平成21年3月17日
原子分子データ活動に関する研究会
原子力機構東京事務所（東京・千代田区）

原子・分子・イオンの衝突に関する調査
低電離 W イオンの電荷変化断面積

京都大学大学院工学研究科　伊藤秋男

委託研究　原子・分子・イオンの衝突に関する調査
　　低電離 W イオンの電荷変化断面積（V）

（文献調査・データシート作成）

（電荷変化断面積測定）

平成 6 年度まで
　　$C^{+,\,2+,\,3+}$ + H_2, CO_2, CH_4, C_2H_6, C_3H_8

平成 7～9 年度 低電離金属イオンの電荷変化断面積（Ⅰ）（Ⅱ）（Ⅲ）
　　$Cr^{+,\,2+,\,3+}$,　$Be^{+,\,2+}$ + He, Ne, Ar, Kr, H_2, CO, CO_2, CH_4, C_2H_6, C_3H_8

平成 10～12 年度　　低電離 Ni イオンの電荷変化断面積（Ⅰ）（Ⅱ）（Ⅲ）
　　$Ni^{+,\,2+}$ + He, Ne, Ar, Kr, H_2, CO, CO_2, N_2, CH_4, C_2H_6, C_3H_8

平成 13～15 年度　　低電離 Fe イオンの電荷変化断面積（Ⅰ）（Ⅱ）（Ⅲ）
　　$Fe^{+,\,2+}$,　$Be^{+,\,2+}$,　$B^{+,\,2+}$ + He, Ne, Ar, Kr, H_2, CO, CO_2, N_2, CH_4, C_2H_6, C_3H_8

平成 16～20 年度　　低電離 W イオンの電荷変化断面積（Ⅰ）（Ⅱ）（Ⅲ）（Ⅳ）（Ⅴ）
　　W^+ + He, Ne, Ar, Kr, H_2, N_2, CH_4, C_2H_6（測定継続中）
　　W^{2+} + He, Ar, Kr,CH_4, C_2H_6（測定継続中）

本委託調査からの発展と関連発表（平成 20 年度）

文献調査 → データサーバ構築 （2006 年 10 月プロトタイプ稼働），断面積測定 → 国際会議・論文発表

- Makoto Imai,
  Recent charge transfer cross section measurements for fusion related materials,
  June 9 – 13, 2008, IAEA Headquarter, Vienna, Austria.
- M. Imai , M.V. Khoma, O.M. Karbovanets, Y. Kikuchi, M. Saito, Y. Haruyama, M.I. Karbovanets, A. Itoh, R.J. Buenker,
  Charge transfer processes in collisions of slow highly charged ions with polar molecules CO and C_3H_8 ,
  The14th International Conference on the Physics of Highly Charged Ions (HCI 2008),
  September 1 – 5, 2008, Chofu, Japan.
- Makoto Imai , Akio Itoh, and Hirotaka Kubo,
  Production and compilation of charge changing cross sections of ion-atom and ion-molecule collisions,
  The 6th International Conference on Atomic and Molecular Data and Their Applications (ICAMDATA 2008),
  October 28 – 31, 2008, Beijing, China.
- Makoto IMAI,
  Electron Capture Cross Section for W^+ and W^{2+} Ions Colliding with Gaseous Targets & Compilation of Charge Changing Cross Section of Energetic Ion Collisions,
  March 11, 2009, NFRI, Daejeon, Korea.
  March 12, 2009, KAERI, Daejeon, Korea. (informal round-table)
  Electron Capture Cross Section for W^+ and W^{2+} Ions Colliding with Gaseous Targets,
  March 12, 2009, 漢陽大學校, 安山, Korea. (informal round-table)
- M. V. Khoma, M. Imai, O. M. Karbovanets, Y. Kikuchi, M. Saito, Y. Haruyama, M. I. Karbovanets, I. Yu. Kretinin, A. Itoh, R. J. Buenker,
  A simple theoretical approach of electron capture processes in collisions of atomic ions with polar targets,
  Chemical Physics 352 (2008) pp. 142 – 146 . Be^{2+} + CO, B^{2+} + CO, Be^{2+} + C_3H_8 single electron capture
- M. V. Khoma, M. Imai, O. M. Karbovanets, Y. Kikuchi, M. Saito, Y. Haruyama, M. I. Karbovanets, I. Yu. Kretinin, A. Itoh, R. J. Buenker,
  Charge transfer processes in collisions of slow highly charged ions with polar molecules CO and C_3H_8,
  Journal of Physics: Conf. Ser., to be published. Be^{2+} + CO, B^{2+} + CO, Be^{2+} + C_3H_8 double electron capture

