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Configuration interaction and radiative decay rates in trebly ionized tungsten (W IV)

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Abstract

Radiative decay rates are obtained for the first time for allowed (E1) and forbidden (M1, E2) transitions in trebly ionized tungsten (W IV). Our calculations, motivated by strong interest for low-density plasmas and fusion research, illustrate in a convincing way the importance of core–valence correlation effects which substantially increase the lifetimes and, accordingly, decrease the transition probabilities of this heavy ion. Due to the lack of experimental data for W IV, the reliability of the theoretical ‘f’ values can only be tested by comparison of numerical results obtained with two independent (i.e. multiconfiguration Dirac–Fock and relativistic Hartree–Fock with core-polarization effects (HFR+CPOL)) methods well suited for investigating the atomic structure of heavy ions.

1. Introduction

Atomic data for tungsten ions are of crucial importance in plasma physics in particular in relation with the development of future thermonuclear fusion reactors in which this element will be used as a plasma-facing material (see, e.g., Lipschultz *et al* 2001, Federici *et al* 2001, Neu *et al* 2005, Pospieszczyk 2006, Skinner 2008, 2009). In fusion reactors, tungsten will be sputtered from the wall as a neutral element and the determination of the W influx rate to the core plasma will depend on a calculation of transport from the wall surface through the scrape-off layer. In that context, the identification of emission lines from all ionization stages of tungsten, including the lowest ones and thus W IV, will greatly aid modelling of the plasma edge and scrape-off layer transport and facilitate the analysis of net tungsten influx rates.

In highly charged tungsten ions, the bulk of lines emitted by hot plasmas can hardly be disentangled and their analysis generally requires global methods (e.g. UTA approaches), while, in lowly or moderately charged ions, the analysis of the individual lines is relevant in spite of the density of the lines and of the complexity of the spectra. A line-by-line analysis of the spectrum emitted by the W^{3+} ion, and also by the neighbouring ions, is thus in order and further justifies this work.

So far, no radiative decay rates are available for W IV lines and the analysis of the term system of this ion is still very fragmentary. The ground configuration of W IV is $5d^3$ with $^4F_{3/2}$ as the lowest level. The first excited configurations are $5d^26s$, $5d6s^2$, $5d^26p$ and 5d6s6p. All experimentally known energy levels are reported in the compilation of Kramida and Shirai (2009), which is essentially based on the investigations by Iglesias *et al* (1985) who analysed the W IV spectrum in the region of 60–260 nm using a sliding-spark discharge. These authors identified a total of 774 lines and determined all the 37 levels of the $5d^3$, $5d^26s$ and $5d6s^2$ even configurations and all the 68 levels of the $5d^26p$ and 5d6s6p odd configurations.

We propose, in this paper, a first set of radiative parameters for W IV. This work is an extension of similar investigations carried out recently in W I (Quinet *et al* 2011), W II (Nilsson *et al* 2008) and W III (Palmeri *et al* 2008) ions and as well of a critical evaluation of decay rates for electric dipole and also forbidden transitions in W I, W II and W III (Quinet *et al* 2010).

2. Computations

The ideal way to obtain transition probabilities in an atom or ion is to combine accurate lifetime measurements with

Table 1. Parameters used in HFR$_{43}$ calculations.

Configuration	Parity	HFR$_{43}$	Fitted	Fitted/HFR$_{43}$
		Even parity		
5d^3	E_{av}		20 749	
	F^2(5d,5d)	59 722	50 201	0.84
	F^4(5d,5d)	39 571	33 335	0.84
	α	–	19	–
	β	–	−499	–
	ζ_{5d}	2926	2723	0.93
5d^{2}6s	E_{av}	–	50 519	–
	F^2(5d,5d)	61 588	51 743	0.84
	F^4(5d,5d)	40 951	34 881	0.85
	α	–	−4	–
	β	–	−371	–
	ζ_{5d}	3121	2918	0.94
	G^2(5d,6s)	21 797	19 824	0.91
5d6s^2	E_{av}		94 113	
	ζ_{5d}	3319	3111	0.94
5d^3-5d^{2}6s	R^2(5d5d,5d6s)	−26 715	−22 361	0.84
5d^3-5d6s^2	R^2(5d5d,6s6s)	20 533	Fixed	–
5d^{2}6s-5d6s^2	R^2(5d5d,5d6s)	−22 673	Fixed	–
		Odd parity		
5d^{2}6p	E_{av}	–	112 388	–
	F^2(5d,5d)	62 144	52 522	0.85
	F^4(5d,5d)	41 367	35 263	0.85
	α	–	21	
	β	–	−526	
	ζ_{5d}	3175	3045	0.96
	ζ_{6p}	6774	7914	1.17
	F^2(5d,6p)	26 944	23 274	0.86
	G^1(5d,6p)	12 263	10 886	0.89
	G^3(5d,6p)	10 217	7949	0.78
5d6s6p	E_{av}	–	152 787	–
	ζ_{5d}	3370	3262	0.97
	ζ_{6p}	7635	8751	1.15
	F^2(5d,6p)	28 171	26 457	0.94
	G^2(5d,6s)	21 614	18 285	0.85
	G^1(5d,6p)	12 408	11 444	0.92
	G^3(5d,6p)	10 516	11 961	1.14
	G^1(6s,6p)	45 053	32 129	0.71
5d^{2}6p-5d6s6p	R^2(5d5d,5d6s)	−26 572	−22 193 (linked)	0.84
	R^2(5d6p,6s6p)	−23 148	−19 333 (linked)	0.84
	R^1(5d6p,6s6p)	−21 353	−17 834 (linked)	0.84

branching fraction determinations (using experimental or theoretical methods). In practice, however, the experiment is able to provide a limited number of results and needs to be superseded by computational approaches. The reliability of the theoretical models has to be established by comparison with reliable experimental data or with theoretical data obtained in a completely independent way. In the latter case, convergence of the two sets of results helps to assess their reliability. Useful information about the choice of the model can be provided eventually by isoelectronic comparisons with neighbouring ions. This approach was followed here.

In a previous work, in the nearby isoelectronic ion Ta III (Fivet *et al* 2008), excellent agreement was obtained between HFR+CPOL lifetimes (for a description of the method see Cowan (1981) and Quinet *et al* (1999)) and the accurate experimental values measured for 5d^{2}6p states by the time-resolved laser-induced fluorescence (TR-LIF) spectroscopy. We have adopted the same physical model here considering a set of 43 configurations (5d^3, 5d^{2}6s, 5d6s^2, 5d^{2}6d, 5d6p^2, 5d6d^2, 5d5f^2, 5d6f^2, 5d6s6d, 5d6p5f, 5d6p6f, 5d5f6f, 6s^{2}6d, 6s6p^2, 6p^{2}6d, 6s6d^2, 6d^3, 6s5f^2, 6d5f^2, 6s6f^2, 6d6f^2 and 5d^{2}6p, 5d^{2}5f, 5d^{2}6f, 5d6s6p, 5d6s5f, 5d6s6f, 5d6p6d, 5d6d5f, 5d6d6f, 6s^{2}6p, 6s^{2}5f, 6s^{2}6f, 6p^{2}5f, 6p^{2}6f, 6p^3, 6p6d^2, 6d^{2}5f, 6d^{2}6f, 6p5f^2, 6p6f^2, 5f^{2}6f, 5f6f^2) and this model is referred to as HFR$_{43}$ throughout this paper.

In the present case, we considered for the core-polarization potential a 4f^{14} erbium-like core surrounded by three valence electrons. For the dipole polarizability, we adopted the value $\alpha_d = 2.50\,a_0^3$, which corresponds to a W VII ionic core and was found by considering the behaviour of α_d along the erbium isoelectronic sequence (Fraga *et al* 1976). The cut-off radius used was the HFR mean radius of the outermost core orbital 5p, i.e. $r_c = 1.18\,a_0$.

The *ab initio* calculated energy levels are generally not close enough to the experimental ones and a least-squares fitting adjustment of the average energies (E_{av}), Slater

Table 2. Comparison of radiative lifetimes computed in this work for odd-parity levels of W IV.

