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Wavelengths, transition probabilities and oscillator strengths for M-shell transitions in tungsten ions with partially filled 3*p* subshell

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Abstract: Wavelengths, transition probabilities and oscillator strengths have been calculated for M-shell electric dipole (E1) transitions in Al-like W^{61+} through Cl-like W^{57+}, with partially filled 3*p*subshell.Thefully relativistic multiconfiguration Dirac-Fock (MCDF) method, taking quantum electrodynamical (QED) effect and Breit correction into account, was used in the calculations. Calculated energy levels of M-shell excited states in Al-like through Cl-like W ions from the method were compared with some available theoretical and experimental results, and good agreement with them was achieved.

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Key words: MCDF method, energy level, M-shell transition, 3*p*-subshell, tungsten ion.

1. Introduction

As a promising material for plasma-facing components in future magnetic confinement fusion (MCF) reactors, tungsten is gaining great interesting in both theoretical and applied atomic physics[1].In order for the plasma-facing components to withstand the high particle and power load produced by particles escaping from magnetic confinement, tungsten is projected to be the wall material of choice because of its favorable properties of tungsten, such as low sputtering yield, high-energy threshold of sputtering, low tritium retention, high re-deposition efficiency and

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excellent thermal properties [2,3].Due to high Z (Z=74), tungsten ions penetrating into the plasma will not be fully stripped even in the hot core. Many different ionization stages will contribute to a measured spectrum. Accurate and abundant atomic data are needed to develop diagnostics for plasma parameters [4]. The data include wavelengths, transition probabilities and oscillator strengths for a large range of charge states of tungsten.

However, atomic data of high-Z ions are scarce and elaborate to produce, because of the high computational effort needed to perform calculations for these ions as well as more pronounced relativistic effects [5]. Present-day magnetic confinement experiments have core temperatures of a few KeV, where tungsten ionizes to M-shell charge states [6,16]. Between approximately 10 and 60 Å the strongest tungsten emission is expected to be due to n=3 to n=3 transitions in the M-shell ions [7,8]. In recent years, much progress in the investigation of atomic data in tungsten ions has been made [9]. An extensive review and critical compilation of experimental data on highly-ionized tungsten was made by Kramida et al. [10]. Biedermann et al. [3] investigated the soft x-ray lines at 0.56nm from Cu-like W^{45+} to V-like W^{50+} ions originating from 3*d*-4*f* transitions, which also are observed in the high-temperature core plasma of the ASDEX Upgrade tokamak. Pütterich et al. [5] observed and analyzed the spectra of Mn-like W^{49+} through Br-like W^{39+} in the regions 5-8 Å, around 50 Å, and between 100 and 300 Å. Ralchenko et al. [11] reported the measurements and analysis of extreme ultraviolet (EUV) spectra (4-20 nm) of Ca-like W^{54+} to Na-like W^{63+} obtained with an EBIT. Ralchenko et al. [12] also measured the extreme ultraviolet spectra between 10 and 25 nm from highly charged ions of tungsten with an open 3*d* shell in Co-like W^{47+} through K-like W^{55+}.Using a microcalorimeter spectrometer at the LLNL SuperEBIT facility, Clementson et al. [13] investigated the spectra of Zn-like W^{44+} through Co-like W^{47+} in the wide soft X-ray region between 3 and 12 Å. Clementson et al. [14] also studied $3s_{1/2}$-$3p_{3/2}$ and $3p_{1/2}$-$3d_{3/2}$ transitions in K-like W^{55+} through Ne-like W^{64+}. There have some progresses in theoretical aspect. Using RMBPT method, Safronova et al. [15] calculated energy levels and radiative rates of W^{70+}, W^{69+}, W^{62+}, W^{61+}, W^{54+}, W^{44+},

W^{27+}, and W^{4+} (Be-, B-, Mg-, Al-, Ca-, Zn-, Ag-, and Yb-like). Clementson et al. [16] used the Flexible Atomic Code to calculated the atomic structure and spectra of Ge-like W^{42+} through V-like W^{51+}, including energy levels, radiative lifetimes, spectral line positions, transition probability rates, and oscillator strengths. Using the multi-configuration Dirac-Fock (MCDF), Aggarwal et al. [17,18] calculated energy levels and radiative rates for transitions in Cl-like $W^{57+}$and Br-like W^{39+}. Hu et al. [19] presented a theoretical study of atomic characteristics of ten tungsten ions (Li-, Be-, B-, Na-, Mg-, Al-, Cu-, Zn-, Ga- and Ag-like) in a broad range of wavelengths, energy levels and transition probabilities. Lennartsson et al. [20] reported spectra and measured wavelengths of intrashell n=3 transitions in highly charged tungsten ions with partially filled 3*p* and 3*d* valence shells, Al-like W^{61+}through Fe-like W^{48+}. However, for the tungsten ions with partially filled 3*p* and 3*d*subshells, the correlation effects dominate most of the remaining uncertainty in atomic calculations [21,22], and currently there is no systematic and complete atomic dataset about these tungsten ions.

In this work, we use the extended relativistic MCDF method to calculate the energy levels of M-shell excited states in Al-like W^{61+} through Cl-like W^{57+}, with partially filled 3*p* subshell, taking the QED effect and Breit correction into account. In the calculations, the General-Purpose Relativistic Atomic Structure Program 2 ($GRASP^2$) was used. We compare the calculated energy levels from this method with some available theoretical and experimental results, and a good agreement was obtained. Finally, we provide a dataset of M-shell transitions including wavelengths, electron transition probabilities and oscillator strengths in Al-like W^{61+} through Cl-like W^{57+}(Al-, Si-, P-, S-, and Cl-like tungsten ions).

2. Theoretical method

In a general way, in calculations of the highly ionized atoms, the relativistic effect and QED effect must be taken into consideration, because the velocity of electrons is fast and the nuclear potential energy is very strong. In this work, we use $GRASP^2$ basing on the fully relativistic MCDF method, which is a version of GRASP

developed by Norrington [23] from the MCDF code originally published by Grant et al. [24,25] and improved by Dyall and coworkers [26]. Considering convergence and time-consuming issue of the optimal level，the computations were done with the extended average level option. The relevant configurations considered in calculations of Al-, Si-, P-, S-, and Cl-like tungsten ions, are illustrated in detail in section 3.2. In multi-electron system, the configuration correlation effect is a very important factor that influences the computational accuracy. Previously, our research team proved that when the number of valence electrons is not less than three, taking valance-valance (VV) correlation into account is appropriate [27]. Therefore, in the present calculation, VV correlation is adopted.

Here we give a brief outline of the multiconguration Dirac-Fock (MCDF) method.

In the MCDF method, the dominant interactions in an N-electrons atom or ion are included in the Dirac-Coulomb Hamiltonian

$$\hat{H}_{DC} = \sum_{i=1}^{N} \hat{H}_i + \sum_{i<j}^{N} \left| \hat{r}_i - \hat{r}_j \right|^{-1}, \tag{1}$$

where $\hat{H}_i$ represents the Dirac-Coulomb Hamiltonian of the i th electron. In other words, it is the one-body contribution of i th electron for the whole system, which can be defined as

$$\hat{H}_i = c\alpha \cdot \hat{P}_i + (\beta - 1)c^2 + V_{nuc}(\hat{r}_i) \tag{2}$$

where $V_{nuc}(\hat{r}_i)$ denotes the nuclear field and c denotes the speed of light in vacuum. α and β are Dirac vector and scalar matrix, respectively. $\hat{P}_i$ is the momentum operator of i th electron.

The atomic state functions (ASFs) describing different fine structure states are obtained as linear combinations of symmetry adapted configuration state functions (CSFs)

$$\left| \Gamma PJM \right\rangle = \sum_{r=1}^{n_c} c_{r\Gamma} \left| \gamma_r PJM \right\rangle, \tag{3}$$

where n_c is the number of CSF and $c_{r\Gamma}$ is mixing coefficient of configuration. The contributions from Breit interaction and QED effect consisting of vacuum polarization

and self-energy, are generally added as a perturbation correction. Within the unit time (h^3/me^4), the atom spontaneously decays from β state transition to α state, the transition probability [28] is defined as

$$A_{\beta\to\alpha} = [j_\beta]^{-1} \sum_{m_\alpha, m_\beta} 2\pi \left| M_{\alpha\beta} \right|^2 . \tag{4}$$

According to the irreducible tensor theory, the above equation can be written as

$$A_{\beta\to\alpha} = 2\alpha\omega \frac{[j_\alpha]}{[L]} \begin{pmatrix} j_\alpha & L & j_\beta \\ 1/2 & 0 & 1/2 \end{pmatrix}^2 \left| \overline{M}_{\alpha\beta} \right|^2 . \tag{5}$$

Then, the oscillator strength is defined as

$$f_{\beta\to\alpha} = \frac{[j_\beta]}{[j_\alpha]} \frac{A_{\beta\to\alpha}}{2\theta\omega^2} \tag{6}$$

with $\theta = 4\pi^2 e^2 / mc$.

