

# 原子分子イオンの衝突に関する調査と 低電離 W イオンの電荷変化断面積

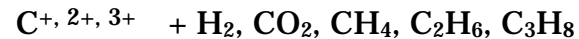
京都大学大学院工学研究科 伊藤秋男

委託研究 原子・分子・イオンの衝突に関する調査

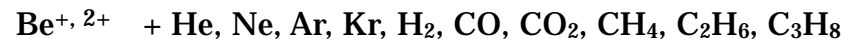
(文献調査・データシート作成)

(電荷変化断面積測定)

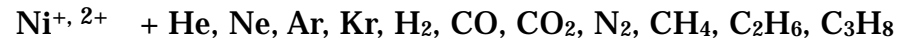
平成6年度まで



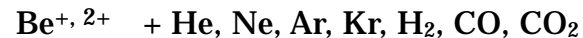
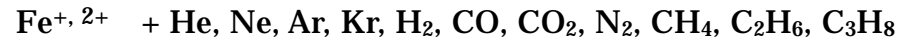
平成7~9年度 低電離金属イオンの電荷変化断面積( )( )( )



平成10~12年度 低電離 Ni イオンの電荷変化断面積( )( )( )



平成13~15年度 低電離 Fe イオンの電荷変化断面積( )( )( )



平成16~19年度 低電離 W イオンの電荷変化断面積



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

- 今井誠 科学研究費補助金 基盤研究(C) 平成18~19年度  
核融合プラズマ中の高Z不純物に関する**電荷変換断面積測定**と**データサーバ構築**.
- **Makoto Imai**, Akio Itoh, Manabu Saito, Yoichi Haruyama and Hirotaka Kubo,  
**Production and compilation** of charge changing cross sections of ion-atom and ion-molecule collisions,  
The International Conference on Photonic, Electronic and Atomic Collisions (ICPEAC XXV),  
July 25 – 31, 2007, Freiburg, Germany.
- Makoto IMAI,  
**Electron Capture Cross Section for W<sup>+</sup> Ion Colliding with Gaseous Targets & Compilation of Charge Changing Cross Section of Energetic Ion Collisions**,  
Core University Program Workshop, November 12 – 14, 2007, NFRI, Daejeon, Korea.
- M. V. Khoma, M. Imai, O. M. Karbovanets, Y. Kikuchi, M. Saito, Y. Haruyama, I. Yu. Kretinin, M. I. Karbovanets,  
A. Itoh, R. J. Buenker,  
A simple theoretical approach of electron capture processes in collisions of atomic ions with polar targets,  
ready for submission. **Be<sup>2+</sup> + CO, B<sup>2+</sup> + CO, Be<sup>2+</sup> + C<sub>3</sub>H<sub>8</sub>**

Electron Capture Cross Section for  
W<sup>+</sup> Ion Colliding with Gaseous Targets  
Compilation of Charge Changing Cross Sections of  
Energetic-Ion Collisions


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京都大学 原子核工学専攻  
今井 誠



Core University Program Workshop,  
NFRI, Daejeon, Nov 13, 2007

Outline

- Production (measurements) of charge changing (e-capture) cross sections of some fusion-related collision systems at Kyoto Univ.  
Be<sup>1,2+</sup>, B<sup>1,2+</sup>, C<sup>1,2,3+</sup>, Cr<sup>1,2+</sup>, Fe<sup>+</sup>, Ni<sup>1,2+</sup>, W<sup>+</sup>  
+ He, Ne, Ar, Kr, H<sub>2</sub>, CO, CO<sub>2</sub>, N<sub>2</sub>, CH<sub>4</sub>, C<sub>2</sub>H<sub>6</sub>, C<sub>3</sub>H<sub>8</sub>
- Brief introduction to Japanese databases at JAEA and NIFS
- Compilation of experimental charge changing cross sections from literature (co-operative activity between JAEA and Kyoto Univ.)
  - Compilation since 1983
  - Electric version started in 2006  
<http://toshi3.nucleng.kyoto-u.ac.jp:5560/isqlplus/>