文献調査・データシート作成

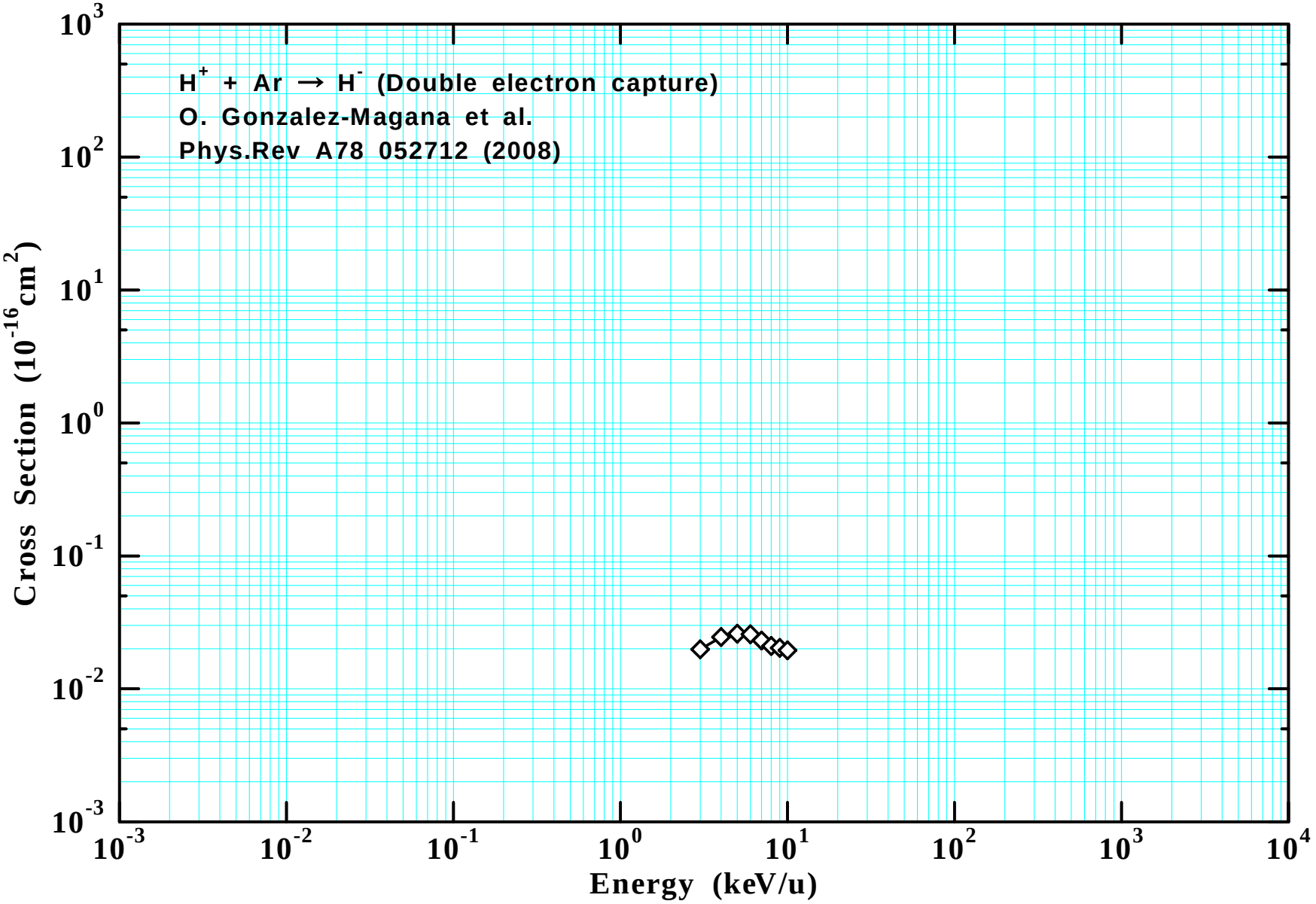
抽出文献数

対象年	全断面積	部分断面積	その他	計
1983～1990	73			73
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	2	2	7	11
2003	12	1	12	25
2004	12	1	8	21
2005	16	4	19	39
2006	5	2	11	18
2007	13	2	4	19
2008	6	0	11	17
計	252	58	94	404