3. Results and discussion

3.1. Energy levels

We have compared the present calculated energy levels with some available theoretical and experimental results. At the same time, for each energy level, we provide the percentage of the dominant configuration in the level compositions. In Table 1, the calculated energy levels of some M-shell excited states for Al-like through Cl-like tungsten ions are listed along with those from the NIST database [28] and other published works [10,15,17,30]. All energy levels in Table 1 are given in units of eV. The energy levels calculated by Safranova et al. [15] are given in units of cm^{-1} for Al-likeW^{61+}, and we convert the units of $cm^{-1}$to eV using the conversion factor 8065.54465 cm^{-1}/eV as recommended by the CODATA [31]. In the same way, the units of Ryd [17] is convertedto eV according to 1 Ryd=13.606 eV. Safranova et al. [15] calculated the wavelengthes of some transitions in Al-like$W^{61+}$and Cl-likeW^{57+}, and we convert the wavelengthes to energy levels using the conversion factors 12414.41ÅeV/*hc*. For Al-likeW^{61+}, we compare our energy levels with the results of NIST and from RMBPT calculated by Safranova et al. [15]. It is observed that the calculations agree well with the experimental and theoretical data, and the difference is less than 0.2%. For example, the difference of the energy level of the

configuration $3s3p^2\ ^4P_{1/2}$ between our result and the experimental value is only 0.181%, and the difference between our result and the value from Safranovaet al. [15] is only 0.068%. For Si-like, P-like and S-like W ions, the results of NIST, Kramida et al. [10] and Clementson et al. [30]are compared with our results. As Table 1 indicates, the differences between their results and ours are less than 1%, except for a few of levels (see, for example, the $3s^23p3d\ ^3D_1$, $3s3p^4\ ^2P_{3/2}$ and $3s^23p^33d(^2P)^3P_0$ levels) where the difference is as much as1.849%. The reason for this is not known to the authors, but it is possible that the present results do not include higher-order relativistic effects. In addition, the limited configurations considered in calculations are very important factors which cause the differences. For Cl-likeW^{57+}, we compare our energy levels with the results of NIST, Clementson et al. [31] and from GRASP calculated by Aggarwal et al. [17]. The largest difference between experimental results and ours is less than 0.9%, such as the configuration of $3s^23p^43d\ ^4F_{9/2,}$ and the minimum is only 0.058%, such as $3s^23p^43d\ ^4F_{7/2}$. At the same time, the calculations also agree well with the theoretical data [17]. Based on this comparison as well as the one shown in Table 1, we consider that calculated energy levels listed are accurate to within 1%, and the overall good agreement of the calculated values by GRASP[2] is satisfactory.

Table 1. Comparison of the energy levels (in eV) of some M-shell excited states for Al-, Si-, P-, S-, and Cl-like tungsten ions between the present calculated results and other experimental and theoretical values. Note that $1s^22s^22p^6$ is omitted in configuration.

Ion	Configuration	term	pcnt.(%)	Level(eV)		
				Present	Expt.	Theor.
Al-like W^{61+}	$3s^23p$	$^2P_{1/2}$	100.00	0		0
	$3s3p^2$	$^4P_{1/2}$	99.19	167.147	167.45[a]	167.261[b]
	$3s^23p$	$^2P_{3/2}$	100.00	363.205	363.7[a]	363.101[b]
	$3s3p^2$	$^4P_{3/2}$	72.18	500.137	500.34[a]	500.064[b]
	$3s3p^2$	$^4P_{5/2}$	99.66	518.640		518.176[b]
	$3s3p^2$	$^2D_{3/2}$	71.88	539.266	539.98[a]	539.287[b]
	$3s3p^2$	$^2P_{1/2}$	98.89	549.664	549.99[a]	549.330[b]
	$3s^23d$	$^2D_{3/2}$	100.00	597.697	597.34[a]	
Si-like W^{60+}	$3s^23p^2$	$^3P_0$	99.94	0		
	$3s^23p^2$	$^3P_1$	100.00	347.766	347.4[c]	

Ion	Configuration	term	pcnt.(%)	Level(eV)		
				Present	Expt.	Theor.
	$3s^23p^2$	$^3P_2$	99.96	714.227	711[d]	
	$3s^23p^2$	$^1D_2$	99.96	357.662	357.76[a]	
	$3s3p^3$	$^3P_2$	99.27	517.965	519.87[a]	
	$3s3p^3$	$^3P_0$	100.00	895.433	888[d]	
	$3s3p^3$	$^3P_1$	54.35	915.828	905[d]	
		$^3D_1$	45.04			
		$^3S_1$	0.61			
	$3s3p^3$	$^3D_1$	99.34	546.432	543.96[a]	
	$3s3p^3$	$^3D_2$	69.08	918.405		
		$^1D_2$	30.20			
		$^3P_2$	0.41			
		$^5S_2$	0.31			
	$3s3p^3$	$^3D_3$	100.00	878.049	877[d]	
	$3s^23p3d$	$^3D_1$	99.87	601.024	611.66[a]	
P-like W^{59+}	$3s^23p^3$	$^2P_{3/2}$	99.91	0		
	$3s^23p^3$	$^2P_{1/2}$	100.00	370.579	367.6[c]	
	$3s^23p^23d$	$^4F_{3/2}$	99.82	229.140	229.69[a]	
	$3s^23p^23d$	$^2D_{5/2}$	99.03	324.628	325.2[d]	
	$3s^23p^3$	$^4S_{3/2}$	99.89	341.429	341[c]	
	$3s^23p^3$	$^2D_{5/2}$	100.00	353.920	353.14[a]	
	$3s^23p^3$	$^2D_{3/2}$	99.92	715.038	710[d]	
	$3s3p^4$	$^4P_{5/2}$	99.70	521.380	516.08[a]	
	$3s3p^4$	$^2P_{3/2}$	99.27	557.624	547.5[d]	
	$3s3p^4$	$^2S_{1/2}$	99.49	551.129	547[d]	
	$3s^23p^23d$	$(^1D)^2D_{3/2}$	95.07	613.346	621.2[a]	
	$3s^23p^23d$	$(^3P)^4P_{5/2}$	49.50	607.716	610.19[a]	
		$^4D_{5/2}$	46.22			
		$(^3P)^2D_{5/2}$	3.04			
		$^4F_{5/2}$	0.70			
		$(^3P)^2F_{5/2}$	0.43			
S-like W^{58+}	$3s^23p^4$	$^3P_2$	99.96	0		
	$3s^23p^4$	$^3P_0$	99.93	19.250	19[c]	
	$3s^23p^33d$	$^5D_2$	99.35	233.335	234.81[a]	
	$3s^23p^33d$	$^5D_3$	98.02	242.241	243.78[a]	
	$3s^23p^33d$	$(^2P)^3P_0$	99.73	947.106	970[d]	

Ion	Configuration	term	pcnt.(%)	Level(eV)		
				Present	Expt.	Theor.
	$3s^23p^33d$	$^3P_1$	95.03	959.098	972[d]	
	$3s^23p^33d$	$^5D_0$	99.66	242.290	242.9[d]	
	$3s^23p^33d$	$^3D_3$	98.51	966.014	970[d]	
	$3s^23p^33d$	$^3P_2$	98.55	969.730	973[d]	
	$3s^23p^33d$	$^5D_4$	99.75	317.297	319.175[a]	
	$3s^23p^33d$	$^3D_2$	98.75	327.331	326[d]	
	$3s^23p^33d$	$^3D_3$	96.71	344.909	344[d]	
	$3s^23p^33d$	$(^4S)^3D_1$	98.61	356.309	353[d]	
	$3s3p^5$	$^3P_2$	100.00	530.223	530.99[a]	
	$3s3p^5$	$^3P_1$	99.40	558.030	553[d]	
	$3s^23p^33d$	$^3G_3$	49.91	616.655	615.4[a]	
		$(^2D)^3F_3$	47.00			
		$(^2D)^3D_3$	1.38			
		$(^4S)^3D_3$	1.32			
		$(^2P)^3F_3$	0.25			
	$3s^23p^33d$	$^3F_2$	82.79	615.438	622.19[a]	
	$3s^23p^33d$	$(^2P)^3D_1$	88.14	637.845	627.71[a]	
Cl-like W^{57+}	$3s^23p^5$	$^2P_{3/2}$	100.00	0		0
	$3s^23p^5$	$^2P_{1/2}$	100.00	349.088	347[d]	347.44[e]
	$3s^23p^43d$	$(^3P)^4F_{3/2}$	91.96	235.079	235.98[a]	355.175[e]
	$3s^23p^43d$	$^4F_{5/2}$	97.04	241.862	242.104[a]	242.962[e]
	$3s^23p^43d$	$^4D_{1/2}$	98.49	243.513	243.1[d]	243.813[e]
	$3s^23p^43d$	$^4F_{7/2}$	99.66	245.738	245.594[a]	246.633[e]
	$3s^23p^43d$	$(^3P)^4P_{3/2}$	90.52	265.255	264.7[d]	266.11[e]
	$3s^23p^43d$	$^4D_{7/2}$	99.50	314.136	316.735[a]	317.206[e]
	$3s^23p^43d$	$^4F_{9/2}$	99.97	316.061	318.91[a]	319.466[e]
	$3s^23p^43d$	$(^3P)^4P_{1/2}$	98.12	327.502	327.6[d]	326.198[e]
	$3s^23p^43d$	$(^3P)^4D_{3/2}$	97.16	356.933	355.5[d]	
	$3s^23p^43d$	$^4D_{5/2}$	66.55	362.653	361.9[d]	
		$^4P_{5/2}$	28.86			
		$^4F_{5/2}$	2.83			
		$(^3P)^2D_{5/2}$	1.15			
		$(^3P)^2F_{5/2}$	0.56			
	$3s^23p^43d$	$(^3P)^4P_{5/2}$	69.85	346.206	347[d]	348.617[e]
		$^4D_{5/2}$	29.96			

