NIST DATABASE WORK ON SPECTRA OF LIGHT ELEMENTS AND BRIEF UPDATE FOR TUNGSTEN

JOSEPH READER

Atomic Spectroscopy Group

National Institute of Standards and Technology, USA

IAEA Research Coordination Meeting

Vienna, Austria

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National Institute of
Standards and Technology
U.S. Department of Commerce

Participants

Experimental Research: (EBIT)	J. Gillaspy, Yu. Ralchenko, J. Reader,
Postdoctoral:	Y. Podpaly (MIT/Alcator)
Theoretical :	Ch. Froese-Fischer*, Yu. Ralchenko*,
Data Assessment and Compilations:	A. Kramida, J. Reader, E. Saloman*, J. Fuhr*, L. Podobedova*, J. Sansonetti*, W. Wiese*,
Database Development:	Y. Ralchenko*, A. Kramida, R. Ibacache,

*Contractor/Guest Researcher

NIST United States Department of Commerce
National Institute of Standards and Technology

Projects at NIST on Light Elements

A. Atomic Spectra Database

B. Bibliographic Databases

B. F and Ne transition probabilities; Motional Stark effect in H

C. Other Light Elements

D. W and other heavy elements

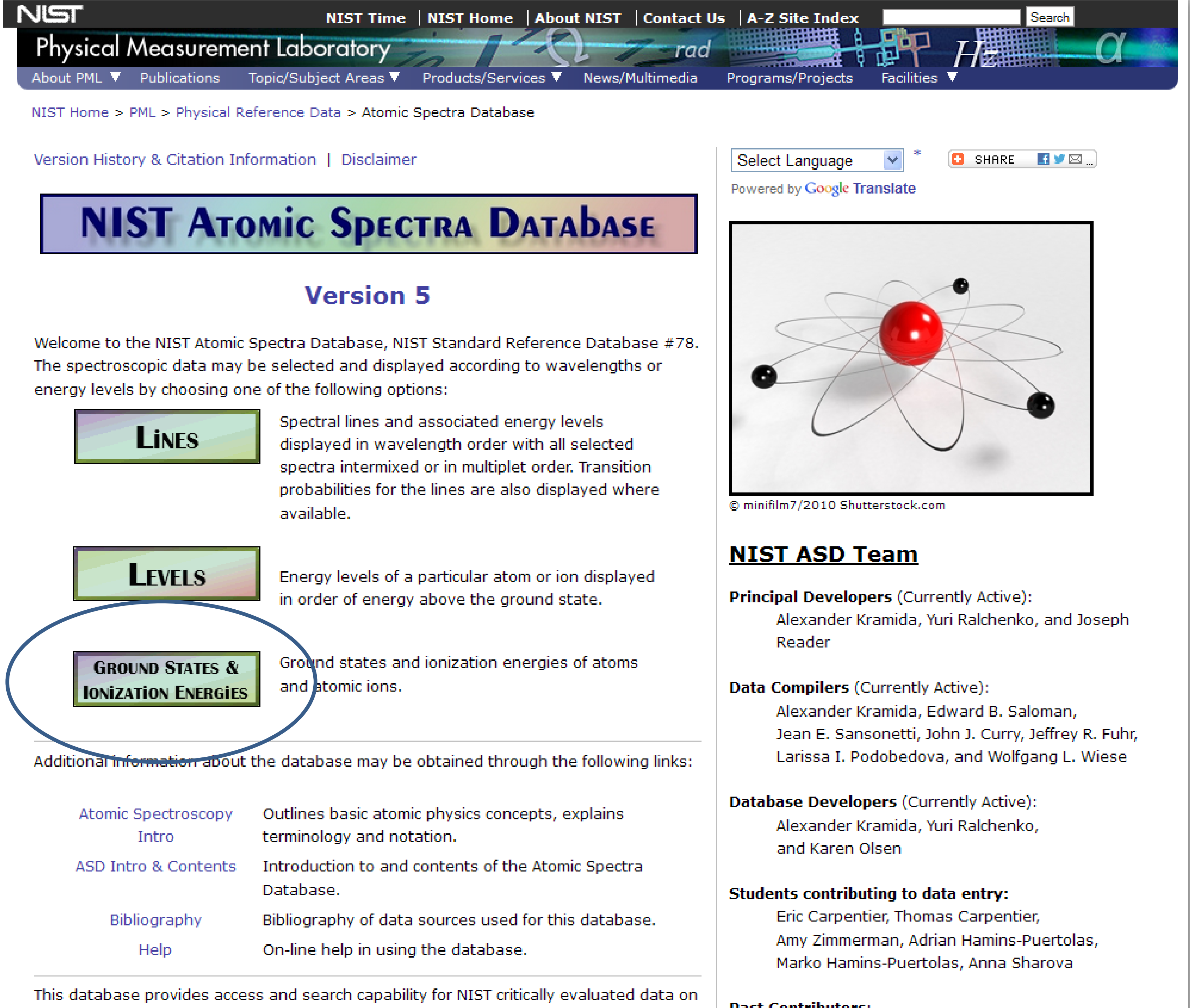
Databases

Atomic Spectra Database

- Version 5.0.0 (July 2012)
- 950 spectra
- 194,000 transition wavelengths
- 106,000 energy levels
- Auxiliary tools
  - Grotrian diagram
  - Saha-equil. radiation plot for arbitrary plasma parameters
  - Line ID plot
  - FLYCHK spectral modeling
- ~1000 queries/day

Bibliographic Databases

- Energy Levels and Wavelengths
- Atomic transition probabilities
- Line shapes and shifts



NIST ATOMIC SPECTRA DATABASE

Version 5

Welcome to the NIST Atomic Spectra Database, NIST Standard Reference Database #78. The spectroscopic data may be selected and displayed according to wavelengths or energy levels by choosing one of the following options:

LINES	Spectral lines and associated energy levels displayed in wavelength order with all selected spectra intermixed or in multiplet order. Transition probabilities for the lines are also displayed where available.
LEVELS	Energy levels of a particular atom or ion displayed in order of energy above the ground state.
GROUND STATES & IONIZATION ENERGIES	Ground states and ionization energies of atoms and atomic ions.

Additional information about the database may be obtained through the following links:

Atomic Spectroscopy Intro	Outlines basic atomic physics concepts, explains terminology and notation.
ASD Intro & Contents	Introduction to and contents of the Atomic Spectra Database.
Bibliography	Bibliography of data sources used for this database.
Help	On-line help in using the database.

This database provides access and search capability for NIST critically evaluated data on

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NIST ASD Team

Principal Developers (Currently Active):
Alexander Kramida, Yuri Ralchenko, and Joseph Reader

Data Compilers (Currently Active):
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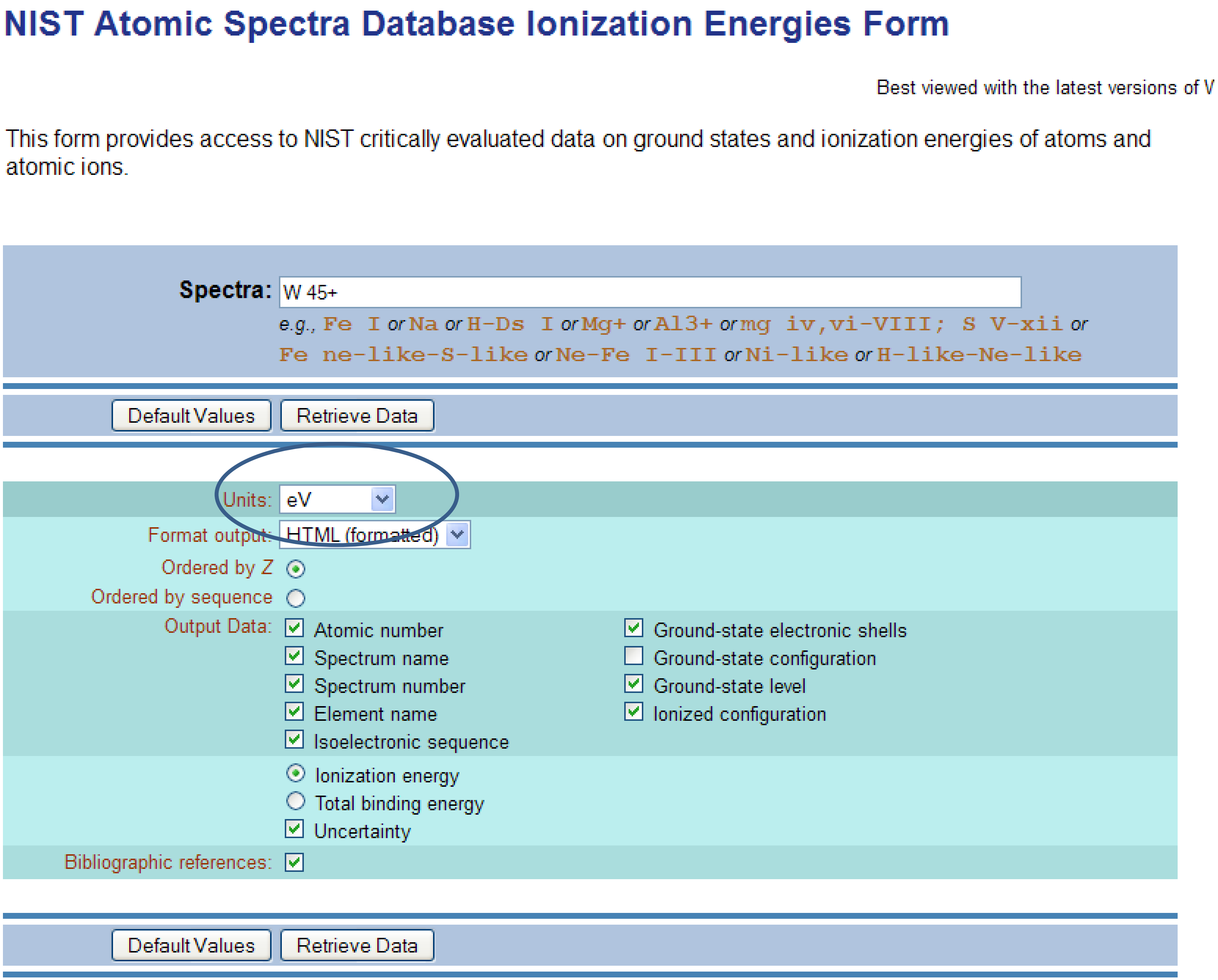
Database Developers (Currently Active):
Alexander Kramida, Yuri Ralchenko, and Karen Olsen

Students contributing to data entry:
Eric Carpentier, Thomas Carpentier, Amy Zimmerman, Adrian Hamins-Puertolas, Marko Hamins-Puertolas, Anna Sharova

Past Contributors:



NIST Atomic Spectra Database Ionization Energies Form

Best viewed with the latest versions of V

This form provides access to NIST critically evaluated data on ground states and ionization energies of atoms and atomic ions.

Spectra: W 45+

e.g., `Fe I` *or* `Na` *or* `H-Ds I` *or* `Mg+` *or* `Al3+` *or* `mg iv,vi-VIII; S V-xii` *or* `Fe ne-like-S-like` *or* `Ne-Fe I-III` *or* `Ni-like` *or* `H-like-Ne-like`

Default Values | Retrieve Data

Units: eV

Format output: HTML (formatted)

Ordered by Z ●

Ordered by sequence ○

Output Data:

- ☑ Atomic number
- ☑ Spectrum name
- ☑ Spectrum number
- ☑ Element name
- ☑ Isoelectronic sequence
- ☑ Ground-state electronic shells
- ☐ Ground-state configuration
- ☑ Ground-state level
- ☑ Ionized configuration

