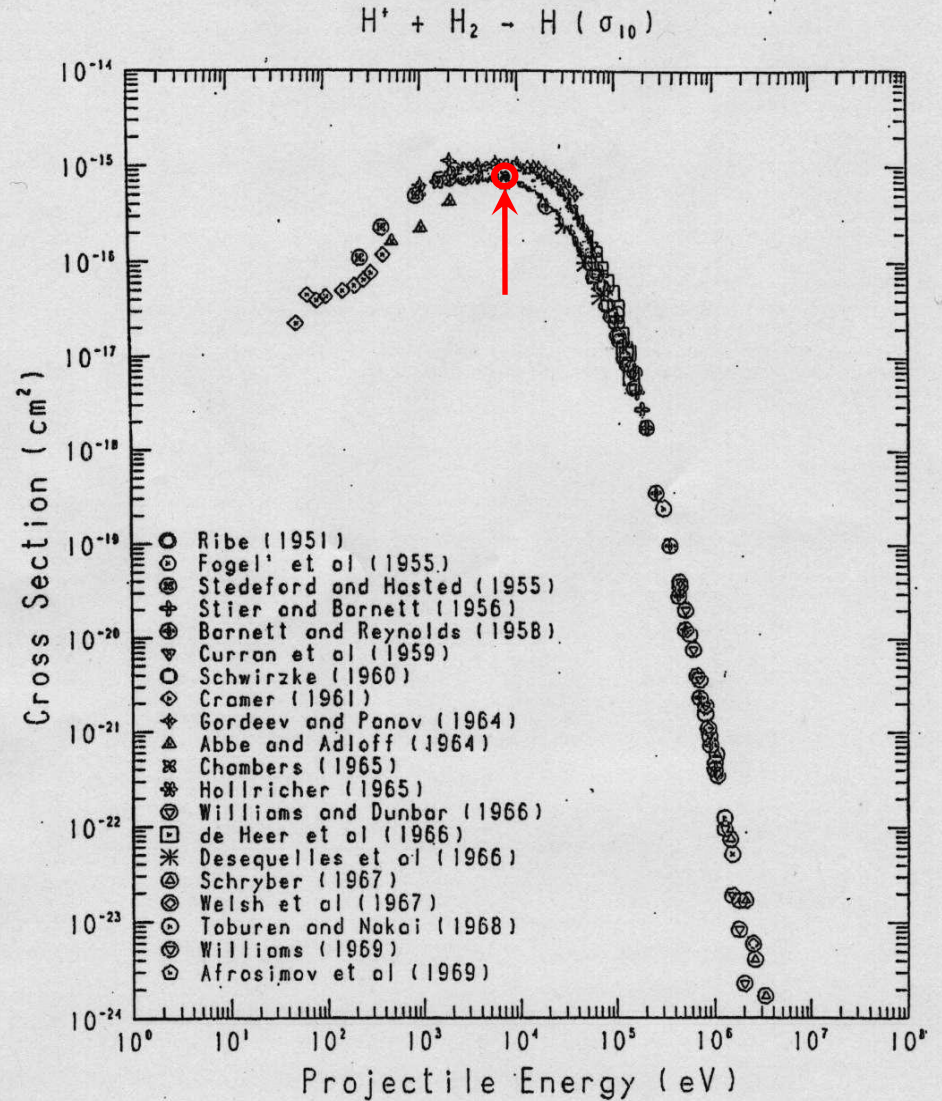


Data Processing

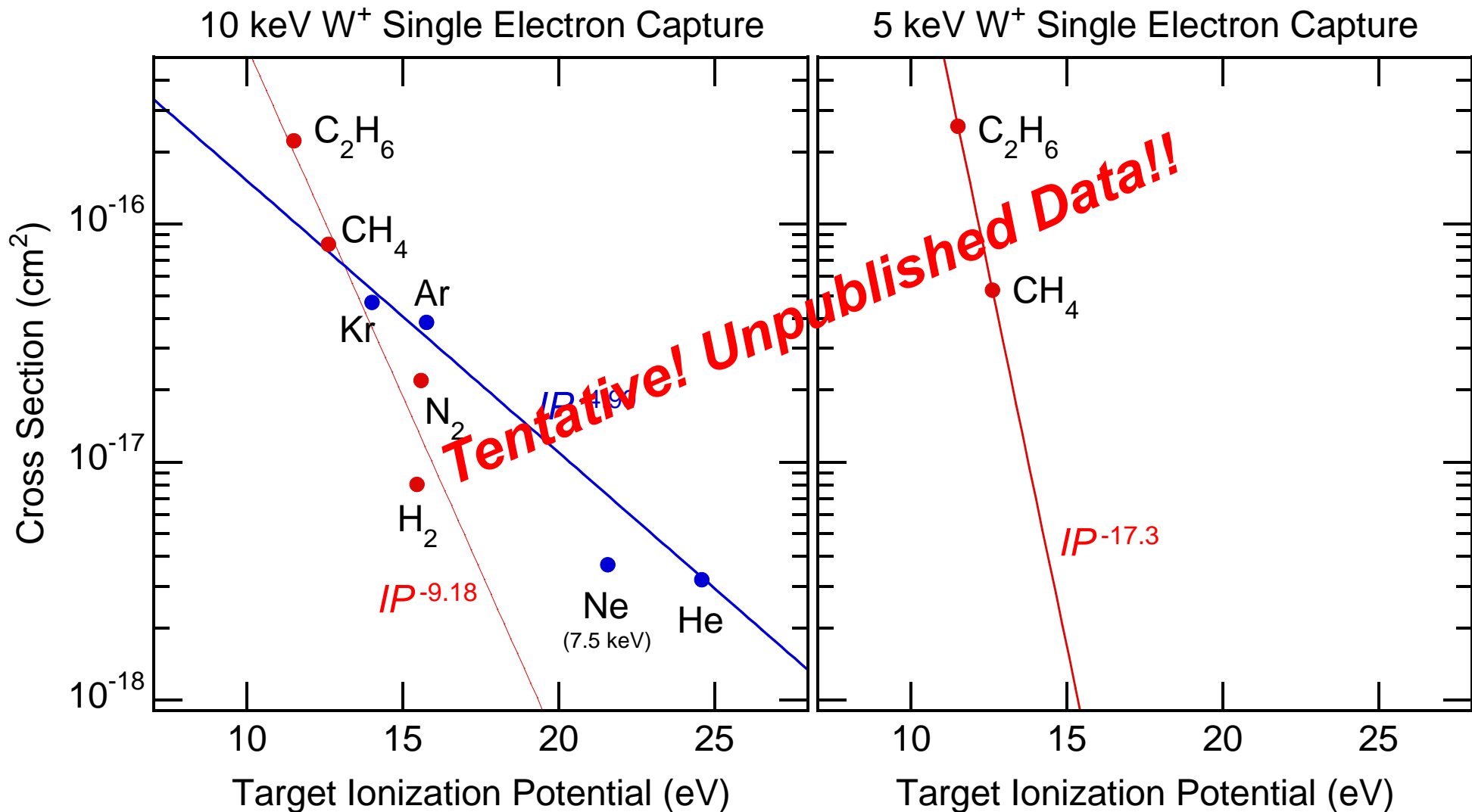
Growth Curve for 5 keV W⁺



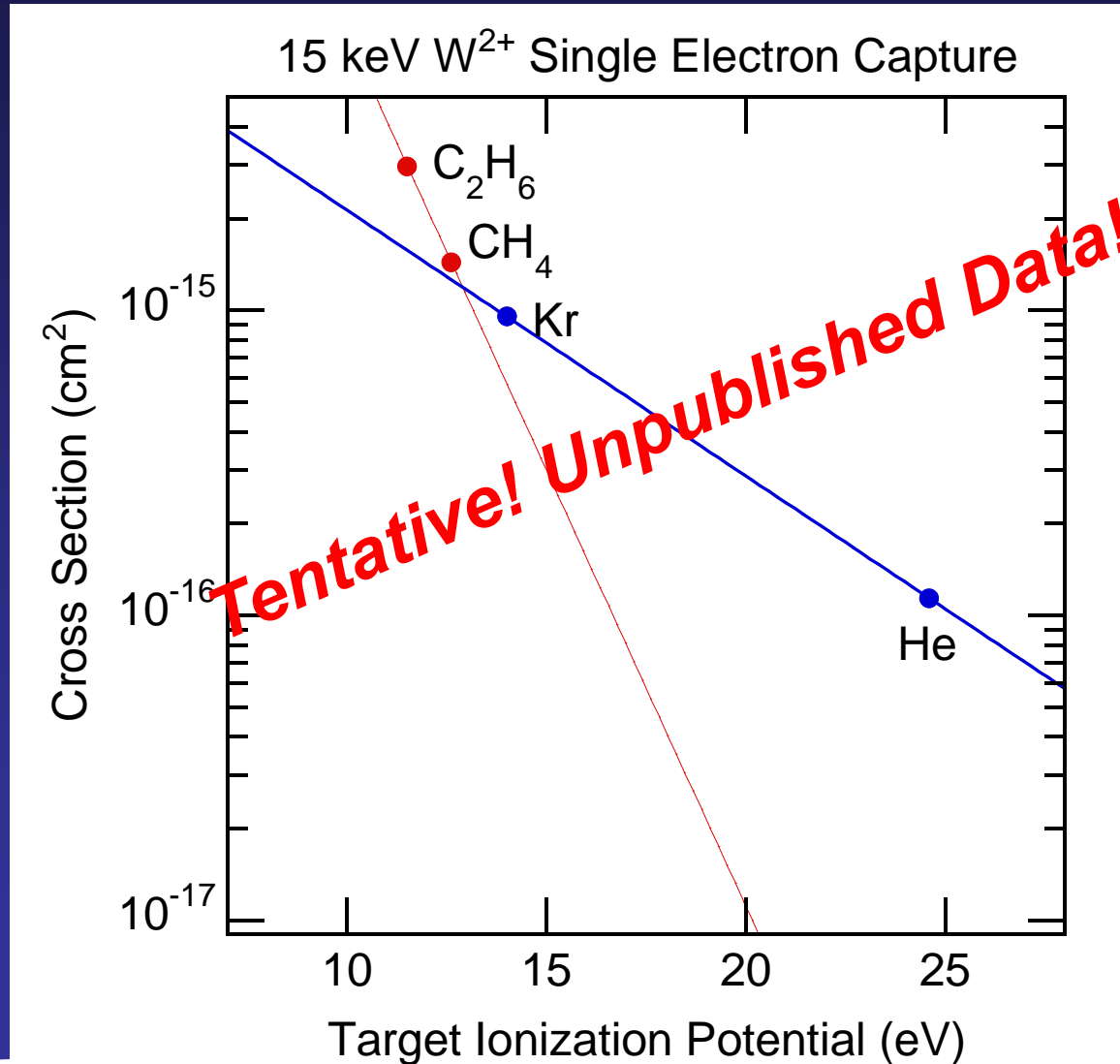
Bench mark for 7.5 keV H⁺ + H₂ collision



Single Electron Capture Cross Sections for W^+ Ions on Gas Targets at 10 and 5 keV (54 and 27 eV/u)