Ion	Configuration	term	pcnt.(%)	Level(eV)		
				Present	Expt.	Theor.
		$(^1D)^2F_{5/2}$	0.10			
		$(^1S)^2D_{5/2}$	0.05			
		$(^3P)^2F_{5/2}$	0.01			
	$3s3p^6$	$^2S_{1/2}$	100.00	564.522	560[d]	542.475[e]
	$3s^23p^43d$	$(^1D)^2P_{1/2}$	88.51	575.081	574[d]	572.581[e]
	$3s^23p^43d$	$(^3P)^2P_{3/2}$	74.23	587.061	584[d]	583.293[e]
	$3s^23p^43d$	$(^3P)^2D_{5/2}$	60.95	589.055	591[d]	591.408[e]
		$(^3P)^2F_{5/2}$	38.72			
		$(^1D)^2D_{5/2}$	0.08			
		$^4P_{5/2}$	0.08			
		$^4F_{5/2}$	0.07			
	$3s^23p^43d$	$^2F_{7/2}$	99.93	597.287	594.1[d]	592.797[e]
	$3s^23p^43d$	$(^3P)^2F_{5/2}$	60.34	624.781	622.91[a]	
		$(^3P)^2D_{5/2}$	37.80			
		$^4D_{5/2}$	1.25			
		$^4P_{5/2}$	0.42			
		$(^1D)^2F_{5/2}$	0.13			
	$3s^23p^43d$	$(^3P)^2D_{3/2}$	71.99	626.770	625.74[a]	627.201[e]
	$3s^23p^43d$	$(^3P)^2P_{1/2}$	86.51	632.359	631.9[a]	634.476[e]

Present: Present results from GRASP[2].

[a] NIST

[b]Safranova et al. [15].

[c] Kramida et al. [10].

[d] Clementson et al. [30].

[e] Aggarwal et al. [17].

3.2. Wavelengths, transition probabilities and oscillator strengths

The configuration state functions used in the calculations are listed in Table 2. In addition, the number of fine-structure levels produced and the total number of E1 transitions are also listed in Table 2.

Table 2. Configuration state functions included in the structure calculations. n=3, 4, 5; n*=4, 5. Note that $1s^22s^22p^6$ is omitted in configuration.

	Al-like W^{61+}	Si-like W^{60+}	P-like W^{59+}	S-like W^{58+}	Cl-like W^{57+}
State configurations	$3s^23p$	$3s^23p^2$	$3s^23p^3$	$3s^23p^4$	$3s^23p^5$
	$3s^2nd$	$3s^23pnd$	$3s^23p^2nd$	$3s^23p^3nd$	$3s^23p^4nd$
	$3s^2n^*s$	$3s^23pn^*s$	$3s^23p^2n^*s$	$3s^23p^3n^*s$	$3s^23p^4n^*s$

	3s3pnp	3s3p^{2}np	3s3p^{3}np	3s3p^{4}np	3s3p^{5}np
Number of levels produced	52	143	214	227	139
Total number of transitions	87	423	804	633	192

The wavelengths, transition probabilities and oscillator strengths for allowed M-shell E1 transitions calculated using GRASP^2 are listed in Tables A1-A5 in appendix for 5 ionic states of tungsten, from Al-like W^{61+} to Cl-like W^{57+}. In order to validate the present method and make sure that the calculations based on the present model are accurate, according to indicator [32,33] that the agreement between length and velocity gauges, the ratios of the velocity gauge to the length gauge are given in the tables. It is observed that the ratios are all in the range of 0.88 to 1.03. According to non-relativistic [34,35] and relativistic [36] points of view, the length gauge has higher preference than the velocity gauge. For this reason, we use the length gauge in both present work and previous work [27,37]. For Al-like W^{61+}, the relevant configurations are $(1s^22s^22p^6)3s^23p$, $3s^23d$, $3s^24s$, $3s^24d$, $3s^25s$, $3s^25d$, $3s3p^2$, 3s3p4p, 3s3p5p for the even and odd parities, respectively, resulting in 52 fine-structure levels and 87 E1 transitions. Considering the limited space, we only list the transitions of which transition probabilities are greater than 10^{13} in Table A1. For Si-like W^{60+}, the configurations of $3s^23p^2$, $3s^23p3d$, $3s^23p4s$, $3s^23p4d$, $3s^23p5s$, $3s^23p5d$, $3s3p^3$, $3s3p^24p$, $3s3p^25p$ are included in the calculations. These configurations produce 143 levels and 423 E1 transitions in total. In Table A2, some transitions of which transition probabilities are greater than 10^{13} are listed. For P-like W^{59+}, our calculations include $3s^23p^3$, $3s^23p^23d$, $3s^23p^24s$, $3s^23p^24d$, $3s^23p^25s$, $3s^23p^25d$, $3s3p^4$, $3s3p^34p$, $3s3p^35p$. Then 214 levels and 804 E1 transitions are obtained, and some of which have been listed in Table A3. In a similar way, we get 633 E1 transitions of S-like W^{58+} and 192 E1 transitions of Cl-like W^{57+}, respectively. For S-like W^{58+}, our calculations include $3s^23p^4$, $3s^23p^33d$, $3s^23p^34s$, $3s^23p^34d$, $3s^23p^35s$, $3s^23p^35d$, $3s3p^5$, $3s3p^44p$ and$3s3p^45p$. For Cl-like W^{57+}, our calculations include $3s^23p^5$, $3s^23p^43d$, $3s^23p^44s$, $3s^23p^44d$

and$3s^2 3p^4 5s$, $3s^2 3p^4 5d$, $3s3p^6$, $3s3p^5 4p$ and$3s3p^5 5p$. Some transitions of which transition probabilities are greater than 10^{13} are listed in Table A4 and Table A5, respectively.

4. Conclusions

In this paper, we calculate the energy levels of M-shell excited states (Δn=0,1,2) in Al-like W^{61+} through Cl-like W^{57+}, with partially filled 3*p* subshell, using the extended relativistic MCDF method, taking the QED effect and Breit correction into account. In the calculations, the General-Purpose Relativistic Atomic Structure Program 2 (GRASP[2]) was used. Compared with the theoretical and experimental results to test the validity of this method, it is found that our results of energy levels from this method are reliable and reasonable. Additionally, we provide a dataset of M-shell transitions including wavelengths, electron transition probabilities and oscillator strengths in Al-like W^{61+} through Cl-like W^{57+}, with partially filled 3*p* subshell. Hopefully, our calculations will help line identification in future experiments.

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References

[1]A.Loarte, B.Lipschultz, A.SKukushkin.Chapter 4: Power and particle control. Nucl. Fusion **47**,S203 (2007).

[2] J. Clementson, P.Beiersdorfer, G. V. Brown, M.F.Gu.Phys. Scr. **81**,015301(2010)

[3] C.Biedermann, R.Radtke, R. Seidel，T.Pütterich. Phys. Scr. **T134**,014026(2009)

[4] I. Martinson, Rep. Prog. Phys.**52**,157(1989)

[5] T. Pütterich, R.Neu, R. Dux, A.D.Whiteford, M.G.O'Mullane, the ASDEX Upgrade Team.Plasma Phys. Control. Fusion **50**,085016(2008)

[6] P. Neill, C. Harris, A. S. Safranova, S. Hamasha, S.Hansen, U. I. Safranova, P. Beiersdorfer. Can.J.Phys., **82**,931(2004).

[7] C. Biedermann, R. Radtke, R. Seidel, T. Pütterich. Phys.Scr., **T134**,014026(2009).

[8] J. Clementson. Ph.D. thesis, LundUniversity, 2010.

[9] A. Kramida. Can. J. Phys. **89**,551(2011).

[10] A. E. Kramida, T. Shirai. At. Data Nucl. Data Tables. **95**,305(2009).

[11] Y. Ralchenko, I.N.Draganic, J. N. Tan, J.D.Gillaspy, J. M.Pomeroy,J. Reader, U. Feldman, G. E. Holland. J. Phys. B: At. Mol. Opt. Phys. **41**,021003(2008)

[12] Y. Ralchenko, I. N. Draganić, D. Osin, J. D. Gillaspy, J. Reader. Phys. Rev. A**83**,032517(2011)

[13] J. Clementson, P.Beiersdorfer, G. V. Brown, M. F.Gu.Phys. Scr. **81**,015301(2010)

[14] J. Clementson, P. Beiersdorfer. Phys. Rev. A**81**,052509(2010)

[15] U. I. Safronova, A. S. Safronova. J. Phys. B: At. Mol. Opt. Phys. **43**,074026(2010)

[16] J. Clementson, P. Beiersdorfer, T. Brage, M.F. Gu. At. Data Nucl. DataTables.**100**,577(2014)

[17] K.M. Aggarwal, F. P. Keenan. At. Data Nucl. Data Tables.**100**,1603(2014)

[18] K.M. Aggarwal, F. P. Keenan. At. Data Nucl. Data Tables.**100**,1399(2014)

[19] F. Hu, C.K. Wang, J.M. Yang, G. Jiang, L.H. Hao. Phys. Scr. **84**,015302(2011)

[20] T. Lennartsson, J. Clementson, P. Beiersdorfer. Phys. Rev. A**87**,062505(2012).

[21] M. H. Chen, K. T. Cheng. J. Phys. B **43**,074019(2010).

[22] K. T. Cheng, M. H. Chen, W. R. Johnson, J. Sapirstein. Can. J. Phys. **86**,33(2008).