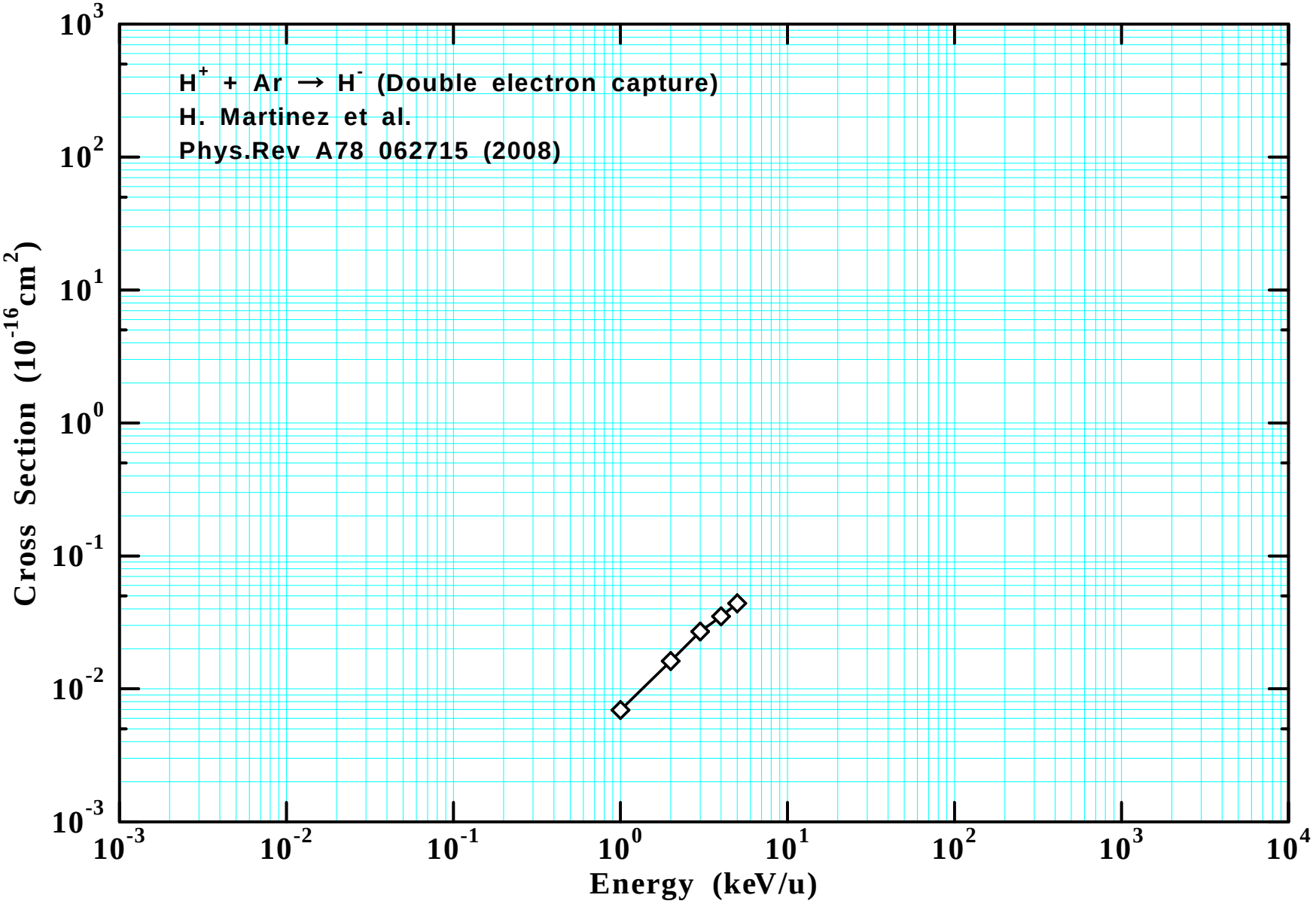
調査対象学術雑誌

- 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

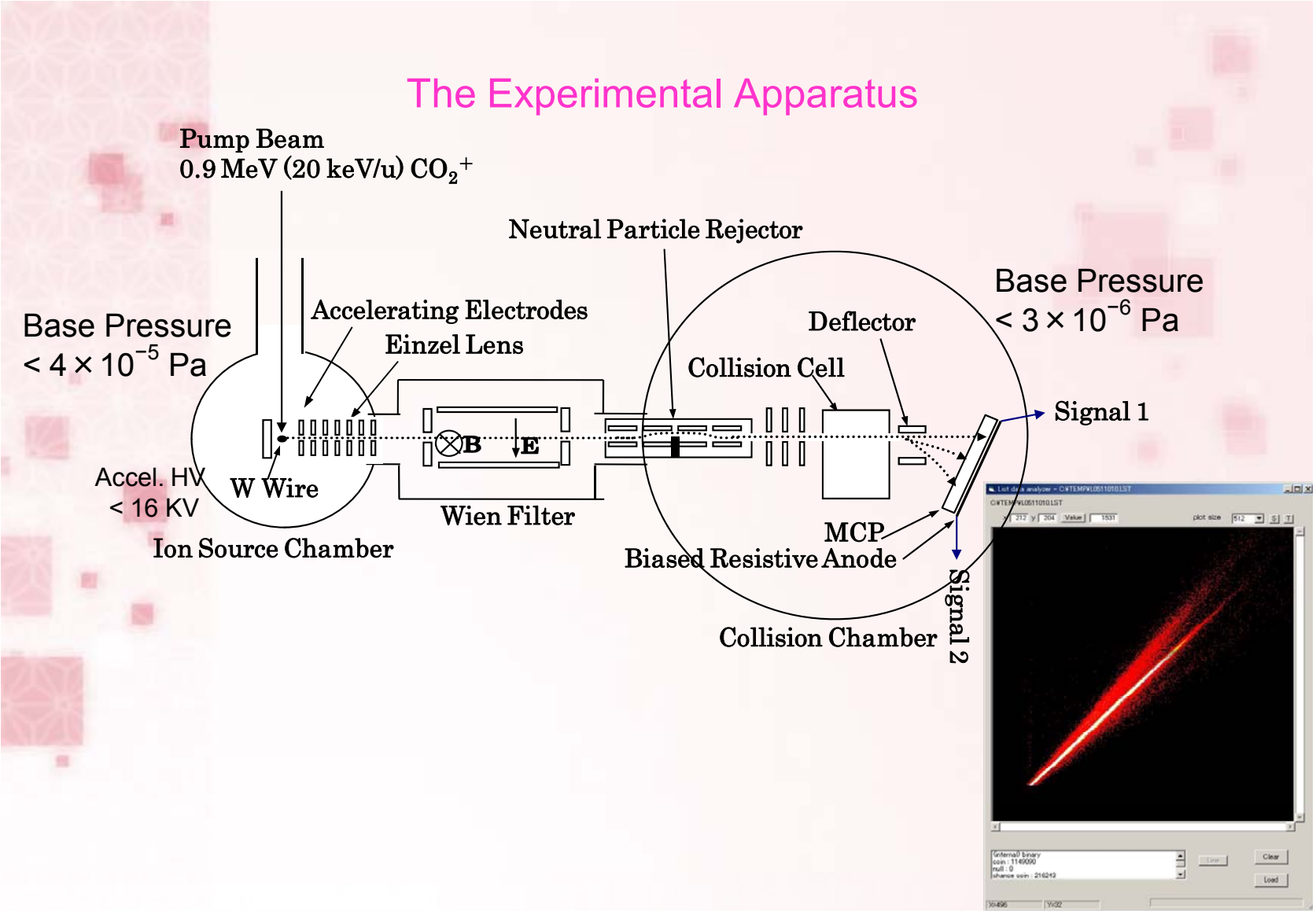
文献調査・データシート作成



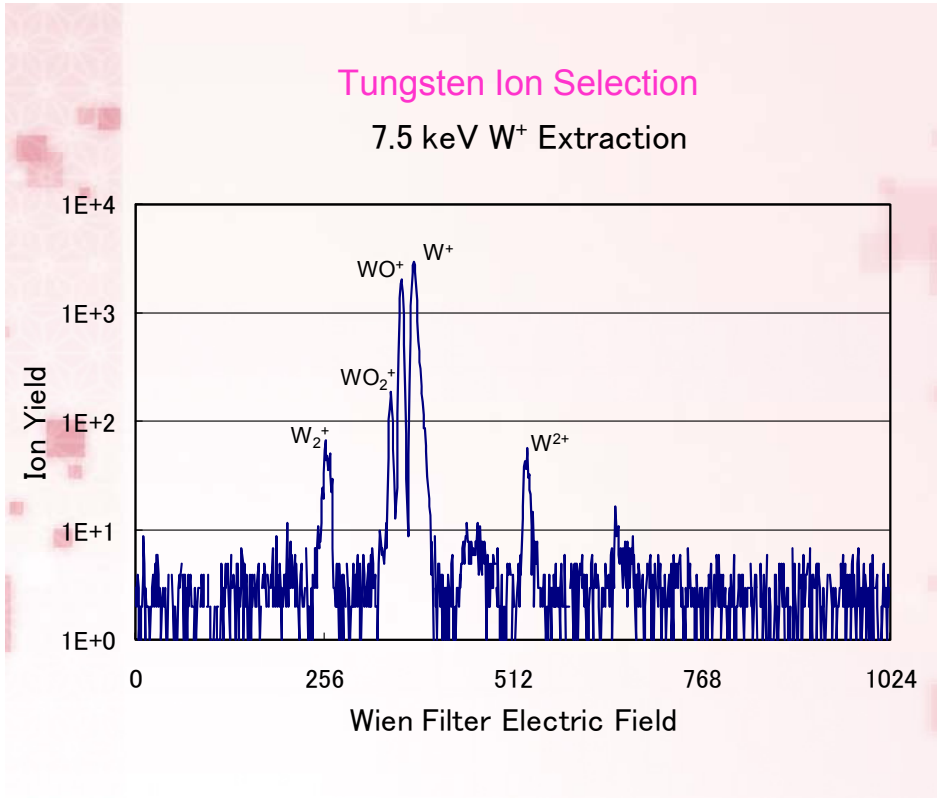
文献調査・データシート作成

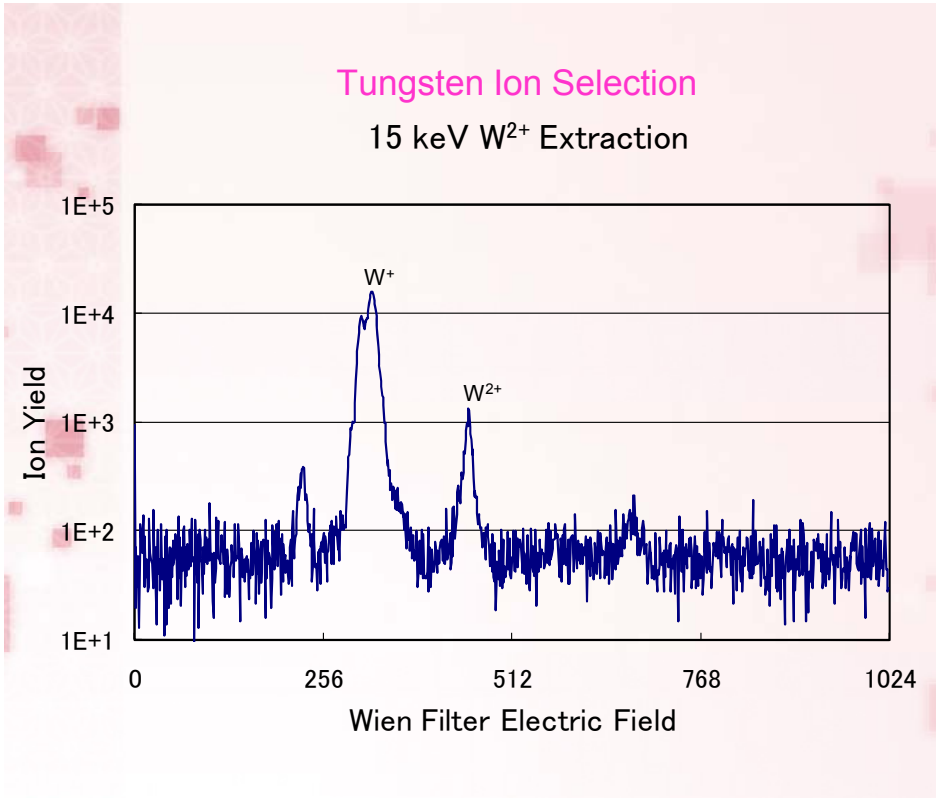


断面積測定－実験装置


The Experimental Apparatus
Pump Beam
0.9 MeV (20 keV/u) CO_2^+
Neutral Particle Rejector
Base Pressure
< 4 × 10^{-5} Pa
Accelerating Electrodes
Einzel Lens
Deflector
Collision Cell
Base Pressure
< 3 × 10^{-6} Pa
Signal 1
B
E
Accel. HV
