

Atomic Structure and Spectroscopy of Highly Charged Tungsten Ions and Relevance to ITER Diagnostics.

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Outline

Our EBITS

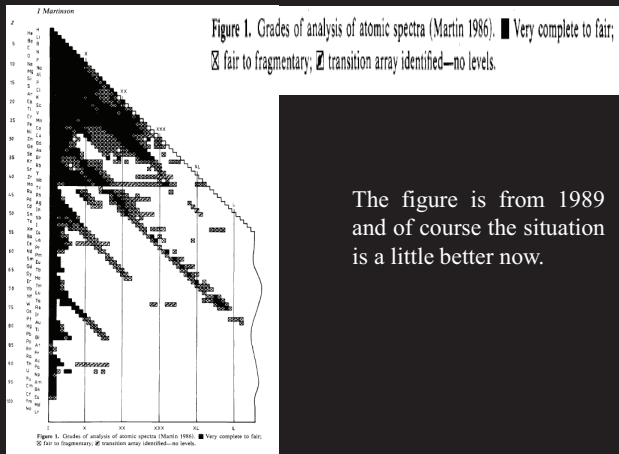
Visible spectroscopy of Tungsten

soft x ray spectroscopy of tungsten

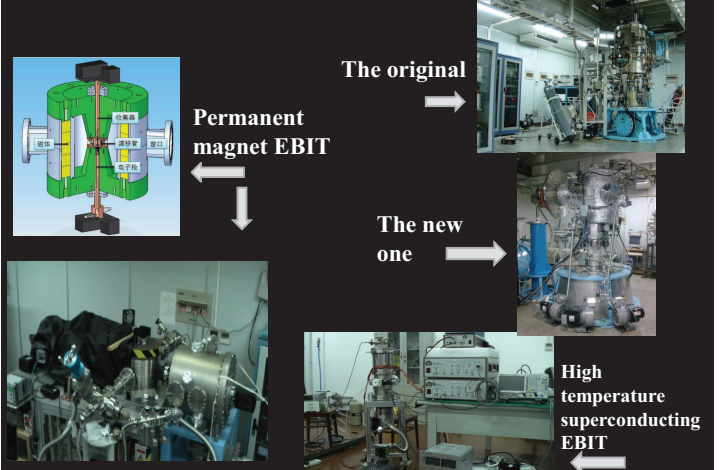
Energy levels

summary

How much is known concerning the spectroscopy of Tungsten



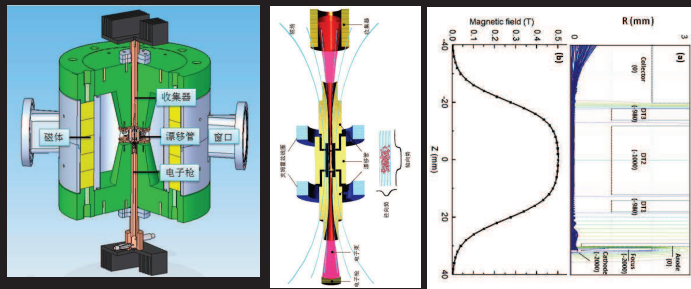
The Shanghai Electron Beam Ion Traps



2. SH-PermEBIT装置简介

Shanghai permanent magnet EBIT(永磁EBIT)

设计参数: 能量: 250-5000eV 束流: 10 mA 磁场: 0.5T



超低能量EBIT

目标: 为ITER

边界等离子体的分解研究服务

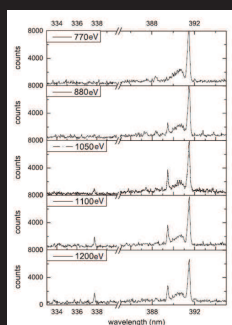
国家	名称	最能极限
日本	Cobit	150eV
德国	FLASH-EBIT	105eV
德国	Berlin-EBIT	190eV
美国	Livermore EBIT	140eV
中国	SH-PermEBIT	60eV
中国	SH-HtscEBIT	30eV

Visible spectroscopy

Ag-like Ions

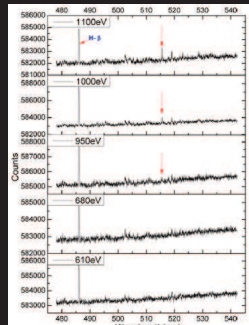
a single 4f electron outside the closed $4d^{10}$ shell, i.e. a $2F$ ground term

Ag-like Tungsten



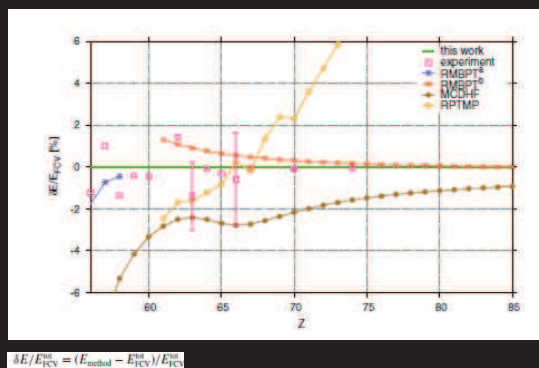
PHYSICAL REVIEW A 86, 062501 (2012)

