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

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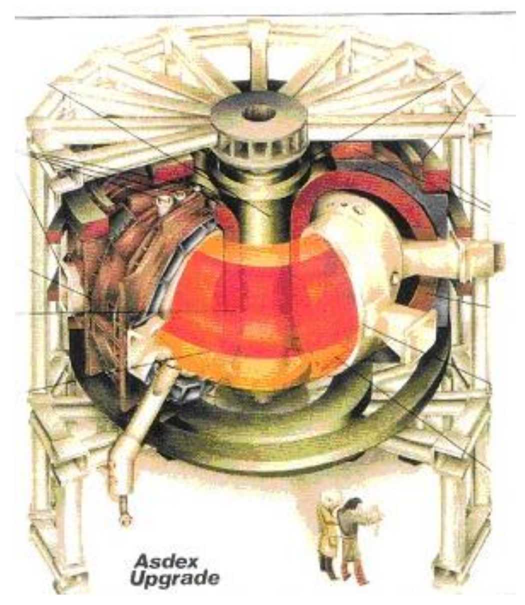
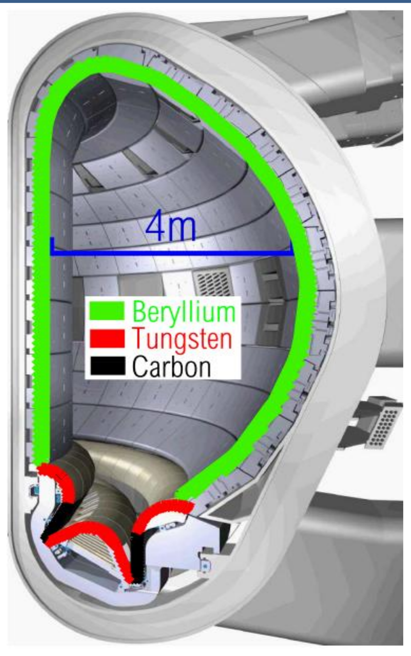
Introduction