● Ionization energy
○ Total binding energy
☑ Uncertainty

Bibliographic references: ☑

Default Values | Retrieve Data

At. Num.	Sp. Name.	Sp. Num.	El. name	Isoel. Seq.	Ground Shells [a]	Ground Level	Ionized Level	Ionization Energy [b] (eV)	References
74	W I	1	Tungsten	W	$[\mathrm{Xe}]4f^{14}5d^46s^2$	$^5\mathrm{D}_0$	$5d^46s\ ^6\mathrm{D}_{1/2}$	7.86403(10)	L11604
74	W II	2	Tungsten	Ta	$[\mathrm{Xe}]4f^{14}5d^46s$	$^6\mathrm{D}_{1/2}$	$5d^4\ ^5\mathrm{D}_0$	[16.37(15)]	L12177
74	W III	3	Tungsten	Hf	$[\mathrm{Xe}]4f^{14}5d^4$	$^5\mathrm{D}_0$	$5d^3\ ^4\mathrm{F}_{3/2}$	[26.0(4)]	L9087
74	W IV	4	Tungsten	Lu	$[\mathrm{Xe}]4f^{14}5d^3$	$^4\mathrm{F}_{3/2}$	$5d^2\ ^3\mathrm{F}_2$	[38.2(4)]	L9087
74	W V	5	Tungsten	Yb	$[\mathrm{Xe}]4f^{14}5d^2$	$^3\mathrm{F}_2$	$5d\ ^2\mathrm{D}_{3/2}$	[51.6(3)]	L9087
74	W VI	6	Tungsten	Tm	$[\mathrm{Xe}]4f^{14}5d$	$^2\mathrm{D}_{3/2}$	$4f^{14}\ ^1\mathrm{S}_0$	[64.77(4)]	L4597
74	W VII	7	Tungsten	Er	$[\mathrm{Xe}]4f^{14}$	$^1\mathrm{S}_0$	$4f^{13}5p^6\ ^2\mathrm{F}^\circ_{7/2}$	[122.0(1)]	L3694
74	W VIII	8	Tungsten	Ho	$[\mathrm{Xe}]4f^{13}$	$^2\mathrm{F}^\circ_{7/2}$	$4f^{14}5p^4\ ^3\mathrm{P}_2$	[141.2(12)]	L9087
74	W IX	9	Tungsten	Dy	$[\mathrm{Cd}]4f^{14}5p^4$	$^3\mathrm{P}_2$	$4f^{14}5p^3\ ^2\mathrm{P}^\circ_{3/2}$	[160.2(12)]	L9087
74	W X	10	Tungsten	Tb	$[\mathrm{Cd}]4f^{14}5p^3$	$^2\mathrm{P}^\circ_{3/2}$	$4f^{14}5p^2\ ^3\mathrm{P}_0$	[179.0(12)]	L9087
74	W XI	11	Tungsten	Gd	$[\mathrm{Cd}]4f^{14}5p^2$	$^3\mathrm{P}_0$	$4f^{13}5p^2\ ^4\mathrm{F}^\circ_{7/2}$	[208.9(12)]	L9087
74	W XII	12	Tungsten	Eu	$[\mathrm{Cd}]4f^{13}5p^2$	$^4\mathrm{F}^\circ_{7/2}$	$4f^{14}\ ^1\mathrm{S}_0$	[231.6(12)]	L9087
74	W XIII	13	Tungsten	Sm	$[\mathrm{Cd}]4f^{14}$	$^1\mathrm{S}_0$	$4f^{13}5s^2\ ^2\mathrm{F}^\circ_{7/2}$	[258.3(12)]	L9087
74	W XIV	14	Tungsten	Pm	$[\mathrm{Cd}]4f^{13}$	$^2\mathrm{F}^\circ_{7/2}$	$4f^{12}5s^2\ ^3\mathrm{H}_6$	[290.7(12)]	L9087
74	W XV	15	Tungsten	Nd	$[\mathrm{Cd}]4f^{12}$	$^3\mathrm{H}_6$	$4f^{11}5s^2\ ^4\mathrm{I}^\circ_{15/2}$	[325.3(15)]	L9087
74	W XVI	16	Tungsten	Pr	$[\mathrm{Cd}]4f^{11}$	$^4\mathrm{I}^\circ_{15/2}$	$4f^{11}5s\ ^5\mathrm{I}^\circ_8$	[361.9(15)]	L9087
74	W XVII	17	Tungsten	Ce	$[\mathrm{Kr}]4d^{10}4f^{11}5s$	$^5\mathrm{I}^\circ_8$	$4f^{11}\ ^4\mathrm{I}^\circ_{15/2}$	[387.9(12)]	L9087
74	W XVIII	18	Tungsten	La	$[\mathrm{Kr}]4d^{10}4f^{11}$	$^4\mathrm{I}^\circ_{15/2}$	$4f^{10}\ ^5\mathrm{I}_8$	[420.7(14)]	L9087
74	W XIX	19	Tungsten	Ba	$[\mathrm{Kr}]4d^{10}4f^{10}$	$^5\mathrm{I}_8$	$4f^9\ ^6\mathrm{H}^\circ_{15/2}$	[462.1(14)]	L9087
74	W XX	20	Tungsten	Cs	$[\mathrm{Kr}]4d^{10}4f^9$	$^6\mathrm{H}^\circ_{15/2}$	$4f^8\ ^7\mathrm{F}_6$	[502.6(14)]	L9087
74	W XXI	21	Tungsten	Xe	$[\mathrm{Kr}]4d^{10}4f^8$	$^7\mathrm{F}_6$	$4f^7\ ^8\mathrm{S}^\circ_{7/2}$	[543.4(14)]	L9087
74	W XXII	22	Tungsten	I	$[\mathrm{Kr}]4d^{10}4f^7$	$^8\mathrm{S}^\circ_{7/2}$	$4f^6\ ^7\mathrm{F}_0$	[594.5(15)]	L9087
74	W XXIII	23	Tungsten	Te	$[\mathrm{Kr}]4d^{10}4f^6$	$^7\mathrm{F}_0$	$4f^5\ ^6\mathrm{H}^\circ_{5/2}$	[640.6(15)]	L9087
74	W XXIV	24	Tungsten	Sb	$[\mathrm{Kr}]4d^{10}4f^5$	$^6\mathrm{H}^\circ_{5/2}$	$4f^4\ ^5\mathrm{I}_4$	[685.6(16)]	L9087
74	W XXV	25	Tungsten	Sn	$[\mathrm{Kr}]4d^{10}4f^4$	$^5\mathrm{I}_4$	$4f^3\ ^4\mathrm{I}^\circ_{9/2}$	[734.1(17)]	L9087
74	W XXVI	26	Tungsten	In	$[\mathrm{Kr}]4d^{10}4f^3$	$^4\mathrm{I}^\circ_{9/2}$	$4f^2\ ^3\mathrm{H}_4$	[784.4(19)]	L9087
74	W XXVII	27	Tungsten	Cd	$[\mathrm{Kr}]4d^{10}4f^2$	$^3\mathrm{H}_4$	$4f\ ^2\mathrm{F}^\circ_{5/2}$	[833.4(19)]	L9087
74	W XXVIII	28	Tungsten	Ag	$[\mathrm{Kr}]4d^{10}4f$	$^2\mathrm{F}^\circ_{5/2}$	$4d^{10}\ ^1\mathrm{S}_0$	[881.4(16)]	L9087
74	W XXIX	29	Tungsten	Pd	$[\mathrm{Kr}]4d^{10}$	$^1\mathrm{S}$	$4d^9\ ^2\mathrm{D}$	[illegible]	L9087

um.	Sp. Name.	Sp. Num.	El. name	Isoel. Seq.	Ground Shells [a]	Ground Level	Ionized Level	Ionization Energy [b] (eV)	References
54	Xe I	1	Xenon	Xe	$[Cd]5p^6$	$^1S_0$	$5s^2 5p^5\ ^2P^\circ_{3/2}$	$12.129843_{(2)}$	L12013,L9794,L6426
55	Cs II	2	Cesium	Xe	$[Cd]5p^6$	$^1S_0$	$5s^2 5p^5\ ^2P^\circ_{3/2}$	$23.15744_{(6)}$	L6838
56	Ba III	3	Barium	Xe	$[Cd]5p^6$	$^1S_0$	$5s^2 5p^5\ ^2P^\circ_{3/2}$	$35.8438_{(25)}$	L6983
57	La IV	4	Lanthanum	Xe	$[Cd]5p^6$	$^1S_0$	$5s^2 5p^5\ ^2P^\circ_{3/2}$	$[49.95_{(6)}]$	L3974
58	Ce V	5	Cerium	Xe	$[Cd]5p^6$	$^1S_0$	$5s^2 5p^5\ ^2P^\circ_{3/2}$	$[65.55_{(25)}]$	L3974
59	Pr VI	6	Praseodymium	Xe	$[Cd]5p^6$	$^1S_0$	$4f 5s^2 5p^{4\circ}$	$(82_{(4)})$	L582
60	Nd VII	7	Neodymium	Xe	$[Cd]4f^2 5p^4$		$4f^2 5s^2 5p^{3\circ}$	$(99_{(5)})$	L582
61	Pm VIII	8	Promethium	Xe	$[Cd]4f^3 5p^3$		$4f^3 5s^2 5p^{2\circ}$	$(120_{(6)})$	L582
62	Sm IX	9	Samarium	Xe	$[Cd]4f^4 5p^2$		$4f^4 5s^2 5p^\circ$	$(141_{(7)})$	L582
63	Eu X	10	Europium	Xe	$[Cd]4f^5 5p$		$4f^5 5s^{2\circ}$	$(161_{(8)})$	L582
64	Gd XI	11	Gadolinium	Xe	$[Cd]4f^5 5p$		$4f^5 5s^{2\circ}$	$(183_{(9)})$	L582
65	Tb XII	12	Terbium	Xe	$[Cd]4f^6$		$4f^5 5s^{2\circ}$	$(216_{(11)})$	L582
66	Dy XIII	13	Dysprosium	Xe	$[Cd]4f^6$		$4f^6 5s^\circ$	$(259_{(12)})$	L582
67	Ho XIV	14	Holmium	Xe	$[Cd]4f^6$		$4f^6 5s^\circ$	$(284_{(14)})$	L582
68	Er XV	15	Erbium	Xe	$[Kr]4d^{10}4f^7 5s$	°	$4f^7\ ^8S^\circ_{7/2}$	$(311_{(16)})$	L582
69	Tm XVI	16	Thulium	Xe	$[Kr]4d^{10}4f^8$	$^7F_6$	$4f^7\ ^8S^\circ_{7/2}$	$(352_{(17)})$	L582
70	Yb XVII	17	Ytterbium	Xe	$[Kr]4d^{10}4f^8$	$^7F_6$	$4f^7\ ^8S^\circ_{7/2}$	$(396_{(20)})$	L582
71	Lu XVIII	18	Lutetium	Xe	$[Kr]4d^{10}4f^8$	$^7F_6$	$4f^7\ ^8S^\circ_{7/2}$	$(438_{(22)})$	L582
72	Hf XIX	19	Hafnium	Xe	$[Kr]4d^{10}4f^8$	$^7F_6$	$4f^7\ ^8S^\circ_{7/2}$	$(481_{(24)})$	L582
73	Ta XX	20	Tantalum	Xe	$[Kr]4d^{10}4f^8$	$^7F_6$	$4f^7\ ^8S^\circ_{7/2}$	$(526_{(30)})$	L582
74	W XXI	21	Tungsten	Xe	$[Kr]4d^{10}4f^8$	$^7F_6$	$4f^7\ ^8S^\circ_{7/2}$	$[543.4_{(14)}]$	L9087
75	Re XXII	22	Rhenium	Xe	$[Kr]4d^{10}4f^8$	$^7F_6$	$4f^7\ ^8S^\circ_{7/2}$	$(619_{(30)})$	L582
76	Os XXIII	23	Osmium	Xe	$[Kr]4d^{10}4f^8$	$^7F_6$	$4f^7\ ^8S^\circ_{7/2}$	$(670_{(30)})$	L582
77	Ir XXIV	24	Iridium	Xe	$[Kr]4d^{10}4f^8$	$^7F_6$	$4f^7\ ^8S^\circ_{7/2}$	$(720_{(40)})$	L582
78	Pt XXV	25	Platinum	Xe	$[Kr]4d^{10}4f^8$	$^7F_6$	$4f^7\ ^8S^\circ_{7/2}$	$(760_{(40)})$	L582
79	Au XXVI	26	Gold	Xe	$[Kr]4d^{10}4f^8$	$^7F_6$	$4f^7\ ^8S^\circ_{7/2}$	$(820_{(40)})$	L582
80	Hg XXVII	27	Mercury	Xe	$[Kr]4d^{10}4f^8$	$^7F_6$	$4f^7\ ^8S^\circ_{7/2}$	$(880_{(40)})$	L582
81	Tl XXVIII	28	Thallium	Xe	$[Kr]4d^{10}4f^8$	$^7F_6$	$4f^7\ ^8S^\circ_{7/2}$	$(930_{(50)})$	L582
82	Pb XXIX	29	Lead	Xe	$[Kr]4d^{10}4f^8$	$^7F_6$	$4f^7\ ^8S^\circ_{7/2}$	$(990_{(50)})$	L582
83	Bi XXX	30	Bismuth	Xe	$[Kr]4d^{10}4f^8$	$^7F_6$	$4f^7\ ^8S^\circ_{7/2}$	$(1\ 100_{(50)})$	L582

PROBLEM WITH: “Systematic calculation of total atomic energies of ground state configurations,” Rodrigues, Indelicato, Santos, Patte, and Parente, Atomic Data and Nuclear Data Tables 86, 117-233 (2004).

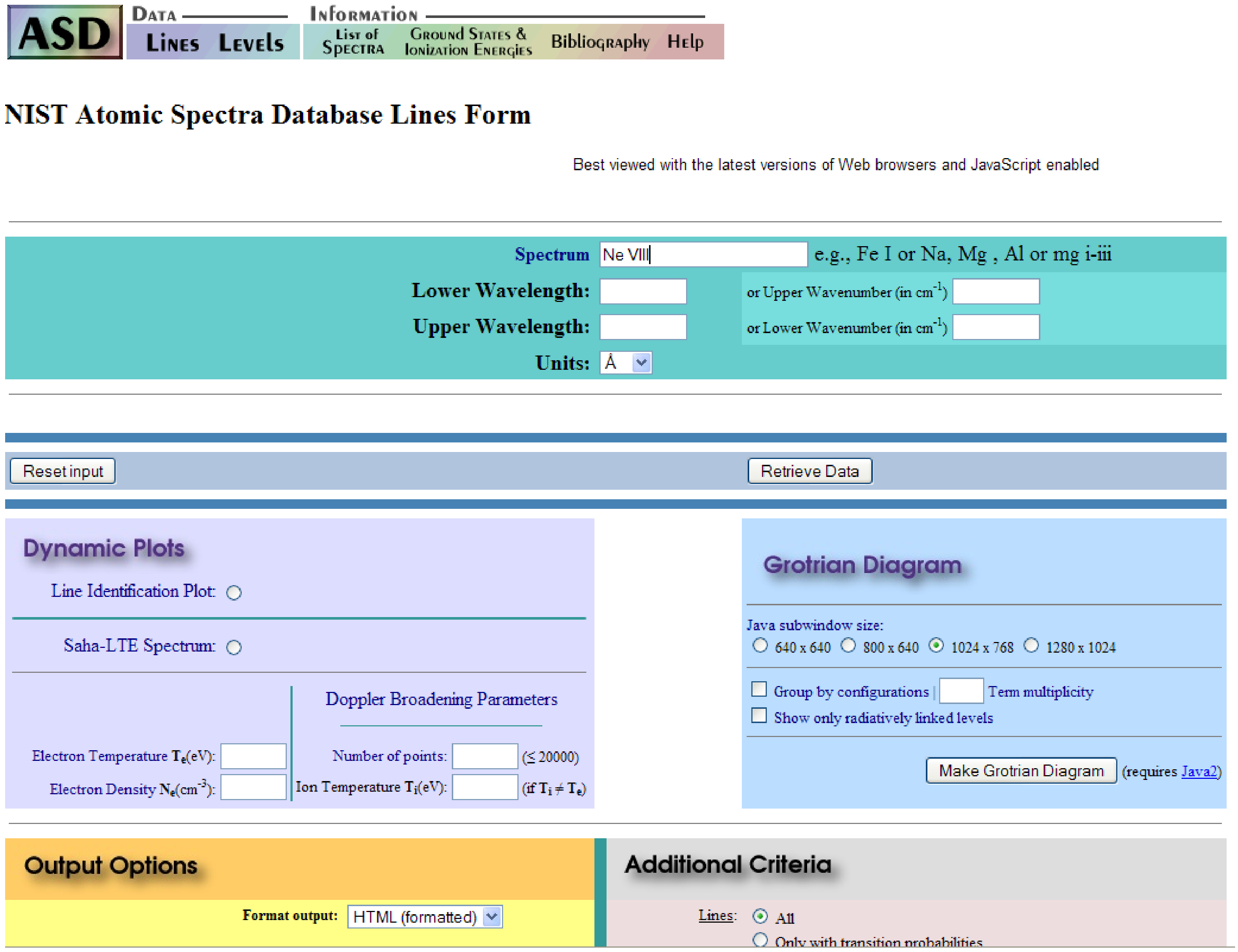
Assumed ground state configurations clearly incorrect for many ions (neglect of shell collapse at beginning of lanthanide and actinide series).