Ag-like Ytterbium



J. Phys. B: At. Mol. Opt. Phys. 47 (2014) 185004

Ground state fine structure M1 transition in Ag-like ions

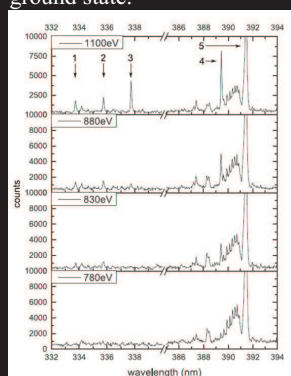


$$\Delta E/E_{CV} = (E_{\text{method}} - E_{CV}^{\text{ex}})/E_{CV}^{\text{ex}}$$

PHYSICAL REVIEW A 89, 062511 (2014)

Cd-like Tungsten (W^{26+})

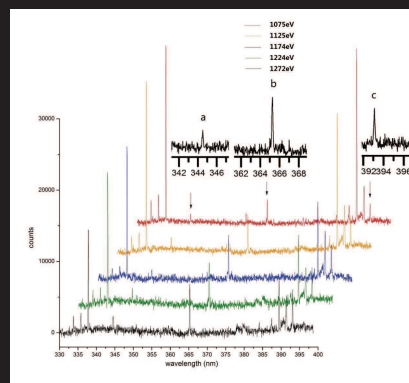
two 4f electrons leading to 13 energy levels making up the ground state.



Totally we identified 7 lines to be from Cd-like W

Accepted Phys Rev A, october 2014

Pd-like Tungsten (W^{28+})



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soft x ray spectral region

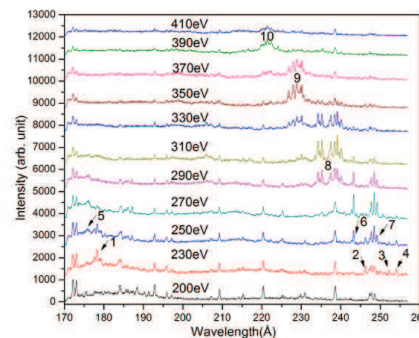
NIST data base 108 lines in region 200 – 400 Å

ITER soft x ray spectrometer

We have investigated the soft x ray spectra of $W^{(11-15)+}$ and identified a number of lines/spectral features in the region 200 – 400 Å.

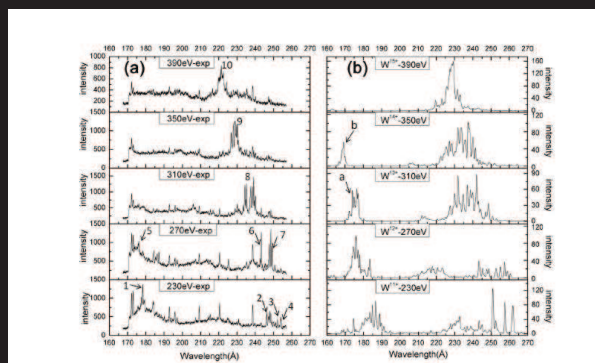
Also down to W^{7+}

Soft x ray tungsten spectroscopy



In preparation for publication

Soft x ray tungsten spectroscopy, experiment vrs. simulation



Energy level diagram for W^{26+} showing transitions between various states. The x-axis represents Total angular momentum, J , ranging from 0 to 6. The y-axis represents energy, ranging from 0 to 180,000. The diagram shows several energy levels and transitions between them.

States and their approximate energies (from top to bottom):

- $1S_0$ (J=0, ~175,000)
- $3P_0$ (J=0, ~70,000)
- $3P_1$ (J=1, ~85,000)
- $3P_2$ (J=2, ~105,000)
- $1D_2$ (J=2, ~100,000)
- $3F_2$ (J=2, ~20,000)
- $3F_3$ (J=3, ~40,000)
- $3F_4$ (J=4, ~65,000)
- $1G_4$ (J=4, ~35,000)
- $3H_4$ (J=4, ~5,000)
- $3H_5$ (J=5, ~25,000)
- $3H_6$ (J=6, ~45,000)
- $1I_6$ (J=6, ~85,000)

Transitions are indicated by red and blue lines:

- Red lines (likely Lyman series): $1S_0 \rightarrow 3P_0$, $3P_1 \rightarrow 3F_2$, $3P_2 \rightarrow 3F_3$, $1D_2 \rightarrow 3F_3$, $3F_4 \rightarrow 1G_4$, $3H_4 \rightarrow 3H_5$, $3H_5 \rightarrow 3H_6$.
- Blue lines (likely Balmer series): $1S_0 \rightarrow 3P_1$, $3P_2 \rightarrow 3F_4$, $1D_2 \rightarrow 3F_4$, $1G_4 \rightarrow 3H_6$, $3H_6 \rightarrow 1I_6$.