Level[a]	Energy[a] (cm^{-1})	Lifetime (ns)			
		MCDF$_{16}$	HFR$_{16}$	HFR$_{43}$	HFR$_{43}$+CPOL
$5d^2(^3F)6p\ ^4G^\circ_{5/2}$	85 289.99	1.06	1.06	1.16	1.39
$5d^2(^3F)6p\ ^4F^\circ_{3/2}$	89 893.06	0.42	0.45	0.49	0.56
$5d^2(^3F)6p\ ^4G^\circ_{7/2}$	92 845.71	0.84	0.84	0.92	1.10
$5d^2(^3F)6p\ ^4F^\circ_{5/2}$	94 525.28	0.51	0.50	0.55	0.63
$5d^2(^3P)6p\ ^4D^\circ_{1/2}$	98 463.71	0.27	0.34	0.35	0.40
$5d^2(^3P)6p\ ^4D^\circ_{5/2}$	98 691.76	0.45	0.52	0.54	0.64
$5d^2(^3F)6p\ ^4G^\circ_{9/2}$	99 028.26	0.68	0.64	0.69	0.81
$5d^2(^1D)6p\ ^2D^\circ_{3/2}$	99 867.18	0.45	0.48	0.54	0.63
$5d^2(^3F)6p\ ^4F^\circ_{7/2}$	100 322.36	0.38	0.41	0.45	0.51
$5d^2(^3F)6p\ ^2D^\circ_{3/2}$	100 449.92	0.30	0.32	0.34	0.39
$5d^2(^3P)6p\ ^2S^\circ_{1/2}$	101275.42	0.36	0.39	0.40	0.47
$5d^2(^3F)6p\ ^2F^\circ_{7/2}$	102867.63	0.36	0.31	0.34	0.39
$5d^2(^3F)6p\ ^4D^\circ_{5/2}$	103216.51	0.28	0.28	0.30	0.35
$5d^2(^3F)6p\ ^4D^\circ_{1/2}$	103682.37	0.69	0.47	0.52	0.61
$5d^2(^3P)6p\ ^4D^\circ_{3/2}$	103952.54	0.31	0.35	0.38	0.43
$5d^2(^3F)6p\ ^4F^\circ_{9/2}$	105263.40	0.38	0.44	0.47	0.56
$5d^2(^3F)6p\ ^2G^\circ_{7/2}$	106730.40	0.35	0.38	0.41	0.47
$5d^2(^3F)6p\ ^2F^\circ_{5/2}$	106754.40	0.45	0.47	0.51	0.60
$5d^2(^1G)6p\ ^2G^\circ_{7/2}$	108871.96	0.34	0.43	0.46	0.53
$5d^2(^3F)6p\ ^4D^\circ_{3/2}$	108922.34	0.54	0.41	0.46	0.54
$5d^2(^3F)6p\ ^4G^\circ_{11/2}$	109190.30	0.65	0.61	0.66	0.80
$5d^2(^3P)6p\ ^4S^\circ_{3/2}$	109882.34	0.30	0.34	0.38	0.43
$5d^2(^1G)6p\ ^2H^\circ_{9/2}$	110252.75	0.40	0.43	0.46	0.54
$5d^2(^1D)6p\ ^2F^\circ_{5/2}$	110658.47	0.28	0.27	0.30	0.34
$5d^2(^3F)6p\ ^4D^\circ_{7/2}$	111515.16	0.23	0.24	0.27	0.30
$5d^2(^3P)6p\ ^4P^\circ_{1/2}$	112861.20	0.32	0.33	0.36	0.42
$5d^2(^3P)6p\ ^4P^\circ_{3/2}$	113533.11	0.37	0.37	0.40	0.47
$5d^2(^3F)6p\ ^2D^\circ_{5/2}$	113620.96	0.38	0.42	0.46	0.54
$5d^2(^3P)6p\ ^4P^\circ_{5/2}$	115317.71	0.46	0.47	0.48	0.56
$5d^2(^3F)6p\ ^2G^\circ_{9/2}$	115422.93	0.27	0.23	0.26	0.29
$5d^2(^3P)6p\ ^4D^\circ_{7/2}$	116110.43	0.36	0.34	0.36	0.43
$5d^2(^1D)6p\ ^2P^\circ_{3/2}$	116421.86	0.31	0.32	0.34	0.39
$5d^2(^1D)6p\ ^2P^\circ_{1/2}$	117725.20	0.31	0.35	0.40	0.46
$5d^2(^3P)6p\ ^2D^\circ_{3/2}$	119041.11	0.31	0.28	0.32	0.36
$5d^2(^1D)6p\ ^2D^\circ_{5/2}$	119079.04	0.43	0.34	0.39	0.44
$5d^2(^1G)6p\ ^2G^\circ_{9/2}$	119694.03	0.28	0.33	0.37	0.43
$5d^2(^1D)6p\ ^2F^\circ_{7/2}$	121644.05	0.23	0.27	0.28	0.33
$5d^2(^3P)6p\ ^2P^\circ_{1/2}$	121677.79	0.41	0.36	0.36	0.42
$5d^2(^1G)6p\ ^2H^\circ_{11/2}$	122847.40	0.47	0.45	0.49	0.58
$5d^2(^3P)6p\ ^2D^\circ_{5/2}$	123216.93	0.32	0.37	0.41	0.48
$5d^2(^1G)6p\ ^2F^\circ_{7/2}$	123908.20	0.34	0.32	0.36	0.42
$5d^2(^3P)6p\ ^2P^\circ_{3/2}$	126076.70	0.38	0.35	0.40	0.46
$5d^2(^1G)6p\ ^2F^\circ_{5/2}$	127077.24	0.37	0.35	0.38	0.45
$5d(^2D)6s6p(^3P^\circ)\ ^4F^\circ_{3/2}$	130118.60	0.52	0.71	0.72	0.83
$5d^2(^1S)6p\ ^2P^\circ_{1/2}$	133358.14	0.32	0.31	0.32	0.37
$5d(^2D)6s6p(^3P^\circ)\ ^4F^\circ_{5/2}$	133 785.47	0.47	0.63	0.64	0.74
$5d(^2D)6s6p(^3P^\circ)\ ^4D^\circ_{1/2}$	134 379.44	0.24	0.30	0.34	0.39
$5d(^2D)6s6p(^3P^\circ)\ ^4D^\circ_{3/2}$	135823.21	0.27	0.34	0.35	0.40
$5d(^2D)6s6p(^3P^\circ)\ ^4D^\circ_{5/2}$	140317.03	0.27	0.33	0.34	0.39
$5d(^2D)6s6p(^3P^\circ)\ ^4F^\circ_{7/2}$	140788.56	0.48	0.55	0.55	0.63
$5d^2(^1S)6p\ ^2P^\circ_{1/2}$	142203.49	0.38	0.33	0.36	0.42
$5d(^2D)6s6p(^3P^\circ)\ ^2D^\circ_{5/2}$	143533.47	0.32	0.42	0.43	0.49
$5d(^2D)6s6p(^3P^\circ)\ ^4P^\circ_{3/2}$	145569.33	0.31	0.42	0.42	0.49
$5d(^2D)6s6p(^3P^\circ)\ ^4D^\circ_{7/2}$	146205.65	0.29	0.33	0.35	0.40
$5d(^2D)6s6p(^3P^\circ)\ ^2D^\circ_{3/2}$	146750.22	0.30	0.36	0.39	0.44
$5d(^2D)6s6p(^3P^\circ)\ ^4P^\circ_{1/2}$	147405.37	0.36	0.41	0.42	0.48
$5d(^2D)6s6p(^3P^\circ)\ ^4P^\circ_{5/2}$	149758.30	0.32	0.40	0.40	0.46
$5d(^2D)6s6p(^3P^\circ)\ ^4F^\circ_{9/2}$	150422.00	0.75	0.79	0.76	0.87

Table 2. (Continued.)

Level[a]	Energy[a] (cm^{-1})	Lifetime (ns) MCDF$_{16}$	HFR$_{16}$	HFR$_{43}$	HFR$_{43}$+CPOL
5d(^{2}D)6s6p(^{3}P$^\circ$) ^{2}F$^\circ_{5/2}$	155752.99	0.29	0.35	0.35	0.40
5d(^{2}D)6s6p(^{3}P$^\circ$) ^{2}P$^\circ_{3/2}$	157 726.0	0.32	0.23	0.24	0.29
5d(^{2}D)6s6p(^{3}P$^\circ$) ^{2}F$^\circ_{7/2}$	157 984.23	0.24	0.26	0.27	0.30
5d(^{2}D)6s6p(^{3}P$^\circ$) ^{2}P$^\circ_{1/2}$	162 651.8	0.35	0.34	0.39	0.44
5d(^{2}D)6s6p(^{1}P$^\circ$) ^{2}F$^\circ_{5/2}$	163375.42	0.15	0.14	0.15	0.18
5d(^{2}D)6s6p(^{1}P$^\circ$) ^{2}D$^\circ_{3/2}$	163536.02	0.12	0.18	0.17	0.20
5d(^{2}D)6s6p(^{1}P$^\circ$) ^{2}P$^\circ_{1/2}$	168767.50	0.17	0.17	0.16	0.20
5d(^{2}D)6s6p(^{1}P$^\circ$) ^{2}D$^\circ_{5/2}$	169912.91	0.12	0.13	0.12	0.15
5d(^{2}D)6s6p(^{1}P$^\circ$) ^{2}F$^\circ_{7/2}$	171306.23	0.16	0.17	0.18	0.22
5d(^{2}D)6s6p(^{1}P$^\circ$) ^{2}P$^\circ_{3/2}$	174786.10	0.15	0.15	0.14	0.17

[a] Level designations and energies from Kramida and Shirai (2009).

integrals (F^k, G^k, R^k), spin–orbit integrals (ζ_{nl}) and effective interaction parameters (α, β) is required. For that purpose, the experimental levels compiled by Kramida and Shirai (2009) were considered. Thus, 37 even levels belonging to the 5d^3, 5d^{2}6s and 5d6s^2 configurations were fitted with 16 variable parameters, while 68 odd levels belonging to the 5d^{2}6p and 5d6s6p configurations were fitted with 19 adjustable parameters. The optimized values of these parameters are given in table 1. The mean deviations in the fitting procedure were found to be equal to 40 cm^{-1} for the even parity and 159 cm^{-1} for the odd parity. The difference between the mean deviations is essentially due to the fact that odd-parity states are much more affected by intermediate coupling and configuration interaction effects than even-parity levels. Indeed, it was found that the calculated average purity of the wavefunctions in the *LS* coupling for 5d^3, 5d^{2}6s and 5d6s^2 even levels was equal to 75%, while the corresponding value for 5d^{2}6p and 5d6s6p odd levels only reached 50%.