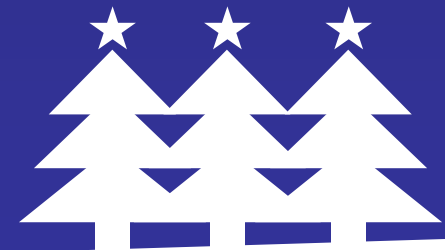
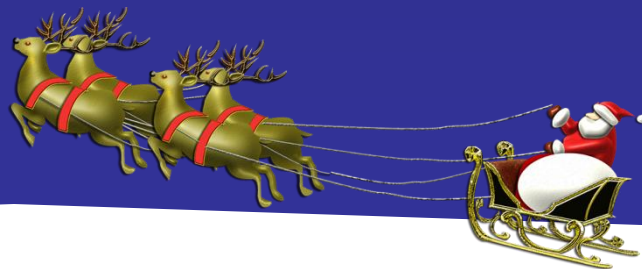


Single Electron Capture Cross Sections for W^{2+} Ions on Gas Targets at 15 keV (82 eV/u)



Summary

- Charge exchange cross sections (both experimental and theoretical) for W ions are still scarce in the literature.
- We can produce reliable cross sections for W^+ and W^{2+} between 5–16 and 10–32 keV, respectively, but not for W^{3+} or higher.
- Reduction of impact energy should be possible.
- Theoretical study by several groups is under the way.