[23] P.H.Norrington.2002, Available from :<http://www.am.qub.ac.uk/>

[24] I.P.Grant, B.J. McKenzie. P.H. Norrington, D.F. Mayers, N.C. Pyper, Comput.Phys. Commun.**21**,207(1980).

[25] B.J. McKenzie, I.P. Grant, P.H. Norrington. Comput. Phys. Commun. **21**,233(1980).

[26] K.G. Dyall. I.P. Grant, C.T. Johnson, F.A. Parpia, E.P. Plummer. Comput. Phys. Commun. **55**,425(1989).

[27] M. Xu, G. Jiang, M. Wu, X. Li,G. Bian, F. Hu. Can. J. Phys. **94**,563(2016).

[28] I. P. Grant. J. Phys. B **7**,1458(1974).

[29] The NIST Atomic Spectra Database http://www.nist.gov/pml/data/asd.cfm

[30] J. Clementson, P. Beiersdorfer,G. V. Brown, M. F.Gu, H. Lundberg, Y. Podpaly, E. Träbert.

Can. J. Phys. **89**,571(2011)

[31] P.J. Mohr, B.N. Taylor, D.B. Newell, The 2006 CODATA Recommended Values ofthe Fundamental Physical Constants, Web Version 5.0. Available at:<physics.nist.gov/constants/>, National Institute of Standards andTechnology, Gaithersburg, MD, September 2007.

[32] A.Hibbert. J. Phys. B: At. Mol. Opt. Phys. **36**,4703(2003).

[33] M.C. Martins, J.P. Santos, A.M. Costa, F. Parente. Eur. Phys. J. D.**39**,167(2006).

[34] A.F. Starace, Phys. Rev. A **3**, 1242 (1971)

[35] A.F. Starace, Phys. Rev. A**8**, 1141 (1971)

[36] A. Derevianko, I.M. Savukov, W.R. Johnson, D.R. Plante, Phys. Rev. A **58**, 4453 (1998)

[37] M. Xu, G. Jiang, B. Deng, G. Bian. At. Data Nucl. Data Tables.**100**,1357(2014).

Appendix

Table A1. Wavelengths (in Å), transition probabilities(in s^{-1}), oscillator strengths (*gf*) and the ratio of velocity to length rates (A_v/A_l) for Al-like W^{61+}. Note that $1s^22s^22p^6$ is omitted in configuration.

No.	states		λ(Å)	A(s^{-1})	*gf*	A_v/A_l
	Upper	Lower				
1	$3s^24s\ ^2S_{1/2}$	$3s^23p\ ^2P_{1/2}$	4.106	1.59E+13	8.03E-02	1.0018
2	$3s^24s\ ^2S_{1/2}$	$3s^23p\ ^2P_{3/2}$	4.678	4.63E+13	3.03E-01	0.9998
3	$3s^24d\ ^2D_{3/2}$	$3s^23p\ ^2P_{1/2}$	3.726	8.50E+13	7.08E-01	0.9852
4	$3s^24d\ ^2D_{3/2}$	$3s^23p\ ^2P_{3/2}$	4.192	1.93E+13	2.04E-01	0.9863
5	$3s^24d\ ^2D_{5/2}$	$3s^23p\ ^2P_{3/2}$	4.142	1.10E+14	1.69E+00	0.9858
6	$3s^25s\ ^2S_{1/2}$	$3s^23p\ ^2P_{3/2}$	3.063	2.08E+13	5.85E-02	0.9973
7	$3s^25d\ ^2D_{3/2}$	$3s^23p\ ^2P_{1/2}$	2.713	4.77E+13	2.11E-01	0.9843
8	$3s^24d\ ^2D_{5/2}$	$3s^23p\ ^2P_{3/2}$	2.939	5.71E+13	4.44E-01	0.9841
9	$3s3p4p(^3P)^4P_{1/2}$	$3s^23p\ ^2P_{1/2}$	3.844	1.95E+13	8.66E-02	0.9095
10	$3s3p4p(^3P)^4D_{3/2}$	$3s^23p\ ^2P_{1/2}$	3.825	4.06E+13	3.56E-01	0.9009
11	$3s3p4p(^3P)^4D_{1/2}$	$3s^23p\ ^2P_{1/2}$	3.811	2.13E+13	9.27E-02	0.8939
12	$3s3p4p(^3P)^4S_{3/2}$	$3s^23p\ ^2P_{1/2}$	3.674	1.63E+13	1.32E-01	0.9985
13	$3s3p4p(^3P)^2P_{1/2}$	$3s^23p\ ^2P_{1/2}$	3.654	6.26E+13	2.51E-01	0.9897
14	$3s3p4p(^3P)^4P_{3/2}$	$3s^23p\ ^2P_{1/2}$	3.654	4.66E+13	3.73E-01	0.9897
15	$3s3p4p(^3P)^2D_{3/2}$	$3s^23p\ ^2P_{3/2}$	3.837	1.54E+13	1.36E-01	0.9054
16	$3s3p4p(^3P)^4P_{5/2}$	$3s^23p\ ^2P_{3/2}$	3.834	4.03E+13	5.33E-01	0.9049
17	$3s3p4p(^3P)^2S_{1/2}$	$3s^23p\ ^2P_{3/2}$	3.789	3.94E+13	1.69E-01	0.8848
18	$3s3p4p(^3P)^2P_{3/2}$	$3s^23p\ ^2P_{3/2}$	3.787	2.82E+13	2.43E-01	0.8821
19	$3s3p4p(^1P)^2D_{3/2}$	$3s^23p\ ^2P_{3/2}$	3.673	3.76E+13	3.04E-01	0.9972
20	$3s3p4p(^3P)^2D_{5/2}$	$3s^23p\ ^2P_{3/2}$	3.668	3.13E+13	3.78E-01	0.7965
21	$3s3p4p(^1P)^2P_{1/2}$	$3s^23p\ ^2P_{3/2}$	3.663	6.54E+13	2.63E-01	0.9943
22	$3s3p4p(^1P)^2D_{5/2}$	$3s^23p\ ^2P_{3/2}$	3.631	3.23E+13	3.84E-01	0.9794
23	$3s3p4p(^1P)^2P_{3/2}$	$3s^23p\ ^2P_{3/2}$	3.626	2.28E+13	1.80E-01	0.9776
24	$3s3p5p(^3P)^4P_{1/2}$	$3s^23p\ ^2P_{1/2}$	2.702	1.38E+13	3.02E-02	0.9047
25	$3s3p5p(^3P)^4D_{3/2}$	$3s^23p\ ^2P_{1/2}$	2.692	2.20E+13	9.58E-02	0.8988
26	$3s3p5p(^3P)^4S_{3/2}$	$3s^23p\ ^2P_{1/2}$	2.658	1.18E+13	4.98E-02	0.9134
27	$3s3p5p(^3P)^2P_{1/2}$	$3s^23p\ ^2P_{1/2}$	2.648	3.62E+13	7.61E-02	0.9070
28	$3s3p5p(^3P)^4P_{3/2}$	$3s^23p\ ^2P_{1/2}$	2.648	2.45E+13	1.03E-01	0.9070
29	$3s3p5p(^3P)^4P_{5/2}$	$3s^23p\ ^2P_{3/2}$	2.698	2.19E+13	1.43E-01	0.9033
30	$3s3p5p(^3P)^2S_{1/2}$	$3s^23p\ ^2P_{3/2}$	2.676	2.02E+13	4.34E-02	0.9914
31	$3s3p5p(^3P)^2P_{3/2}$	$3s^23p\ ^2P_{3/2}$	2.675	1.52E+13	6.54E-02	0.9853
32	$3s3p5p(^1P)^2D_{3/2}$	$3s^23p\ ^2P_{3/2}$	2.657	2.43E+13	1.03E-01	0.9105
33	$3s3p5p(^3P)^2D_{5/2}$	$3s^23p\ ^2P_{3/2}$	2.656	1.68E+13	1.07E-01	0.9129
34	$3s3p5p(^1P)^2P_{1/2}$	$3s^23p\ ^2P_{3/2}$	2.654	3.75E+13	7.92E-02	0.9125
35	$3s3p5p(^1P)^2D_{5/2}$	$3s^23p\ ^2P_{3/2}$	2.634	1.99E+13	1.24E-01	0.9979
36	$3s3p5p(^1P)^2P_{3/2}$	$3s^23p\ ^2P_{3/2}$	2.634	1.05E+13	4.37E-02	0.9977

Table A2. Wavelengths (in Å), transition probabilities (in s^{-1}), oscillator strengths (*gf*) and the ratio of velocity to length rates (A_v/A_l) for Si-like W^{60+}. Note that $1s^22s^22p^6$ is omitted in configuration.