The reliability of the HFR+CPOL method (based on a perturbational treatment of relativistic effects including the spin–orbit, mass–velocity and Darwin one-body relativistic corrections in the Hartree–Fock equations) was established by comparing the radiative parameters obtained using this approximation with the relativistic multiconfiguration Dirac–Fock (MCDF) approach in the form described by Grant *et al* (1980) and McKenzie *et al* (1980). To do so, the latest version of the general-purpose relativistic atomic structure package (GRASP) developed by Norrington (2009) was used in the extended average level (EAL) mode. Relativistic two-body Breit interaction and quantum electrodynamics (QED) corrections such as self-energy and vacuum polarization were included in the calculations, while nuclear effects were estimated by considering a uniform charge distribution with the usual atomic weight of tungsten, i.e. 183.85 amu. The non-relativistic configurations retained in the MCDF model were chosen amongst those of the above HFR$_{43}$ model having the strongest interactions with the 5d^3, 5d^{2}6s, 5d6s^2, 5d^{2}6p and 5d6s6p configurations. More precisely, the following 16 configurations were included in the multiconfiguration expansion: 5d^3, 5d^{2}6s, 5d6s^2, 5d^{2}6d, 5d6p^2, 5d6d^2, 5d6s6d, 6s^{2}6d, 6s6p^2, 6s6d^2 (even parity) and 5d^{2}6p, 5d6s6p, 5d6p6d, 6s^{2}6p, 6p^3, 6p6d^2 (odd parity). Moreover, in this calculation (referred to as MCDF$_{16}$), transition energies were replaced by experimental values when computing transition probabilities. It was verified that MCDF$_{16}$ results, obtained in both the length (Babushkin) and velocity (Coulomb) gauges, were in rather good agreement, the mean ratio $A_{\text{velocity}}/A_{\text{length}}$ being found equal to 0.93 (for $A \geqslant 10^9$ s^{-1}), 1.07 (for $A \geqslant 10^8$ s^{-1}) and 1.10 (for $A \geqslant 10^7$ s^{-1}). As a consequence, only the length form results will be considered throughout the paper. In order to make a significant comparison, the same set of 16 configurations was included in a HFR model (HFR$_{16}$) in which a semi-empirical adjustment of the radial parameters was performed in the same way as the one carried out in the extended HFR$_{43}$ model described above.

3. Results

In table 2, we compare the radiative lifetimes computed using our different approaches for all experimentally known odd-parity levels. It is worth noting that MCDF$_{16}$ and HFR$_{16}$ values are in good agreement (within ~10–20%) for most levels, the only exceptions occurring for the 5d^{2}6p levels at 103 682.37 and 108 922.34 cm^{-1} and the 5d6s6p levels at 130 118.60, 133 785.47, 143 533.47, 145 569.33 and 157 726.0 cm^{-1} for which larger discrepancies (up to 30–40%) can be observed. This overall good agreement between MCDF and HFR methods used with the same limited set of configurations gives solid support to HFR theoretical results obtained using more extended multiconfiguration expansion and including core-polarization effects. The importance of these latter effects are clearly illustrated in table 2, where HFR$_{43}$+CPOL lifetimes appear systematically 15–20% longer than HFR$_{43}$ values, while HFR$_{16}$ and HFR$_{43}$ results in general do not differ by more than a few per cent.

Transition probabilities (gA) and oscillator strengths (log gf) calculated using the HFR$_{43}$+CPOL method described above are reported in table 3 for a set of W IV lines ranging from 93 to 238 nm. Only transitions involving energy levels below 140 000 cm^{-1} and with log $gf \geqslant -1$ are listed in the table. A more detailed table is available in our database on sixth-row elements (DESIRE) at http://w3.umons.ac.be/astro/desire.shtml.

Table 3. Oscillator strengths (log gf) and transition probabilities (gA) for W IV lines. Only transitions involving energy levels below 140 000 cm^{-1} and with log $gf \geqslant -1$ are listed. $A(B)$ stands for $A \times 10^{B}$.

	Lower level[a]			Upper level[a]				
λ[a] (nm)	E (cm$^{-1)}$	Configuration	J	E (cm^{-1})	Configuration	J	log gf[d]	gA[d] (s^{-1})
93.5852	9256.39	5d^3	9/2	116110.43	5d^{2}6p	7/2	−0.63	1.81(9)
94.1917	9256.39	5d^3	9/2	115422.93	5d^{2}6p	9/2	−0.74	1.37(9)
94.8412	16 204.85	5d^3	9/2	121644.05	5d^{2}6p	7/2	−0.83	1.09(9)
96.2334	6744.63	5d^3	7/2	110658.47	5d^{2}6p	5/2	−0.84	1.05(9)
96.7961	22 766.37	5d^3	5/2	126076.70	5d^{2}6p	3/2	−0.99	7.21(8)
96.9379	18 519.01	5d^3	3/2	121677.79	5d^{2}6p	1/2	−0.78	1.18(9)
98.1462	17 189.88	5d^3	5/2	119079.04	5d^{2}6p	5/2	−0.97	7.42(8)
98.7410	0.00	5d^3	3/2	101275.42	5d^{2}6p	1/2	−0.95	7.63(8)
98.9187	32 692.40	5d^{2}6s	3/2	133785.47	5d6s6p	5/2	−0.90	8.62(8)
99.0135[b]	9256.39	5d^3	9/2	110252.75	5d^{2}6p	9/2	−0.77	1.17(9)
99.0995	25 167.81	5d^3	3/2	126076.70	5d^{2}6p	3/2	−0.95	7.56(8)
99.2760	35 093.78	5d^{2}6s	5/2	135823.21	5d6s6p	3/2	0.05	7.57(9)
99.3795	22223.06	5d^3	11/2	122847.40	5d^{2}6p	11/2	0.11	8.63(9)
99.5519[c]	22766.37	5d^3	5/2	123216.93	5d^{2}6p	5/2	−0.79	1.09(9)
99.5869	3537.49	5d^3	5/2	103952.54	5d^{2}6p	3/2	−0.42	2.52(9)
100.0142	6744.63	5d^3	7/2	106730.40	5d^{2}6p	7/2	−0.55	1.86(9)
100.0664	9256.39	5d^3	9/2	109190.30	5d^{2}6p	11/2	−0.63	1.56(9)
100.1883	24096.03	5d^3	9/2	123908.20	5d^{2}6p	7/2	−0.21	4.15(9)
100.3860	9256.39	5d^3	9/2	108871.96	5d^{2}6p	7/2	−0.23	3.94(9)
100.8681	27937.63	5d^3	5/2	127077.24	5d^{2}6p	5/2	−0.28	3.43(9)
101.0914	17189.88	5d^3	5/2	116110.43	5d^{2}6p	7/2	−0.61	1.59(9)
101.1354	22766.37	5d^3	5/2	121644.05	5d^{2}6p	7/2	−0.90	8.19(8)
101.3254[c]	35093.78	5d^{2}6s	5/2	133785.47	5d6s6p	5/2	−0.03	6.04(9)
101.5604	0.00	5d^3	3/2	98463.71	5d^{2}6p	1/2	−0.32	3.08(9)
101.6677	15260.92	5d^3	7/2	113620.96	5d^{2}6p	5/2	−0.93	7.57(8)
101.8965	27937.63	5d^3	5/2	126076.70	5d^{2}6p	3/2	−0.86	8.94(8)
101.9082	17189.88	5d^3	5/2	115317.71	5d^{2}6p	5/2	−0.36	2.82(9)
101.9897	25167.81	5d^3	3/2	123216.93	5d^{2}6p	5/2	−0.98	6.71(8)
102.5137	24096.03	5d^3	9/2	121644.05	5d^{2}6p	7/2	0.30	1.27(10)
102.5948	22223.06	5d^3	11/2	119694.03	5d^{2}6p	9/2	−0.08	5.27(9)
102.6419	32692.40	5d^{2}6s	3/2	130118.60	5d6s6p	3/2	−0.17	4.33(9)
103.1859	3537.49	5d^3	5/2	100449.92	5d^{2}6p	3/2	−0.15	4.44(9)
103.5910	10220.65	5d^3	3/2	106754.40	5d^{2}6p	5/2	−0.89	7.96(8)
103.6163	25167.81	5d^3	3/2	121677.79	5d^{2}6p	1/2	−0.49	2.03(9)
103.6570	6744.63	5d^3	7/2	103216.51	5d^{2}6p	5/2	0.19	9.63(9)
103.7952	17 189.88	5d^3	5/2	113533.11	5d^{2}6p	3/2	−0.24	3.58(9)
104.1589	9256.39	5d^3	9/2	105 263.40	5d^{2}6p	9/2	0.09	7.53(9)
104.6044	24096.03	5d^3	9/2	119694.03	5d^{2}6p	9/2	0.11	7.87(9)
104.7165	28412.13	5d^3	7/2	123908.20	5d^{2}6p	7/2	−0.23	3.59(9)
104.8244	15260.92	5d^3	7/2	110658.47	5d^{2}6p	5/2	0.17	8.95(9)
104.9200	16204.85	5d^3	9/2	111 515.16	5d^{2}6p	7/2	0.42	1.59(10)
105.0920	3537.49	5d^3	5/2	98691.76	5d^{2}6p	5/2	−0.25	3.43(9)
105.1511	18519.01	5d^3	3/2	113 620.96	5d^{2}6p	5/2	−0.81	9.30(8)
105.4802	28412.13	5d^3	7/2	123216.93	5d^{2}6p	5/2	−0.35	2.68(9)
105.8243	18364.76	5d^3	1/2	112861.20	5d^{2}6p	1/2	−0.52	1.78(9)
105.9970	18519.01	5d^3	3/2	112861.20	5d^{2}6p	1/2	−0.73	1.09(9)
106.0164	17189.88	5d^3	5/2	111515.16	5d^{2}6p	7/2	−0.74	1.09(9)
106.3286	16204.85	5d^3	9/2	110252.75	5d^{2}6p	9/2	0.17	8.65(9)
106.6873	10220.65	5d^3	3/2	103952.54	5d^{2}6p	3/2	−0.59	1.52(9)
106.7742	22766.37	5d^3	5/2	116421.86	5d^{2}6p	3/2	−0.11	4.53(9)
106.8247[c]	9256.39	5d^3	9/2	102867.63	5d^{2}6p	7/2	0.20	9.22(9)
106.8247[c]	15260.92	5d^3	7/2	108871.96	5d^{2}6p	7/2	−0.51	1.79(9)
106.8628	6744.63	5d^3	7/2	100322.36	5d^{2}6p	7/2	0.09	7.24(9)
107.2597	28412.13	5d^3	7/2	121644.05	5d^{2}6p	7/2	−0.61	1.42(9)
107.2963	22223.06	5d^3	11/2	115422.93	5d^{2}6p	9/2	0.57	2.14(10)
107.8839	17189.88	5d^3	5/2	109882.34	5d^{2}6p	3/2	−0.79	9.45(8)
108.0410	25167.81	5d^3	3/2	117725.20	5d^{2}6p	1/2	−0.40	2.27(9)
108.3616	6744.63	5d^3	7/2	99028.26	5d^{2}6p	9/2	−0.48	1.90(9)
108.4838	11772.92	5d^3	1/2	103952.54	5d^{2}6p	3/2	−0.96	6.19(8)
108.6786	24096.03	5d^3	9/2	116110.43	5d^{2}6p	7/2	−0.25	3.20(9)
108.8026	11772.92	5d^3	1/2	103682.37	5d^{2}6p	1/2	−0.67	1.22(9)

Table 3. (Continued.)