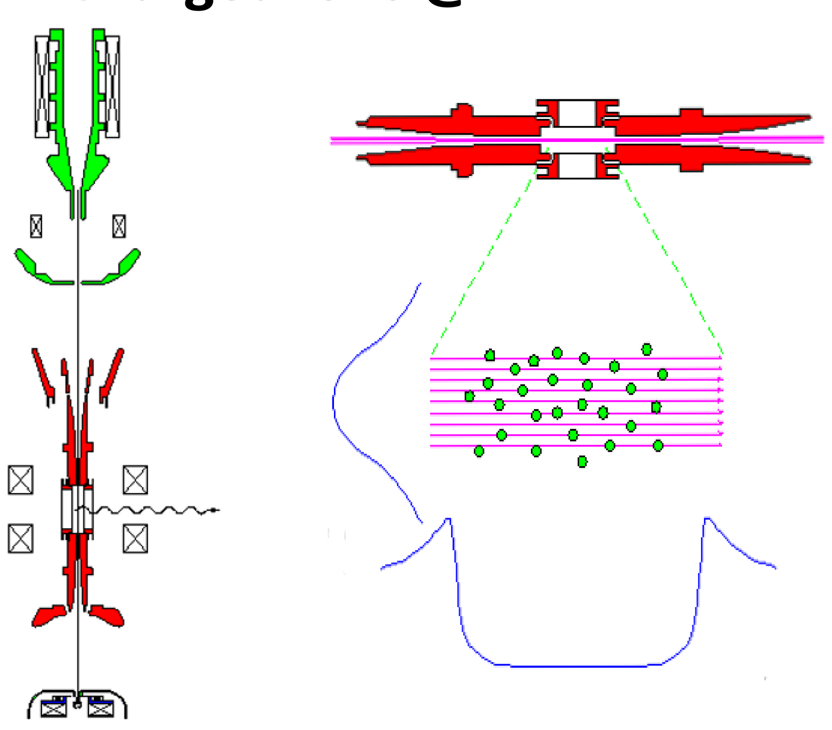


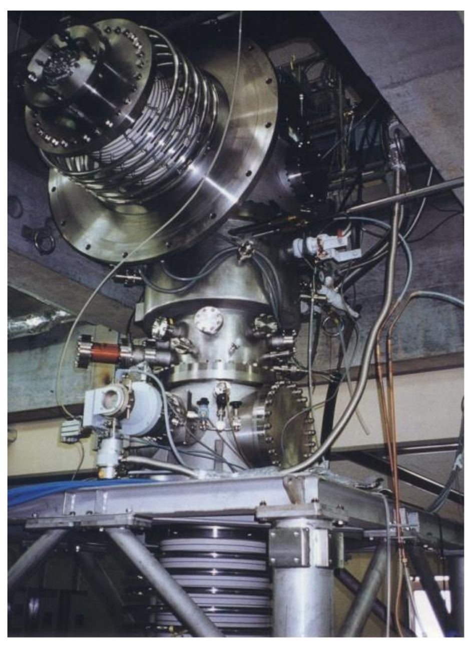
M1 transition in highly charged ions

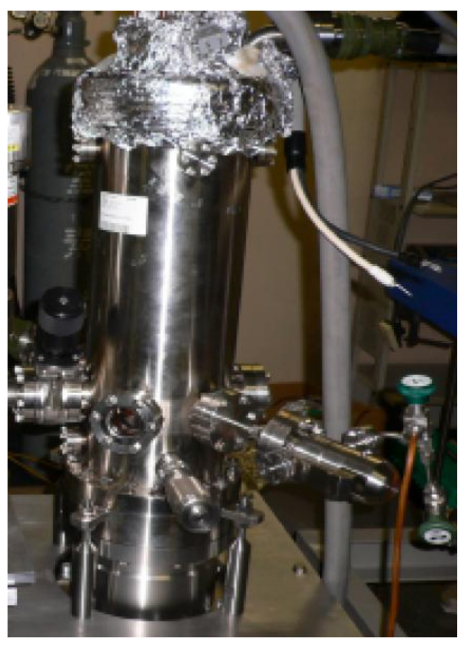
- The fine structure splitting of the ground and lower excited state of highly charged ions comes into the range of **visible light emissions**.
- Magnetic dipole (M1) resonance transitions are available between **the ground state fine structure multiplets**.
- Visible lines are of the great advantage 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

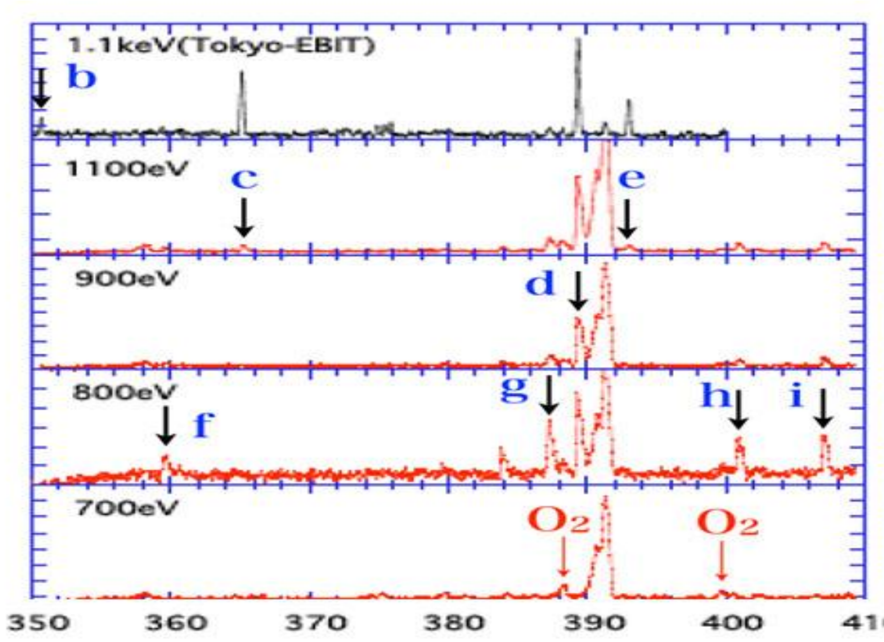
Experimental Investigation on Highly charged ions @ EBIT