Example:

For $W^{20+:}$ Rodrigues et al. : IP=484 eV

NIST 543.4±1.4 eV

ABOUT 1000 CASES



NIST Atomic Spectra Database Lines Form

Best viewed with the latest versions of Web browsers and JavaScript enabled

Spectrum: Ne VIII   e.g., Fe I or Na, Mg , Al or mg i-iii

Lower Wavelength: or Upper Wavenumber (in cm^{-1})

Upper Wavelength: or Lower Wavenumber (in cm^{-1})

Units: Å

Dynamic Plots

Line Identification Plot: ○

Saha-LTE Spectrum: ○

Doppler Broadening Parameters

Electron Temperature T_e(eV):

Electron Density N_e(cm^{-3}):

Number of points: (≤ 20000)

Ion Temperature T_i(eV): (if $T_i \neq T_e$)

Grotrian Diagram

Java subwindow size:
○ 640 x 640 ○ 800 x 640 ● 1024 x 768 ○ 1280 x 1024

☐ Group by configurations | Term multiplicity
☐ Show only radiatively linked levels

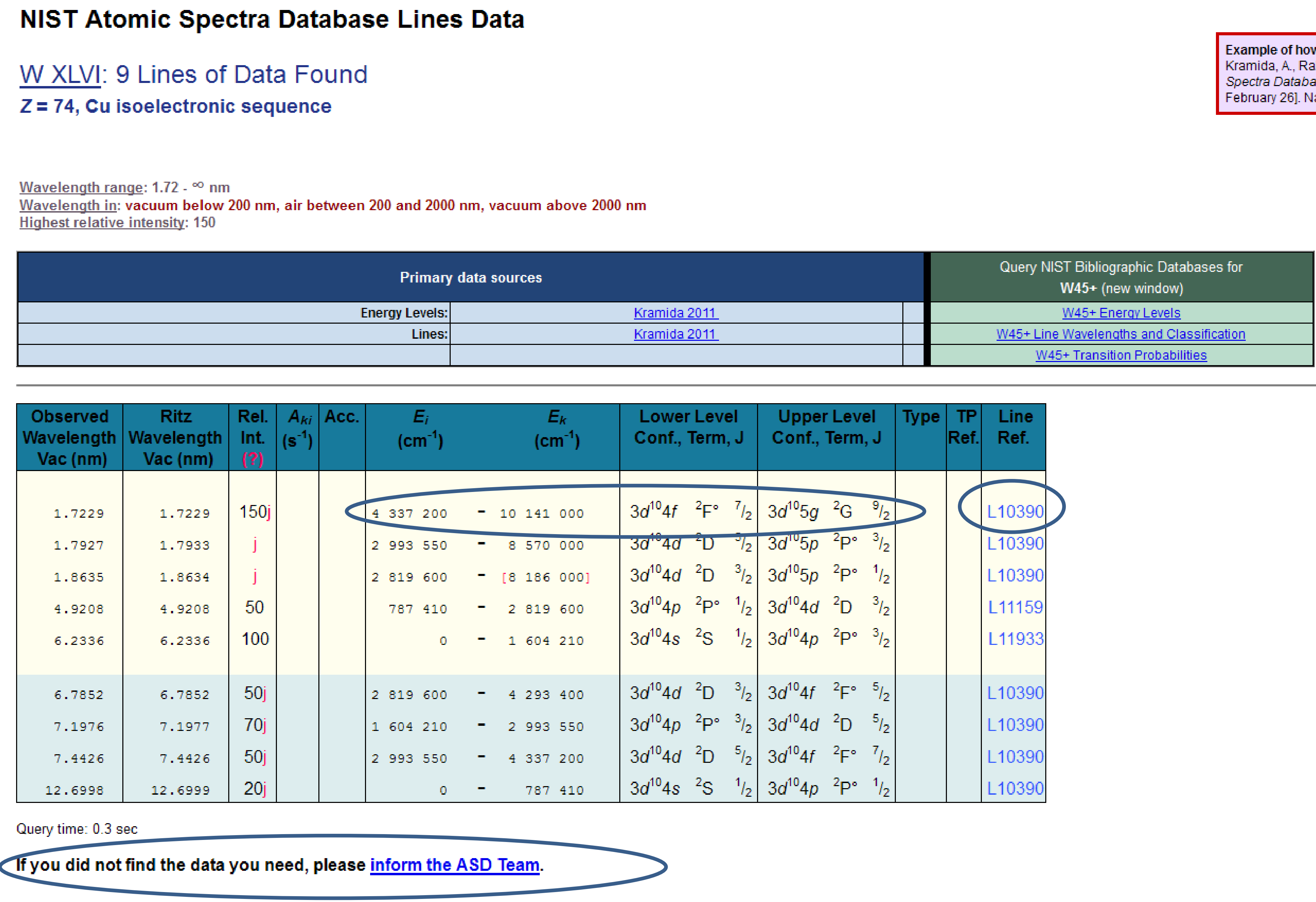
(requires Java2)

Output Options

Format output: HTML (formatted)

Additional Criteria

Lines: ● All
○ Only with transition probabilities



NIST Atomic Spectra Database Lines Data

Example of how
Kramida, A., Ra
Spectra Databa
February 26]. Na

W XLVI: 9 Lines of Data Found

Z = 74, Cu isoelectronic sequence

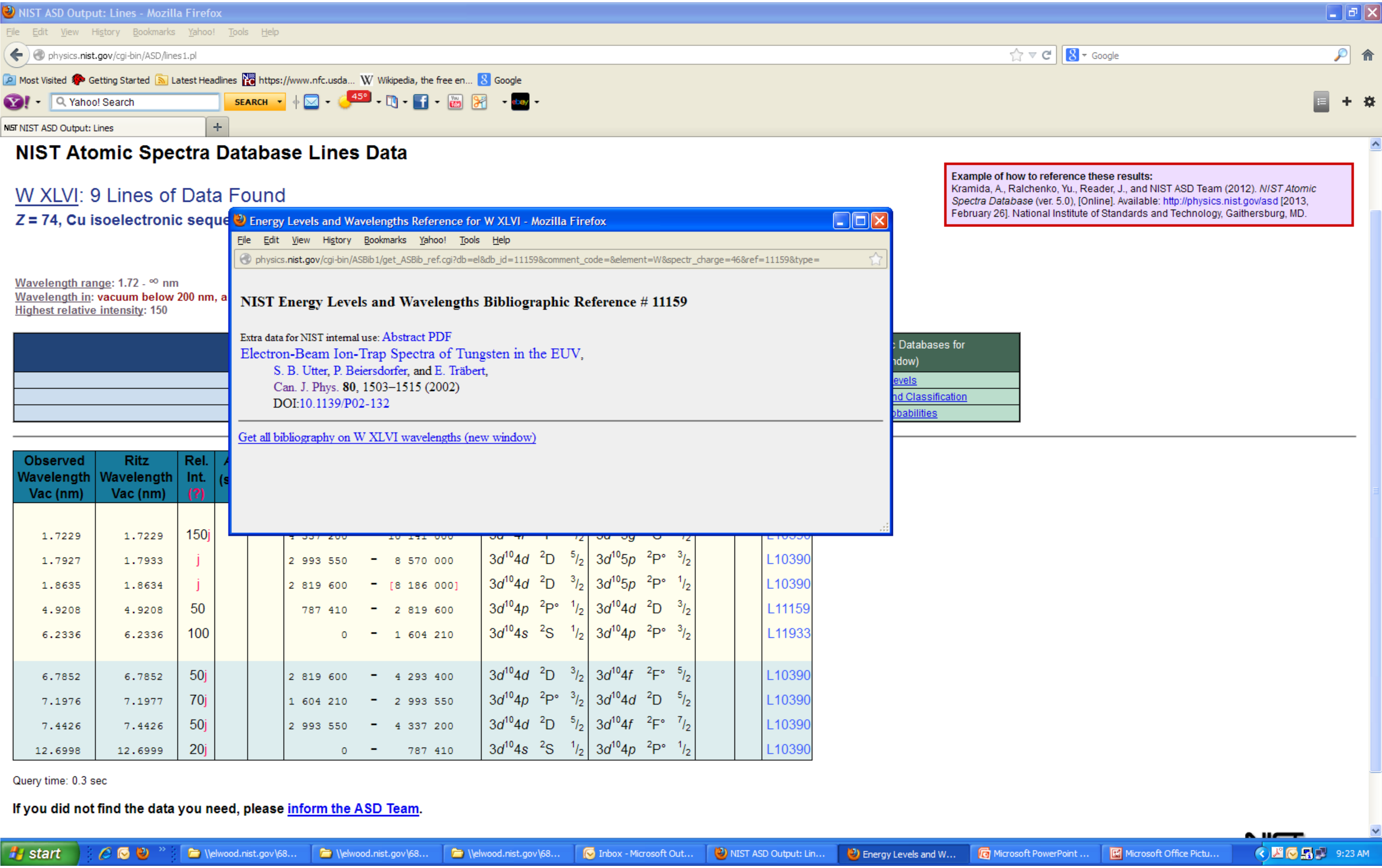
Wavelength range: 1.72 - ∞ nm
Wavelength in: **vacuum below 200 nm, air between 200 and 2000 nm, vacuum above 2000 nm**
Highest relative intensity: 150

Primary data sources			Query NIST Bibliographic Databases for **W45+** (new window)
Energy Levels:	Kramida 2011		W45+ Energy Levels
Lines:	Kramida 2011		W45+ Line Wavelengths and Classification
			W45+ Transition Probabilities

Observed Wavelength Vac (nm)	Ritz Wavelength Vac (nm)	Rel. Int. (?)	A_{ki} (s^{-1})	Acc.	E_i (cm^{-1})		E_k (cm^{-1})	Lower Level Conf., Term, J	Upper Level Conf., Term, J	Type	TP Ref.	Line Ref.
1.7229	1.7229	150j			4 337 200	-	10 141 000	$3d^{10}4f$ $^2F^\circ$ $^7/_2$	$3d^{10}5g$ ^2G $^9/_2$			L10390
1.7927	1.7933	j			2 993 550	-	8 570 000	$3d^{10}4d$ ^2D $^5/_2$	$3d^{10}5p$ $^2P^\circ$ $^3/_2$			L10390
1.8635	1.8634	j			2 819 600	-	[8 186 000]	$3d^{10}4d$ ^2D $^3/_2$	$3d^{10}5p$ $^2P^\circ$ $^1/_2$			L10390
4.9208	4.9208	50			787 410	-	2 819 600	$3d^{10}4p$ $^2P^\circ$ $^1/_2$	$3d^{10}4d$ ^2D $^3/_2$			L11159
6.2336	6.2336	100			0	-	1 604 210	$3d^{10}4s$ ^2S $^1/_2$	$3d^{10}4p$ $^2P^\circ$ $^3/_2$			L11933
6.7852	6.7852	50j			2 819 600	-	4 293 400	$3d^{10}4d$ ^2D $^3/_2$	$3d^{10}4f$ $^2F^\circ$ $^5/_2$			L10390
7.1976	7.1977	70j			1 604 210	-	2 993 550	$3d^{10}4p$ $^2P^\circ$ $^3/_2$	$3d^{10}4d$ ^2D $^5/_2$			L10390
7.4426	7.4426	50j			2 993 550	-	4 337 200	$3d^{10}4d$ ^2D $^5/_2$	$3d^{10}4f$ $^2F^\circ$ $^7/_2$			L10390
12.6998	12.6999	20j			0	-	787 410	$3d^{10}4s$ ^2S $^1/_2$	$3d^{10}4p$ $^2P^\circ$ $^1/_2$			L10390

Query time: 0.3 sec

If you did not find the data you need, please inform the ASD Team.



NIST Atomic Spectra Database Lines Data

W XLVI: 9 Lines of Data Found

Z = 74, Cu isoelectronic seque

Wavelength range: 1.72 - ∞ nm
Wavelength in: vacuum below 200 nm, a
Highest relative intensity: 150

Example of how to reference these results:
Kramida, A., Ralchenko, Yu., Reader, J., and NIST ASD Team (2012). *NIST Atomic Spectra Database* (ver. 5.0), [Online]. Available: http://physics.nist.gov/asd [2013, February 26]. National Institute of Standards and Technology, Gaithersburg, MD.

