Visible M1 transition of the ground state and CRM of W^{26+}-W^{27+} ions

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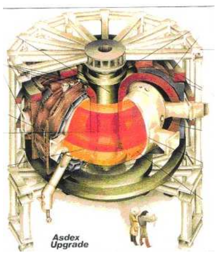
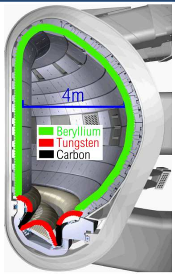
Introduction



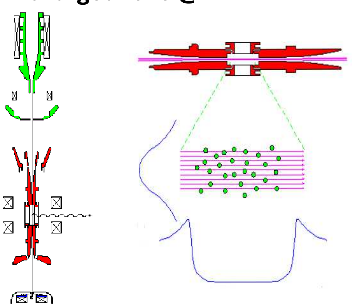


M1 transition in highly charged ions

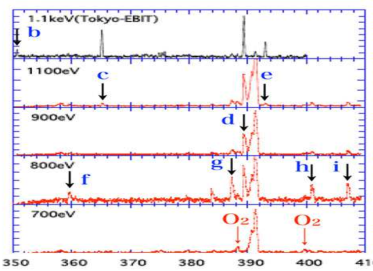
- The fine structure splitting of the ground and lower excited state of highly charged ions comes into the range of **visible light emissions**.
- Magnetic dipole (M1) resonance transitions are available between **the ground state fine structure multiplets**.
- Visible lines are of the great advantage for the purpose of plasma diagnostics because of their **ease of the spectroscopic measurement**.
- M1 lines are expected to **suffer less radiation trapping effects** from the surrounding ions.

Accurate atomic data of highly charged ions are helpful for plasma diagnostics

Experimental Investigation on Highly charged ions @ EBIT



Tokoy-EBIT @ Eel. Comm.Univ CoBIT @ NIFS



Theoretical Methods (MCDF)

Atomic State function(ASF):

$$|\Psi_\alpha(\mathrm{PJM})\rangle = \sum_r^{n_c} c_\gamma(\alpha)|\gamma_r PJM\rangle$$

Active Space:

n=5, $AS_{n=5}$={4d,4f,5s,5p,5d}

n=6, $AS_{n=6}$ = $AS_{n=5}$ +{6s,6p,6d,5f}

n=7, $AS_{n=7}$ = $AS_{n=6}$ + {7s,7p,7d,6f}

CSFs:

Single & Double substitution from n=4 to AS

Variation condition

$$\delta[\langle\Psi_\alpha(\mathrm{PJM})|H|\Psi_\alpha(\mathrm{PJM})\rangle/\langle\Psi_\alpha(\mathrm{PJM})|\Psi_\alpha(\mathrm{PJM})\rangle]=0$$

Relativistic Configuration Interaction:

Breit Interaction, Vacuum polarization and self-energy effects.

Oscillator Strength of M1 transition

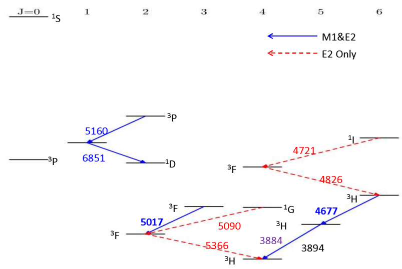
$$f_{i\to j} = \frac{\pi c}{2(2L+1)\omega^2}\left|\langle\Psi_f(P_f J_f M_f)|l+2s|\Psi_i(P_i J_i M_i)\rangle\right|^2$$

Transition Probability of M1 transition:

$$A_{ij} = 2\frac{(\Delta E_{ij})^2}{c^3}\frac{g_j}{g_i}f_{j\to i}$$

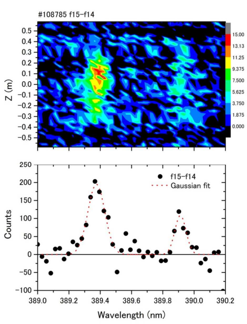
Results

Possible visible transitions between the W^{26+} ground state multiplets



Tran	Wavelength(Å)	Type	$A_{ij}(s^{-1})$	Obs. Wavelength*(nm)
$^3H_5 \to {}^3H_4$	3884.34	M1	3.94(2)	389.4, 390.9
		E2	1.69(-3)	
$^3H_6 \to {}^3H_5$	4677.96	M1	2.05(2)	464.636
		E2	3.31(-4)	
$^1I_6 \to {}^3F_4$	4721.59	M1	2.90(-2)	
$^3F_4 \to {}^3H_6$	4826.63	E2	6.36(-4)	
$^3F_3 \to {}^3F_2$	5017.99	M1	1.75(2)	502.153
		E2	7.28(-5)	
$^1G_4 \to {}^3F_2$	5090.88	M1	1.82(-4)	
$^3P_2 \to {}^3P_1$	5160.06	M1	6.43(1)	
		E2	6.65(-4)	
$^3F_2 \to {}^3H_4$	5366.71	M1	7.33(-3)	
$^3P_1 \to {}^1D_2$	6851.63	M1	2.33(1)	
		E2	9.59(-6)	

*Z.Fei et.al., *Phys. Rev. A.*, **90**,052517 (2014)



A spectrum of emission lines from highly charged tungsten ions observed at LHD (shot #108785). The scale on the right hand side of the top panel shows photon counts per pixel of the CCD detector.