	Lower level[a]			Upper level[a]				
λ[a] (nm)	E (cm$^{-1)}$	Configuration	J	E (cm^{-1})	Configuration	J	log gf[d]	gA[d] (s^{-1})
109.2687	18364.76	5d^3	1/2	109882.34	5d^{2}6p	3/2	−0.64	1.27(9)
109.2973	15260.92	5d^3	7/2	106754.40	5d^{2}6p	5/2	−0.53	1.67(9)
109.3259	15260.92	5d^3	7/2	106730.40	5d^{2}6p	7/2	0.03	6.02(9)
109.4527	18519.01	5d^3	3/2	109882.34	5d^{2}6p	3/2	−0.29	2.84(9)
109.4970	24096.03	5d^3	9/2	115422.93	5d^{2}6p	9/2	−0.37	2.37(9)
109.5511	28412.13	5d^3	7/2	119694.03	5d^{2}6p	9/2	−0.82	8.45(8)
109.5844	25167.81	5d^3	3/2	116421.86	5d^{2}6p	3/2	−0.60	1.39(9)
109.7651	27937.63	5d^3	5/2	119041.11	5d^{2}6p	3/2	0.03	5.89(9)
109.8239	10220.65	5d^3	3/2	101275.42	5d^{2}6p	1/2	−0.45	1.96(9)
109.9046	3537.49	5d^3	5/2	94525.28	5d^{2}6p	5/2	−0.20	3.52(9)
110.0660	22766.37	5d^3	5/2	113620.96	5d^{2}6p	5/2	−0.43	2.03(9)
110.1725	22766.37	5d^3	5/2	113533.11	5d^{2}6p	3/2	−1.00	5.44(8)
110.2937	28412.13	5d^3	7/2	119079.04	5d^{2}6p	5/2	−0.04	5.03(9)
110.4269	18364.76	5d^3	1/2	108922.34	5d^{2}6p	3/2	−0.65	1.22(9)
110.4659	16204.85	5d^3	9/2	106730.40	5d^{2}6p	7/2	−0.84	7.89(8)
110.6149	18519.01	5d^3	3/2	108922.34	5d^{2}6p	3/2	−0.44	1.97(9)
110.7341	45516.94	5d^{2}6s	1/2	135823.21	5d6s6p	3/2	−0.60	1.37(9)
110.8284	10220.65	5d^3	3/2	100449.92	5d^{2}6p	3/2	−0.44	1.96(9)
111.2430	0.00	5d^3	3/2	89893.06	5d^{2}6p	3/2	−0.09	4.36(9)
111.3934	9256.39	5d^3	9/2	99028.26	5d^{2}6p	9/2	−0.19	3.45(9)
111.5491	10220.65	5d^3	3/2	99867.18	5d^{2}6p	3/2	−0.87	7.31(8)
111.9710	3537.49	5d^3	5/2	92845.71	5d^{2}6p	7/2	−0.55	1.52(9)
113.0310	10220.65	5d^3	3/2	98691.76	5d^{2}6p	5/2	−0.98	5.47(8)
113.0539	25167.81	5d^3	3/2	113620.96	5d^{2}6p	5/2	−0.50	1.67(9)
113.3329	18519.01	5d^3	3/2	106754.40	5d^{2}6p	5/2	−0.64	1.20(9)
113.5143	11772.92	5d^3	1/2	99867.18	5d^{2}6p	3/2	−0.48	1.73(9)
113.5980	22223.06	5d^3	11/2	110252.75	5d^{2}6p	9/2	−0.73	9.66(8)
113.6934	15260.92	5d^3	7/2	103216.51	5d^{2}6p	5/2	−0.63	1.21(9)
113.7758	22766.37	5d^3	5/2	110658.47	5d^{2}6p	5/2	−0.75	9.28(8)
114.0268	28412.13	5d^3	7/2	116110.43	5d^{2}6p	7/2	−0.14	3.71(9)
114.3914	24096.03	5d^3	9/2	111515.16	5d^{2}6p	7/2	−0.82	7.74(8)
114.7892	22766.37	5d^3	5/2	109882.34	5d^{2}6p	3/2	−0.74	9.19(8)
115.0674	28412.13	5d^3	7/2	115317.71	5d^{2}6p	5/2	−0.88	6.63(8)
115.2567	17189.88	5d^3	5/2	103952.54	5d^{2}6p	3/2	−0.77	8.47(8)
115.3894	16204.85	5d^3	9/2	102867.63	5d^{2}6p	7/2	−0.45	1.76(9)
116.1362[c]	22766.37	5d^3	5/2	108871.96	5d^{2}6p	7/2	−0.32	2.40(9)
116.2430	17189.88	5d^3	5/2	103216.51	5d^{2}6p	5/2	−0.89	6.31(8)
116.7169	17189.88	5d^3	5/2	102867.63	5d^{2}6p	7/2	−0.67	1.05(9)
116.9718	25167.81	5d^3	3/2	110658.47	5d^{2}6p	5/2	−0.97	5.20(8)
117.2469	0.00	5d^3	3/2	85289.99	5d^{2}6p	5/2	−0.69	9.92(8)
117.3590	28412.13	5d^3	7/2	113620.96	5d^{2}6p	5/2	−0.97	5.21(8)
118.6169	10220.65	5d^3	3/2	94525.28	5d^{2}6p	5/2	−0.41	1.85(9)
119.0982	22766.37	5d^3	5/2	106730.40	5d^{2}6p	7/2	−0.98	4.91(8)
119.3447	43286.60	5d^3	5/2	127077.24	5d^{2}6p	5/2	−0.36	2.06(9)
119.9961	43741.52	5d^3	3/2	127077.24	5d^{2}6p	5/2	−0.50	1.49(9)
120.2898	17189.88	5d^3	5/2	100322.36	5d^{2}6p	7/2	−0.48	1.53(9)
120.7871	43286.60	5d^3	5/2	126076.70	5d^{2}6p	3/2	−0.42	1.75(9)
120.8885	27937.63	5d^3	5/2	110658.47	5d^{2}6p	5/2	−0.52	1.36(9)
121.4545	43741.52	5d^3	3/2	126076.70	5d^{2}6p	3/2	−0.74	8.13(8)
122.5690	25167.81	5d^3	3/2	106754.40	5d^{2}6p	5/2	−0.54	1.29(9)
123.5568	27937.63	5d^3	5/2	108871.96	5d^{2}6p	7/2	−0.73	8.18(8)
124.0360	43286.60	5d^3	5/2	123908.20	5d^{2}6p	7/2	−0.30	2.19(9)
125.1095	43286.60	5d^3	5/2	123216.93	5d^{2}6p	5/2	−0.85	6.07(8)
125.8253	43741.52	5d^3	3/2	123216.93	5d^{2}6p	5/2	−0.67	9.08(8)
126.9155	27937.63	5d^3	5/2	106730.40	5d^{2}6p	7/2	−0.83	6.09(8)
127.6453	28412.13	5d^3	7/2	106754.40	5d^{2}6p	5/2	−0.85	5.78(8)
130.1214	28412.13	5d^3	7/2	105263.40	5d^{2}6p	9/2	−0.79	6.41(8)
130.1992	22223.06	5d^3	11/2	99028.26	5d^{2}6p	9/2	−0.99	4.02(8)
130.3107	49337.04	5d^{2}6s	5/2	126076.70	5d^{2}6p	3/2	−0.86	5.40(8)
131.9398	43286.60	5d^3	5/2	119079.04	5d^{2}6p	5/2	−0.94	4.40(8)
132.0053	43286.60	5d^3	5/2	119041.11	5d^{2}6p	3/2	−0.77	6.53(8)
132.8391	27937.63	5d^3	5/2	103216.51	5d^{2}6p	5/2	−0.80	5.92(8)

Table 3. (Continued.)