Databases for
ndow)
evels
nd Classification
obabilities

NIST Energy Levels and Wavelengths Bibliographic Reference # 11159

Extra data for NIST internal use: Abstract PDF
Electron-Beam Ion-Trap Spectra of Tungsten in the EUV,
S. B. Utter, P. Beiersdorfer, and E. Träbert,
Can. J. Phys. **80**, 1503–1515 (2002)
DOI:10.1139/P02-132

Get all bibliography on W XLVI wavelengths (new window)

Observed Wavelength Vac (nm)	Ritz Wavelength Vac (nm)	Rel. Int. (?)	A (s													
1.7229	1.7229	150j			4 337 200	-	10 141 000	[illegible]			[illegible]					L10390
1.7927	1.7933	j			2 993 550	-	8 570 000	$3d^{10}4d$	^{2}D	$^{5}/_{2}$	$3d^{10}5p$	^{2}P°	$^{3}/_{2}$			L10390
1.8635	1.8634	j			2 819 600	-	[8 186 000]	$3d^{10}4d$	^{2}D	$^{3}/_{2}$	$3d^{10}5p$	^{2}P°	$^{1}/_{2}$			L10390
4.9208	4.9208	50			787 410	-	2 819 600	$3d^{10}4p$	^{2}P°	$^{1}/_{2}$	$3d^{10}4d$	^{2}D	$^{3}/_{2}$			L11159
6.2336	6.2336	100			0	-	1 604 210	$3d^{10}4s$	^{2}S	$^{1}/_{2}$	$3d^{10}4p$	^{2}P°	$^{3}/_{2}$			L11933
6.7852	6.7852	50j			2 819 600	-	4 293 400	$3d^{10}4d$	^{2}D	$^{3}/_{2}$	$3d^{10}4f$	^{2}F°	$^{5}/_{2}$			L10390
7.1976	7.1977	70j			1 604 210	-	2 993 550	$3d^{10}4p$	^{2}P°	$^{3}/_{2}$	$3d^{10}4d$	^{2}D	$^{5}/_{2}$			L10390
7.4426	7.4426	50j			2 993 550	-	4 337 200	$3d^{10}4d$	^{2}D	$^{5}/_{2}$	$3d^{10}4f$	^{2}F°	$^{7}/_{2}$			L10390
12.6998	12.6999	20j			0	-	787 410	$3d^{10}4s$	^{2}S	$^{1}/_{2}$	$3d^{10}4p$	^{2}P°	$^{1}/_{2}$			L10390

Query time: 0.3 sec

If you did not find the data you need, please inform the ASD Team.

Spectral Data for Negative Ions

(important for neutral beam injection applications)

New in Bibliography Database

Spectra and Energy Levels of Negative Ions

H and Li

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  - **F V – allowed lines – 413**
  - **F VI – allowed lines – 255**
  - **F VI– forbidden lines – 32**
  - **F VII – allowed lines – 18**
  - **F VIII – allowed lines – 76**

- **‘Accurate atomic transition probabilities for neon,’** W. Wiese and J. Fuhr

  - **Ne VI – allowed lines – 621**
  - **Ne VII – allowed lines – 606**
  - **Ne VII – forbidden lines – 32**
  - **Ne VIII – allowed lines – 18**
  - **Ne IX– allowed lines – 80**

Reports of Bibliographic References for

International Bulletin on Atomic and Molecular Data for Fusion

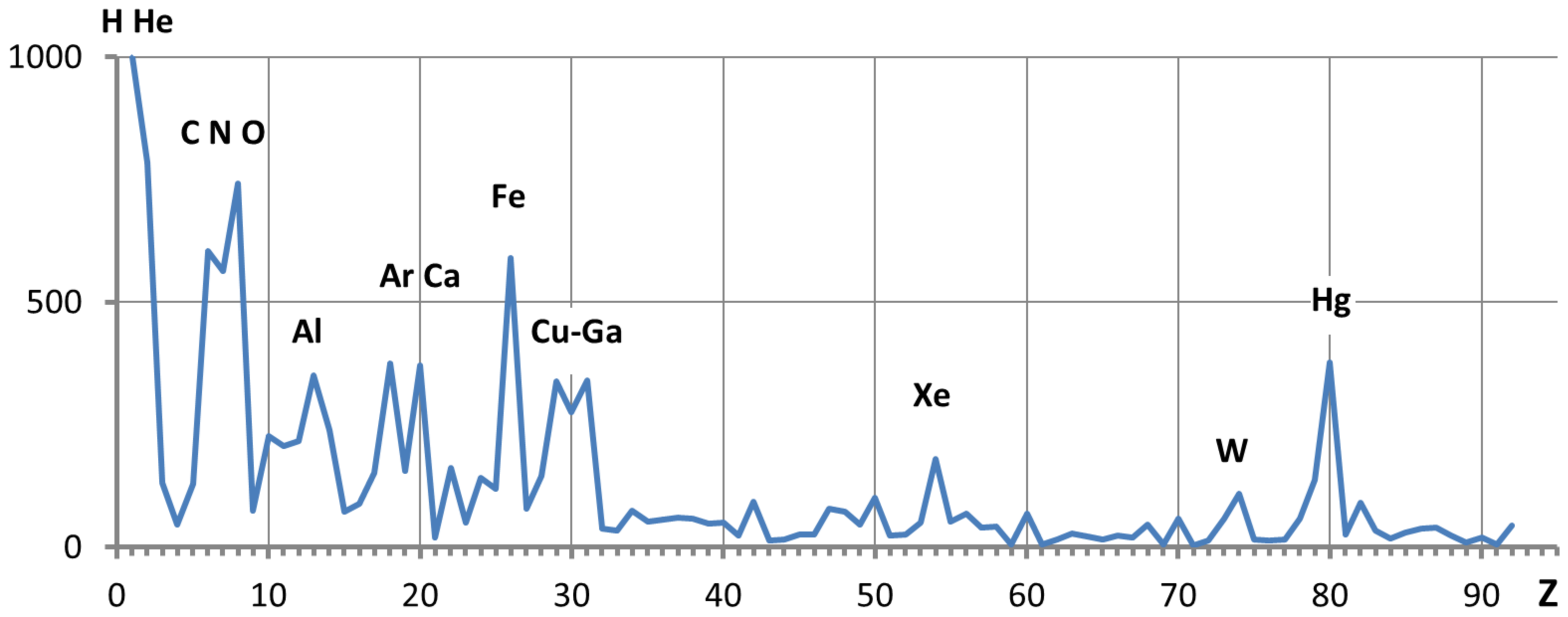
Alexander Kramida

Last Issue: Number 69 – January 2013

Chapter 3 – Bibliography

3.1 Structure and Spectra - 196 papers on energy levels and spectra; 103 papers on transition probabilities

Requests with missing data in ASD per element



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MOTIONAL STARK EFFECT FOR

DIAGNOSTICS OF LOCAL MAGNETIC FIELDS
And
LOCAL PLASMA CONDITIONS

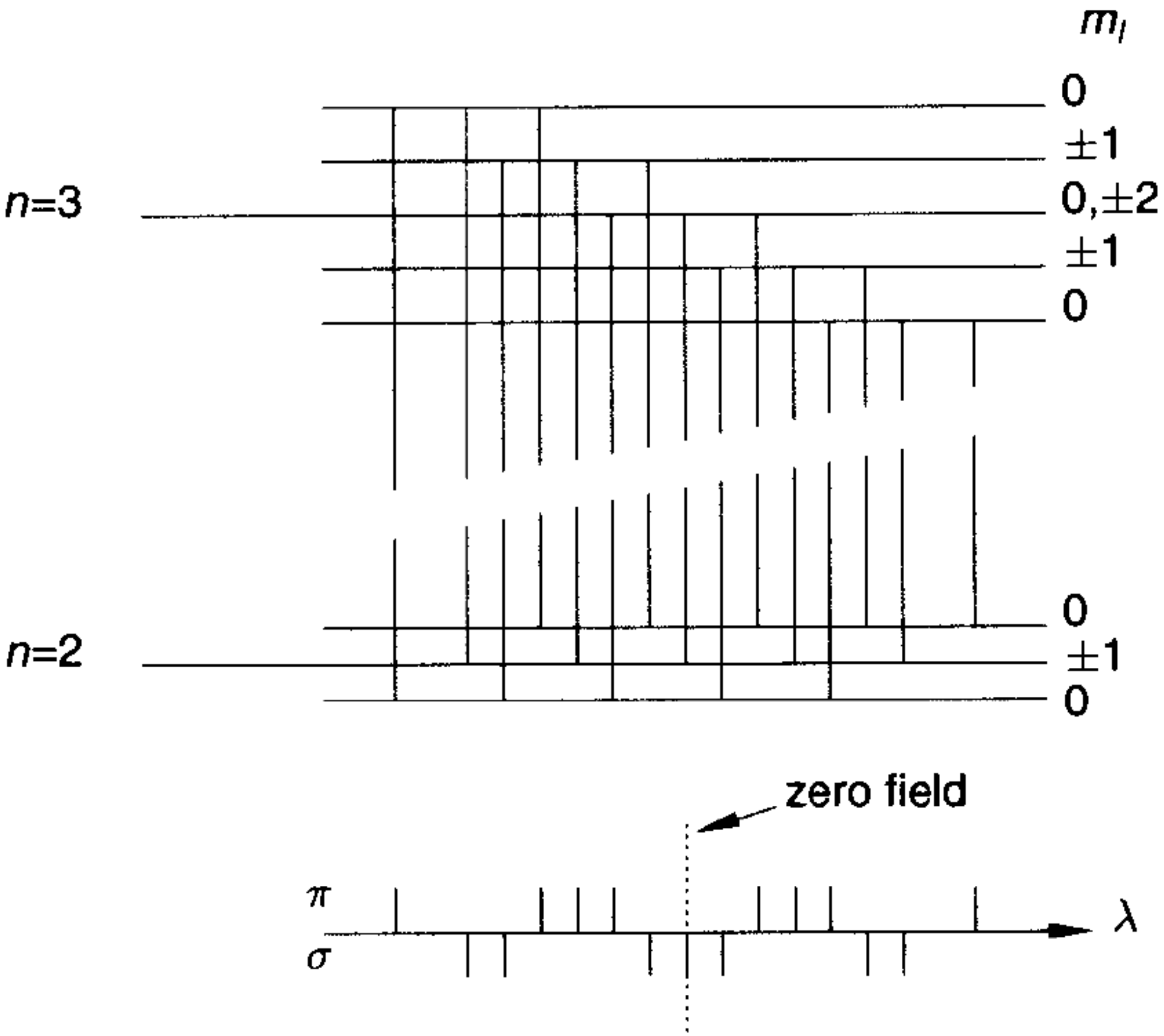
- INJECT BEAMS OF NEUTRAL HYDROGEN ATOMS

- NO-FIELD WAVE FUNCTIONS INCLUDE PRODUCTS OF SPHERICAL HARMONICS

- INDUCED ELECTRIC FIELD E=v x B MIXES THE SPHERICAL STATES AND SPLITS THE LINE MULTIPLETS

- NEW STATES ARE SOLVABLE IN PARABOLIC COORDINATES

- COLLISIONAL RADIATIVE MODELING WITH PARABOLIC STATES



Stark effect in Balmer H alpha line of Hydrogen – 656 nm

- MEASUREMENT OF SPLITTINGS GIVES INFORMATION ABOUT MAGNETIC FIELD STRENGTH

- PROBLEM TO REPRODUCE INTENSITIES OF COMPONENTS

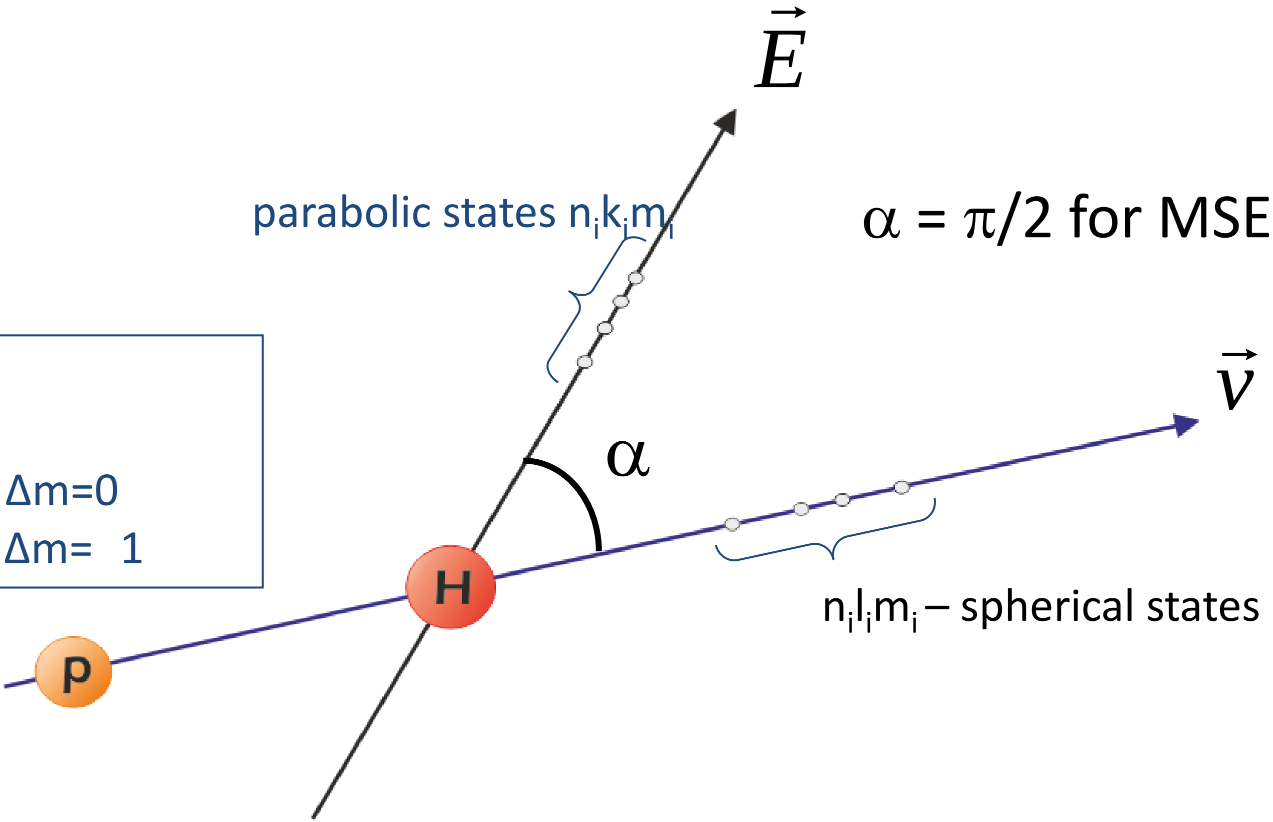
- GIVES INFORMATION ABOUT POPULATIONS OF LEVELS IN THE n=3 CONFIGURATIONS

- PARABOLIC STATES EXPANDED IN TERMS OF SPHERICAL STATES

- COLLISIONAL RADIATIVE MODELING GIVES NON-BOLTZMANN POPULATIONS OF EXCITED STATES

- REPRODUCES COMPONENT RATIOS OBSERVED IN JET PLASMA

Cross sections for parabolic states



$\alpha = \pi/2$ for MSE

Radiative channel
$n_ik_im_i \to n_jk_jm_j$
π – components with Δm=0
σ – components with Δm= 1