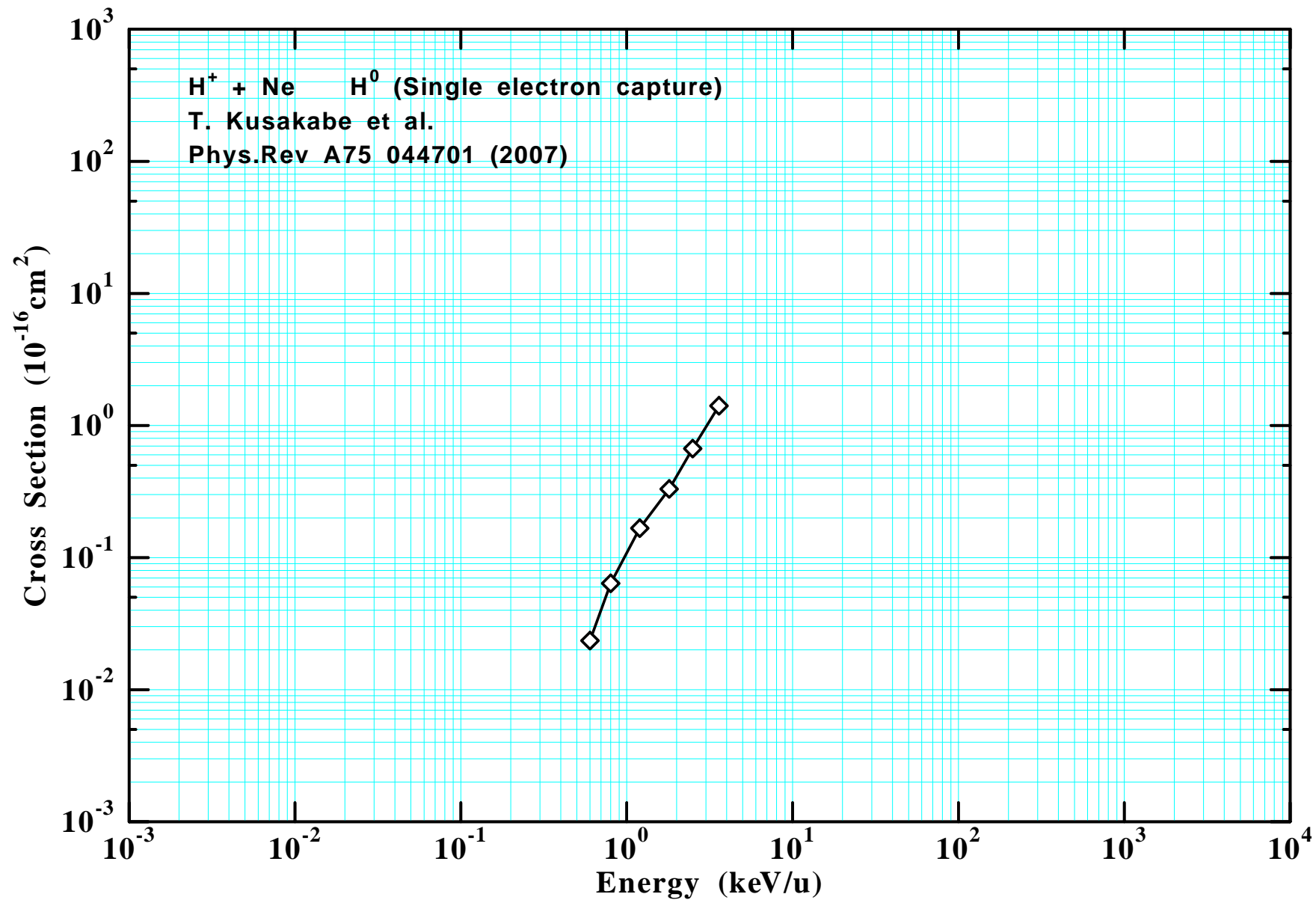
**文献調査・データシート作成**

抽出文献数

対象年	全断面積	部分断面積	その他	計
1983～1989	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	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
計	246	58	83	387

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



## Charge Changing Collision Cross Section Database

### Number of Collected Papers

Year	Total	Partial	Misc	Total
1983–1997	151	33	8	192
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
Total	229	56	71	356

### 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**.

衝突断面積データベース

## Charge Changing Collision Cross Section Database

Inside table "COL", including collision system information

DOCMO #	BRND #	CHG #	PRCHG	TWST #	TARFCHG #	PRLL #	PRLOCHG #	TWLL #	TWRGCHG #	PROCD #	EMY #	EMY #	TEML #	TEML #	PRSD #	PROCD #	PROCD #	PROCD #	METH	FT #
280400	1	0	-1	0	0	0	0	0	0		2290	4100	8100	11000	BL	BL			ATT NORM	T
280400	10	0	-1	0	0	0	0	0	0		2290	1200	8100	11000	BL	BL			ATT NORM	T
280400	4	0	-1	0	0	0	0	0	2	2a	0300	8900	89000	89000	BLD				ID PRC NORM	T
280400	8	0	-1	0	0	0	0	0	2	4a	0300	8900	89000	89000	DL-D				ID PRC NORM	T
280400	3	0	-1	0	0	0	0	0	1	2a	0300	8900	89000	89000	DL-B				ID PRC NORM	T
280400	2	0	-1	0	0	0	0	0	2	2a	0300	8900	89000	89000	DH-D				ID PRC NORM	T
280400	7	0	-1	0	0	0	0	0	1	a	0300	8900	89000	89000	DH-E				ID PRC NORM	T
280400	1	0	-1	0	0	0	0	0	0	0	2670	5200	41700	81000	BL	BL			ATT NORM	T
280400	2	0	-1	0	0	0	0	0	0	0	2670	4900	41700	81000	BL	BL			ATT NORM	T
280400	1	0	-1	0	0	0	0	0	0	0	2670	4900	41700	81000	BL	BL			ATT NORM	T
280400	5	0	-1	0	0	0	0	0	0	2a	0300	8900	89000	89000	DL-B				ID PRC NORM	T
1	93	0	2	C00	0	0	0	0	0		1810	1810	2000	3000	DC				00	F
1	94	0	2	C00	0	0	0	0	0		1384	1810	1000	3000	DC				00	F
1	95	0	2	H0	0	0	0	0	0		1810	1810	2000	3000	DC				00	F
1	92	0	2	0	0	0	0	0	0	0	1384	1810	1000	3000	DC				00	F
1	91	0	2	0	0	0	0	0	0	0	1384	1810	1000	3000	DC				00	F
1	89	0	2	C00	0	0	0	0	0		1810	1810	2000	3000	DC				00	F
1	88	0	2	C0	0	0	0	0	0		1384	1810	1000	3000	DC				00	F
1	83	0	2	H0	0	0	0	0	0		1810	1810	2000	3000	DC				00	F
1	82	0	2	0	0	0	0	0	0	0	1384	1810	1000	3000	DC				00	F
1	81	0	2	0	0	0	0	0	0	0	1384	1810	1000	3000	DC				00	F
1	37	0	1	C00	0	0	0	0	0		455	1384	500	1500	DC				00	F
1	36	0	1	C0	0	0	0	0	0		455	1384	500	1500	DC				00	F
1	35	0	1	H0	0	0	0	0	0		455	1384	500	1500	DC				00	F
1	34	0	1	0	0	0	0	0	0	0	455	1384	500	1500	DC				00	F
1	33	0	1	0	0	0	0	0	0	0	883	1384	700	1500	DC				00	F
1	32	0	1	0	0	0	0	0	0	0	488	1384	800	1500	DC				00	F
1	31	0	1	0	0	0	0	0	0	0	488	1384	800	1500	DC				00	F
1	28	0a	2	C200	0	0a	0	0	0		1770	3800	1000	3100	DC				00	F
1	27	0a	2	C200	0	0a	0	0	0		1770	3800	1000	3100	DC				00	F
1	26	0a	2	C100	0	0a	0	0	0		1770	3800	1000	3100	DC				00	F
1	25	0a	2	H0	0	0a	0	0	0		2887	2500	2400	3200	DC				00	F
1	24	0a	2	0	0	0a	0	0	0	0	1887	2223	1000	3000	DC				00	F
1	23	0a	2	0	0	0a	0	0	0	0	1887	2223	1000	3000	DC				00	F
1	22	0a	2	0	0	0a	0	0	0	0	1887	2223	1000	3000	DC				00	F
1	21	0a	2	0	0	0a	0	0	0	0	1887	2223	1000	3000	DC				00	F
1	18	0a	2	C200	0	0a	0	0	0		1770	3800	1000	3100	DC				00	F
1	17	0a	2	C200	0	0a	0	0	0		1770	3800	1000	3100	DC				00	F
1	16	0a	2	C100	0	0a	0	0	0		1770	3800	1000	3100	DC				00	F
1	15	0a	2	H0	0	0a	0	0	0		1887	2800	1800	3200	DC				00	F