< 16 KV
W Wire
Wien Filter
Ion Source Chamber
MCP
Biased Resistive Anode
Signal 2
Collision Chamber

断面積測定－実験装置


Tungsten Ion Selection
7.5 keV W+ Extraction
Ion Yield
1E+4
1E+3
1E+2
1E+1
1E+0
WO+
W+
WO2+
W2+
W2+
0
256
512
768
1024
Wien Filter Electric Field


Tungsten Ion Selection
15 keV W2+ Extraction
Ion Yield
1E+5
1E+4
1E+3
1E+2
1E+1
W+
W2+
0
256
512
768
1024
Wien Filter Electric Field

How to Derive Cross Sections

Rate equation for W^{i+} intensity $\frac{dF_i(\pi)}{d\pi} = \sum_{j\neq i}\left[F_j(\pi)\sigma_{ji} - F_i(\pi)\sigma_{ij}\right]$,

$$\sum_i F_i(\pi) = 1,$$

where

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

π: Target Thickness (= Density × Length in $/cm^2$)

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

Under the Single Collision Condition, this simultaneous equation reduces to $\frac{I_0}{I_2+I_1+I_0} = \sigma_{10}\pi$, $\frac{I_2}{I_2+I_1+I_0} = \sigma_{12}\pi$,

where

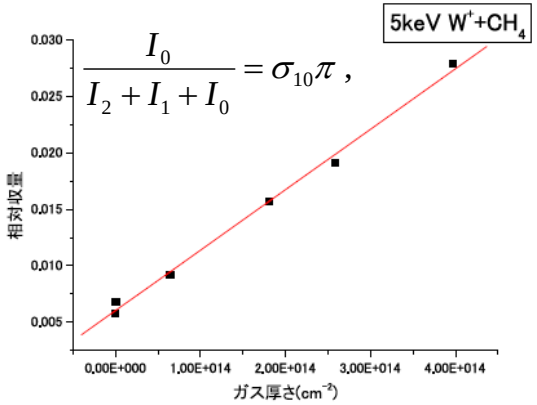
I_2, I_1, I_0: Intensity of W^{2+}, W^{+} and W^{0}, respectively.