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

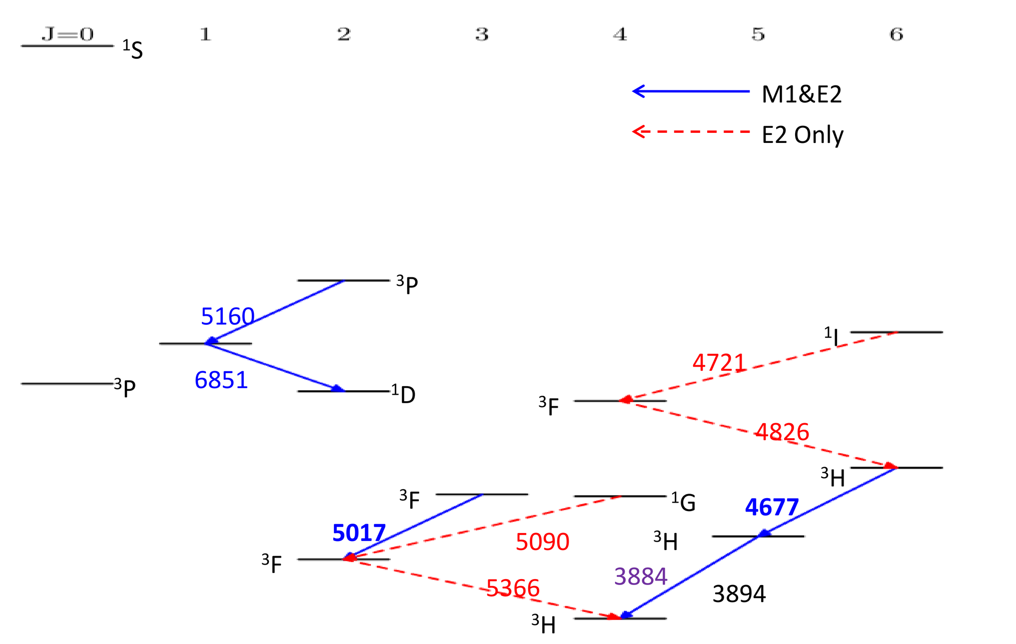
$$f_{i\to j} = \frac{\pi c}{2(2L+1)\omega^2}\left|\langle\Psi_f(P_f J_f M_f)|l+2s|\Psi_i(P_i J_i M_i)\rangle\right|^2$$

Transition Probability of M1 transition:

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

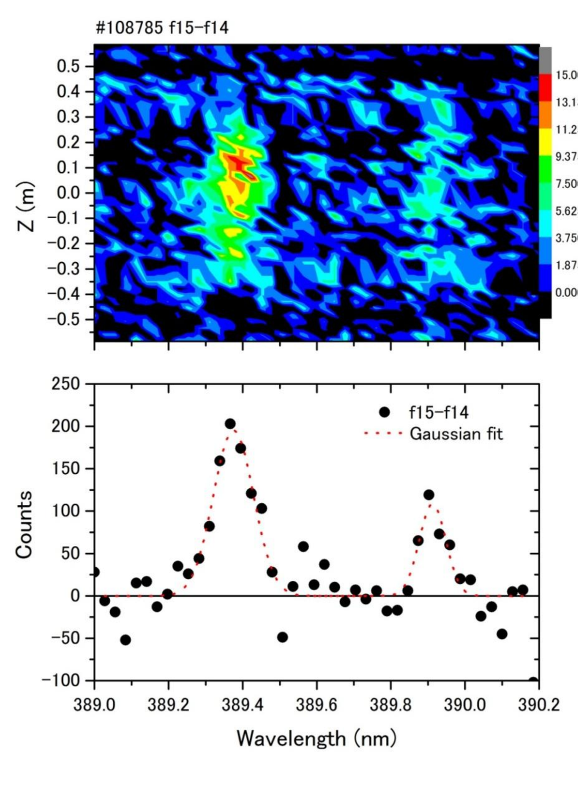
Results

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



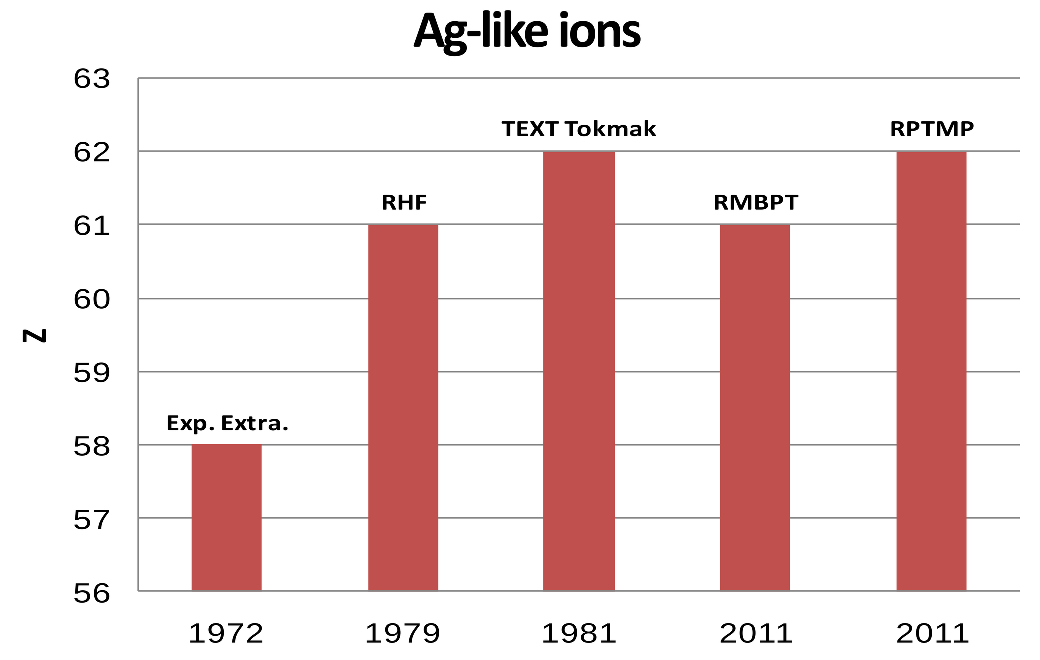
Tran	Wavelength(Å)	Type	$A_{ij}(s^{-1})$	Obs. Wavelength* (nm)
$^3H_5 \to {}^3H_4$	3884.34	M1	3.94(2)	389.4, 390.9
		E2	1.69(-3)	
$^3H_6 \to {}^3H_5$	4677.96	M1	2.05(2)	464.636
		E2	3.31(-4)	
$^1I_6 \to {}^3F_4$	4721.59	M1	2.90(-2)	
$^3F_4 \to {}^3H_6$	4826.63	E2	6.36(-4)	
$^3F_3 \to {}^3F_2$	5017.99	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)