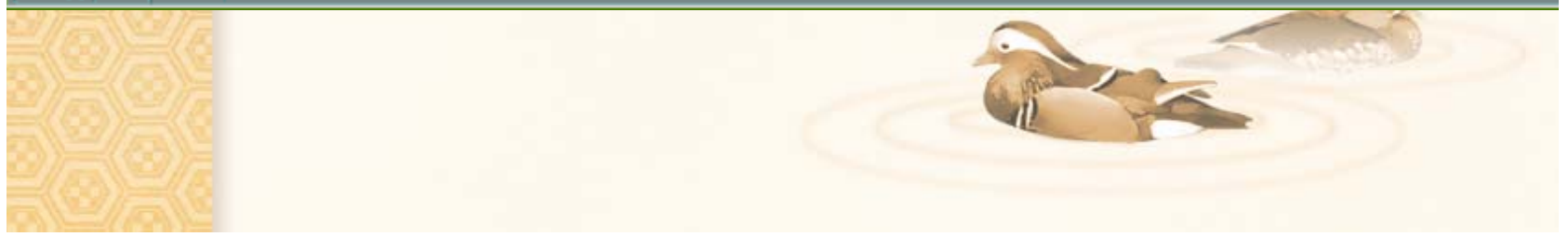


衝突断面積データベース

# Charge Changing Collision Cross Section Database

Inside table "DOC", including document information

DOCNO #	REF #	VOL #	NO #	PAGE #	PAGE2 #	YEAR #	MONTH #	TITLE	A	AUTH1 #	AUTH2 #	AUT
1	JPR9	7		322	318	2006		Production and Comparison of Charge Changing Cross Sections of Ion-Atom and Ion-Molecule Collisions	Mima	T.Shira		M E
2064001	JPR	37	2	403	413	2004	January	Electron transfer and decay processes of highly charged iodine ions	H.Sakai	A.Campo		KH
2064002	JPR	37	23	4578	4583	2004	November	Projectile electron loss and capture in MeV/u collisions of Urap 284 with Hsub 2, Hsub 3 and Ar	RC.Clean	RL.Hudson		YH
2064003	PRK	68	1	812703	9	2004	January	Absolute electron detachment cross sections of atomic anions of the second and third periods incident on noble gases	F.Zappa	G.Jahel		LF3
2064004	PRK	68	5	852704	7	2004	May	Electron capture by HeIsub 3+ ions from atomic hydrogen	R.Rjeud	MC.Banister		CC
2064005	PRK	68	5	852715	6	2004	May	Single- and double-electron-capture collisions of C1sub 9+ (q = 3,4) with CO at keV energies	H.Gao	W.S.Kiong		
2064006	PRK	78	2	822706	8	2004	August	Double- and single-electron transfer in HeIsub 4+ K collisions from E.3 to 4keV. Separation of direct double transfer and two-step successive single-electron transfer	E.Haskell	K.Kadosaka		MI
2064007	PRK	78	3	832712	7	2004	September	Electron loss from 1-4 MeV/u Urap 4,6,18+ ions colliding with He, Hsub 2, and Ar targets	RD.DuBois	ACF.Santos		Th
2064008	PRK	78	3	834701	7	2004	September	Ionization of helium by impact of negative B, O, and F ions	F.Zappa	ALF.Barnes		LF3
2064009	PRK	78	4	842701	9	2004	October	Electron capture and loss by kilo-electron-volt oxygen atoms in collisions with He, Hsub 2, Hsub 3, and CHsub 3	BO.Lindsay	WS.Ya		KF
2064010	PRK	78	4	842716	14	2004	October	Electron-capture cross sections of multiple charged slowsters of carbon, nitrogen, and oxygen in He	K.Yuki	A.Shi		KO
2064011	PRK	78	5	852716	7	2004	November	Isotope effect in charge-transfer collisions of slow HeIsub 4+ and D1sub 9+ ions with Hsub 2, HD, and D2sub 2 molecules	T.Kasakabe	L.Pehl		RJ
2064012	PRK	78	6	862716	8	2004	December	Ionization of water by (20-150-keV) protons: Separation of direct-ionization and electron-capture processes	F.Sobel	S.Eden		BC
2065001	JPR	38	13	1977	1985	2005	June	Electron transfer in collisions of keV hydrogen atoms and ions with methane	BO.Lindsay	WS.Ya		RF
2065002	PRK	71	2	822705	7	2005	February	Charge exchange and dissociative processes in collisions of slow HeIsub 2+ ions with Hsub 2O molecules	B.Szendrak	RM.McCollough		HT
2065003	PRK	71	2	822713	5	2005	February	Collision mechanisms in one-electron capture by HeIsub 2+ ions in collisions with hydrocarbons	B.Szendrak	RM.McCollough		HS
2065004	PRK	71	3	832705	9	2005	March	Cross sections for charge-changing processes involving kilo-electron-volt H and Hsub 2+ with CO and COsub 2	BO.Lindsay	WS.Ya		RF
2065005	PRK	71	3	834702	4	2005	March	Electron capture by HeIsub 4+ ions from atomic hydrogen	CC.Hansen	R.Rjeud		CR
2065006	PRK	71	4	842707	9	2005	April	Charge transfer in low-energy collisions of HeIsub 2+ with atomic hydrogen	CC.Hansen	R.Rjeud		PS
2065007	PRK	72	1	812707	8	2005	July	Charge state-resolved cross sections for electron loss, capture, and ionization in CHap 3+He collisions	T.Kochner	ACF.Santos		H L
2065008	PRK	72	1	812713	7	2005	July	Reaction molecular distributions for transfer ionization in fast proton He collisions	HT.Schmidt	J.Janson		PR
2065009	PRK	72	3	832707	7	2005	September	Ionization cross sections of small cationic carbon clusters in high-energy collisions with helium atoms and stability of multiple charged species	F.Medda	K.Yakovlevov		M C
2065010	PRK	72	3	832708	5	2005	September	HeIsub 2+ and Hsub 2+ ionization and dissociative ionization by CHap 4+ and CHap 5+ ions at intermediate velocities: Direct and electron loss channels	ALF.Barnes	S.Mattac		F Z
2065011	PRK	72	4	842701	7	2005	October	Single-electron capture processes in slow collisions of HeIsub 2+ ions with CHsub 2, Hsub 3, Hsub 3, and COsub 2	O.Abel-Hira	E.Kamber		SM
2065012	PRK	72	5	852716	7	2005	November	Charge-changing cross sections of HeIsub 0,1+ and HeIsub 0,1+3+ projectiles in CHap 6+	A.Shi	K.Nose		YH







衝突断面積データベース

## Charge Changing Collision Cross Section Database

✿ Select \* from ALEX.DOC where docno=2004002;

The screenshot shows the Oracle SQL\*Plus web interface. At the top, the Oracle logo and 'SQL\*Plus' are visible. Below the header, there is a section for '作業領域' (Working Area) with a text area containing the following SQL query:

```

select docno, sysno from ALEX.DOC
  where docno like '20%' and sysno like '4%';
select * from ALEX.DOC where docno=2004002;
select * from ALEX.DOC where docno=2004002 and sysno=41;
select * from ALEX.DOC where docno=2004002 and sysno=41;
    
```

Below the query area are buttons for '実行' (Execute), 'スクリプトのロード' (Load Script), 'スクリプトの保存' (Save Script), and '取消' (Cancel). The main part of the screen displays a table with the following data:

DOCNO	SYS	DOC NO	PAGE	PAGE TO	YEAR	MONTH	TITLE	AUTH1	AUTH2	AUTH3	AUTH4	AUTH5	AUTH6	AUTH7	AUTH8	AUTH9	DATE	CONSTR	APPT	CONSTR	RAIS	MM	RSATE	FSATE	DOI			
2004002	JPG	37	22	439	450	2004	November	Projectile electron loss and capture in Mn(V) collisions of Uragi 20+ with H <sub>2</sub> O, N <sub>2</sub> , and Ar	RE Otsu	RL Watson	V Hori	AN Pappas	F Peng	Th Stohler												040910	041100	131088095340750702012

At the bottom right of the table area, there is a '次のページ' (Next Page) button.