No.	states		λ(Å)	A(s^{-1})	*gf*	A_v/A_l
	Upper	Lower				
1	$3s^23p4s\ ^3P_1$	$3s^23p^2\ ^3P_0$	4.180	1.01E+13	7.95E-02	1.0133
2	$3s^23p4s\ ^3P_0$	$3s^23p^2\ ^3P_1$	4.746	4.48E+13	1.51E-01	0.9992
3	$3s^23p4s\ ^3P_1$	$3s^23p^2\ ^3P_2$	4.761	3.67E+13	3.75E-01	1.0045
4	$3s^23p4s\ ^1P_1$	$3s^23p^2\ ^3P_2$	4.169	1.21E+13	9.43E-02	1.0150
5	$3s^23p4s\ ^3P_2$	$3s^23p^2\ ^1D_2$	4.751	2.19E+13	3.71E-01	0.9982
6	$3s^23p4s\ ^1P_1$	$3s^23p^2\ ^1D_2$	4.743	3.82E+13	3.86E-01	1.0008
7	$3s^23p4s\ ^1P_1$	$3s^23p^2\ ^1S_0$	4.782	1.46E+13	1.50E-01	1.0145
8	$3s^23p4d\ ^3D_1$	$3s^23p^2\ ^3P_0$	3.781	1.06E+14	6.84E-01	0.9981
9	$3s^23p4d\ ^3D_1$	$3s^23p^2\ ^3P_1$	4.235	1.61E+13	1.30E-01	0.9970
10	$3s^23p4d\ ^3D_2$	$3s^23p^2\ ^3P_1$	4.188	9.43E+13	1.24E+00	0.9932
11	$3s^23p4d\ ^3P_2$	$3s^23p^2\ ^3P_1$	3.768	3.95E+13	4.20E-01	0.9935
12	$3s^23p4d\ ^3P_1$	$3s^23p^2\ ^3P_1$	3.762	6.64E+13	4.23E-01	0.9904
13	$3s^23p4d\ ^3P_0$	$3s^23p^2\ ^3P_1$	3.759	8.11E+13	1.72E-01	0.9869
14	$3s^23p4d\ ^{3F}_2$	$3s^23p^2\ ^3P_2$	4.255	1.65E+13	2.24E-01	1.0022
15	$3s^23p4d\ ^3D_2$	$3s^23p^2\ ^3P_2$	4.203	1.01E+13	1.34E-01	0.9978
16	$3s^23p4d\ ^{3F}_3$	$3s^23p^2\ ^3P_2$	4.201	1.02E+14	1.90E+00	0.9981
17	$3s^23p4d\ ^3P_2$	$3s^23p^2\ ^3P_2$	3.780	4.08E+13	4.37E-01	0.9952
18	$3s^23p4d\ ^3P_1$	$3s^23p^2\ ^3P_2$	3.774	1.44E+13	9.20E-02	0.9873
19	$3s^23p4d\ ^3D_3$	$3s^23p^2\ ^3P_2$	3.774	7.97E+13	1.19E+00	0.9946
20	$3s^23p4d\ ^3P_2$	$3s^23p^2\ ^1D_2$	4.246	1.07E+13	1.45E-01	0.9856
21	$3s^23p5s\ ^3P_0$	$3s^23p^2\ ^3P_1$	3.112	2.02E+13	2.93E-02	0.9960
22	$3s^23p5s\ ^3P_1$	$3s^23p^2\ ^3P_2$	3.120	1.67E+13	7.29E-02	1.0005
23	$3s^23p5s\ ^1P_1$	$3s^23p^2\ ^1D_2$	3.113	1.72E+13	7.49E-02	0.9982
24	$3s^23p5d\ ^3D_1$	$3s^23p^2\ ^3P_0$	2.761	6.04E+13	2.07E-01	0.9927
25	$3s^23p5d\ ^3D_2$	$3s^23p^2\ ^3P_1$	2.983	4.96E+13	3.31E-01	0.9868
26	$3s^23p5d\ ^3P_2$	$3s^23p^2\ ^3P_1$	2.752	2.26E+13	1.29E-01	0.9870
27	$3s^23p5d\ ^3P_1$	$3s^23p^2\ ^3P_1$	2.751	3.79E+13	1.29E-01	0.9859
28	$3s^23p5d\ ^3P_0$	$3s^23p^2\ ^3P_1$	2.750	4.58E+13	5.20E-02	0.9848
29	$3s3p^24p(^4P)^5D_1$	$3s^23p^2\ ^3P_0$	3.868	3.52E+13	2.37E-01	0.9914
30	$3s3p^24p(^4P)^5P_1$	$3s^23p^2\ ^3P_0$	3.691	4.69E+13	2.87E-01	0.9797
31	$3s3p^24p(^4P)^3P_1$	$3s^23p^2\ ^3P_1$	3.891	1.02E+13	6.94E-02	1.0053
32	$3s3p^24p(^4P)^3D_2$	$3s^23p^2\ ^3P_1$	3.884	2.72E+13	3.07E-01	0.9996
33	$3s3p^24p(^4P)^3P_0$	$3s^23p^2\ ^3P_1$	3.828	3.41E+13	7.50E-02	0.9687
34	$3s3p^24p(^4P)^3S_1$	$3s^23p^2\ ^3P_1$	3.827	2.22E+13	1.46E-01	0.9707
35	$3s3p^24p(^2P)^3S_1$	$3s^23p^2\ ^3P_1$	3.714	2.76E+13	1.71E-01	0.9936
36	$3s3p^24p(^2P)^3P_2$	$3s^23p^2\ ^3P_1$	3.709	2.20E+13	2.27E-01	0.9876
37	$3s3p^24p(^2P)^1S_0$	$3s^23p^2\ ^3P_1$	3.699	4.76E+13	9.77E-02	0.9825

38	$3s3p^24p(^2P)^1D_2$	$3s^23p^2\,^3P_1$	3.659	2.35E+13	2.36E-01	0.9646
39	$3s3p^24p(^2P)^1P_1$	$3s^23p^2\,^3P_1$	3.652	1.59E+13	9.53E-02	0.9604
40	$3s3p^24p(^4P)^5D_3$	$3s^23p^2\,^3P_2$	3.874	3.49E+13	5.50E-01	0.9943
41	$3s3p^24p(^4P)^5P_2$	$3s^23p^2\,^3P_2$	3.861	1.85E+13	2.07E-01	0.9891
42	$3s3p^25p(^4P)^5D_1$	$3s^23p^2\,^3P_0$	2.732	1.93E+13	6.47E-02	0.9815
43	$3s3p^25p(^4P)^5P_1$	$3s^23p^2\,^3P_0$	2.687	2.80E+13	9.11E-02	0.9748
44	$3s3p^25p(^4P)^3D_2$	$3s^23p^2\,^3P_1$	2.740	1.64E+13	9.23E-02	0.9875
45	$3s3p^24p(^4P)^3P_0$	$3s^23p^2\,^3P_1$	2.710	1.72E+13	1.89E-02	0.9647
46	$3s3p^25p(^4P)^3S_1$	$3s^23p^2\,^3P_1$	2.710	1.21E+13	3.98E-02	0.9658
47	$3s3p^25p(^2P)^3S_1$	$3s^23p^2\,^3P_1$	2.697	1.89E+13	6.18E-02	0.9823
48	$3s3p^25p(^2P)^3P_2$	$3s^23p^2\,^3P_1$	2.696	1.28E+13	6.97E-02	0.9811
49	$3s3p^25p(^2P)^1S_0$	$3s^23p^2\,^3P_1$	2.694	2.79E+13	3.04E-02	0.9787
50	$3s3p^25p(^2P)^1D_2$	$3s^23p^2\,^3P_1$	2.667	1.54E+13	8.19E-02	0.9609
51	$3s3p^25p(^4P)^5D_3$	$3s^23p^2\,^3P_2$	2.734	1.91E+13	1.50E-01	0.9832
52	$3s3p^25p(^4P)^5S_2$	$3s^23p^2\,^3P_2$	2.716	1.09E+13	6.04E-02	0.9710
53	$3s3p^25p(^4P)^3D_1$	$3s^23p^2\,^3P_2$	2.712	1.16E+13	3.85E-02	0.9672

Table A3. Wavelengths (in Å), transition probabilities (in s^{-1}), oscillator strengths (*gf*) and the ratio of velocity to length rates (A_v/A_l) for P-like W^{59+}. Note that $1s^22s^22p^6$ is omitted in configuration.