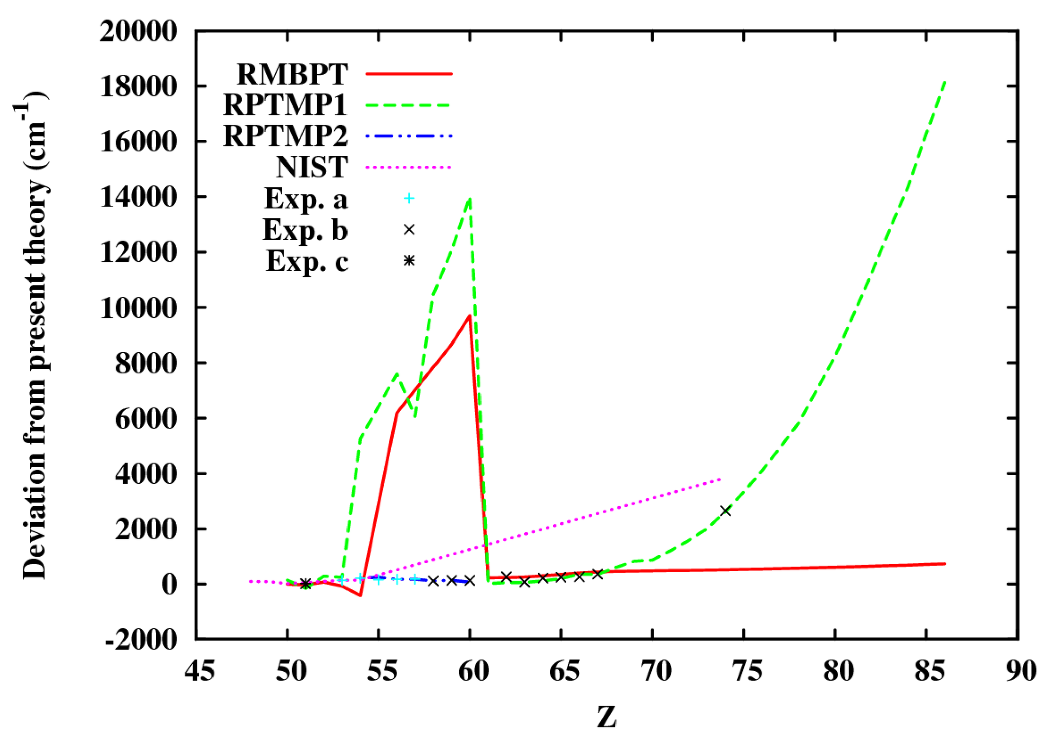
A spectrum of emission lines from highly charged tungsten ions observed at LHD (shot #108785). The scale on the right hand side of the top panel shows photon counts per pixel of the CCD detector.

The argument on the change of the ground state for Ag-like ions



Z	$5s-4f_{5/2}$	$5s-4f_{7/2}$	NIST		Z	$5s-4f_{5/2}$	$5s-4f_{7/2}$
47	−0.230	−0.230		−0.247	70	3.144	3.057
48	−0.478	−0.478	−0.494	−0.494	71	3.593	3.496
49	−0.725	−0.725	−0.738	−0.738	72	4.059	3.951
50	−0.953	−0.953	−0.958	−0.958	73	4.542	4.421
51	−1.136	−1.135	−1.126	−1.126	74	5.040	4.907
52	−1.249	−1.249			75	5.554	5.406
53	−1.283	−1.283	−1.235	−1.236	76	6.082	5.920
54	−1.256	−1.258	−1.209	−1.211	77	6.625	6.448
55	−1.182	−1.186			78	7.182	6.988
56	−1.069	−1.075			79	7.752	7.541
57	−0.923	−0.932			80	8.336	8.105
58	−0.747	−0.759			81	8.932	8.681
59	−0.544	−0.560			82	9.540	9.268
60	−0.316	−0.335			83	10.170	9.875
61	−0.064	−0.088			84	10.800	10.482
62	0.575	0.547			85	11.912	11.569
63	0.508	0.474			86	12.567	12.198
64	0.826	0.787			87	13.231	12.833
65	1.165	1.119			88	13.903	13.476
66	1.523	1.470			89	14.582	14.124
67	1.901	1.841			90	15.269	14.779
68	2.297	2.229			91	15.962	15.438
69	2.712	2.634			92	16.661	16.101

Deviation on the fine splitting of the ground state of Ag-like ions



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

References

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