## Charge Changing Collision Cross Section Database

Select \* from ALEX.COL where docno=2004002 and sysno=41;

The screenshot shows the Oracle iSQL\*Plus web interface. The browser address bar displays the URL: `http://booth.nucleing.kyoto-u.ac.jp:5580/iSQL*Plus/Workspace/Event/ExecPage`. The page title is "ORACLE iSQL\*Plus". The user is logged in as "BOAMDATA@kaso".

The "作業領域" (Work Area) section contains the following SQL query:

```
SQL, PL/SQLおよびSQL*Plus文を入力してください。
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;
```

Below the query, there are buttons for "実行" (Execute), "スクリプトのロード" (Load Script), "スクリプトの保存" (Save Script), and "取消" (Cancel).

The results are displayed in a table with the following columns: DOCNO, SYSNO, PROJ1, PROJ1CHG, TARG1, TARG1CHG, PROJ2, PROJ2CHG, TARG2, TARG2CHG, PROD, EMIN, EMAX, TMIN, TMAX, PROC, PROC2, PROC3, PROC4, PROC5, METH, F.

DOCNO	SYSNO	PROJ1	PROJ1CHG	TARG1	TARG1CHG	PROJ2	PROJ2CHG	TARG2	TARG2CHG	PROD	EMIN	EMAX	TMIN	TMAX	PROC	PROC2	PROC3	PROC4	PROC5	METH	F
2004002	41	U		20	Ar	0	U	27	Ar		3500000	6500000	833000000	1550000000	SC					GR	T

At the bottom right, there is a button labeled "次のページ" (Next Page).

## Charge Changing Collision Cross Section Database

- Select \* from ALEX.DATA where docno=2004002 and sysno=41;

The screenshot shows the iSQL\*Plus web interface in a Mozilla Firefox browser. The browser address bar shows the URL: `http://toshi@nuclear.kyoto-u.ac.jp:5560/izsqlplus/workspace/ux/?event=nextPage`. The page header includes the Oracle iSQL\*Plus logo and navigation links for login, change password, and help. The user is logged in as 'IDAMDATA@nasa'. The main content area is titled '作業領域' (Work Area) and contains a text input field with the following SQL query:

```
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;
```

Below the query input field are buttons for '実行' (Execute), 'スクリプトのロード' (Load Script), 'スクリプトの保存' (Save Script), and '取消' (Cancel). The results of the query are displayed in a table with the following data:

DOCNO	SYSNO	E	TE	CS	EERR	TEERR	CSERR
2004002	41	3600000	833000000	1.1200E-17			8.9000E-19
2004002	41	6600000	1560000000	3.9000E-19			9.0000E-20