No.	states		λ(Å)	A(s^{-1})	*gf*	A_v/A_l
	Upper	Lower				
1	$3s^23p^24s\,^4P_{1/2}$	$3s^23p^3\,^4S_{3/2}$	4.836	4.26E+13	2.99E-01	1.0051
2	$3s^23p^24s\,^4P_{5/2}$	$3s^23p^3\,^4S_{3/2}$	4.24	1.01E+13	1.63E-01	1.0094
3	$3s^23p^24s\,^2P_{3/2}$	$3s^23p^3\,^2D_{3/2}$	4.829	1.70E+13	2.37E-01	0.9993
4	$3s^23p^24s\,^2P_{1/2}$	$3s^23p^3\,^2D_{3/2}$	4.820	3.69E+13	2.57E-01	1.0025
5	$3s^23p^24s\,^4P_{5/2}$	$3s^23p^3\,^2D_{5/2}$	4.833	1.96E+13	4.12E-01	1.0014
6	$3s^23p^24s\,^4P_{3/2}$	$3s^23p^3\,^2D_{5/2}$	4.827	3.07E+13	4.29E-01	1.0045
7	$3s^23p^24d(^3P)^4F_{3/2}$	$3s^23p^3\,^2S_{3/2}$	4.305	1.80E+13	2.00E-01	1.0072
8	$3s^23p^24d(^3P)^4F_{5/2}$	$3s^23p^3\,^2S_{3/2}$	4.253	9.77E+13	1.59E+00	1.0009
9	$3s^23p^24d(^3P)^4P_{3/2}$	$3s^23p^3\,^2S_{3/2}$	3.841	3.02E+13	2.67E-01	1.0062
10	$3s^23p^24d(^3P)^4P_{5/2}$	$3s^23p^3\,^2S_{3/2}$	3.837	1.94E+13	2.57E-01	1.0059
11	$3s^23p^24d(^3P)^4D_{5/2}$	$3s^23p^3\,^2S_{3/2}$	3.826	8.01E+13	1.06E+00	1.0040
12	$3s^23p^24d(^3P)^4D_{3/2}$	$3s^23p^3\,^2S_{3/2}$	3.823	7.06E+13	6.19E-01	1.0029
13	$3s^23p^24d(^3P)^4D_{1/2}$	$3s^23p^3\,^2S_{3/2}$	3.819	9.36E+13	4.09E-01	0.9978
14	$3s^23p^24d(^3P)^4P_{3/2}$	$3s^23p^3\,^2D_{3/2}$	4.300	1.13E+13	1.26E-01	0.9928
15	$3s^23p^24d(^3P)^4P_{1/2}$	$3s^23p^3\,^2D_{3/2}$	4.294	1.24E+13	6.86E-02	0.9974
16	$3s^23p^24d(^3P)^2D_{5/2}$	$3s^23p^3\,^2D_{3/2}$	4.247	1.34E+14	2.18E+00	0.9986
17	$3s^23p^24d(^3P)^2P_{3/2}$	$3s^23p^3\,^2D_{3/2}$	4.243	5.95E+13	6.43E-01	0.9970
18	$3s^23p^25s\,^4P_{1/2}$	$3s^23p^3\,^4S_{3/2}$	3.174	1.94E+13	5.86E-02	0.9979
19	$3s^23p^25s\,^2P_{1/2}$	$3s^23p^3\,^2D_{3/2}$	3.168	1.67E+13	5.02E-02	0.9967
20	$3s^23p^25s\,^4P_{3/2}$	$3s^23p^3\,^2D_{5/2}$	3.170	1.31E+13	7.87E-02	0.9981
21	$3s^23p^25s\,^2D_{3/2}$	$3s^23p^3\,^2P_{3/2}$	3.174	1.97E+13	1.19E-01	0.9991

22	$3s^23p^25d(^3P)^4F_{5/2}$	$3s^23p^3\,^2S_{3/2}$	3.039	5.22E+13	4.33E-01	0.9923
23	$3s^23p^25d(^3P)^4P_{3/2}$	$3s^23p^3\,^2S_{3/2}$	2.810	1.63E+13	7.74E-02	0.9970
24	$3s^23p^25d(^3P)^4P_{5/2}$	$3s^23p^3\,^2S_{3/2}$	2.809	2.29E+13	1.62E-01	0.9990
25	$3s^23p^25d(^3P)^4D_{5/2}$	$3s^23p^3\,^2S_{3/2}$	2.803	3.35E+13	2.37E-01	0.9956
26	$3s^23p^25d(^3P)^4D_{3/2}$	$3s^23p^3\,^2S_{3/2}$	2.802	4.16E+13	1.96E-01	0.9947
27	$3s^23p^25d(^3P)^4D_{1/2}$	$3s^23p^3\,^2S_{3/2}$	2.801	5.40E+13	1.27E-01	0.9925
28	$3s^23p^25d(^3P)^2D_{5/2}$	$3s^23p^3\,^2D_{3/2}$	3.035	7.06E+13	5.85E-01	0.9899
29	$3s^23p^25d(^3P)^2P_{3/2}$	$3s^23p^3\,^2D_{3/2}$	3.034	2.61E+13	1.44E-01	0.9889
30	$3s^23p^25d(^3P)^2F_{5/2}$	$3s^23p^3\,^2D_{3/2}$	3.027	1.39E+13	1.14E-01	0.9855
31	$3s^23p^25d(^1D)^2D_{3/2}$	$3s^23p^3\,^2D_{3/2}$	2.794	3.46E+13	1.62E-01	0.9884
32	$3s^23p^25d(^1D)^2F_{5/2}$	$3s^23p^3\,^2D_{3/2}$	2.793	1.99E+13	1.40E-01	0.9896
33	$3s^23p^25d(^1D)^2P_{1/2}$	$3s^23p^3\,^2D_{3/2}$	2.793	4.41E+13	1.03E-01	0.9873
34	$3s^23p^25d(^3P)^2F_{7/2}$	$3s^23p^3\,^2D_{5/2}$	3.045	1.32E+13	1.47E-01	0.9956
35	$3s^23p^25d(^3P)^2F_{5/2}$	$3s^23p^3\,^2D_{5/2}$	3.037	3.90E+13	3.24E-01	0.9908
36	$3s^23p^25d(^3P)^4D_{7/2}$	$3s^23p^3\,^2D_{5/2}$	3.037	7.33E+13	8.11E-01	0.9911
37	$3s3p^34p(^5S)^6P_{3/2}$	$3s^23p^3\,^4S_{3/2}$	3.923	1.25E+13	1.16E-01	1.0042
38	$3s3p^34p(^5S)^6P_{5/2}$	$3s^23p^3\,^4S_{3/2}$	3.920	3.32E+13	4.59E-01	1.0009
39	$3s3p^34p(^5S)^4P_{1/2}$	$3s^23p^3\,^4S_{3/2}$	3.876	3.26E+13	1.47E-01	0.9764
40	$3s3p^34p(^5S)^4P_{3/2}$	$3s^23p^3\,^4S_{3/2}$	3.874	2.32E+13	2.09E-01	0.9804
41	$3s3p^34p(^3S)^4P_{3/2}$	$3s^23p^3\,^4S_{3/2}$	3.749	2.58E+13	2.17E-01	0.9999
42	$3s3p^34p(^5S)^4P_{5/2}$	$3s^23p^3\,^4S_{3/2}$	3.742	2.27E+13	2.86E-01	0.9920
43	$3s3p^34p(^3S)^4P_{1/2}$	$3s^23p^3\,^4S_{3/2}$	3.737	4.65E+13	1.95E-01	0.9898
44	$3s3p^34p(^3S)^4P_{5/2}$	$3s^23p^3\,^4S_{3/2}$	3.707	2.24E+13	2.76E-01	0.9775
45	$3s3p^34p(^3S)^2P_{3/2}$	$3s^23p^3\,^4S_{3/2}$	3.701	1.72E+13	1.41E-01	0.9735
46	$3s3p^34p(^3D)^4D_{3/2}$	$3s^23p^3\,^2D_{3/2}$	3.932	1.09E+13	1.01E-01	1.0074
47	$3s3p^35p(^5S)^6P_{5/2}$	$3s^23p^3\,^4S_{3/2}$	2.775	1.82E+13	1.26E-01	0.9888
48	$3s3p^35p(^5S)^4P_{1/2}$	$3s^23p^3\,^4S_{3/2}$	2.752	1.70E+13	3.85E-02	0.9712
49	$3s3p^35p(^5S)^4P_{3/2}$	$3s^23p^3\,^4S_{3/2}$	2.752	1.26E+13	5.70E-02	0.9734
50	$3s3p^35p(^3S)^4P_{3/2}$	$3s^23p^3\,^4S_{3/2}$	2.732	1.78E+13	7.96E-02	0.9881
51	$3s3p^35p(^5S)^4P_{5/2}$	$3s^23p^3\,^4S_{3/2}$	2.730	1.25E+13	8.38E-02	0.9860
52	$3s3p^35p(^3S)^4P_{1/2}$	$3s^23p^3\,^4S_{3/2}$	2.729	2.77E+13	6.19E-02	0.9844
53	$3s3p^35p(^3S)^4P_{5/2}$	$3s^23p^3\,^4S_{3/2}$	2.709	1.45E+13	9.58E-02	0.9716
54	$3s3p^35p(^3D)^4P_{5/2}$	$3s^23p^3\,^2D_{3/2}$	2.778	1.65E+13	1.15E-01	0.9906
55	$3s3p^35p(^3P)^4D_{3/2}$	$3s^23p^3\,^2D_{3/2}$	2.744	1.42E+13	3.21E-02	0.9645
56	$3s3p^35p(^1D)^2F_{5/2}$	$3s^23p^3\,^2D_{3/2}$	2.736	1.07E+13	7.19E-02	0.9896
57	$3s3p^35p(^3D)^2P_{1/2}$	$3s^23p^3\,^2D_{3/2}$	2.734	2.21E+13	4.95E-02	0.9887

Table A4. Wavelengths (in Å), transition probabilities (in s^{-1}), oscillator strengths (*gf*) and the ratio of velocity to length rates (A_v/A_l) for S-like W^{58+}. Note that $1s^22s^22p^6$ is omitted in configuration.