	Lower level[a]			Upper level[a]				
λ[a] (nm)	E (cm$^{-1)}$	Configuration	J	E (cm^{-1})	Configuration	J	log gf[d]	gA[d] (s^{-1})
133.4574	27937.63	5d^3	5/2	102867.63	5d^{2}6p	7/2	−0.75	6.60(8)
134.0638	39029.73	5d^{2}6s	7/2	113620.96	5d^{2}6p	5/2	−0.53	1.11(9)
134.1000	49337.04	5d^{2}6s	5/2	123908.20	5d^{2}6p	7/2	−0.86	5.15(8)
134.3080	28412.13	5d^3	7/2	102867.63	5d^{2}6p	7/2	−0.82	5.60(8)
135.3545	49337.04	5d^{2}6s	5/2	123216.93	5d^{2}6p	5/2	−0.73	6.77(8)
135.4484	35093.78	5d^3	5/2	108922.34	5d^{2}6p	3/2	−0.34	1.68(9)
137.2007	43224.40	5d^{2}6s	9/2	116110.43	5d^{2}6p	7/2	−0.58	9.27(8)
137.9578	39029.73	5d^{2}6s	7/2	111515.16	5d^{2}6p	7/2	−0.38	1.46(9)
138.5070	43224.40	5d^{2}6s	9/2	115422.93	5d^{2}6p	9/2	−0.07	2.96(9)
139.5466	35093.78	5d^{2}6s	5/2	106754.40	5d^{2}6p	5/2	−0.48	1.15(9)
139.5935	35093.78	5d^{2}6s	5/2	106730.40	5d^{2}6p	7/2	−0.84	4.99(8)
139.6088	39029.73	5d^{2}6s	7/2	110658.47	5d^{2}6p	5/2	−0.68	7.09(8)
140.0568	47679.55	5d^{2}6s	3/2	119079.04	5d^{2}6p	5/2	−0.54	9.81(8)
140.1314	47679.55	5d^{2}6s	3/2	119041.11	5d^{2}6p	3/2	−0.62	8.20(8)
140.4036	39029.73	5d^{2}6s	7/2	110252.75	5d^{2}6p	9/2	−0.76	5.86(8)
140.8649	32692.40	5d^{2}6s	3/2	103682.37	5d^{2}6p	1/2	−0.43	1.25(9)
141.0338	45516.94	5d^{2}6s	1/2	116421.86	5d^{2}6p	3/2	−0.67	7.19(8)
141.7953	32692.40	5d^{2}6s	3/2	103216.51	5d^{2}6p	5/2	−0.70	6.53(8)
142.0678	52828.24	5d^{2}6s	7/2	123216.93	5d^{2}6p	5/2	−0.39	1.34(9)
142.8101	46087.55	5d^{2}6s	5/2	116110.43	5d^{2}6p	7/2	−0.28	1.72(9)
143.1797	39029.73	5d^{2}6s	7/2	108871.96	5d^{2}6p	7/2	−0.66	7.16(8)
144.4456	46087.55	5d^{2}6s	5/2	115317.71	5d^{2}6p	5/2	−0.50	9.99(8)
145.2249	35093.78	5d^{2}6s	5/2	103952.54	5d^{2}6p	3/2	−0.99	3.21(8)
145.5503	58372.54	5d^{2}6s	7/2	127077.24	5d^{2}6p	5/2	0.14	4.38(9)
145.8088	32692.40	5d^{2}6s	3/2	101275.42	5d^{2}6p	1/2	−0.95	3.59(8)
146.4327	43224.40	5d^{2}6s	9/2	111515.16	5d^{2}6p	7/2	−0.40	1.25(9)
146.5662[b]	43286.60	5d^3	5/2	111515.16	5d^{2}6p	7/2	−0.70	6.19(8)
146.7939	35093.78	5d^{2}6s	5/2	103216.51	5d^{2}6p	5/2	−0.36	1.36(9)
147.0235	45516.94	5d^{2}6s	1/2	113533.11	5d^{2}6p	3/2	−0.17	2.06(9)
147.5490	35093.78	5d^{2}6s	5/2	102867.63	5d^{2}6p	7/2	0.01	3.15(9)
147.5851	32692.40	5d^{2}6s	3/2	100449.92	5d^{2}6p	3/2	−0.39	1.24(9)
147.6570	39029.73	5d^{2}6s	7/2	106754.40	5d^{2}6p	5/2	−1.00	3.05(8)
147.7089	39029.73	5d^{2}6s	7/2	106730.40	5d^{2}6p	7/2	−0.25	1.71(9)
147.8455	47679.55	5d^{2}6s	3/2	115317.71	5d^{2}6p	5/2	0.04	3.34(9)
148.0747	46087.55	5d^{2}6s	5/2	113620.96	5d^{2}6p	5/2	−0.87	4.15(8)
148.7682	51860.40	5d^{2}6s	3/2	119079.04	5d^{2}6p	5/2	−0.33	1.41(9)
148.8653	32692.40	5d^{2}6s	3/2	99867.18	5d^{2}6p	3/2	−0.30	1.51(9)
149.1903	43224.40	5d^{2}6s	9/2	110252.75	5d^{2}6p	9/2	−0.08	2.48(9)
149.5532	52828.24	5d^{2}6s	7/2	119694.03	5d^{2}6p	9/2	−0.32	1.42(9)
149.5704	57050.05	5d^{2}6s	9/2	123908.20	5d^{2}6p	7/2	0.06	3.41(9)
149.6973	56415.54	5d^{2}6s	5/2	123216.93	5d^{2}6p	5/2	−0.47	1.01(9)
149.7604	49337.04	5d^{2}6s	5/2	116110.43	5d^{2}6p	7/2	0.03	3.17(9)
150.9416	52828.24	5d^{2}6s	7/2	119079.04	5d^{2}6p	5/2	−0.61	7.11(8)
150.9806	39029.73	5d^{2}6s	7/2	105263.40	5d^{2}6p	9/2	0.38	7.01(9)
151.5162	32692.40	5d^{2}6s	3/2	98691.76	5d^{2}6p	5/2	−0.11	2.25(9)
151.5932	43224.40	5d^{2}6s	9/2	109190.30	5d^{2}6p	11/2	0.64	1.26(10)
151.6497	47679.55	5d^{2}6s	3/2	113620.96	5d^{2}6p	5/2	−0.73	5.36(8)
151.8257	51860.40	5d^{2}6s	3/2	117725.20	5d^{2}6p	1/2	−0.54	8.35(8)
151.8518	47679.55	5d^{2}6s	3/2	113533.11	5d^{2}6p	3/2	−0.60	7.25(8)
151.9813	57050.05	5d^{2}6s	9/2	122847.40	5d^{2}6p	11/2	0.61	1.17(10)
152.0418	32692.40	5d^{2}6s	3/2	98463.71	5d^{2}6p	1/2	−0.83	4.25(8)
152.3285	43224.40	5d^{2}6s	9/2	108871.96	5d^{2}6p	7/2	−0.78	4.76(8)
152.5885	58372.54	5d^3	7/2	123908.20	5d^{2}6p	7/2	0.03	3.07(9)
152.8405	46087.55	5d^{2}6s	5/2	111515.16	5d^{2}6p	7/2	−0.89	3.69(8)
153.0081	35093.78	5d^{2}6s	5/2	100449.92	5d^{2}6p	3/2	−0.94	3.26(8)
153.3066[c]	56415.54	5d^{2}6s	5/2	121644.05	5d^{2}6p	7/2	0.36	6.48(9)
153.3066[c]	35093.78	5d^{2}6s	5/2	100322.36	5d^{2}6p	7/2	−0.49	9.16(8)
153.4172	47679.55	5d^{2}6s	3/2	112861.20	5d^{2}6p	1/2	−0.46	9.84(8)
154.8682	46087.55	5d^{2}6s	5/2	110658.47	5d^{2}6p	5/2	−0.81	4.30(8)
154.8905	51860.40	5d^{2}6s	3/2	116421.86	5d^{2}6p	3/2	−0.17	1.88(9)
155.3630[b]	45516.94	5d^{2}6s	1/2	109882.34	5d^{2}6p	3/2	−0.81	4.33(8)

Table 3. (Continued.)