## Charge Changing Collision Cross Section Database

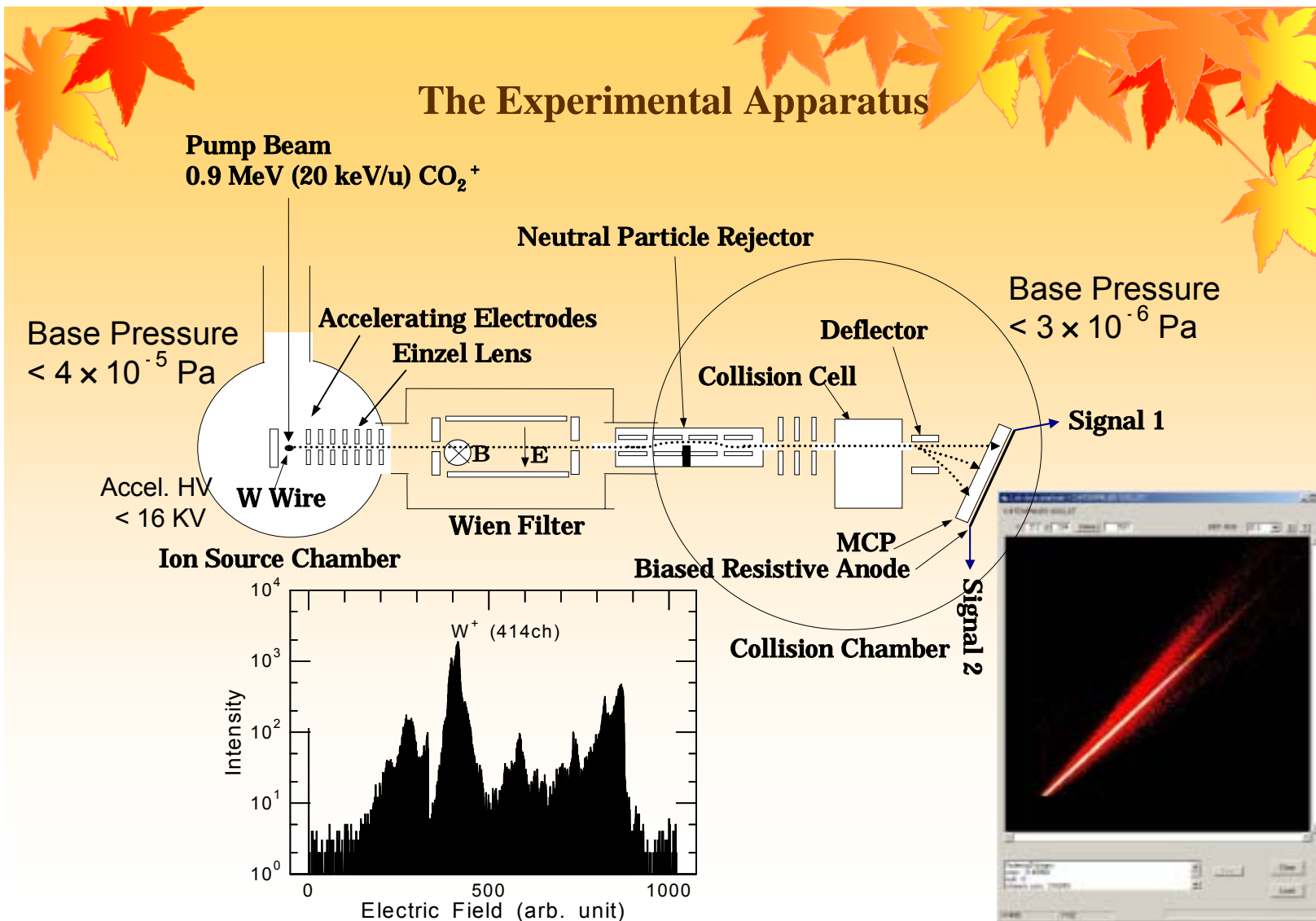
### Plan for 2008

- Retroactive input of data for previous period and other journals
- **Joining IAEA Genie Network**

2008 年中に今井が渡澳して作業することを同意済み

The screenshot shows the GENIE website interface. The main heading is "GENIE A General Internet Search Engine for Atomic Data". The page is divided into several sections: "Transition Probabilities", "Wavelengths", and "Energy Levels" on the left; a central "Genie" logo; and "Electron Impact Cross Sections and/or Rate Coefficients" on the right. The right section includes a search input field, a "Select the process:" dropdown menu, and a list of databases