No.	states		λ(Å)	A(s^{-1})	*gf*	A_v/A_l
	Upper	Lower				
1	$3s^23p^34s\,^5S_2$	$3s^23p^4\,^3P_2$	4.914	2.02E+13	3.66E-01	0.9995

2	$3s^2 3p^3 4s\ ^3S_1$	$3s^2 3p^4\ ^3P_2$	4.906	3.54E+13	3.83E-01	1.0023
3	$3s^2 3p^3 4s\ ^3S_1$	$3s^2 3p^4\ ^3P_0$	4.946	1.35E+13	1.49E-01	1.0158
4	$3s^2 3p^3 4s\ ^3D_1$	$3s^2 3p^4\ ^3P_1$	4.918	3.49E+13	3.80E-01	1.0062
5	$3s^2 3p^3 4s\ ^3P_0$	$3s^2 3p^4\ ^3P_1$	4.872	2.14E+13	7.61E-02	0.9869
6	$3s^2 3p^3 4s\ ^3D_2$	$3s^2 3p^4\ ^1D_2$	4.915	3.66E+13	6.62E-01	1.0055
7	$3s^2 3p^3 4s\ ^3P_1$	$3s^2 3p^4\ ^1D_2$	4.889	1.76E+13	1.89E-01	0.9924
8	$3s^2 3p^3 4s\ ^1P_1$	$3s^2 3p^4\ ^1D_2$	4.296	1.20E+13	9.92E-02	1.0061
9	$3s^2 3p^3 4s\ ^1P_1$	$3s^2 3p^4\ ^1S_0$	4.909	2.79E+13	3.02E-01	1.0020
10	$3s^2 3p^3 4d(^4S)^5D_2$	$3s^2 3p^4\ ^3P_2$	4.363	1.03E+13	1.48E-01	0.9978
11	$3s^2 3p^3 4d(^4S)^5D_1$	$3s^2 3p^4\ ^3P_2$	4.356	1.76E+13	1.50E-01	1.0013
12	$3s^2 3p^3 4d(^4S)^3D_2$	$3s^2 3p^4\ ^3P_2$	4.308	6.81E+13	9.48E-01	1.0004
13	$3s^2 3p^3 4d(^4S)^3D_3$	$3s^2 3p^4\ ^3P_2$	4.307	1.55E+14	3.02E+00	1.0006
14	$3s^2 3p^3 4d(^2D)^3D_2$	$3s^2 3p^4\ ^3P_2$	3.888	1.77E+13	2.00E-01	1.0041
15	$3s^2 3p^3 4d(^2D)^3F_3$	$3s^2 3p^4\ ^3P_2$	3.885	4.34E+13	6.88E-01	1.0074
16	$3s^2 3p^3 4d(^2D)^3F_2$	$3s^2 3p^4\ ^3P_2$	3.872	7.48E+13	8.41E-01	1.0016
17	$3s^2 3p^3 4d(^2D)^3G_3$	$3s^2 3p^4\ ^3P_2$	3.870	5.19E+13	8.16E-01	1.0041
18	$3s^2 3p^3 4d(^2D)^3D_1$	$3s^2 3p^4\ ^3P_2$	3.869	8.60E+13	5.79E-01	0.9996
19	$3s^2 3p^3 4d(^4S)^5D_1$	$3s^2 3p^4\ ^3P_0$	4.388	1.21E+13	1.05E-01	1.0204
20	$3s^2 3p^3 4d(^4S)^3D_1$	$3s^2 3p^4\ ^3P_0$	4.327	9.14E+13	7.70E-01	1.0100
21	$3s^2 3p^3 4d(^2P)^3D_1$	$3s^2 3p^4\ ^3P_0$	3.875	7.49E+13	5.06E-01	1.0006
22	$3s^2 3p^3 4d(^2D)^1P_1$	$3s^2 3p^4\ ^3P_0$	3.868	1.49E+13	1.00E-01	1.0164
23	$3s^2 3p^3 4d(^2D)^3P_0$	$3s^2 3p^4\ ^3P_1$	4.370	2.92E+13	8.37E-02	1.0009
24	$3s^2 3p^3 4d(^2D)^1P_1$	$3s^2 3p^4\ ^3P_1$	4.314	6.56E+13	5.49E-01	1.0014
25	$3s^2 3p^3 4d(^2D)^1D_2$	$3s^2 3p^4\ ^3P_1$	4.312	1.44E+14	2.01E+00	1.0028
26	$3s^2 3p^3 4d(^2D)^1S_0$	$3s^2 3p^4\ ^3P_1$	4.300	5.09E+13	1.41E-01	0.9991
27	$3s^2 3p^3 5s\ ^3S_1$	$3s^2 3p^4\ ^3P_2$	3.227	1.61E+13	7.53E-02	0.9962
28	$3s^2 3p^3 5s\ ^3D_1$	$3s^2 3p^4\ ^3P_1$	3.233	1.58E+13	7.44E-02	0.9984
29	$3s^2 3p^3 5s\ ^3D_2$	$3s^2 3p^4\ ^1D_2$	3.231	1.61E+13	1.26E-01	0.9976
30	$3s^2 3p^3 5s^1\ ^1P_1$	$3s^2 3p^4\ ^1S_0$	3.228	1.26E+13	5.90E-02	0.9946
31	$3s^2 3p^3 5d(^4S)^3D_2$	$3s^2 3p^4\ ^3P_2$	3.088	3.63E+13	2.60E-01	0.9918
32	$3s^2 3p^3 5d(^4S)^3D_3$	$3s^2 3p^4\ ^3P_2$	3.088	8.26E+13	8.27E-01	0.9921
33	$3s^2 3p^3 5d(^2D)^3D_2$	$3s^2 3p^4\ ^3P_2$	2.855	1.40E+13	8.54E-02	0.9976
34	$3s^2 3p^3 5d(^2D)^3F_3$	$3s^2 3p^4\ ^3P_2$	2.854	2.94E+13	2.52E-01	1.0003
35	$3s^2 3p^3 5d(^2D)^3F_2$	$3s^2 3p^4\ ^3P_2$	2.846	4.05E+13	2.46E-01	0.9940
36	$3s^2 3p^3 5d(^2D)^3G_3$	$3s^2 3p^4\ ^3P_2$	2.846	2.46E+13	2.09E-01	0.9968
37	$3s^2 3p^3 5d(^2D)^3D_1$	$3s^2 3p^4\ ^3P_2$	2.846	5.03E+13	1.83E-01	0.9927
38	$3s^2 3p^3 5d(^4S)^3D_1$	$3s^2 3p^4\ ^3P_0$	3.101	4.90E+13	2.12E-01	1.0006
39	$3s^2 3p^3 5d(^2D)^1P_1$	$3s^2 3p^4\ ^3P_0$	2.849	2.86E+13	1.05E-01	0.9980
40	$3s^2 3p^3 5d(^2D)^3S_1$	$3s^2 3p^4\ ^3P_0$	2.848	2.53E+13	9.24E-02	0.9948
41	$3s^2 3p^3 5d(^2D)^3P_0$	$3s^2 3p^4\ ^3P_1$	3.106	1.54E+13	2.22E-02	0.9912
42	$3s^2 3p^3 5d(^2P)^3F_2$	$3s^2 3p^4\ ^3P_1$	3.093	4.17E+13	1.79E-01	0.9949
43	$3s^2 3p^3 5d(^2P)^3D_1$	$3s^2 3p^4\ ^3P_1$	3.092	6.88E+13	4.93E-01	0.9945

44	$3s^23p^35d(^2D)^1S_0$	$3s^23p^4\,^3P_1$	3.083	2.64E+13	3.76E-02	0.9896
45	$3s^23p^35d(^2D)^3S_1$	$3s^23p^4\,^3P_1$	3.082	2.45E+13	1.05E-01	0.9873
46	$3s3p^44p(^4P)^5D_2$	$3s^23p^4\,^3P_2$	3.965	1.25E+13	1.47E-01	1.0039
47	$3s3p^44p(^4P)^5D_3$	$3s^23p^4\,^3P_2$	3.961	3.24E+13	5.34E-01	1.0025
48	$3s3p^44p(^4P)^5D_1$	$3s^23p^4\,^3P_2$	3.907	3.34E+13	2.30E-01	0.9752
49	$3s3p^44p(^4P)^5P_2$	$3s^23p^4\,^3P_2$	3.905	2.07E+13	2.36E-01	0.9749
50	$3s3p^44p(^4P)^5P_3$	$3s^23p^4\,^3P_2$	3.795	1.55E+13	2.34E-01	1.0027
51	$3s3p^44p(^4P)^5P_1$	$3s^23p^4\,^3P_2$	3.788	3.37E+13	2.17E-01	1.0000
52	$3s3p^44p(^4P)^5S_2$	$3s^23p^4\,^3P_2$	3.775	3.57E+13	3.81E-01	0.9936
53	$3s3p^44p(^4P)^3D_3$	$3s^23p^4\,^3P_2$	3.741	2.73E+13	4.01E-01	0.9769
54	$3s3p^44p(^4P)^3P_1$	$3s^23p^4\,^3P_0$	3.940	3.27E+13	2.29E-01	0.9917
55	$3s3p^44p(^4P)^3S_1$	$3s^23p^4\,^3P_0$	3.766	4.17E+13	2.66E-01	0.9894
56	$3s3p^44p(^2P)^1D_2$	$3s^23p^4\,^3P_1$	3.955	2.48E+13	2.90E-01	1.0001
57	$3s3p^44p(^2P)^3P_0$	$3s^23p^4\,^3P_1$	3.903	3.58E+13	8.17E-02	0.976
58	$3s3p^44p(^2S)^1P_1$	$3s^23p^4\,^1S_0$	3.757	4.21E+13	2.67E-01	0.9853
59	$3s3p^45p(^4P)^5D_3$	$3s^23p^4\,^3P_2$	2.814	1.78E+13	1.48E-01	0.9904
60	$3s3p^45p(^4P)^5D_1$	$3s^23p^4\,^3P_2$	2.785	1.75E+13	6.10E-02	0.9700
61	$3s3p^45p(^4P)^5P_2$	$3s^23p^4\,^3P_2$	2.785	1.08E+13	6.30E-02	0.9702
62	$3s3p^45p(^4P)^5P_1$	$3s^23p^4\,^3P_2$	2.769	2.25E+13	7.76E-02	0.9895
63	$3s3p^45p(^4P)^5S_2$	$3s^23p^4\,^3P_2$	2.767	1.93E+13	1.11E-01	0.9881
64	$3s3p^45p(^4P)^3D_3$	$3s^23p^4\,^3P_2$	2.743	1.57E+13	1.24E-01	0.9714
65	$3s3p^45p(^4P)^3P_1$	$3s^23p^4\,^3P_0$	2.803	1.78E+13	6.29E-02	0.9825
66	$3s3p^45p(^4P)^3S_1$	$3s^23p^4\,^3P_0$	2.758	2.55E+13	8.71E-02	0.9821
67	$3s3p^45p(^2P)^1D_2$	$3s^23p^4\,^3P_1$	2.811	1.50E+13	8.91E-02	0.9886
68	$3s3p^45p(^2P)^3P_0$	$3s^23p^4\,^3P_1$	2.783	1.96E+13	2.28E-02	0.9699
69	$3s3p^45p(^2P)^3S_1$	$3s^23p^4\,^3P_1$	2.782	1.24E+13	4.31E-02	0.9673

Table A5. Wavelengths (in Å), transition probabilities (in s^{-1}), oscillator strengths (*gf*) and the ratio of velocity to length rates (A_v/A_l) for Cl-like W^{57+}. Note that $1s^22s^22p^6$ is omitted in configuration.