Parabolic states expanded as linear combination of spherical states
Marchuk et al (2009), Delabie et al (2010), Marchuk et al (2011), Ralchenko et al (2012)

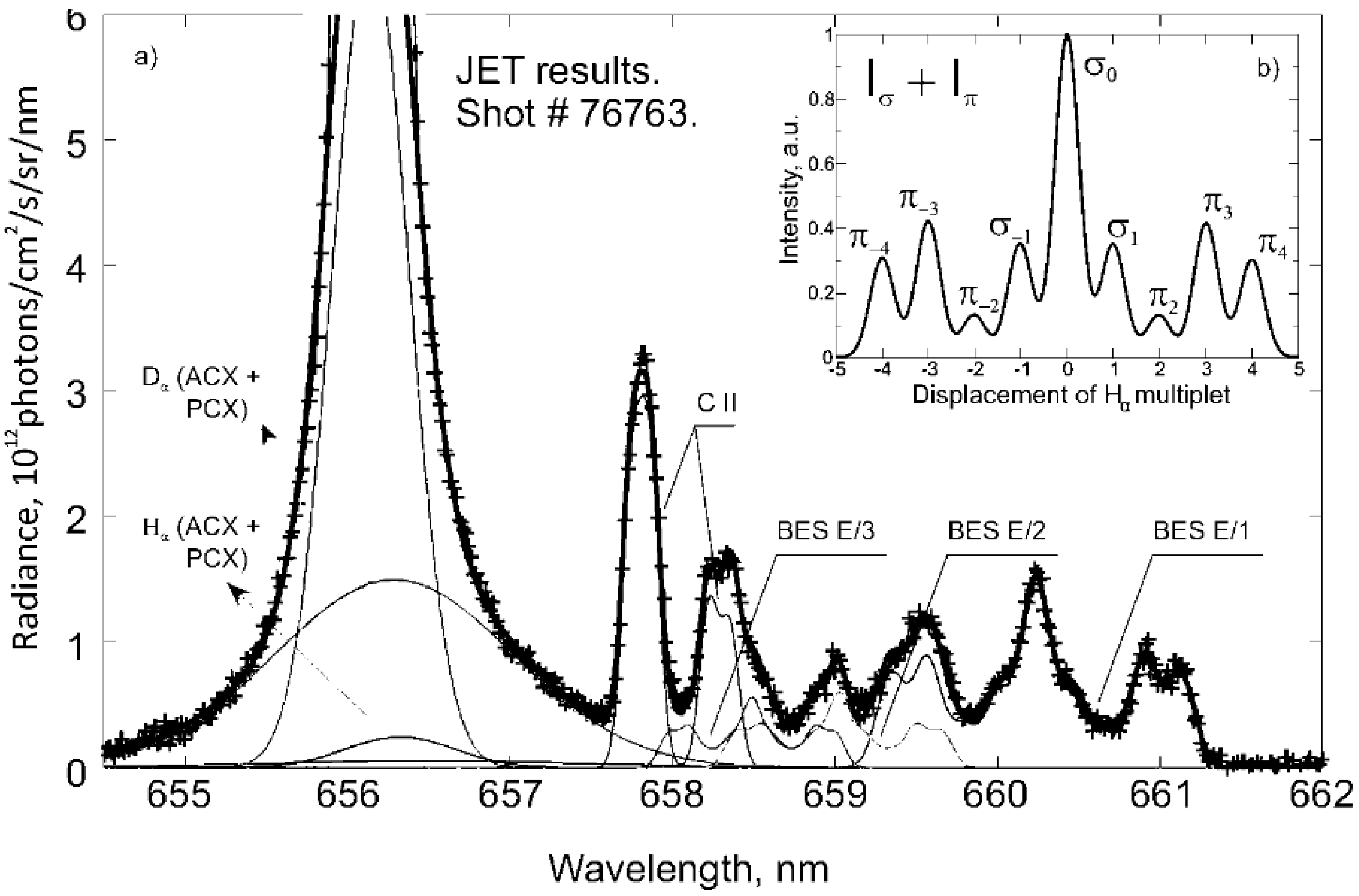


FIGURE 1. Beam emission spectrum of D_α line measured on the JET tokamak [10]. The experimental spectrum is shown by a line with pluses, the fit components are shown by solid lines. The PCX and ACX components of D_α and H_α lines are observed at 656 nm. The multiplet of C II edge lines is identified at 658 nm. The overlapping Doppler-shifted MSE lines of the first, second and third energy beam components extend between 658 and 661 nm. Inset b) shows the statistical intensities of σ- and π-components [11] of H_α line multiplet at the observation angle of 90°.

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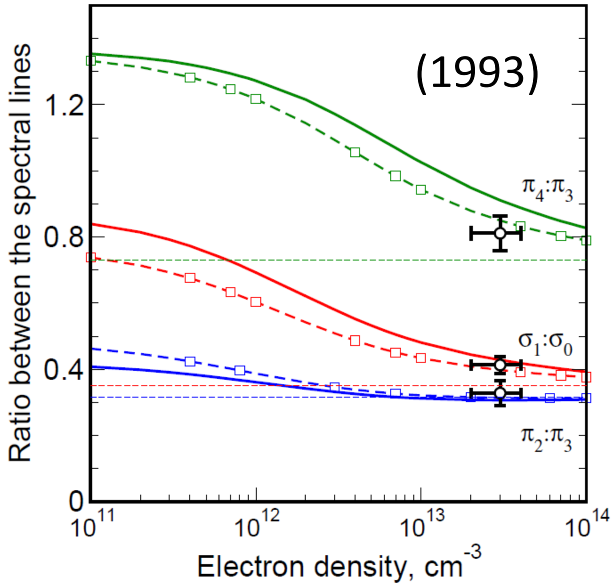
Theory vs Experiment



- Experiment 1993 - JET
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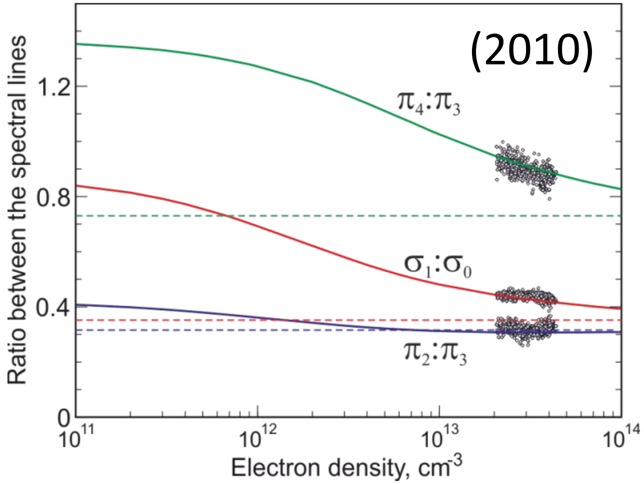
- Solid: $Z_{eff} = 1$
- Horizontal dashed: statistical limit
- Dashed w/ symbols: $Z_{eff} = 2$ (C^{6+})



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- Solid: $Z_{eff} = 1$
- Horizontal dashed: statistical limit
- **NEW EXP. ALCATOR C-MOD TO TEST CONFIRM PREDICTED LINE RATIOS**

New Papers on W

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New NIST Papers on W

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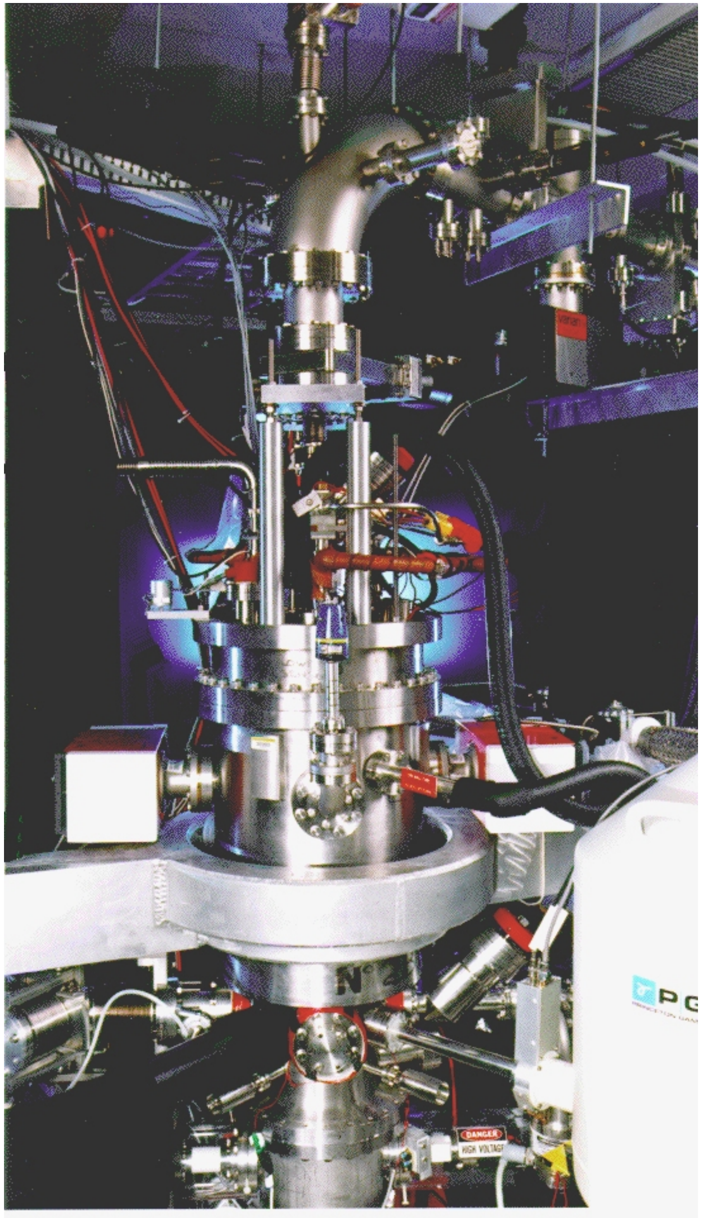
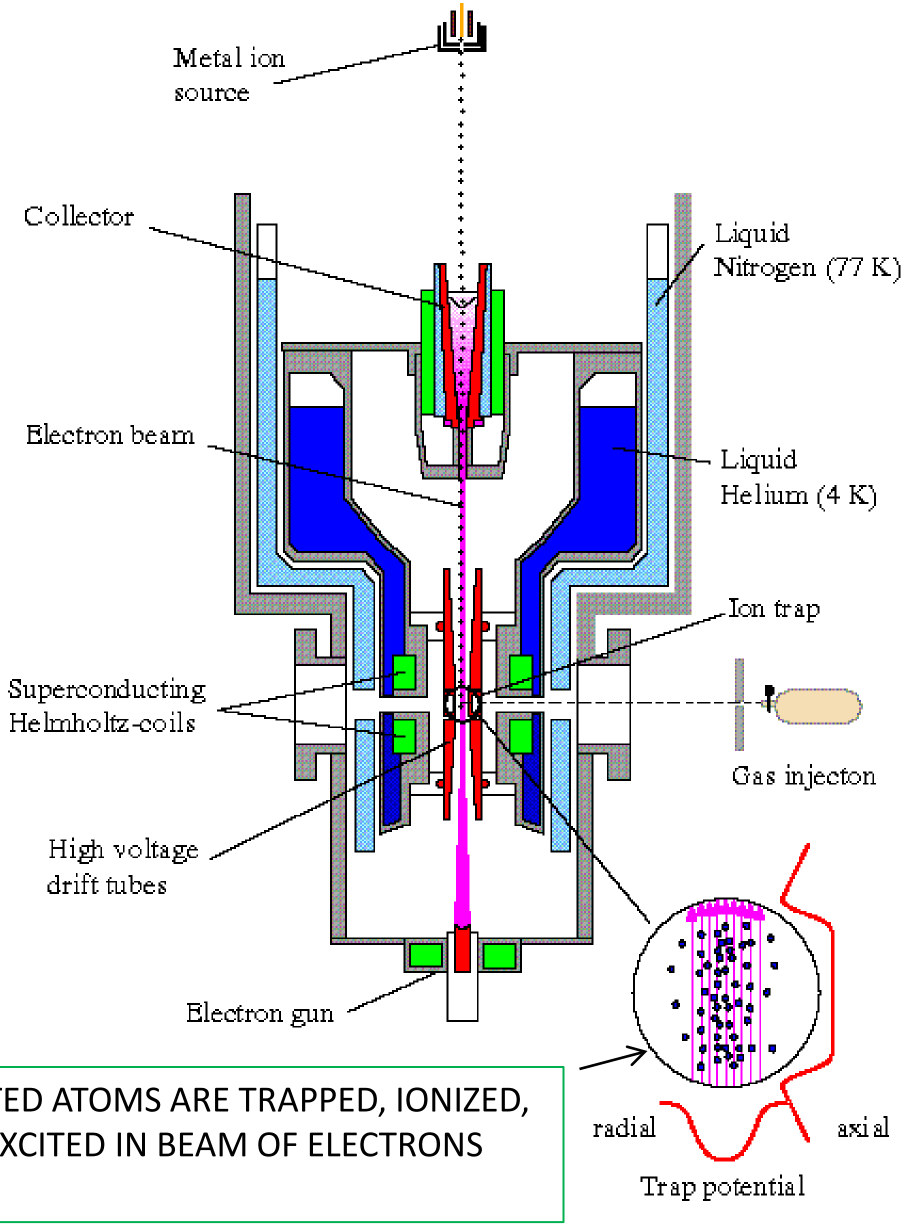
NIST ELECTRON BEAM ION TRAP "EBIT"