with checkboxes: "IAEA ALADDI Database", "IAEA AMBIS Database", "CAMSD Collision Program", and "IAEA Atomic Cross Sections". The footer contains links for "Contacts", "ALADDI", "AMBIS", "A+M Data Unit", and "IAEA".

# 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

$\pi$ : Target Thickness (= Density  $\times$  Length in /cm<sup>2</sup>)

$\sigma_{ji}$ : Charge Transfer Cross Section (cm<sup>2</sup>)  $W^{j+} \rightarrow W^{i+}$

Under the Single Collision Condition, this simultaneous equation

reduces to

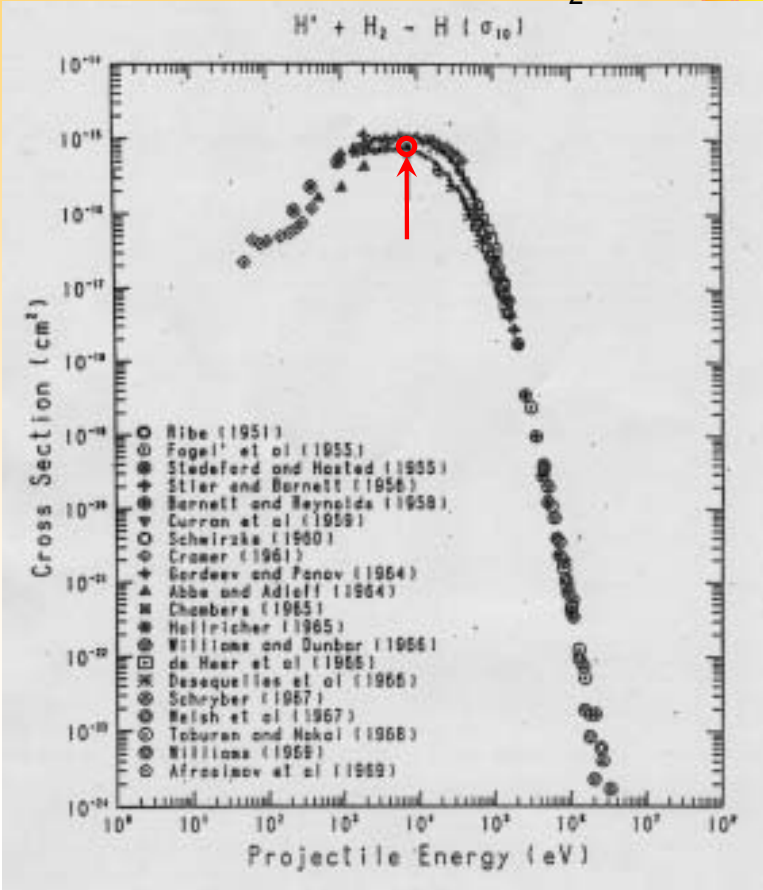
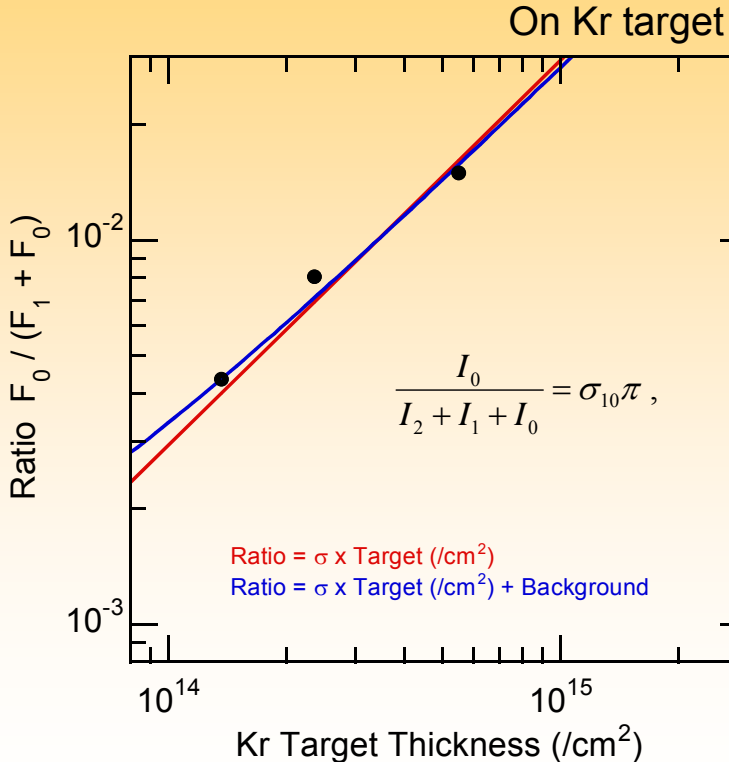
$$\frac{I_0}{I_2 + I_1 + I_0} = \sigma_{10}\pi, \quad \frac{I_2}{I_2 + I_1 + I_0} = \sigma_{12}\pi,$$