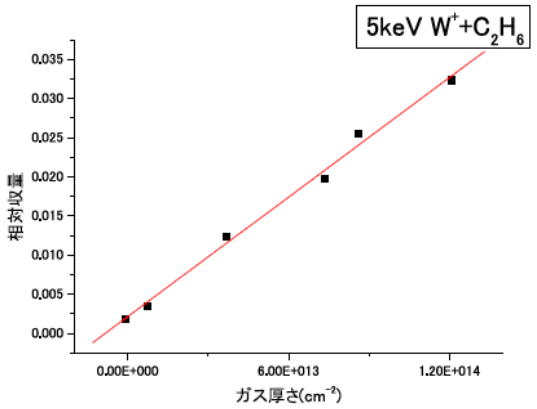
断面積測定

Data Processing

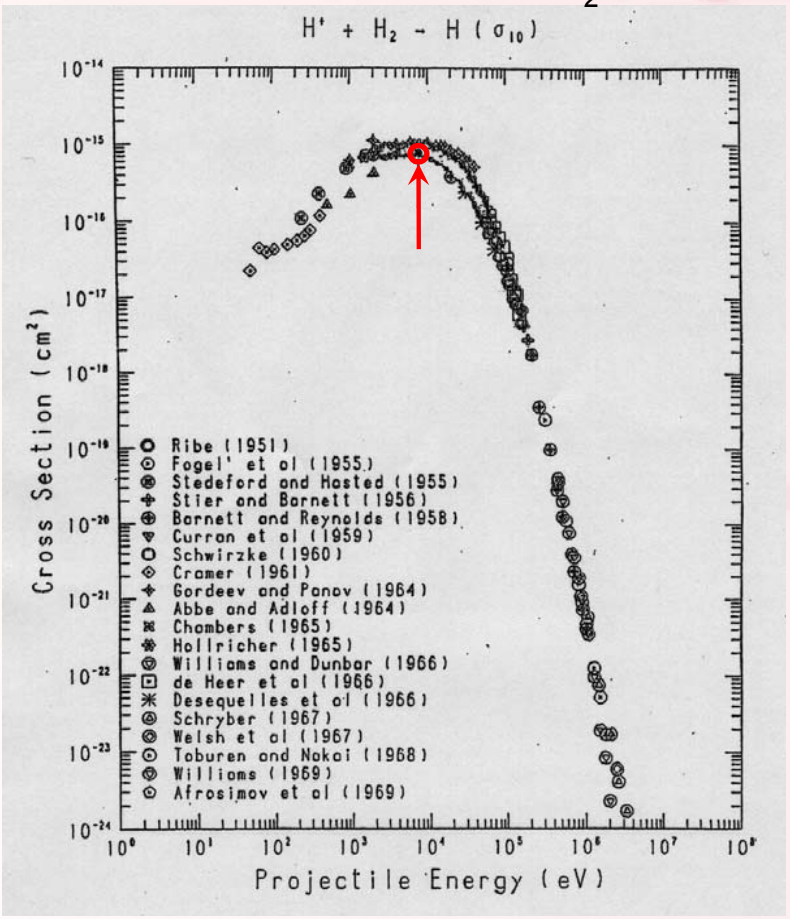
Growth Curve for 5 keV W^+

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

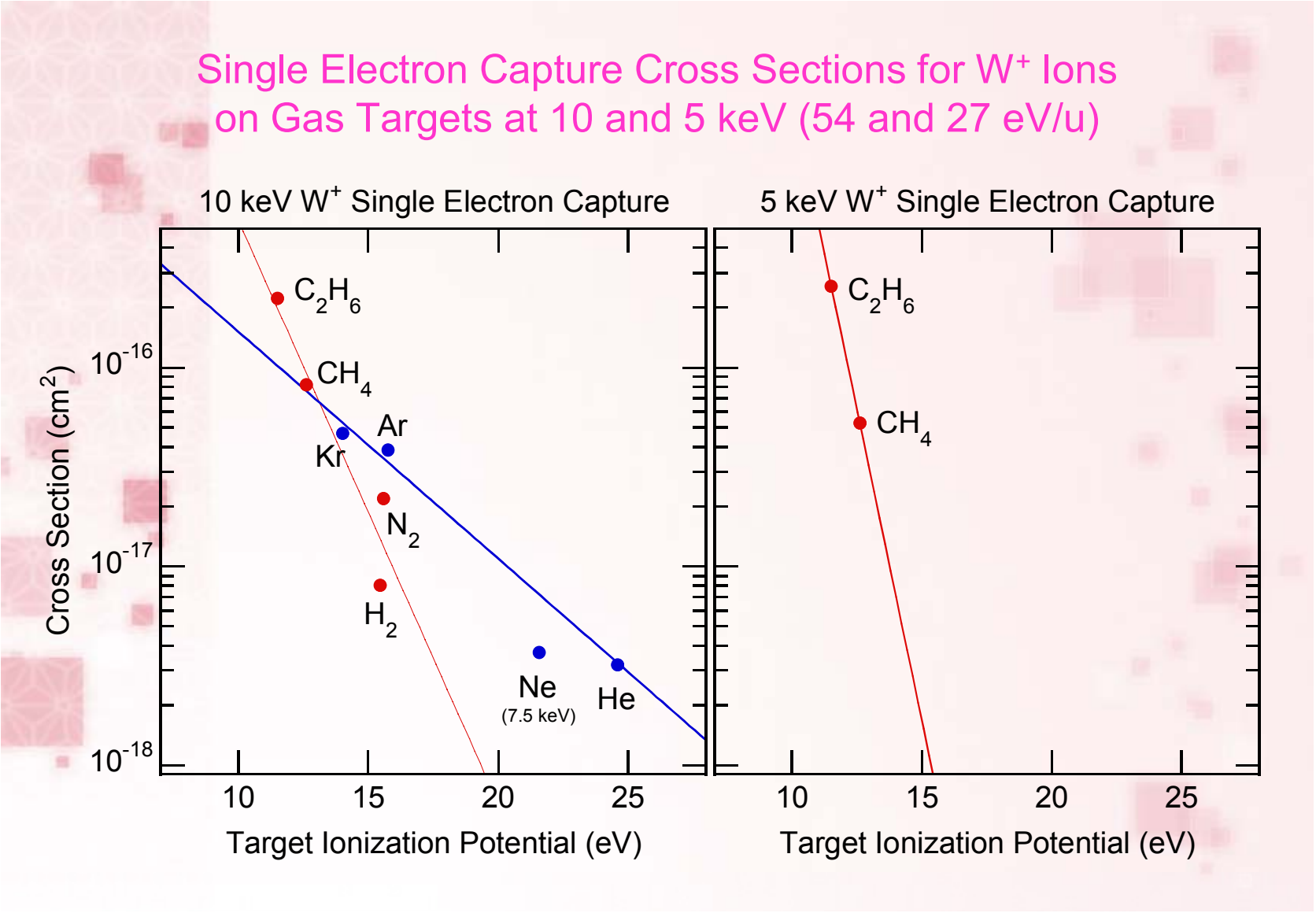




Bench mark for 7.5 keV $H^+ + H_2$ collision

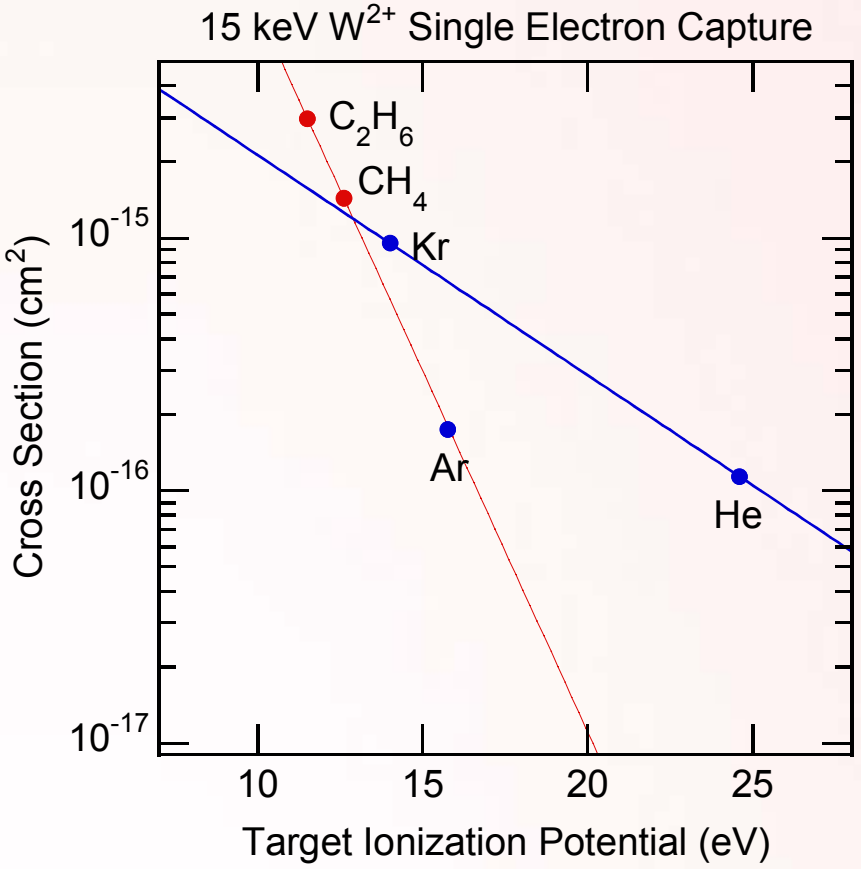


断面積測定結果