No.	states		λ(Å)	A(s^{-1})	*gf*	A_v/A_l
	Upper	Lower				
1	$3s^23p^44s\,^4P_{3/2}$	$3s^23p^5\,^2P_{3/2}$	5.002	4.03E+13	6.04E-01	1.0057
2	$3s^23p^44s\,^4P_{1/2}$	$3s^23p^5\,^2P_{3/2}$	4.967	2.03E+13	1.50E-01	0.9902
3	$3s^23p^44s\,^2P_{1/2}$	$3s^23p^5\,^2P_{1/2}$	5.006	2.64E+13	1.99E-01	1.0056
4	$3s^23p^44s\,^2P_{3/2}$	$3s^23p^5\,^2P_{1/2}$	4.988	2.67E+13	3.98E-01	0.9997
5	$3s^23p^44s\,^2S_{1/2}$	$3s^23p^5\,^2P_{1/2}$	4.360	1.45E+13	8.26E-02	0.9965
6	$3s^23p^44d(^3P)^4D_{1/2}$	$3s^23p^5\,^2P_{3/2}$	4.427	2.80E+13	1.64E-01	1.0036
7	$3s^23p^44d(^3P)^4P_{1/2}$	$3s^23p^5\,^2P_{3/2}$	4.376	4.75E+13	2.73E-01	1.0060
8	$3s^23p^44d(^3P)^4D_{5/2}$	$3s^23p^5\,^2P_{3/2}$	4.372	1.56E+14	2.67E+00	1.0045
9	$3s^23p^44d(^3P)^4D_{3/2}$	$3s^23p^5\,^2P_{3/2}$	4.370	1.32E+14	1.51E+00	1.0029
10	$3s^23p^44d(^3P)^4P_{5/2}$	$3s^23p^5\,^2P_{3/2}$	4.343	2.24E+13	3.80E-01	0.9912
11	$3s^23p^44d(^3P)^2D_{5/2}$	$3s^23p^5\,^2P_{3/2}$	3.933	4.91E+13	6.84E-01	1.0072

12	$3s^2 3p^4 4d(^3P)^2P_{1/2}$	$3s^2 3p^5\ ^2P_{3/2}$	3.924	9.19E+13	4.24E-01	1.0024
13	$3s^2 3p^4 4d(^3P)^2D_{3/2}$	$3s^2 3p^5\ ^2P_{3/2}$	3.919	8.78E+13	8.09E-01	0.9998
14	$3s^2 3p^4 4d(^3P)^2F_{5/2}$	$3s^2 3p^5\ ^2P_{3/2}$	3.917	4.19E+13	5.79E-01	1.0037
15	$3s^2 3p^4 5s\ ^4P_{3/2}$	$3s^2 3p^5\ ^2P_{3/2}$	3.292	1.84E+13	1.19E-01	0.9956
16	$3s^2 3p^4 5s\ ^2P_{1/2}$	$3s^2 3p^5\ ^2P_{1/2}$	3.293	1.21E+13	3.93E-02	0.9953
17	$3s^2 3p^4 5s\ ^2P_{3/2}$	$3s^2 3p^5\ ^2P_{1/2}$	3.285	1.18E+13	7.62E-02	0.9904
18	$3s^2 3p^4 5d(^3P)^4D_{1/2}$	$3s^2 3p^5\ ^2P_{3/2}$	3.159	1.43E+13	4.28E-02	0.9922
19	$3s^2 3p^4 5d(^3P)^4P_{3/2}$	$3s^2 3p^5\ ^2P_{3/2}$	3.146	2.53E+13	7.50E-02	0.9961
20	$3s^2 3p^4 5d(^3P)^4P_{1/2}$	$3s^2 3p^5\ ^2P_{3/2}$	3.146	4.46E+13	2.64E-01	0.9966
21	$3s^2 3p^4 5d(^3P)^4D_{5/2}$	$3s^2 3p^5\ ^2P_{3/2}$	3.145	7.60E+13	6.76E-01	0.9957
22	$3s^2 3p^4 5d(^3P)^4D_{3/2}$	$3s^2 3p^5\ ^2P_{3/2}$	3.142	2.64E+13	1.56E-01	0.9920
23	$3s^2 3p^4 5d(^3P)^4P_{5/2}$	$3s^2 3p^5\ ^2P_{3/2}$	3.130	1.86E+13	1.64E-01	0.9859
24	$3s^2 3p^4 5d(^3P)^2P_{3/2}$	$3s^2 3p^5\ ^2P_{3/2}$	2.900	2.91E+13	2.20E-01	0.9995
25	$3s^2 3p^4 5d(^3P)^2P_{1/2}$	$3s^2 3p^5\ ^2P_{3/2}$	2.893	5.26E+13	1.32E-01	0.9939
26	$3s^2 3p^4 5d(^3P)^2D_{3/2}$	$3s^2 3p^5\ ^2P_{3/2}$	2.892	4.49E+13	2.25E-01	0.9939
27	$3s^2 3p^4 5d(^3P)^2F_{5/2}$	$3s^2 3p^5\ ^2P_{3/2}$	2.892	2.29E+13	1.72E-01	0.9965
28	$3s3p^5 4p(^3P)^4D_{3/2}$	$3s^2 3p^5\ ^2P_{3/2}$	3.996	1.09E+13	1.04E-01	0.9963
29	$3s3p^5 4p(^3P)^4D_{5/2}$	$3s^2 3p^5\ ^2P_{3/2}$	3.992	3.20E+13	4.58E-01	0.9977
30	$3s3p^5 4p(^3P)^4D_{1/2}$	$3s^2 3p^5\ ^2P_{3/2}$	3.949	3.43E+13	1.61E-01	0.9784
31	$3s3p^5 4p(^3P)^4P_{3/2}$	$3s^2 3p^5\ ^2P_{3/2}$	3.948	1.97E+13	1.84E-01	0.9735
32	$3s3p^5 4p(^3P)^4S_{3/2}$	$3s^2 3p^5\ ^2P_{3/2}$	3.824	2.81E+13	2.47E-01	0.9970
33	$3s3p^5 4p(^3P)^4P_{5/2}$	$3s^2 3p^5\ ^2P_{3/2}$	3.821	1.76E+13	2.31E-01	0.9996
34	$3s3p^5 4p(^3P)^4P_{1/2}$	$3s^2 3p^5\ ^2P_{3/2}$	3.811	3.82E+13	1.66E-01	0.9960
35	$3s3p^5 4p(^3P)^2D_{5/2}$	$3s^2 3p^5\ ^2P_{3/2}$	3.784	2.29E+13	2.94E-01	0.9799
36	$3s3p^5 4p(^3P)^2D_{3/2}$	$3s^2 3p^5\ ^2P_{3/2}$	3.781	1.43E+13	1.22E-01	0.9797
37	$3s3p^5 5p(^3P)^4D_{5/2}$	$3s^2 3p^5\ ^2P_{3/2}$	2.847	1.75E+13	1.28E-01	0.9861
38	$3s3p^5 5p(^3P)^4D_{1/2}$	$3s^2 3p^5\ ^2P_{3/2}$	2.825	1.88E+13	4.50E-02	0.9715
39	$3s3p^5 5p(^3P)^4P_{3/2}$	$3s^2 3p^5\ ^2P_{3/2}$	2.825	1.01E+13	4.82E-02	0.9687
40	$3s3p^5 5p(^3P)^4S_{3/2}$	$3s^2 3p^5\ ^2P_{3/2}$	2.804	1.87E+13	8.83E-02	0.9875
41	$3s3p^5 5p(^3P)^4P_{5/2}$	$3s^2 3p^5\ ^2P_{3/2}$	2.803	1.06E+13	7.49E-02	0.9887
42	$3s3p^5 5p(^3P)^4P_{1/2}$	$3s^2 3p^5\ ^2P_{3/2}$	2.801	2.28E+13	5.36E-02	0.9877
43	$3s3p^5 5p(^3P)^2D_{5/2}$	$3s^2 3p^5\ ^2P_{3/2}$	2.782	1.37E+13	9.50E-02	0.9736