	Lower level[a]			Upper level[a]				
λ[a] (nm)	E (cm$^{-1)}$	Configuration	J	E (cm^{-1})	Configuration	J	log gf[d]	gA[d] (s^{-1})
155.5596	49337.04	5d^{2}6s	5/2	113620.96	5d^{2}6p	5/2	−0.60	6.87(8)
155.7952	39029.73	5d^{2}6s	7/2	103216.51	5d^{2}6p	5/2	−0.55	7.64(8)
156.6463	39029.73	5d^{2}6s	7/2	102867.63	5d^{2}6p	7/2	−0.60	6.85(8)
157.2377	35093.78	5d^{2}6s	5/2	98691.76	5d^{2}6p	5/2	−0.47	9.19(8)
157.4654[b]	43224.40	5d^{2}6s	9/2	106730.40	5d^{2}6p	7/2	−0.95	2.99(8)
157.7148	45516.94	5d^{2}6s	1/2	108922.34	5d^{2}6p	3/2	−0.98	2.79(8)
158.0219	52828.24	5d^{2}6s	7/2	116110.43	5d^{2}6p	7/2	−0.60	6.68(8)
158.0490	58372.54	5d^{2}6s	7/2	121644.05	5d^{2}6p	7/2	−0.50	8.58(8)
159.1471	46087.55	5d^{2}6s	5/2	108922.34	5d^{2}6p	3/2	−0.50	8.42(8)
159.2746	46087.55	5d^{2}6s	5/2	108871.96	5d^{2}6p	7/2	−0.35	1.18(9)
159.5825	56415.54	5d^{2}6s	5/2	119079.04	5d^{2}6p	5/2	−0.28	1.36(9)
159.6317	57050.05	5d^{2}6s	9/2	119694.03	5d^{2}6p	9/2	0.15	3.65(9)
159.7573	52828.24	5d^{2}6s	7/2	115422.9	5d^{2}6p	9/2	0.09	3.24(9)
160.2657	64680.96	5d^{2}6s	3/2	127077.24	5d^{2}6p	5/2	−0.77	4.43(8)
160.8282	49337.04	5d^{2}6s	5/2	111515.16	5d^{2}6p	7/2	−0.34	1.19(9)
161.1613	59628.18	5d^{2}6s	1/2	121677.79	5d^{2}6p	1/2	−0.87	3.47(8)
161.1893	43224.40	5d^{2}6s	9/2	105263.40	5d^{2}6p	9/2	−0.44	9.28(8)
161.9156[b]	51860.40	5d^{2}6s	3/2	113620.96	5d^{2}6p	5/2	−0.70	5.07(8)
162.8773	64680.96	5d^{2}6s	3/2	126076.70	5d^{2}6p	3/2	−0.04	2.27(9)
163.0746[c]	58372.54	5d^{2}6s	7/2	119694.03	5d^{2}6p	9/2	0.15	3.51(9)
163.1516	39029.73	5d^{2}6s	7/2	100322.36	5d^{2}6p	7/2	−0.42	9.54(8)
163.2849	47679.55	5d^{2}6s	3/2	108922.34	5d^{2}6p	3/2	−0.94	2.89(8)
163.9323[b]	51860.40	5d^{2}6s	3/2	112861.20	5d^{2}6p	1/2	−0.78	4.11(8)
164.4933	52828.24	5d^{2}6s	7/2	113620.96	5d^{2}6p	5/2	−0.28	1.30(9)
164.8999	46087.55	5d^{2}6s	5/2	106730.40	5d^{2}6p	7/2	−0.08	2.06(9)
165.1658	49337.04	5d^{2}6s	5/2	109882.34	5d^{2}6p	3/2	−0.56	6.72(8)
166.6491[b]	56415.54	5d^{2}6s	5/2	116421.86	5d^{2}6p	3/2	−0.99	2.46(8)
166.6707	39029.73	5d^{2}6s	7/2	99028.26	5d^{2}6p	9/2	−0.01	2.34(9)
167.6112	39029.73	5d^{2}6s	7/2	98691.76	5d^{2}6p	5/2	−0.91	2.93(8)
167.6638	43224.40	5d^{2}6s	9/2	102867.63	5d^{2}6p	7/2	−0.43	8.87(8)
167.9688	49337.04	5d^{2}6s	5/2	108871.96	5d^{2}6p	7/2	−0.39	9.53(8)
168.2611	35093.78	5d^{2}6s	5/2	94525.28	5d^{2}6p	5/2	−0.54	6.82(8)
168.3141	59628.18	5d^{2}6s	1/2	119041.11	5d^{2}6p	3/2	−0.15	1.69(9)
169.3183	57050.05	5d^{2}6s	9/2	116110.43	5d^{2}6p	7/2	−0.87	3.12(8)
169.7732	56415.54	5d^{2}6s	5/2	115317.71	5d^{2}6p	5/2	−0.82	3.48(8)
170.0742	51860.40	5d^{2}6s	3/2	110658.47	5d^{2}6p	5/2	−0.22	1.38(9)
170.3957	52828.24	5d^{2}6s	7/2	111515.16	5d^{2}6p	7/2	−0.28	1.20(9)
170.8351	64680.96	5d^{2}6s	3/2	123216.93	5d^{2}6p	5/2	−0.26	1.25(9)
171.1285	45516.94	5d^{2}6s	1/2	103952.54	5d^{2}6p	3/2	−0.92	2.71(8)
171.3126	57050.05	5d^{2}6s	9/2	115422.93	5d^{2}6p	9/2	−0.55	6.46(8)
171.9231	45516.94	5d^{2}6s	1/2	103682.37	5d^{2}6p	1/2	−0.90	2.86(8)
172.1259	59628.18	5d^{2}6s	1/2	117725.20	5d^{2}6p	1/2	−0.83	3.33(8)
172.8156	46087.55	5d^{2}6s	5/2	103952.54	5d^{2}6p	3/2	−0.59	5.76(8)
173.1535	35093.78	5d^{2}6s	5/2	92845.71	5d^{2}6p	7/2	0.08	2.65(9)
173.1969	58372.54	5d^{2}6s	7/2	116110.43	5d^{2}6p	7/2	−0.89	2.90(8)
174.1415	52828.24	5d^{2}6s	7/2	110252.75	5d^{2}6p	9/2	−0.46	8.00(8)
174.1625	49337.04	5d^{2}6s	5/2	106754.40	5d^{2}6p	5/2	−0.33	1.03(9)
174.8227	32692.40	5d^{2}6s	3/2	89893.06	5d^{2}6p	3/2	−0.45	7.61(8)
175.0422	46087.55	5d^{2}6s	5/2	103216.51	5d^{2}6p	5/2	−0.98	2.29(8)
175.0775[b]	56415.54	5d^{2}6s	5/2	113533.11	5d^{2}6p	3/2	−0.63	5.06(8)
175.1365	43224.40	5d^{2}6s	9/2	100322.36	5d^{2}6p	7/2	0.05	2.41(9)
175.2833	58372.54	5d^{2}6s	7/2	115422.93	5d^{2}6p	9/2	−0.08	1.80(9)
175.4475	64680.96	5d^{2}6s	3/2	121677.79	5d^{2}6p	1/2	−0.68	4.52(8)
176.1182	46087.55	5d^{2}6s	5/2	102867.63	5d^{2}6p	7/2	−0.63	5.05(8)
177.7052	47679.55	5d^{2}6s	3/2	103952.54	5d^{2}6p	3/2	−0.31	1.03(9)
179.1987	43224.40	5d^{2}6s	9/2	99028.26	5d^{2}6p	9/2	0.14	2.88(9)
180.0605	47679.55	5d^{2}6s	3/2	103216.51	5d^{2}6p	5/2	−0.52	6.17(8)
180.1947	39029.73	5d^{2}6s	7/2	94525.28	5d^{2}6p	5/2	−0.08	1.73(9)
182.4848	35093.78	5d^{2}6s	5/2	89893.06	5d^{2}6p	3/2	−0.27	1.06(9)
183.6041	57050.05	5d^{2}6s	9/2	111515.16	5d^{2}6p	7/2	−0.45	7.05(8)
183.8300[b]	64680.96	5d^{2}6s	3/2	119079.04	5d^{2}6p	5/2	−0.75	3.49(8)
183.9514	46087.55	5d^{2}6s	5/2	100449.92	5d^{2}6p	3/2	−0.55	5.64(8)

Table 3. (Continued.)

	Lower level[a]			Upper level[a]				
λ[a] (nm)	E (cm^{-1})	Configuration	J	E (cm^{-1})	Configuration	J	log gf[d]	gA[d] (s^{-1})
184.3559	56415.54	5d^{2}6s	5/2	110658.47	5d^{2}6p	5/2	−0.38	8.25(8)
185.4391	52828.24	5d^{2}6s	7/2	106754.40	5d^{2}6p	5/2	−0.71	3.82(8)
185.5213	52828.24	5d^{2}6s	7/2	106730.40	5d^{2}6p	7/2	−0.33	9.15(8)
185.5997	49337.04	5d^{2}6s	5/2	103216.51	5d^{2}6p	5/2	−0.43	7.11(8)
185.8182	39029.73	5d^{2}6s	7/2	92845.71	5d^{2}6p	7/2	−0.10	1.55(9)
186.5815	47679.55	5d^{2}6s	3/2	101275.42	5d^{2}6p	1/2	−0.74	3.49(8)
187.0317	56415.54	5d^{2}6s	5/2	109882.34	5d^{2}6p	3/2	−0.22	1.14(9)
187.9601	57050.05	5d^{2}6s	9/2	110252.75	5d^{2}6p	9/2	0.04	2.05(9)
188.1728	58372.54	5d^{2}6s	7/2	111515.16	5d^{2}6p	7/2	−0.63	4.48(8)
188.8687	45516.94	5d^{2}6s	1/2	98463.71	5d^{2}6p	1/2	−0.45	6.59(8)
189.5004	47679.55	5d^{2}6s	3/2	100449.92	5d^{2}6p	3/2	−1.00	1.86(8)
190.0987	46087.55	5d^{2}6s	5/2	98691.76	5d^{2}6p	5/2	−0.59	4.71(8)
190.1225	32692.40	5d^{2}6s	3/2	85289.99	5d^{2}6p	5/2	−0.02	1.80(9)
190.6355	56415.54	5d^{2}6s	5/2	108871.96	5d^{2}6p	7/2	−0.91	2.27(8)
190.7116	52828.24	5d^{2}6s	7/2	105263.40	5d^{2}6p	9/2	−0.59	4.77(8)
191.9672	51860.40	5d^{2}6s	3/2	103952.54	5d^{2}6p	3/2	−0.93	2.12(8)
192.7521	58372.54	5d^{2}6s	7/2	110252.75	5d^{2}6p	9/2	−0.20	1.13(9)
192.9684[c]	57050.05	5d^{2}6s	9/2	108871.96	5d^{2}6p	7/2	−0.43	6.58(8)
194.7189	51860.40	5d^{2}6s	3/2	103216.51	5d^{2}6p	5/2	−0.95	1.98(8)
195.6454	49337.04	5d^{2}6s	5/2	100449.92	5d^{2}6p	3/2	−0.76	3.03(8)
197.9017	49337.04	5d^{2}6s	5/2	99867.18	5d^{2}6p	3/2	−0.63	4.01(8)
198.0220	58372.54	5d^{2}6s	7/2	108871.96	5d^{2}6p	7/2	−0.31	8.30(8)
199.2181	35093.78	5d^{2}6s	5/2	85289.99	5d^{2}6p	5/2	−0.41	6.55(8)
199.8421	52828.24	5d^{2}6s	7/2	102867.63	5d^{2}6p	7/2	−0.86	2.29(8)
206.3848	46087.55	5d^{2}6s	5/2	94525.28	5d^{2}6p	5/2	−0.59	4.04(8)
207.3454	57050.05	5d^{2}6s	9/2	105263.40	5d^{2}6p	9/2	−0.62	3.70(8)
210.4861	52828.24	5d^{2}6s	7/2	100322.36	5d^{2}6p	7/2	−0.38	6.31(8)
213.4649	51860.40	5d^{2}6s	3/2	98691.76	5d^{2}6p	5/2	−0.79	2.38(8)
213.7992	46087.55	5d^{2}6s	5/2	92845.71	5d^{2}6p	7/2	−0.88	1.91(8)
216.3819	52828.24	5d^{2}6s	7/2	99028.26	5d^{2}6p	9/2	−0.31	7.03(8)
217.4297	64680.96	5d^{2}6s	3/2	110658.47	5d^{2}6p	5/2	−0.78	2.36(8)
237.6076	64680.96	5d^{2}6s	3/2	106754.40	5d^{2}6p	5/2	−0.70	2.35(8)

[a] From Kramida and Shirai (2009) except when otherwise indicated.

[b] Wavelength calculated using the available experimental energy levels.