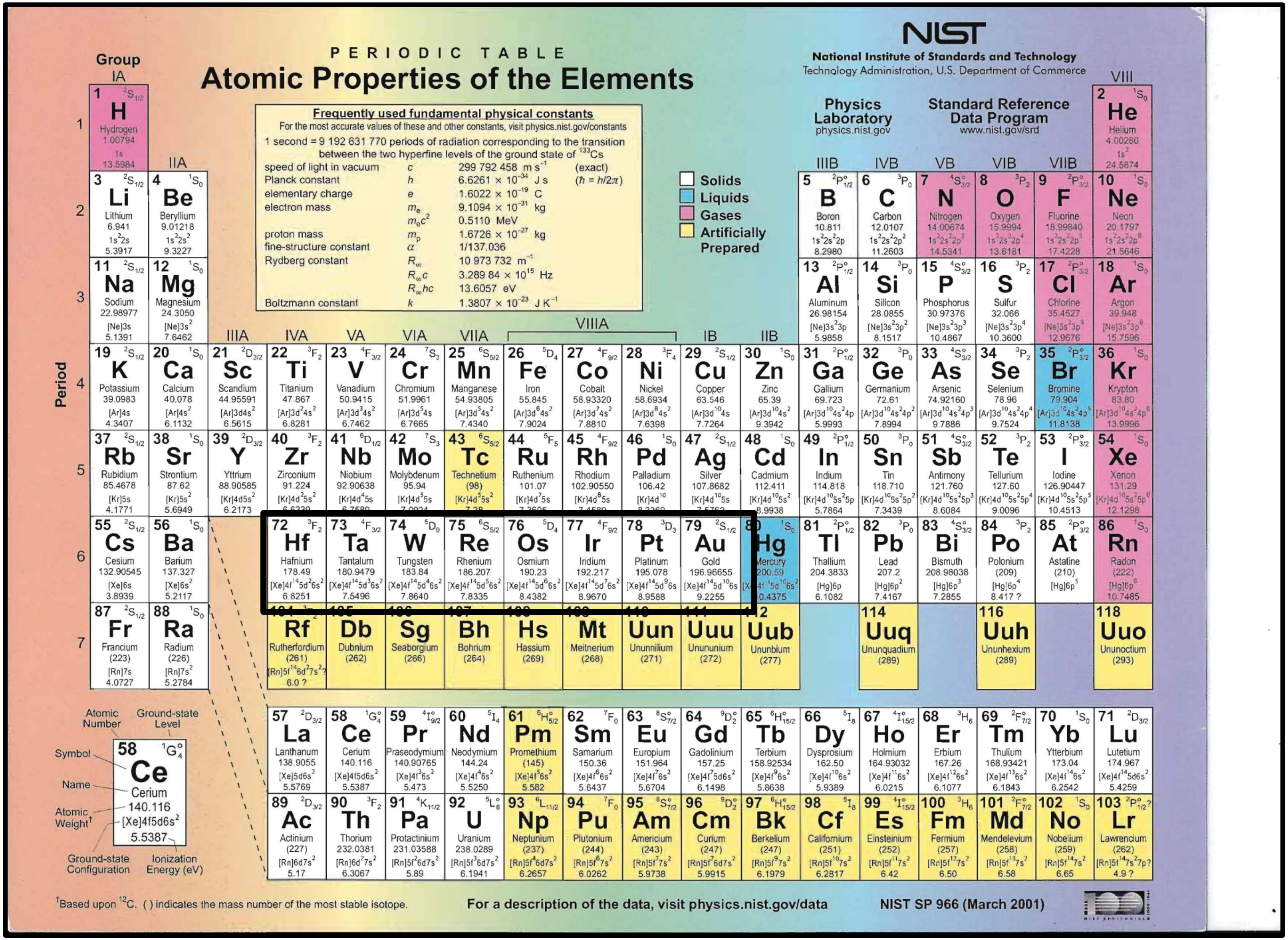


NIST EBIT:

- Maximum beam energy: 33 keV (ionize uranium to U^{90+})
- Energy width: 0.05 eV
- Electron density: ~$10^{11}/cm^3$



INJECTED ATOMS ARE TRAPPED, IONIZED, & EXCITED IN BEAM OF ELECTRONS



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Standard Reference Data Program
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PERIODIC TABLE

Atomic Properties of the Elements

Frequently used fundamental physical constants

For the most accurate values of these and other constants, visit physics.nist.gov/constants

1 second = 9 192 631 770 periods of radiation corresponding to the transition between the two hyperfine levels of the ground state of ^{133}Cs

speed of light in vacuum	c	299 792 458 m s^{-1}	(exact)
Planck constant	h	6.6261×10^{-34} J s	($\hbar = h/2\pi$)
elementary charge	e	1.6022×10^{-19} C	
electron mass	m_e	9.1094×10^{-31} kg	
	m_ec^2	0.5110 MeV	
proton mass	m_p	1.6726×10^{-27} kg	
fine-structure constant	α	1/137.036	
Rydberg constant	R_∞	10 973 732 m^{-1}	
	$R_\infty c$	$3.289\,84 \times 10^{15}$ Hz	
	$R_\infty hc$	13.6057 eV	
Boltzmann constant	k	1.3807×10^{-23} J K^{-1}	

- ☐ Solids
- 🟦 Liquids
- 🟥 Gases
- 🟨 Artificially Prepared

Group

Period	IA	IIA	IIIA	IVA	VA	VIA	VIIA	VIIIA			IB	IIB	IIIB	IVB	VB	VIB	VIIB	VIII
1	1 $^2S_{1/2}$ **H** Hydrogen 1.00794 $1s$ 13.5984																	2 $^1S_0$ **He** Helium 4.00260 $1s^2$ 24.5874
2	3 $^2S_{1/2}$ **Li** Lithium 6.941 $1s^22s$ 5.3917	4 $^1S_0$ **Be** Beryllium 9.01218 $1s^22s^2$ 9.3227											5 $^2P^\circ_{1/2}$ **B** Boron 10.811 $1s^22s^22p$ 8.2980	6 $^3P_0$ **C** Carbon 12.0107 $1s^22s^22p^2$ 11.2603	7 $^4S^\circ_{3/2}$ **N** Nitrogen 14.00674 $1s^22s^22p^3$ 14.5341	8 $^3P_2$ **O** Oxygen 15.9994 $1s^22s^22p^4$ 13.6181	9 $^2P^\circ_{3/2}$ **F** Fluorine 18.99840 $1s^22s^22p^5$ 17.4228	10 $^1S_0$ **Ne** Neon 20.1797 $1s^22s^22p^6$ 21.5646
3	11 $^2S_{1/2}$ **Na** Sodium 22.98977 $[Ne]3s$ 5.1391	12 $^1S_0$ **Mg** Magnesium 24.3050 $[Ne]3s^2$ 7.6462											13 $^2P^\circ_{1/2}$ **Al** Aluminum 26.98154 $[Ne]3s^23p$ 5.9858	14 $^3P_0$ **Si** Silicon 28.0855 $[Ne]3s^23p^2$ 8.1517	15 $^4S^\circ_{3/2}$ **P** Phosphorus 30.97376 $[Ne]3s^23p^3$ 10.4867	16 $^3P_2$ **S** Sulfur 32.066 $[Ne]3s^23p^4$ 10.3600	17 $^2P^\circ_{3/2}$ **Cl** Chlorine 35.4527 $[Ne]3s^23p^5$ 12.9676	18 $^1S_0$ **Ar** Argon 39.948 $[Ne]3s^23p^6$ 15.7596
4	19 $^2S_{1/2}$ **K** Potassium 39.0983 $[Ar]4s$ 4.3407	20 $^1S_0$ **Ca** Calcium 40.078 $[Ar]4s^2$ 6.1132	21 $^2D_{3/2}$ **Sc** Scandium 44.95591 $[Ar]3d4s^2$ 6.5615	22 $^3F_2$ **Ti** Titanium 47.867 $[Ar]3d^24s^2$ 6.8281	23 $^4F_{3/2}$ **V** Vanadium 50.9415 $[Ar]3d^34s^2$ 6.7462	24 $^7S_3$ **Cr** Chromium 51.9961 $[Ar]3d^54s$ 6.7665	25 $^6S_{5/2}$ **Mn** Manganese 54.93805 $[Ar]3d^54s^2$ 7.4340	26 $^5D_4$ **Fe** Iron 55.845 $[Ar]3d^64s^2$ 7.9024	27 $^4F_{9/2}$ **Co** Cobalt 58.93320 $[Ar]3d^74s^2$ 7.8810	28 $^3F_4$ **Ni** Nickel 58.6934 $[Ar]3d^84s^2$ 7.6398	29 $^2S_{1/2}$ **Cu** Copper 63.546 $[Ar]3d^{10}4s$ 7.7264	30 $^1S_0$ **Zn** Zinc 65.39 $[Ar]3d^{10}4s^2$ 9.3942	31 $^2P^\circ_{1/2}$ **Ga** Gallium 69.723 $[Ar]3d^{10}4s^24p$ 5.9993	32 $^3P_0$ **Ge** Germanium 72.61 $[Ar]3d^{10}4s^24p^2$ 7.8994	33 $^4S^\circ_{3/2}$ **As** Arsenic 74.92160 $[Ar]3d^{10}4s^24p^3$ 9.7886	34 $^3P_2$ **Se** Selenium 78.96 $[Ar]3d^{10}4s^24p^4$ 9.7524	35 $^2P^\circ_{3/2}$ **Br** Bromine 79.904 $[Ar]3d^{10}4s^24p^5$ 11.8138	36 $^1S_0$ **Kr** Krypton 83.80 $[Ar]3d^{10}4s^24p^6$ 13.9996
5	37 $^2S_{1/2}$ **Rb** Rubidium 85.4678 $[Kr]5s$ 4.1771	38 $^1S_0$ **Sr** Strontium 87.62 $[Kr]5s^2$ 5.6949	39 $^2D_{3/2}$ **Y** Yttrium 88.90585 $[Kr]4d5s^2$ 6.2173	40 $^3F_2$ **Zr** Zirconium 91.224 $[Kr]4d^25s^2$ 6.6339	41 $^6D_{1/2}$ **Nb** Niobium 92.90638 $[Kr]4d^45s$ 6.7589	42 $^7S_3$ **Mo** Molybdenum 95.94 $[Kr]4d^55s$ 7.0924	43 $^6S_{5/2}$ **Tc** Technetium (98) $[Kr]4d^55s^2$ 7.28	44 $^5F_5$ **Ru** Ruthenium 101.07 $[Kr]4d^75s$ 7.3605	45 $^4F_{9/2}$ **Rh** Rhodium 102.90550 $[Kr]4d^85s$ 7.4589	46 $^1S_0$ **Pd** Palladium 106.42 $[Kr]4d^{10}$ 8.3369	47 $^2S_{1/2}$ **Ag** Silver 107.8682 $[Kr]4d^{10}5s$ 7.5762	48 $^1S_0$ **Cd** Cadmium 112.411 $[Kr]4d^{10}5s^2$ 8.9938	49 $^2P^\circ_{1/2}$ **In** Indium 114.818 $[Kr]4d^{10}5s^25p$ 5.7864	50 $^3P_0$ **Sn** Tin 118.710 $[Kr]4d^{10}5s^25p^2$ 7.3439	51 $^4S^\circ_{3/2}$ **Sb** Antimony 121.760 $[Kr]4d^{10}5s^25p^3$ 8.6084	52 $^3P_2$ **Te** Tellurium 127.60 $[Kr]4d^{10}5s^25p^4$ 9.0096	53 $^2P^\circ_{3/2}$ **I** Iodine 126.90447 $[Kr]4d^{10}5s^25p^5$ 10.4513	54 $^1S_0$ **Xe** Xenon 131.29 $[Kr]4d^{10}5s^25p^6$ 12.1298
6	55 $^2S_{1/2}$ **Cs** Cesium 132.90545 $[Xe]6s$ 3.8939	56 $^1S_0$ **Ba** Barium 137.327 $[Xe]6s^2$ 5.2117		72 $^3F_2$ **Hf** Hafnium 178.49 $[Xe]4f^{14}5d^26s^2$ 6.8251	73 $^4F_{3/2}$ **Ta** Tantalum 180.9479 $[Xe]4f^{14}5d^36s^2$ 7.5496	74 $^5D_0$ **W** Tungsten 183.84 $[Xe]4f^{14}5d^46s^2$ 7.8640	75 $^6S_{5/2}$ **Re** Rhenium 186.207 $[Xe]4f^{14}5d^56s^2$ 7.8335	76 $^5D_4$ **Os** Osmium 190.23 $[Xe]4f^{14}5d^66s^2$ 8.4382	77 $^4F_{9/2}$ **Ir** Iridium 192.217 $[Xe]4f^{14}5d^76s^2$ 8.9670	78 $^3D_3$ **Pt** Platinum 195.078 $[Xe]4f^{14}5d^96s$ 8.9588	79 $^2S_{1/2}$ **Au** Gold 196.96655 $[Xe]4f^{14}5d^{10}6s$ 9.2255	80 $^1S_0$ **Hg** Mercury 200.59 $[X\;4f^{14}5d^{10}6s^2$ 0.4375	81 $^2P^\circ_{1/2}$ **Tl** Thallium 204.3833 $[Hg]6p$ 6.1082	82 $^3P_0$ **Pb** Lead 207.2 $[Hg]6p^2$ 7.4167	83 $^4S^\circ_{3/2}$ **Bi** Bismuth 208.98038 $[Hg]6p^3$ 7.2855	84 $^3P_2$ **Po** Polonium (209) $[Hg]6p^4$ 8.417 ?	85 $^2P^\circ_{3/2}$ **At** Astatine (210) $[Hg]6p^5$	86 $^1S_0$ **Rn** Radon (222) $[Hg]6p^6$ 10.7485
7	87 $^2S_{1/2}$ **Fr** Francium (223) $[Rn]7s$ 4.0727	88 $^1S_0$ **Ra** Radium (226) $[Rn]7s^2$ 5.2784		104 $^3F_2$ **Rf** Rutherfordium (261) $[Rn]5f^{14}6d^27s^2$? 6.0 ?	105 **Db** Dubnium (262)	106 **Sg** Seaborgium (266)	107 **Bh** Bohrium (264)	108 **Hs** Hassium (269)	109 **Mt** Meitnerium (268)	110 **Uun** Ununnilium (271)	111 **Uuu** Unununium (272)	112 **Uub** Ununbium (277)		114 **Uuq** Ununquadium (289)		116 **Uuh** Ununhexium (289)		118 **Uuo** Ununoctium (293)