M1 transitions wavelength of $4d^{10}4f\ ^2F_{5/2} \to {}^2F_{7/2}$ of W^{27+} ions

Method	nm	cm-1
RMBPT-1 [Ivanova E, 2011]	338.41	29,550
RMBPT-2 [Ivanova E, 2007	337.03	29,668
HULLAC [Radtje R, 2007]	342.41	29,205
MCDF [Ding, 2012]	341.09	29,151
EBIT Exp. [Fei Z., 2013]	337.85	29,599
HF [Cheng, 1979]	303.21	33,000
RPTMP [Ivanova E, 2011]	314.77	31,769
ORMAK Exp. [Sugar J, 1981]	314.46	31,800

Collisional-Radiative Model of W^{27+}

Configurations:

$4d^{10}4f^1$; $4d^{10}nl$(n=5-8,all l);$4d^9 4f^2$

Atomic Processes:

Simultaneous Radiative transition, collisional excitation / deexcitation /ionization, Radiative recombination

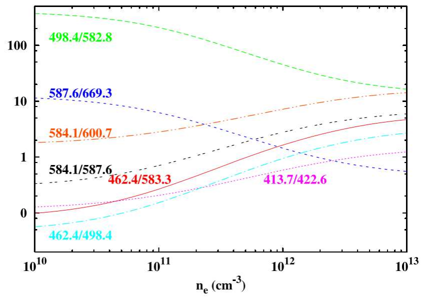
Atomic data:

GRASP2K & FAC

Possible strong transitions of W^{27+}

λ(nm)	$A_{ij}(s^{-1})$	Upper levels	Lower Leves
339.3	295.00	$[4d^{10}4f_{7/2}]_{7/2}$	$[4d^{10}4f_{5/2}]_{5/2}$
376.2	156.80	$[(4d^5_{5/2}4f_{5/2})_2 4f_{7/2}]_{11/2}$	$[(4d^5_{5/2}4f_{5/2})_1 4f_{7/2}]_{9/2}$
380.7	80.63	$[4d^5_{5/2}4f^2_{7/2}]_{11/2}$	$[(4d^5_{5/2}4f_{5/2})_5 4f_{7/2}]_{11/2}$
390.9	62.07	$[(4d^5_{5/2}4f_{5/2})_5 4f_{7/2}]_{13/2}$	$[(4d^5_{5/2}4f_{5/2})_2 4f_{7/2}]_{11/2}$
411.0	134.20	$[(4d^5_{5/2}4f_{5/2})_5 4f_{7/2}]_{11/2}$	$[(4d^5_{5/2}4f_{5/2})_2 4f_{7/2}]_{11/2}$
413.7	70.31	$[4d^5_{5/2}4f^2_{7/2}]_{11/2}$	$[(4d^5_{5/2}4f_{5/2})_5 4f_{7/2}]_{9/2}$
422.6	47.62	$[(4d^5_{5/2}4f_{5/2})_2 4f_{7/2}]_{11/2}$	$[4d^5_{5/2}4f^2_{5/2}]_{13/2}$
462.4	170.10	$[4d^5_{5/2}4f^2_{7/2}]_{11/2}$	$[(4d^5_{5/2}4f_{5/2})_3 4f_{7/2}]_{13/2}$
498.4	51.62	$[4d^5_{5/2}4f^2_{7/2}]_{11/2}$	$[(4d^5_{5/2}4f_{5/2})_1 4f_{7/2}]_{13/2}$
582.8	3.89	$[(4d^5_{5/2}4f_{5/2})_5 4f_{7/2}]_{11/2}$	$[(4d^5_{5/2}4f_{5/2})_3 4f_{7/2}]_{13/2}$
583.3	29.58	$[4d^5_{5/2}4f^2_{7/2}]_{11/2}$	$[4d^5_{5/2}4f^2_{5/2}]_{13/2}$
584.1	84.68	$[4d^5_{5/2}4f^2_{7/2}]_{15/2}$	$[(4d^5_{5/2}4f_{5/2})_5 4f_{7/2}]_{13/2}$
587.6	12.96	$[(4d^5_{5/2}4f_{5/2})_3 4f_{7/2}]_{11/2}$	$[(4d^5_{5/2}4f_{5/2})_5 4f_{7/2}]_{15/2}$
600.7	9.62	$[(4d^5_{5/2}4f_{5/2})_2 4f_{7/2}]_{11/2}$	$[4d^5_{5/2}4f^2_{5/2}]_{9/2}$
669.3	24.04	$[4d^5_{5/2}4f^2_{5/2}]_{13/2}$	$[(4d^5_{5/2}4f_{5/2})_5 4f_{7/2}]_{11/2}$
701.4	34.40	$[(4d^5_{5/2}4f_{5/2})_4 4f_{7/2}]_{13/2}$	$[(4d^5_{5/2}4f_{5/2})_4 4f_{7/2}]_{11/2}$

Potential lines for diagnostics of electron density of of W^{27+} Plasma in EBIT



Conclusion

- The visible M1 transition of W^{26+} and W^{27+} ions has been observed and calculated.
- Some transition lines was assigned by the comparison between experimental and theoretical work.
- Electron correlation effects are significant for accurate calculation on the transition energy.
- Some lines which the intensity ratio are sensitive to the electron density waiting for experimental verification.

Acknowledgement

This work was supported by:

- National Natural Science Foundation of China (NSFC)
- CRP of IAEA

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