[c] Blended line.

[d] This work (HFR$_{43}$+CPOL calculations).

Table 4. Transition probabilities for forbidden lines in W IV. Only transitions for which A-values are greater than 5 s^{-1} and λ shorter than 2000 nm are listed. $A(B)$ stands for $A \times 10^B$.

	Lower level[b]		Upper level[b]			
λ[a] (nm)	E (cm^{-1})	Designation	E (cm^{-1})	Designation	Type	A[c] (s^{-1})
129.9519	10220.65	5d^3 ^{4}P$_{3/2}$	87172.17	5d6s^2 ^{2}D$_{3/2}$	M1+E2	6.93(+0)
138.9686	22766.37	5d^3 ^{2}D$_{5/2}$	94725.05	5d6s^2 ^{2}D$_{5/2}$	M1+E2	1.07(+1)
139.0603	15260.92	5d^3 ^{2}G$_{7/2}$	87172.17	5d6s^2 ^{2}D$_{3/2}$	E2	1.28(+1)
141.5849	24096.03	5d^3 ^{2}G$_{9/2}$	94725.05	5d6s^2 ^{2}D$_{5/2}$	E2	8.93(+0)
143.7665	25167.81	5d^3 ^{2}P$_{3/2}$	94725.05	5d6s^2 ^{2}D$_{5/2}$	M1+E2	9.55(+0)
145.6597	18519.01	5d^3 ^{2}D$_{3/2}$	87172.17	5d6s^2 ^{2}D$_{3/2}$	M1+E2	8.83(+0)
149.7288	27937.63	5d^3 ^{2}F$_{5/2}$	94725.05	5d6s^2 ^{2}D$_{5/2}$	M1+E2	7.90(+0)
150.8002	28412.13	5d^3 ^{2}F$_{7/2}$	94725.05	5d6s^2 ^{2}D$_{5/2}$	M1+E2	2.15(+1)
155.2655	22766.37	5d^3 ^{2}D$_{5/2}$	87172.17	5d6s^2 ^{2}D$_{3/2}$	M1+E2	1.27(+1)
168.8204	27937.63	5d^3 ^{2}F$_{5/2}$	87172.17	5d6s^2 ^{2}D$_{3/2}$	M1+E2	2.98(+1)
169.2366	18519.01	5d^3 ^{2}D$_{3/2}$	77607.89	5d^{2}6s ^{2}S$_{1/2}$	E2	1.71(+1)
170.1837	28412.13	5d^3 ^{2}F$_{7/2}$	87172.17	5d6s^2 ^{2}D$_{3/2}$	E2	7.00(+0)
178.2827	3537.49	5d^3 ^{4}F$_{5/2}$	59628.18	5d^{2}6s ^{2}P$_{1/2}$	E2	7.91(+0)
179.5483	39029.73	5d^{2}6s ^{4}F$_{7/2}$	94725.05	5d6s^2 ^{2}D$_{5/2}$	M1+E2	1.64(+1)
182.3436	22766.37	5d^3 ^{2}D$_{5/2}$	77607.89	5d^{2}6s ^{2}S$_{1/2}$	E2	2.61(+1)
183.5544	32692.40	5d^{2}6s ^{4}F$_{3/2}$	87172.17	5d6s^2 ^{2}D$_{3/2}$	M1+E2	5.79(+0)

Table 4. (Continued.)

	Lower level[b]		Upper level[b]			
λ[a] (nm)	*E* (cm^{-1})	Designation	*E* (cm^{-1})	Designation	Type	*A*[c] (s^{-1})
190.6938	25167.81	$5d^3\ ^2P_{3/2}$	77607.89	$5d^26s\ ^2S_{1/2}$	M1+E2	2.40(+1)
192.0182	35093.78	$5d^26s\ ^4F_{5/2}$	87172.17	$5d6s^2\ ^2D_{3/2}$	M1+E2	2.71(+1)
194.1723	43224.40	$5d^26s\ ^4F_{9/2}$	94725.05	$5d6s^2\ ^2D_{5/2}$	E2	1.04(+1)
194.4071	43286.60	$5d^3\ ^2D_{5/2}$	94725.05	$5d6s^2\ ^2D_{5/2}$	M1+E2	8.24(+0)
202.3331	10220.65	$5d^3\ ^4P_{3/2}$	59628.18	$5d^26s\ ^2P_{1/2}$	E2	2.97(+1)
209.6669	0.00	$5d^3\ ^4F_{3/2}$	47679.55	$5d^26s\ ^4P_{3/2}$	M1+E2	8.03(+0)
218.2744	3537.49	$5d^3\ ^4F_{5/2}$	49337.04	$5d^26s\ ^2F_{5/2}$	E2	6.73(+0)
219.6298	0.00	$5d^3\ ^4F_{3/2}$	45516.94	$5d^26s\ ^4P_{1/2}$	E2	6.11(+1)
220.2538	49337.04	$5d^26s\ ^2F_{5/2}$	94725.05	$5d6s^2\ ^2D_{5/2}$	M1+E2	3.23(+1)
226.4712	3537.49	$5d^3\ ^4F_{5/2}$	47679.55	$5d^26s\ ^4P_{3/2}$	M1+E2	3.01(+1)
227.7950	43286.60	$5d^3\ ^2D_{5/2}$	87172.17	$5d6s^2\ ^2D_{3/2}$	M1+E2	9.32(+0)
229.4353	9256.39	$5d^3\ ^4F_{9/2}$	52828.24	$5d^26s\ ^2F_{7/2}$	M1+E2	1.13(+1)
231.8848	15260.92	$5d^3\ ^2G_{7/2}$	58372.54	$5d^26s\ ^2G_{7/2}$	M1+E2	1.07(+1)
234.7117	6744.63	$5d^3\ ^4F_{7/2}$	49337.04	$5d^26s\ ^2F_{5/2}$	M1+E2	1.59(+1)
237.0760	16204.85	$5d^3\ ^2H_{9/2}$	58372.54	$5d^26s\ ^2G_{7/2}$	E2	1.29(+1)
238.1391	3537.49	$5d^3\ ^4F_{5/2}$	45516.94	$5d^26s\ ^4P_{1/2}$	E2	2.86(+1)
238.5077	22766.37	$5d^3\ ^2D_{5/2}$	64680.96	$5d^26s\ ^2P_{3/2}$	E2	1.22(+1)
238.6089	52828.24	$5d^26s\ ^2F_{7/2}$	94725.05	$5d6s^2\ ^2D_{5/2}$	E2	8.33(+1)
239.2238	15260.92	$5d^3\ ^2G_{7/2}$	57050.05	$5d^26s\ ^2G_{9/2}$	M1+E2	6.31(+0)
242.9124	15260.92	$5d^3\ ^2G_{7/2}$	56415.54	$5d^26s\ ^2D_{5/2}$	M1+E2	1.37(+1)
243.1809	18519.01	$5d^3\ ^2D_{3/2}$	59628.18	$5d^26s\ ^2P_{1/2}$	M1+E2	1.15(+1)
243.3263	46087.55	$5d^26s\ ^4P_{5/2}$	87172.17	$5d6s^2\ ^2D_{3/2}$	M1+E2	8.03(+1)
244.2162	6744.63	$5d^3\ ^4F_{7/2}$	47679.55	$5d^26s\ ^4P_{3/2}$	E2	3.18(+1)
244.7527	16204.85	$5d^3\ ^2H_{9/2}$	57050.05	$5d^26s\ ^2G_{9/2}$	M1+E2	2.31(+1)
249.3792	11772.92	$5d^3\ ^4P_{1/2}$	51860.40	$5d^26s\ ^2D_{3/2}$	M1+E2	5.60(+0)
249.4217	9256.39	$5d^3\ ^4F_{9/2}$	49337.04	$5d^26s\ ^2F_{5/2}$	E2	5.89(+0)
253.0042	25167.81	$5d^3\ ^2P_{3/2}$	64680.96	$5d^26s\ ^2P_{3/2}$	E2	1.61(+1)
260.9539	56415.54	$5d^26s\ ^2D_{5/2}$	94725.05	$5d6s^2\ ^2D_{5/2}$	M1+E2	1.82(+1)
262.7283	18364.76	$5d^3\ ^2P_{1/2}$	56415.54	$5d^26s\ ^2D_{5/2}$	E2	8.15(+0)
263.7978	18519.01	$5d^3\ ^2D_{3/2}$	56415.54	$5d^26s\ ^2D_{5/2}$	M1+E2	1.14(+1)
264.2259	49337.04	$5d^26s\ ^2F_{5/2}$	87172.17	$5d6s^2\ ^2D_{3/2}$	E2	4.19(+1)
265.3490	57050.05	$5d^26s\ ^2G_{5/2}$	94725.05	$5d6s^2\ ^2D_{5/2}$	E2	5.19(+1)
266.1096	15260.92	$5d^3\ ^2G_{7/2}$	52828.24	$5d^26s\ ^2F_{7/2}$	M1+E2	8.78(+0)
266.1323	11772.92	$5d^3\ ^4P_{1/2}$	49337.04	$5d^26s\ ^2F_{5/2}$	E2	8.33(+0)
266.8799	10220.65	$5d^3\ ^4P_{3/2}$	47679.55	$5d^26s\ ^4P_{3/2}$	M1+E2	7.26(+0)
271.4288	9256.39	$5d^3\ ^4F_{9/2}$	46087.55	$5d^26s\ ^4P_{5/2}$	E2	2.43(+1)
272.9687	16204.85	$5d^3\ ^2H_{9/2}$	52828.24	$5d^26s\ ^2F_{7/2}$	M1+E2	1.50(+1)
273.1471	15260.92	$5d^3\ ^2G_{7/2}$	51860.40	$5d^26s\ ^2D_{3/2}$	E2	4.08(+1)
274.0435	6744.63	$5d^3\ ^4F_{7/2}$	43224.40	$5d^26s\ ^4F_{9/2}$	E2	1.25(+1)
275.0029	58372.54	$5d^26s\ ^2G_{7/2}$	94725.05	$5d6s^2\ ^2D_{5/2}$	E2	4.47(+1)
275.6374	28412.13	$5d^3\ ^2F_{7/2}$	64680.96	$5d^26s\ ^2P_{3/2}$	E2	3.58(+1)
276.5475	22223.06	$5d^3\ ^2H_{11/2}$	58372.54	$5d^26s\ ^2G_{7/2}$	E2	1.18(+1)
278.7264	10220.65	$5d^3\ ^4P_{3/2}$	46087.55	$5d^26s\ ^4P_{5/2}$	M1+E2	1.35(+1)
281.6688	3537.49	$5d^3\ ^4F_{5/2}$	39029.73	$5d^26s\ ^4F_{7/2}$	E2	1.60(+1)
283.1084	51860.40	$5d^26s\ ^2D_{3/2}$	87172.17	$5d6s^2\ ^2D_{3/2}$	E2	1.59(+1)
284.8420	59628.18	$5d^26s\ ^2P_{1/2}$	94725.05	$5d6s^2\ ^2D_{5/2}$	E2	5.88(+0)
284.8671	0.00	$5d^3\ ^4F_{3/2}$	35093.78	$5d^26s\ ^4F_{5/2}$	E2	1.58(+1)
287.0494	22223.06	$5d^3\ ^2H_{11/2}$	57050.05	$5d^26s\ ^2G_{9/2}$	M1+E2	3.61(+1)
291.0870	52828.24	$5d^26s\ ^2F_{7/2}$	87172.17	$5d6s^2\ ^2D_{3/2}$	E2	3.70(+1)
291.2790	43286.60	$5d^3\ ^2D_{5/2}$	77607.89	$5d^26s\ ^2S_{1/2}$	E2	2.47(+1)
291.6596	24096.03	$5d^3\ ^2G_{9/2}$	58372.54	$5d^26s\ ^2G_{7/2}$	M1+E2	4.05(+1)
293.3748	15260.92	$5d^3\ ^2G_{7/2}$	49337.04	$5d^26s\ ^2F_{5/2}$	M1+E2	9.91(+0)
294.3086	9256.39	$5d^3\ ^4F_{9/2}$	43224.40	$5d^26s\ ^4F_{9/2}$	M1+E2	2.63(+1)
295.1919	43741.52	$5d^3\ ^2D_{3/2}$	77607.89	$5d^26s\ ^2S_{1/2}$	E2	2.97(+1)
297.0974	22766.37	$5d^3\ ^2D_{5/2}$	56415.54	$5d^26s\ ^2D_{5/2}$	M1+E2	1.48(+1)
301.7334	16204.85	$5d^3\ ^2H_{9/2}$	49337.04	$5d^26s\ ^2F_{5/2}$	E2	2.01(+1)
305.7926	0.00	$5d^3\ ^4F_{3/2}$	32692.40	$5d^26s\ ^4F_{3/2}$	M1+E2	1.48(+1)
309.3208	24096.03	$5d^3\ ^2G_{9/2}$	56415.54	$5d^26s\ ^2D_{5/2}$	E2	1.79(+1)
309.6505	6744.63	$5d^3\ ^4F_{7/2}$	39029.73	$5d^26s\ ^4F_{7/2}$	E2	1.18(+1)
311.5240	45516.94	$5d^26s\ ^4P_{1/2}$	77607.89	$5d^26s\ ^2S_{1/2}$	M1	5.09(+0)
315.4601	27937.63	$5d^3\ ^2F_{5/2}$	59628.18	$5d^26s\ ^2P_{1/2}$	E2	3.16(+1)
316.8024	3537.49	$5d^3\ ^4F_{5/2}$	35093.78	$5d^26s\ ^4F_{5/2}$	M1+E2	7.33(+0)