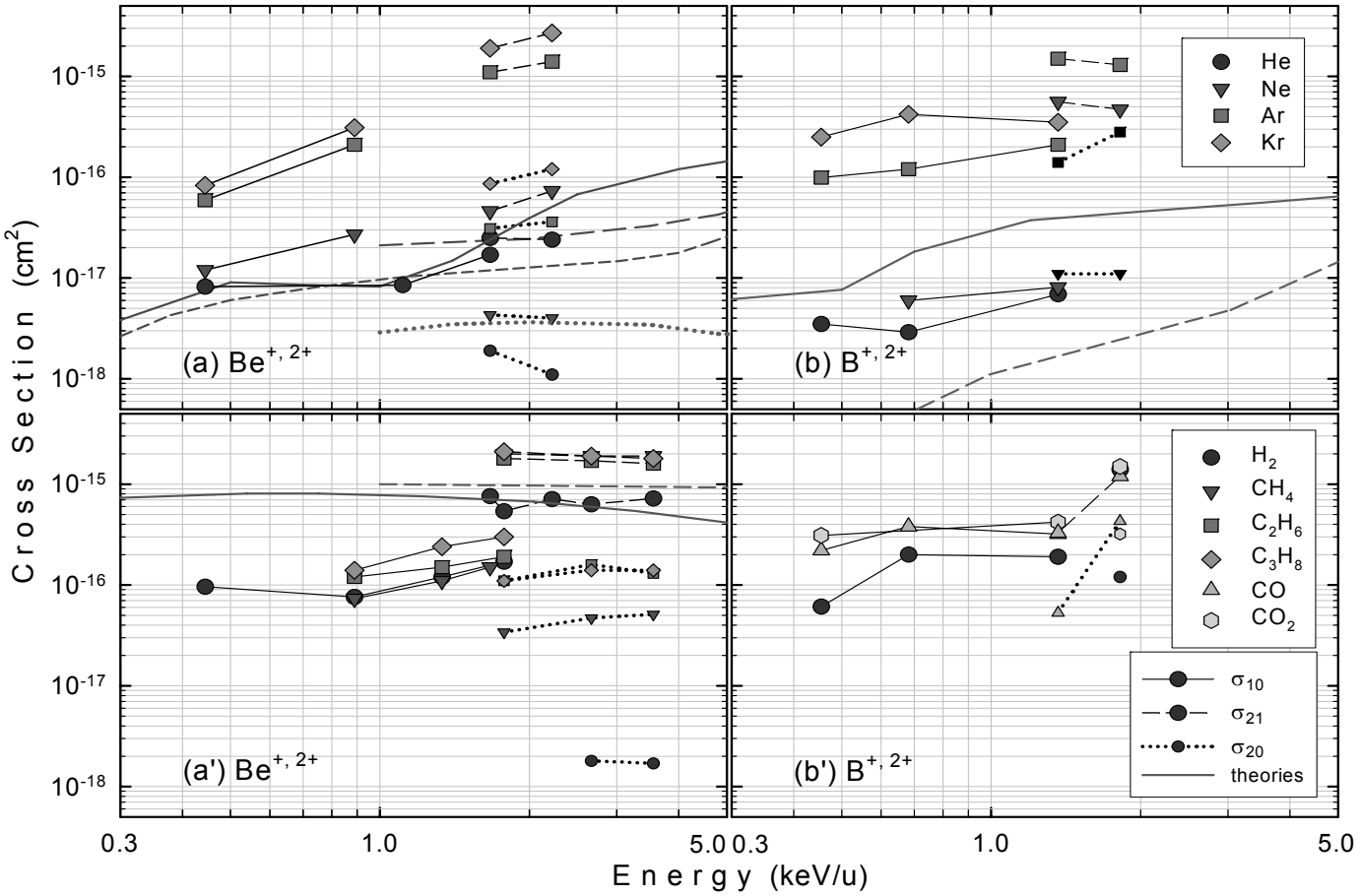

Single Electron Capture Cross Sections for W+ Ions
on Gas Targets at 10 and 5 keV (54 and 27 eV/u)
10 keV W+ Single Electron Capture
5 keV W+ Single Electron Capture
Cross Section (cm2)
10-16
10-17
10-18
C2H6
CH4
Ar
Kr
N2
H2
Ne
(7.5 keV)
He
10
15
20
25
Target Ionization Potential (eV)
Target Ionization Potential (eV)