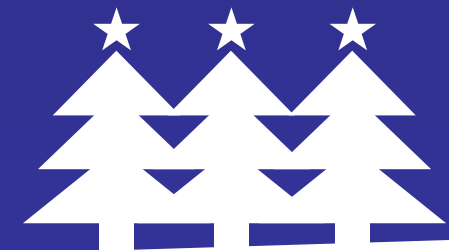
Compilation of Charge Exchanging Cross Sections

Number of Collected Papers

Year	Total	Partial	Misc	Total
1983–1989	57			57
1990	16			16
1991	20			20
1992	12	12		24
1993	7	4		11
1994	10	8		18
1995	10	6	4	20
1996	7	2	2	11
1997	12	1	2	15
1998	5	6	1	12
1999	6	4	5	15
2000	6	1	3	10
2001	18	2	5	25
2002	3	2	6	11
2003	12	1	12	25
2004	12	1	8	21
2005	12	4	11	27
2006	5	2	11	18
2007	13	2	4	19
2008	6	0	9	15
Total	249	58	83	390

Journals under the survey

Atomic Data and Nuclear Data Tables
The European Physical Journal D
Europhysics Letters
JETP
JETP Letters
Journal of Physical and Chemical Reference Data
Journal of the Physical Society of Japan
Journal of Physics B: Atomic, Molecular and Optical Physics
Nuclear Instruments and Methods in Physics Research sect. A
Nuclear Instruments and Methods in Physics Research sect. B
Physica Scripta
Physical Review A
Physics Letters A



Charge Exchange Cross Section Database

Number of Collected Papers

Year	Total	Partial	Misc	Total
1983–1999	162	43	14	219
2000	6	1	3	10
2001	18	2	5	25
2002	3	2	6	11
2003	12	1	12	25
2004	12	1	8	21
2005	12	4	11	27
2006	5	2	11	18
2007	13	2	4	19
2008	6	0	9	15
Total	248	58	84	390

Journals under the survey

Atomic Data and Nuclear Data Tables
The European Physical Journal D
Europhysics Letters
JETP
JETP Letters
Journal of Physical and Chemical Reference Data
Journal of the Physical Society of Japan
Journal of Physics B: Atomic, Molecular and Optical Physics
Nuclear Instruments and Methods in Physics Research sect. A
Nuclear Instruments and Methods in Physics Research sect. B
Physica Scripta
Physical Review A
Physics Letters A

Electric Version:

<http://toshi3.nucleng.kyoto-u.ac.jp:5560/isqlplus/>

UserID: ICAMDATA

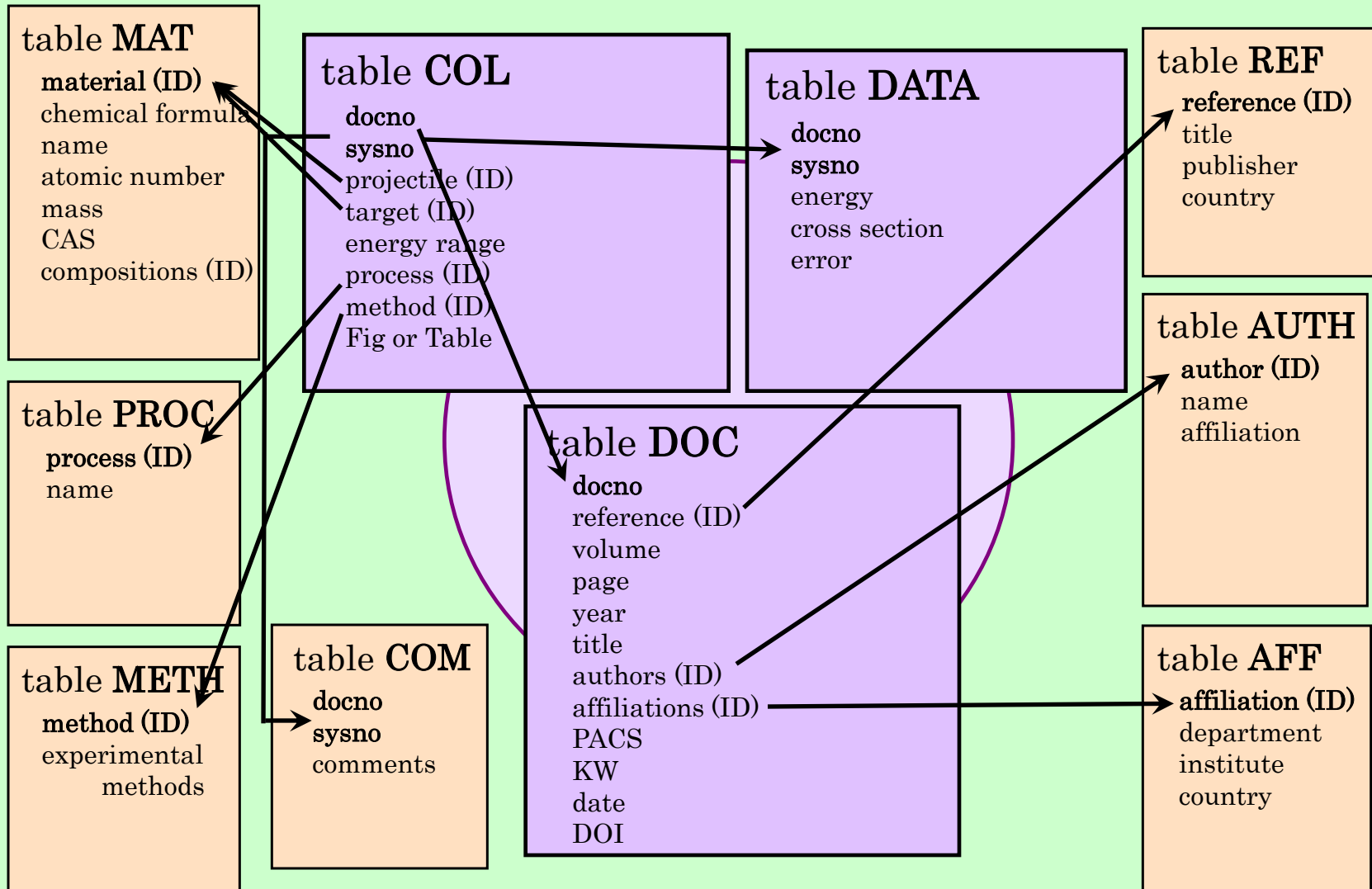
Password: MEUDON (Please do not change!!)

Now contains 1766 cross section data for 486 collision systems with 145 authors' information, taken from 29 articles published in PRA and JPB in 2004, 2005 and 2006.



Charge Exchange Cross Section Database

Database Structure



All the tables are owned by **ALEX**

Charge Exchange Cross Section Database

ISQL*Plus Release 10.1.0.5.0 Production - Mozilla Firefox

ファイル(E) 編集(E) 表示(V) 移動(G) ブックマーク(B) ツール(T) ヘルプ(H)

http://toshi3.nucleng.kyoto-u.ac.jp:5560/isqlplus/workspace.uix?event=nextPage 移動

ORACLE
iSQL*Plus

ログアウト 設定項目 ヘルプ

作業領域 履歴

接続ユーザー ICAMDATA@masa

作業領域

SQL、PL/SQLおよびiSQL*Plus文を入力してください。

消去

```
select docno, sysno from ALEX.COL
  where proj1 like 'U' and targ1 like 'Ar';
select * from ALEX.DOC where docno=2004002;
select * from ALEX.COL where docno=2004002 and sysno=41;
select * from ALEX.DATA where docno=2004002 and sysno=41;
```

実行 スクリプトのロード スクリプトの保存 取消

DOCNO	SYSNO	E	TE	CS	EERR	TEERR	CSERR
2004002	41	3500000	833000000	1.1200E-17			8.9000E-19
2004002	41	6500000	1550000000	3.9000E-19			9.0000E-20

消去