Table 4. (Continued.)

λ^a (nm)	Lower level^b		Upper level^b		Type	A^c (s^{-1})
	E (cm^{-1})	Designation	E (cm^{-1})	Designation		
324.3013	15260.92	$5d^3\ ^2G_{7/2}$	46087.55	$5d^26s\ ^4P_{5/2}$	M1+E2	5.36(+0)
326.6479	22223.06	$5d^3\ ^2H_{11/2}$	52828.24	$5d^26s\ ^2F_{7/2}$	E2	2.73(+1)
327.8855	17189.88	$5d^3\ ^4P_{5/2}$	47679.55	$5d^26s\ ^4P_{3/2}$	E2	1.03(+1)
332.7484	64680.96	$5d^26s\ ^2P_{3/2}$	94725.05	$5d6s^2\ ^2D_{5/2}$	M1+E2	1.46(+1)
334.0354	47679.55	$5d^26s\ ^4P_{3/2}$	77607.89	$5d^26s\ ^2S_{1/2}$	M1+E2	3.39(+1)
334.5456	16204.85	$5d^3\ ^2H_{9/2}$	46087.55	$5d^26s\ ^4P_{5/2}$	E2	9.25(+0)
342.8971	3537.49	$5d^3\ ^4F_{5/2}$	32692.40	$5d^26s\ ^4F_{3/2}$	M1+E2	8.80(+0)
347.1273	58372.54	$5d^26s\ ^2G_{7/2}$	87172.17	$5d6s^2\ ^2D_{3/2}$	E2	5.00(+0)
351.0158	15260.92	$5d^3\ ^2G_{7/2}$	43741.52	$5d^3\ ^2D_{3/2}$	E2	5.60(+0)
352.6434	6744.63	$5d^3\ ^4F_{7/2}$	35093.78	$5d^26s\ ^4F_{5/2}$	M1+E2	5.93(+0)
352.9185	17189.88	$5d^3\ ^4P_{5/2}$	45516.94	$5d^26s\ ^4P_{1/2}$	E2	8.72(+0)
362.9521	59628.18	$5d^26s\ ^2P_{1/2}$	87172.17	$5d6s^2\ ^2D_{3/2}$	M1+E2	6.37(+0)
383.0812	17189.88	$5d^3\ ^4P_{5/2}$	43286.60	$5d^3\ ^2D_{5/2}$	M1+E2	9.57(+0)
388.2773	51860.40	$5d^26s\ ^2D_{3/2}$	77607.89	$5d^26s\ ^2S_{1/2}$	M1+E2	1.14(+1)
403.6394	18519.01	$5d^3\ ^2D_{3/2}$	43286.60	$5d^3\ ^2D_{5/2}$	M1+E2	9.20(+0)
476.6214	22766.37	$5d^3\ ^2D_{5/2}$	43741.52	$5d^3\ ^2D_{3/2}$	M1+E2	6.35(+0)
556.0281	59628.18	$5d^26s\ ^2P_{1/2}$	77607.89	$5d^26s\ ^2S_{1/2}$	M1	1.02(+1)
623.9793	6744.63	$5d^3\ ^4F_{7/2}$	22766.37	$5d^3\ ^2D_{5/2}$	M1	6.58(+0)
632.5807	27937.63	$5d^3\ ^2F_{5/2}$	43741.52	$5d^3\ ^2D_{3/2}$	M1+E2	5.72(+0)
651.3296	27937.63	$5d^3\ ^2F_{5/2}$	43286.60	$5d^3\ ^2D_{5/2}$	M1+E2	7.03(+0)
667.3048	3537.49	$5d^3\ ^4F_{5/2}$	18519.01	$5d^3\ ^2D_{3/2}$	M1+E2	5.88(+0)
852.7584	3537.49	$5d^3\ ^4F_{5/2}$	15260.92	$5d^3\ ^2G_{7/2}$	M1	5.66(+0)
1131.5380	15260.92	$5d^3\ ^2G_{7/2}$	24096.03	$5d^3\ ^2G_{9/2}$	M1	5.12(+0)
1204.7277	10220.65	$5d^3\ ^4P_{3/2}$	18519.01	$5d^3\ ^2D_{3/2}$	M1	7.25(+0)
1516.6127	11772.92	$5d^3\ ^4P_{1/2}$	18364.76	$5d^3\ ^2P_{1/2}$	M1	5.86(+0)

[a] Vacuum ($\lambda < 200$ nm) and air ($\lambda > 200$ nm) wavelengths deduced from the experimental levels of Kramida and Shirai (2009).
[b] From Kramida and Shirai (2009).
[c] This work (HFR$_{43}$+CPOL calculations).

Unfortunately, as already mentioned, neither experimental nor theoretical radiative decay rates have been published so far for this ion. Nevertheless, in view of the discussion made in the previous section, the results obtained in this work are expected to be reliable in particular for the most intense lines for which the estimated accuracy is probably better than 10–15%. Laboratory measurements are, however, strongly needed to confirm this assessment.

Forbidden lines also play an important role in plasma diagnostics because the corresponding radiation intensities are often very sensitive to electron temperature and density. Therefore, wavelengths and transition rates for such forbidden lines in various ionization stages of tungsten must be determined with high confidence. In table 1, we present transition probabilities computed with our HFR$_{43}$+CPOL model for selected magnetic dipole (M1) and electric quadrupole (E2) lines in W IV. When the two types of radiation contribute to the intensity of a line, the sum of both A-values is given.

4. Conclusion

Transition probabilities and oscillator strengths are reported for the first time for allowed and forbidden lines in a W IV ion. Their reliability has been assessed by the comparison of HFR+CPOL and MCDF results and the reasonable convergence of the two sets of results. It is shown that the neglect of core-polarization effects can lead in this ion to lifetimes too short by about 15–20%. HFR$_{43}$+CPOL lifetimes appear systematically longer than HFR$_{43}$ values, while HFR$_{16}$ and HFR$_{43}$ results agree generally well. Experimental lifetimes or transition probabilities in this ion would be most welcome to definitely assess the accuracy of this set of results and, eventually, to refine the present model.

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