where

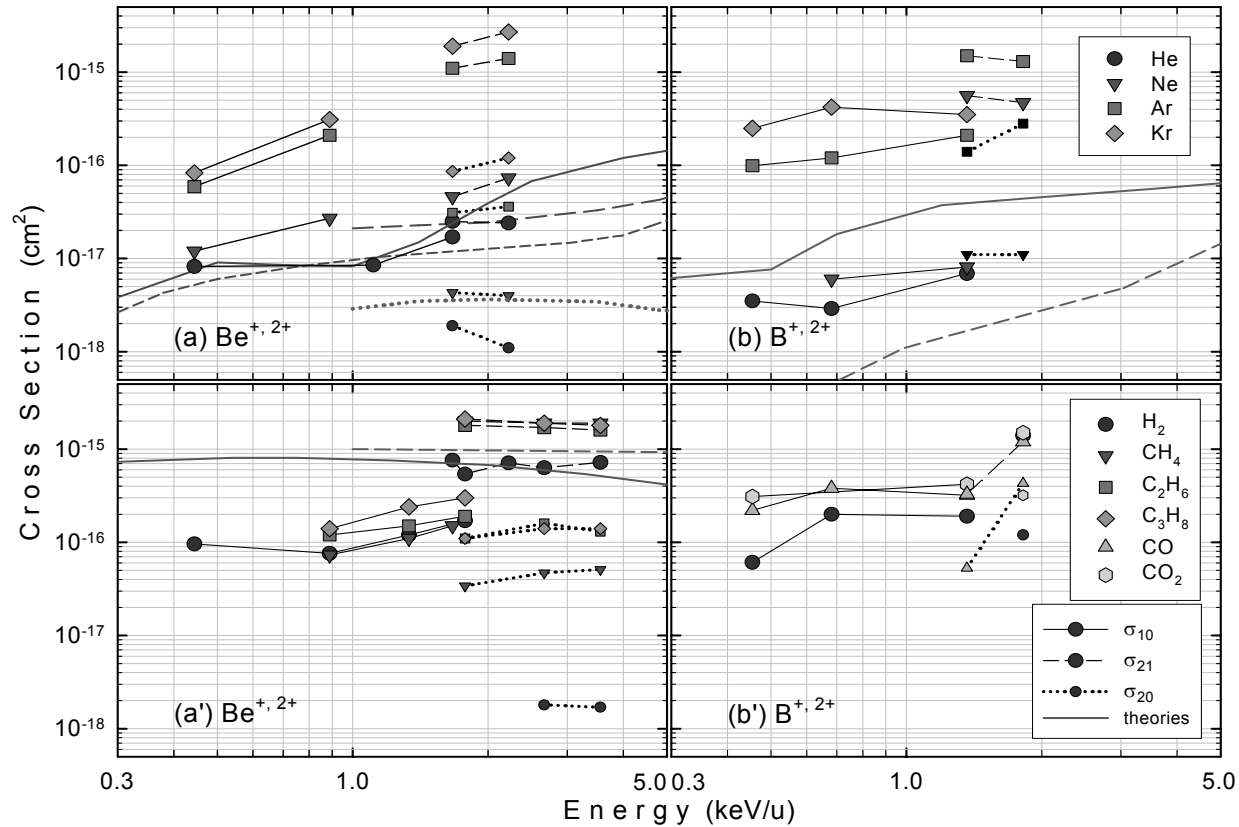
$I_2, I_1, I_0$ : Intensity of  $W^{2+}, W^{+}$  and  $W^0$ , respectively.