断面積測定結果

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



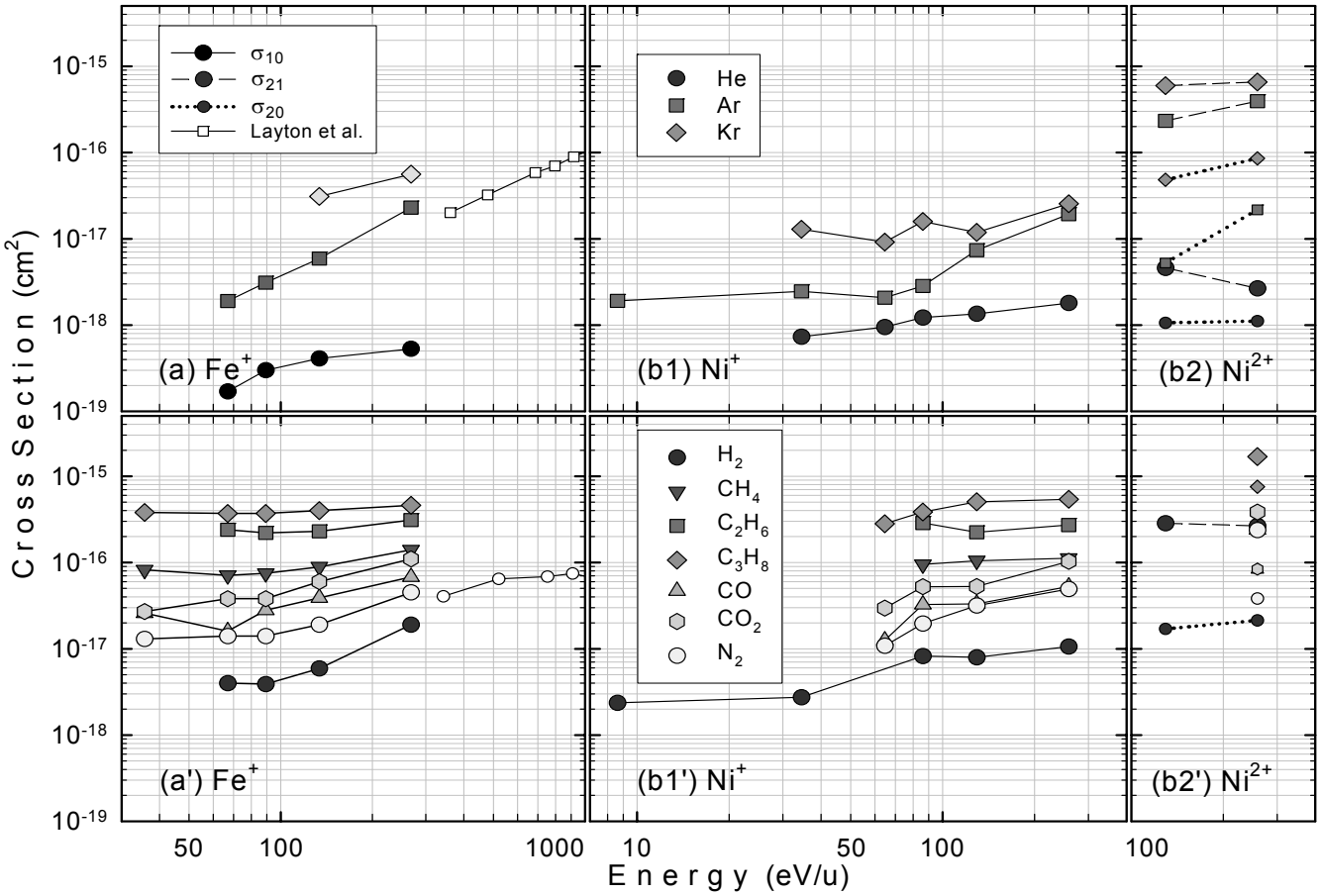
断面積測定結果



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

J. Plasma Fusion Res. SERIES Vol.7, pp.323-326.

断面積測定結果



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

J. Plasma Fusion Res. SERIES Vol.7, pp. 323-326.