Energy level diagram for W^{28+} showing transitions between various states. The y-axis is Energy (cm^{-1}) from 0 to 2010000. The x-axis is J from 0 to 6. States are labeled with $(J, 2J^2)$ and transitions are numbered 1-6.

State	J	$2J^2$	Energy (cm^{-1})
$(0, 0)$	0	0	0
$(1, 2)$	1	2	~1550000
$(2, 8)$	2	8	~1680000
$(3, 18)$	3	18	~1750000
$(4, 32)$	4	32	~1780000
$(5, 50)$	5	50	~1800000
$(6, 72)$	6	72	~1820000

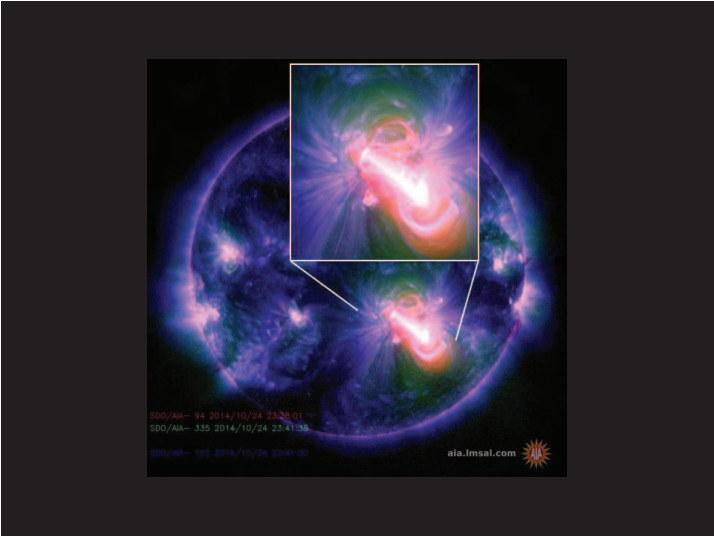
Transitions (numbered 1-6) are shown as lines connecting the states:

- 1: $(0, 0) \rightarrow (1, 2)$
- 2: $(1, 2) \rightarrow (2, 8)$
- 3: $(2, 8) \rightarrow (3, 18)$
- 4: $(3, 18) \rightarrow (4, 32)$
- 5: $(4, 32) \rightarrow (5, 50)$
- 6: $(5, 50) \rightarrow (6, 72)$

The diagram shows the energy levels (in eV) for the W^{13+} ion. The y-axis represents Energy (eV) from 0 to 130. The x-axis shows different electronic configurations: $4f^{11}$, $4f^{12}$, $4f^{13}$, and $4f^{14}$.

Key energy levels and transitions are labeled:

- Configurations:** $4f^{11}$, $4f^{12}$, $4f^{13}$, $4f^{14}$, $5d$, $5p$, $5s$, $5p^2$, $5s^2 5d$, $5s^2 5p^2$, $5s^2 5p$, $5s^2$.
- Transitions:**
 - a:** Transitions from $5p^2$ to $5s^2 5d$ and $5s^2 5p^2$.
 - b:** Transitions from $5p^2$ to $5s^2 5d$.
- Other Labels:** $5p$, $5s$, $5p^2$, $5s^2 5p$, $5s^2$, $5p$, $5s$, $5p^2$, $5s^2 5p$, $5s^2$.



Proposal of a Unique Method to Measure Magnetic Fields in the Solar Corona Facilitated Through an Accidental Degeneracy of Quantum States in the Fe^{9+} Ion

The diagram illustrates the energy levels and transitions for the Fe^{9+} ion. The states are categorized into three main groups:

- Top Group:** $3s^2 3p^4 3d$ with sub-levels labeled $1/2$, $3/2$, $5/2$, and $7/2$.
- Middle Group:** $3s 3p^6 2S$ with a sub-level labeled $1/2$.
- Bottom Group:** $3s^2 3p^5 2P$ with sub-levels labeled $1/2$ and $3/2$.

Transitions are indicated by vertical lines:

- M2:** A solid line transition from the $1/2$ level of the middle group to the $1/2$ level of the bottom group.
- MIT:** A dashed line transition from the $3/2$ level of the top group to the $3/2$ level of the bottom group.
- E1:** A solid line transition from the $5/2$ level of the top group to the $1/2$ level of the middle group.

Small arrows at the bottom of the diagram indicate the direction of the transitions.

Please see the poster presentation by Yang Yang for more details on this