## Data Processing

Bench mark for 7.5 keV H<sup>+</sup> + H<sub>2</sub> collision



測定結果



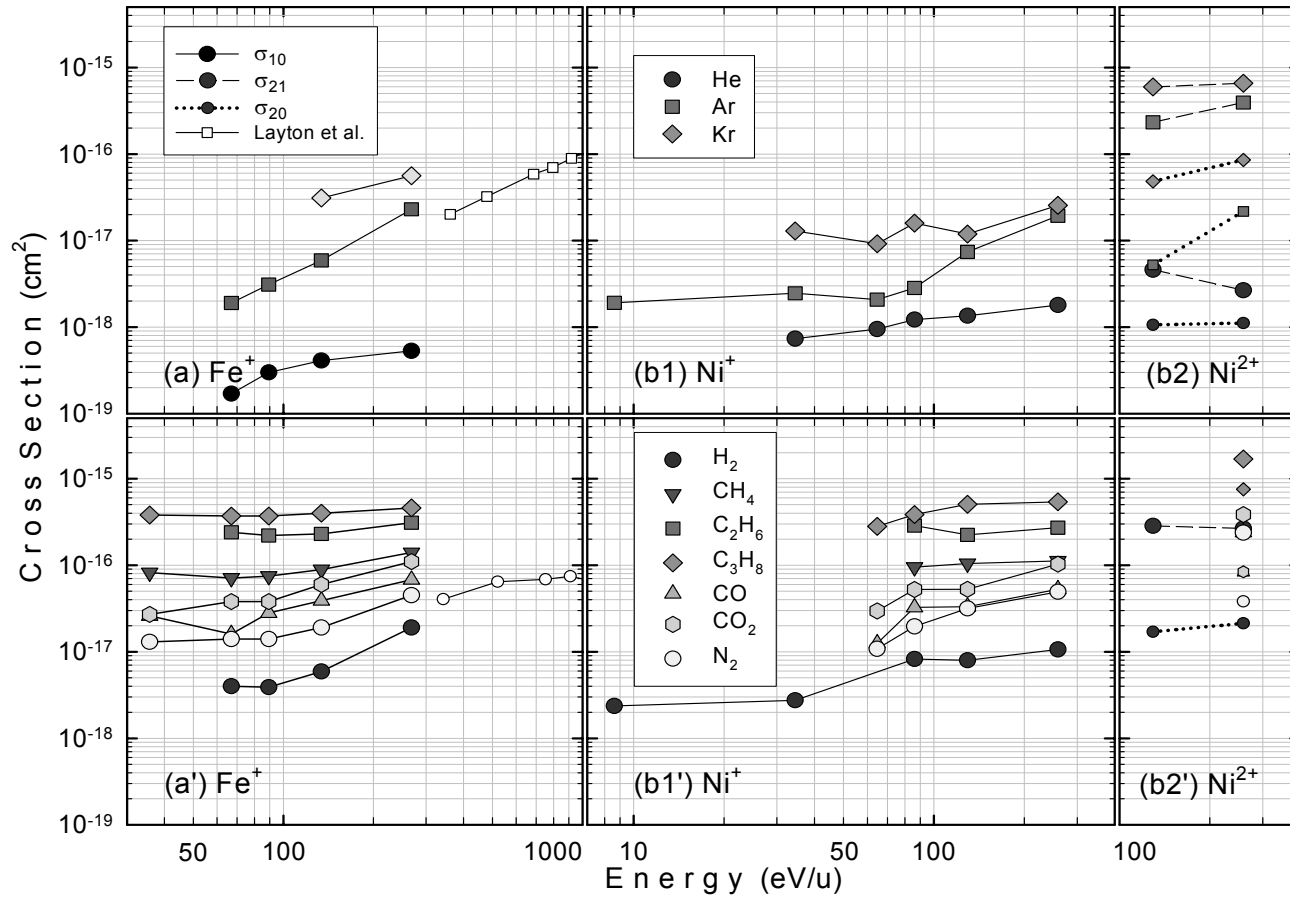
Single and double electron capture cross sections  $\sigma_{10}$ ,  $\sigma_{21}$  and  $\sigma_{20}$  for (a), (a') Be ions and (b), (b') B ions.

Present value: filled symbols connected with full and dashed lines,  $\sigma_{10}$  and  $\sigma_{21}$ , respectively; filled smaller symbols connected with dotted lines,  $\sigma_{20}$ .

Calculated values: (a) open circle with full line,  $\sigma_{10}$  for He by Shimakura; open circle and triangle with dashed line,  $\sigma_{21}$  for He by Fritsch and Suzuki et al., respectively; open circle with dotted line,  $\sigma_{20}$  for He by Fritsch; (a') open circle and triangle with dashed line,  $\sigma_{21}$  for H<sub>2</sub> by Kimura and Lane and Schultz et al., respectively; (b) open circle and triangle with full line,  $\sigma_{10}$  for He by Shimakura et al. and Hansen and Dubois, respectively.

ICAMDATA2004 (October 5–8, 2004, 土岐市); Journal of Plasma and Fusion Research SERIES Vol.7 (2006), pp.323–326.

測定結果



Single and double electron capture cross sections  $\sigma_{10}$ ,  $\sigma_{21}$  and  $\sigma_{20}$  for (a), (a') Fe<sup>+</sup> ion, (b1), (b1') Ni<sup>+</sup> ion and (b2), (b2') Ni<sup>2+</sup> ion. Present value: filled symbols connected with full and dashed lines,  $\sigma_{10}$  and  $\sigma_{21}$ , respectively; filled smaller symbols connected with dotted lines,  $\sigma_{20}$ . Open square and circle with full line in the (a) and (a') sections denote experimental values  $\sigma_{10}$  for Ar and N<sub>2</sub> targets, respectively, by Layton et al.

ICAMDATA2004 (October 5–8, 2004, 土岐市); Journal of Plasma and Fusion Research SERIES Vol.7 (2006), pp.323–326.

測定結果