57 $^2D_{3/2}$ **La** Lanthanum 138.9055 $[Xe]5d6s^2$ 5.5769	58 $^1G^\circ_4$ **Ce** Cerium 140.116 $[Xe]4f5d6s^2$ 5.5387	59 $^4I^\circ_{9/2}$ **Pr** Praseodymium 140.90765 $[Xe]4f^36s^2$ 5.473	60 $^5I_4$ **Nd** Neodymium 144.24 $[Xe]4f^46s^2$ 5.5250	61 $^6H^\circ_{5/2}$ **Pm** Promethium (145) $[Xe]4f^56s^2$ 5.582	62 $^7F_0$ **Sm** Samarium 150.36 $[Xe]4f^66s^2$ 5.6437	63 $^8S^\circ_{7/2}$ **Eu** Europium 151.964 $[Xe]4f^76s^2$ 5.6704	64 $^9D^\circ_2$ **Gd** Gadolinium 157.25 $[Xe]4f^75d6s^2$ 6.1498	65 $^6H^\circ_{15/2}$ **Tb** Terbium 158.92534 $[Xe]4f^96s^2$ 5.8638	66 $^5I_8$ **Dy** Dysprosium 162.50 $[Xe]4f^{10}6s^2$ 5.9389	67 $^4I^\circ_{15/2}$ **Ho** Holmium 164.93032 $[Xe]4f^{11}6s^2$ 6.0215	68 $^3H_6$ **Er** Erbium 167.26 $[Xe]4f^{12}6s^2$ 6.1077	69 $^2F^\circ_{7/2}$ **Tm** Thulium 168.93421 $[Xe]4f^{13}6s^2$ 6.1843	70 $^1S_0$ **Yb** Ytterbium 173.04 $[Xe]4f^{14}6s^2$ 6.2542	71 $^2D_{3/2}$ **Lu** Lutetium 174.967 $[Xe]4f^{14}5d6s^2$ 5.4259
89 $^2D_{3/2}$ **Ac** Actinium (227) $[Rn]6d7s^2$ 5.17	90 $^3F_2$ **Th** Thorium 232.0381 $[Rn]6d^27s^2$ 6.3067	91 $^4K_{11/2}$ **Pa** Protactinium 231.03588 $[Rn]5f^26d7s^2$ 5.89	92 $^5L^\circ_6$ **U** Uranium 238.0289 $[Rn]5f^36d7s^2$ 6.1941	93 $^6L_{11/2}$ **Np** Neptunium (237) $[Rn]5f^46d7s^2$ 6.2657	94 $^7F_0$ **Pu** Plutonium (244) $[Rn]5f^67s^2$ 6.0262	95 $^8S^\circ_{7/2}$ **Am** Americium (243) $[Rn]5f^77s^2$ 5.9738	96 $^9D^\circ_2$ **Cm** Curium (247) $[Rn]5f^76d7s^2$ 5.9915	97 $^6H^\circ_{15/2}$ **Bk** Berkelium (247) $[Rn]5f^97s^2$ 6.1979	98 $^5I_8$ **Cf** Californium (251) $[Rn]5f^{10}7s^2$ 6.2817	99 $^4I^\circ_{15/2}$ **Es** Einsteinium (252) $[Rn]5f^{11}7s^2$ 6.42	100 $^3H_6$ **Fm** Fermium (257) $[Rn]5f^{12}7s^2$ 6.50	101 $^2F^\circ_{7/2}$ **Md** Mendelevium (258) $[Rn]5f^{13}7s^2$ 6.58	102 $^1S_0$ **No** Nobelium (259) $[Rn]5f^{14}7s^2$ 6.65	103 $^2P^\circ_{1/2}$? **Lr** Lawrencium (262) $[Rn]5f^{14}7s^27p$? 4.9 ?

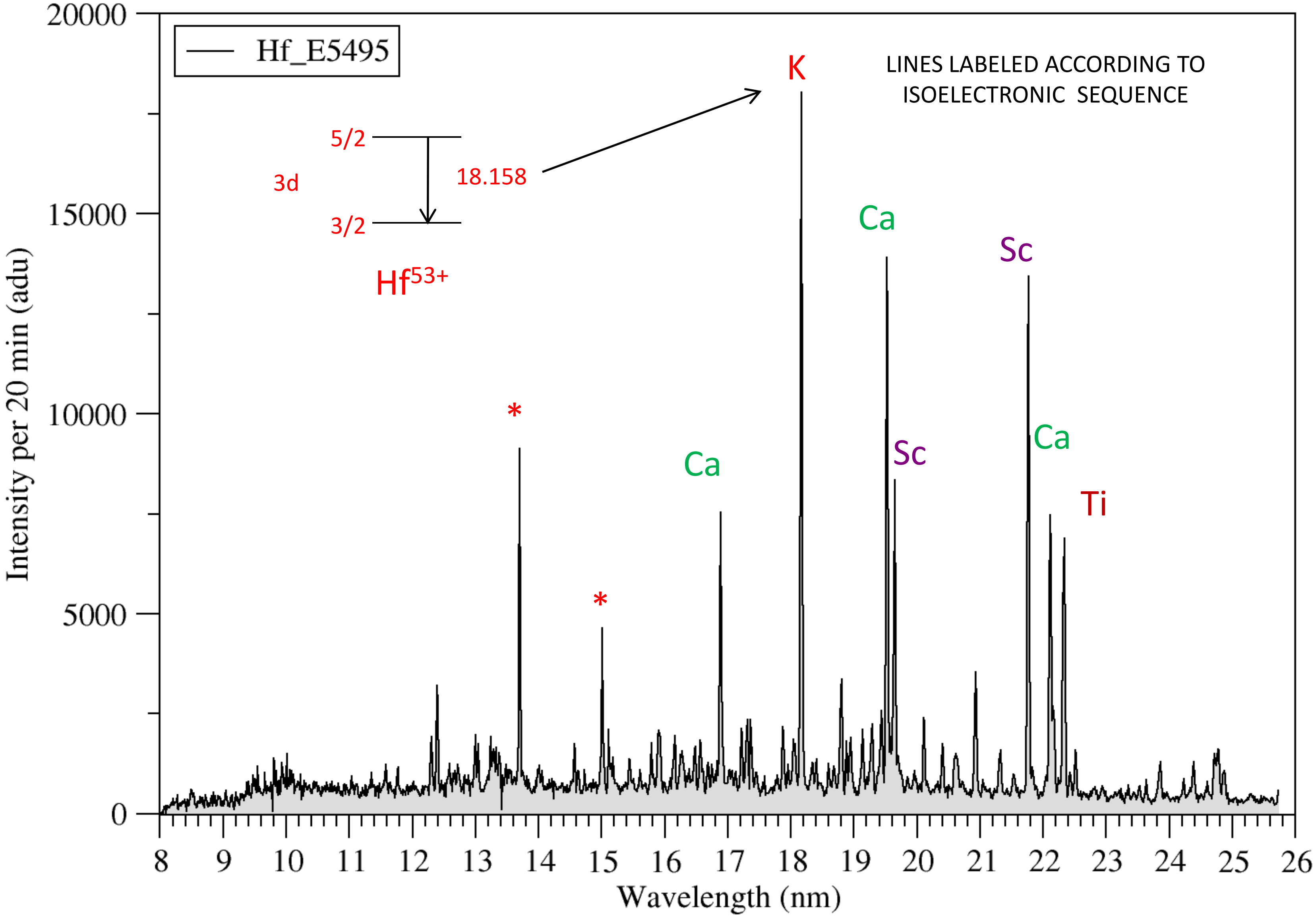
Atomic Number
Ground-state Level
Symbol
Name
Atomic Weight†
Ground-state Configuration
Ionization Energy (eV)

58 $^1G^\circ_4$
Ce
Cerium
140.116
$[Xe]4f5d6s^2$
5.5387

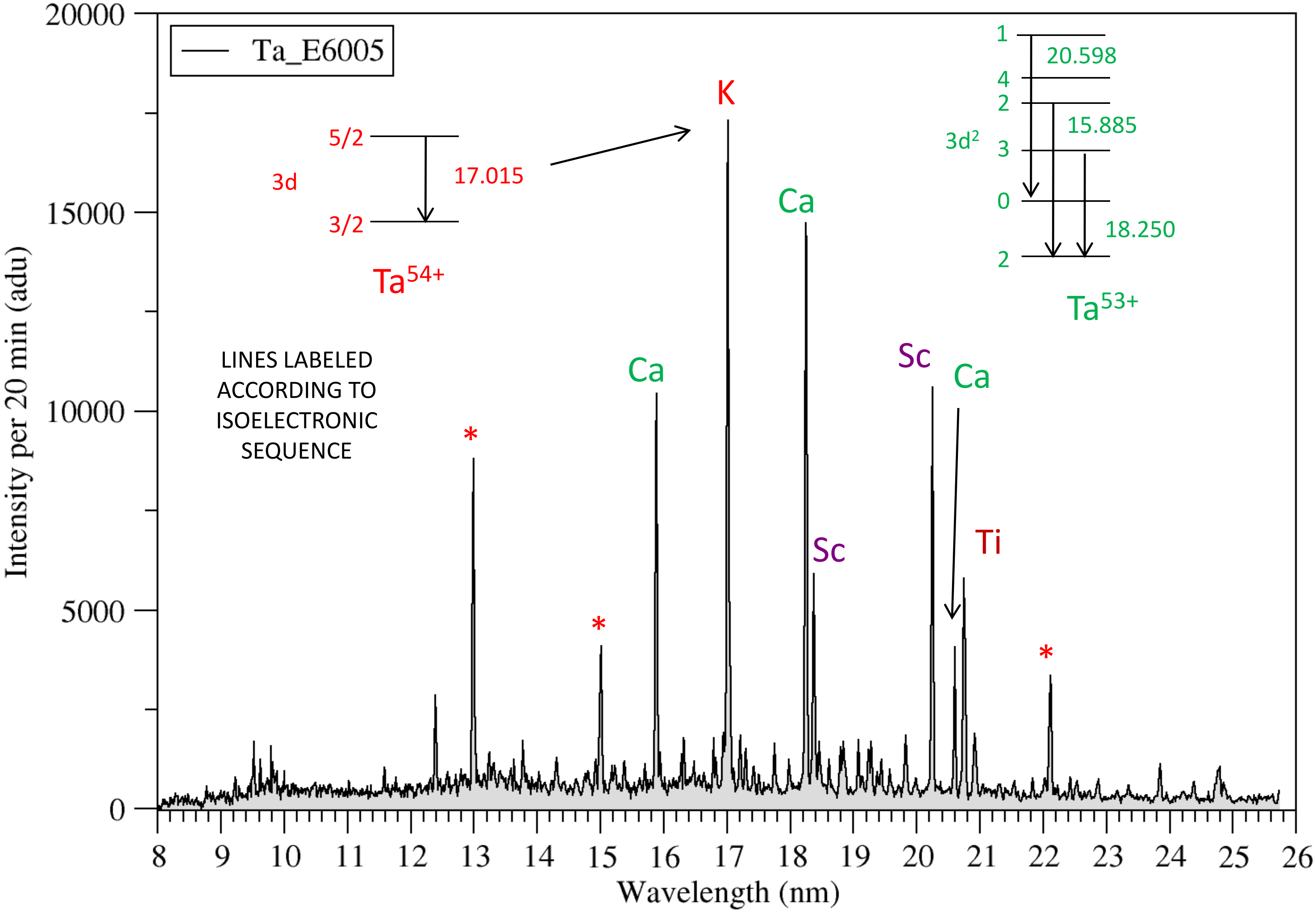
†Based upon ^{12}C. ( ) indicates the mass number of the most stable isotope.

For a description of the data, visit physics.nist.gov/data

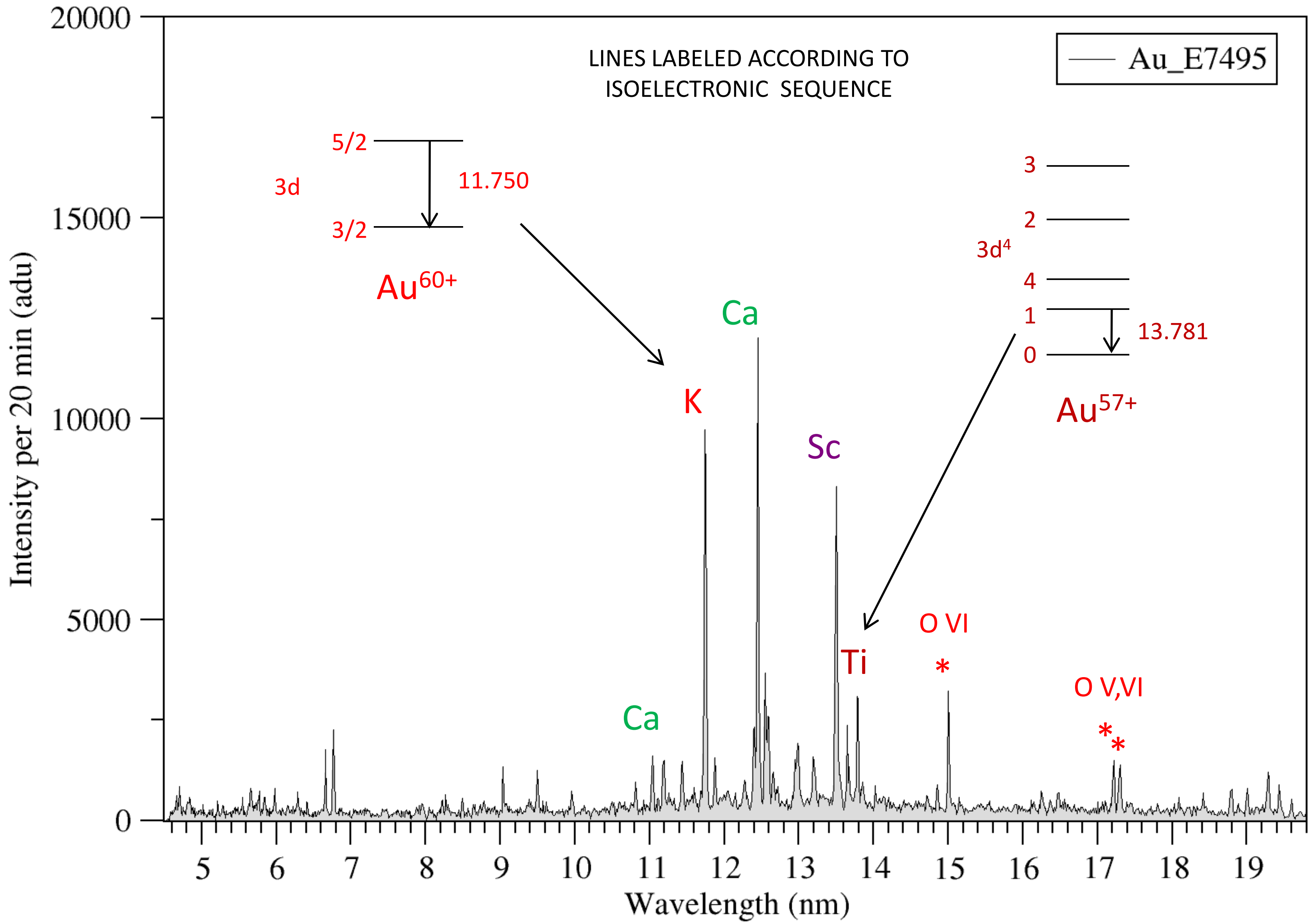
NIST SP 966 (March 2001)

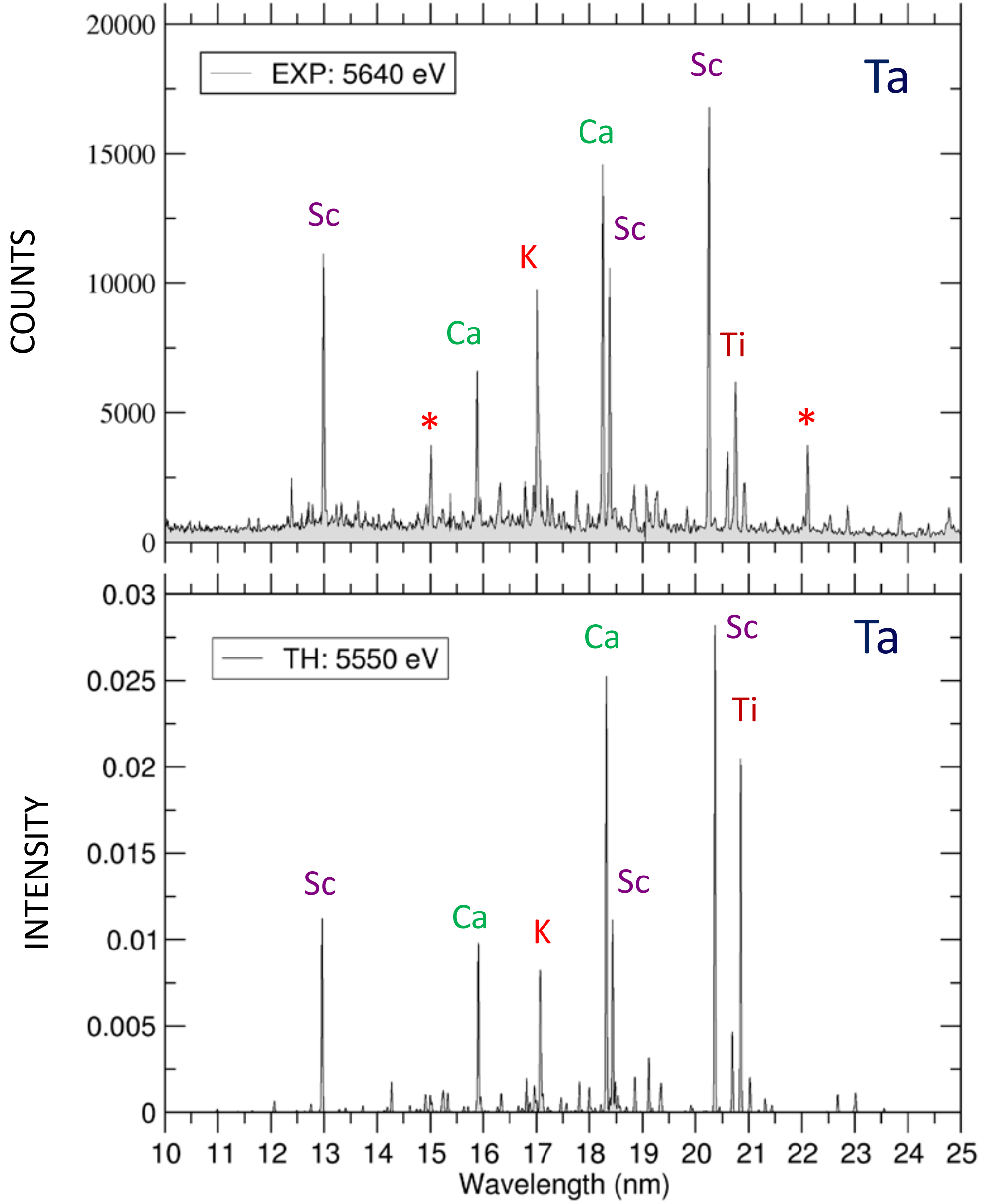


LINES LABELED ACCORDING TO ISOELECTRONIC SEQUENCE



LINES LABELED
ACCORDING TO
ISOELECTRONIC
SEQUENCE


LINES LABELED ACCORDING TO
ISOELECTRONIC SEQUENCE
Au_E7495
5/2
3d
11.750
3/2
Au^{60+}
3
2
3d^4
4
1
13.781
0
Au^{57+}
Ca
K
Sc
Ti
O VI
*
O V,VI
*
*
Ca
Intensity per 20 min (adu)
20000
15000
10000
5000
0
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
Wavelength (nm)


EXP: 5640 eV
Ta
COUNTS
20000
15000
10000
5000
0
Sc
Ca
Sc
K
Ca
Sc
Ti
*
*
TH: 5550 eV
Ta
INTENSITY
0.03
0.025
0.02
0.015
0.01
0.005
0
Ca
Sc
Ti
Sc
Sc
Ca
K
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
Wavelength (nm)

New M1 lines observed – uncertainty 0.002 nm

Hf- 42 lines	Hf^{45+} to Hf^{54+}
Ta- 49 lines	Ta^{45+} to Ta^{57+}
Au- 41 lines	Au^{51+} to Au^{60+}

MODELING DIELECTRONIC RECOMBINATION IN TOKAMAKS

LMN DIELECTRONIC RESONANCES IN 3d^{n} IONS OF TUNGSTEN

“Magnetic-dipole lines in 3d^{n} ions of high-Z elements: identification, diagnostic potential, and dielectronic resonances,” Yu. Ralchenko, J.D. Gillaspy, J. Reader, D. Osin, J.J. Curry, and Y.A. Podpaly, Phys. Scr. (2013), to be published

DIELECTRONIC CAPTURE INTO CONTINUUM

K-like W $(2p^6 3s^2 3p^6 3d)$ + (EBIT)$e^- \rightarrow$ Ca-like W$(2p^5 3s^2 3p^6 3d^2 4\ell)$
(discrete states in the continuum)

AUTOIONIZATION to K-like W with EMISSION OF ELECTRON

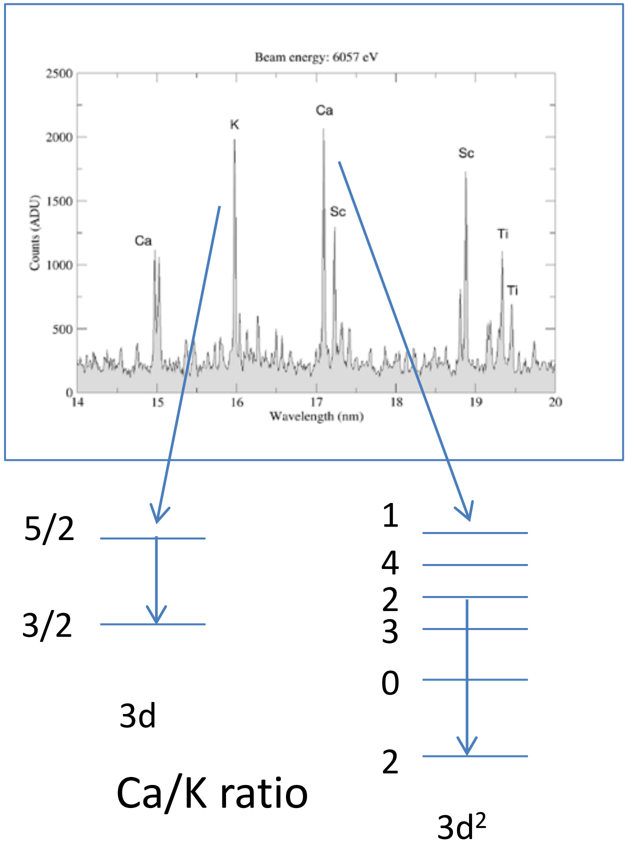
Ca-like W$(2p^5 3s^2 3p^6 3d^2 4\ell) \rightarrow$ K-like W$(2p^6 3s^2 3p^6 3d)$ + e^-

RADIATIVE STABILIZATION

Ca-like W$(2p^5 3s^2 3p^6 3d^2 4\ell) \rightarrow$

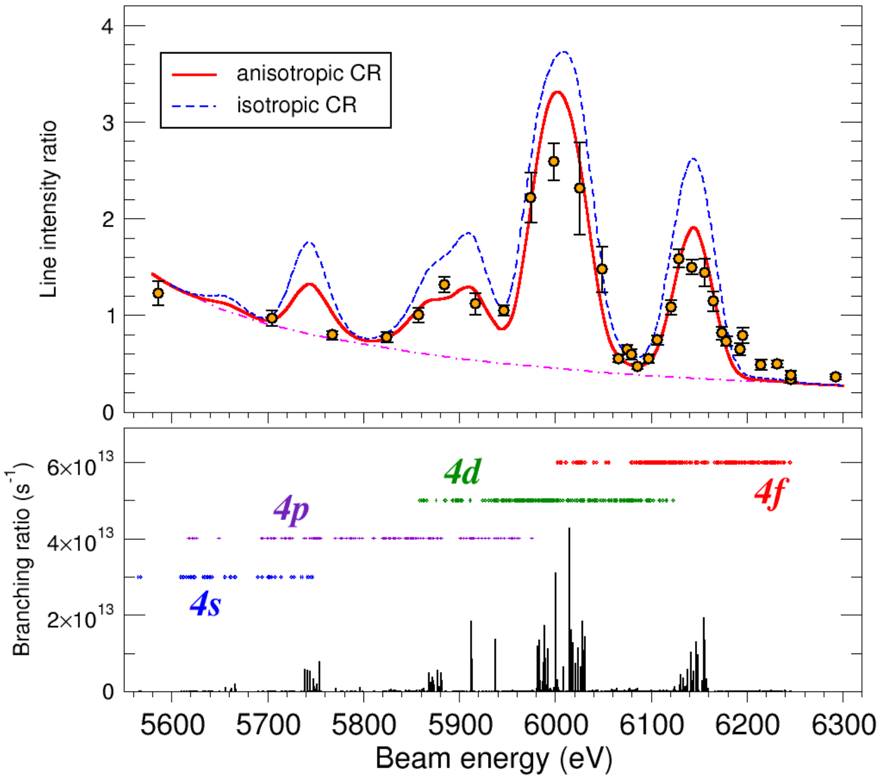
Ca-like W$(2p^6 3s^2 3p^6 3d 4\ell)$ + hν (~9 keV)
Ca-like W$(2p^6 3s 3p^6 3d^2 4\ell)$ + hν (~8 keV)
Ca-like W$(2p^6 3s^2 3p^6 3d^2)$ + hν (~11 keV)

DR



Ca/K ratio

- Use intensity ratios of M1 lines in $3d^n$ ions to analyze modifications of the ionization balance due to dielectronic recombination
- Simultaneous measurement for several ions: Sc/Ca
- Large-scale CR modeling shows importance of anisotropic effects



RESONANCE STRENGTH

Support

U.S. Department of Energy
Office of Fusion Energy Sciences
(DATABASE & EXPERIMENT)

U.S. National Aeronautics
and Space Administration
(DATABASE)