Comment on "Atomic structure calculations for F-like tungsten" by S. Aggarwal [*Chin. Phys B* 23 (2014) 093203]

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Recently, S. Aggarwal [*Chin. Phys. B* **23** (2014) 093203] reported energy levels, radiative rates, and the lifetimes for the lowest 60 levels belonging to the $2s^22p^5$, $2s2p^6$, and $2s^22p^43\ell$ configurations of F-like tungsten. There is no discrepancy for his calculated energies for the levels and the radiative rates for the limited number of E1 transitions, but the reported results for the lifetimes are highly inaccurate. According to our calculations, errors in his reported lifetimes are up to 6 orders of magnitude for several levels. Here we report the correct lifetimes for future comparisons and applications, and also explain the reason for the discrepancies.

Keywords: energy levels, radiative rates, lifetimes, F-like tungsten

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1. Introduction

Atomic data, including energy levels and oscillator strengths or radiative decay rates, are required for many ions in order to model plasmas and/or for diagnostics, such as to determine elemental density, temperature and chemical composition. Generally, lighter ions (with $Z \leq 28$) are important for astrophysical applications whereas heavier ones are more important for lasing and fusion plasmas. An important element of particular interest for studies of fusion plasmas is tungsten (W), because apart from being an important constituent of the reactor walls, it radiates at several of its ionization stages. Considering the requirement of the developing ITER project, atomic data for its ions are in high demand. However, it is not any data, but an accurate and complete set of data which is required for modelling and diagnostics.[1] Recently, S. Aggarwal,[2] henceforth to be referred to as SA, has reported results for energy levels, oscillator strengths (f-values), radiative rates (A-values), line strengths (S-values), and lifetimes (τ) for F-like W LXVI. For his calculations, the modified version of the GRASP (general-purpose relativistic atomic structure package) code was adopted. This code is known as GRASP0 and is freely available at the website `http://web.am.qub.ac.uk/DARC/`. It is a fully relativistic code, based on the jj coupling scheme, and includes further relativistic corrections arising from the Breit interaction and QED (quantum electrodynamics) effects.

SA reported energies and lifetimes for the lowest 60 levels of the $2s^22p^5$, $2s2p^6$, and $2s^22p^43\ell$ configurations of W LXVI, although he included *configuration interaction* (CI) among 359 levels. The additional 299 levels arise from the $2s^22p^44\ell$, $2s^22p^45\ell$ ($\ell \leq 3$), $2s2p^53\ell$, $2s2p^54\ell$, and $2p^63\ell$ configurations, i.e. 23 in total. However, he listed A-values (and other related parameters) for only electric dipole (E1) transitions from the lowest two levels of the ground configuration ($2s^22p^5\ {}^2P^0_{3/2,1/2}$) to higher excited levels. Such limited data are worthless because for the modelling of plasmas a complete set of data, for all transitions, are required. Additionally, for the calculations of τ A-values are also required for the electric quadrupole (E2), magnetic dipole (M1), and magnetic quadrupole (M2) transitions. Because of the limitations of his data, we notice that while his reported A-values are correct, the results for τ are not. Therefore, in this communication we report the correct values of the lifetimes.

2. Calculations

For consistency, we have employed the same version of the GRASP code as adopted by SA.[2] Similarly, for compatibility we use the same option of *extended average level*, as adopted by him. To make comparisons, we have performed three sets of calculations, namely GRASP1: with 113 levels of 11 configurations, i.e., $2s^22p^5$, $2s2p^6$, $2s^22p^43\ell$, $2s2p^53\ell$, and $2p^63\ell$; GRASP2: which includes the same 23 configurations and 359 levels as by SA (see the list in Section 1); and finally GRASP3: which includes a further 142 levels of the $2s^22p^45g$, $2s2p^55\ell$, $2p^64\ell$, and $2p^65\ell$ configurations. Therefore, GRASP3 calculations include 501 levels from 38 configurations in total. This exercise is performed mainly to (i) demonstrate that the inclusion of CI additional to the basic 11 configurations of GRASP1 makes a nominal impact on the calculations of atomic parameters, including τ, and (ii) levels of higher configurations intermix with the lowest 113. There are no (major) differences for energy levels, as may be noted

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from Table 1 in which we list our energies from GRASP3 and those of SA (designated as GRASP4 for convenience although he includes the same levels as in GRASP2). However, results are listed for only the lowest 92 levels, because beyond those levels the $2s^22p^44s$ configurations intermix (see Table 8 of Aggarwal and Keenan[3]). Similarly, there are no differences in A-values between our calculations and those of SA. However, we note here that energies obtained by SA with the *Flexible Atomic Code* (FAC) of Gu[4] and listed in his Table 2 are *incorrect* for some of the levels, particularly the last 5, because these differ with his GRASP calculations by nearly 1 Ryd. We have performed similar calculations with FAC and do not observe any such discrepancies. Furthermore, it is clear from Table 1 that there are many levels missing from the tabulation by SA. It is not apparent from his paper why he excluded these levels, in spite of the inclusion in the calculations. We now focus on the results for τ for which there are large discrepancies.

Table 1. Comparison of energies (in Ryd) and lifetimes (s) for the lowest 92 levels of W LXVI ($a \pm b \equiv a \times 10^{\pm b}$).

Index	Configuration	Level	GRASP3	GRASP4	τ(GRASP1)	τ(GRASP2)	τ(GRASP3)	τ (GRASP4)
1	$2s^22p^5$	$^2P^0_{3/2}$	0.0000	0.0000	–	–	–	–
2	$2s^22p^5$	$^2P^0_{1/2}$	102.0509	120.0486	4.138−11	4.137−11	4.137−11	4.17−11
3	$2s2p^6$	$^2S_{1/2}$	137.6754	137.6940	4.451−14	4.475−14	4.478−14	4.51−14
4	$2s^22p^43s$	$^4P_{5/2}$	621.0743	621.0697	2.596−14	2.609−14	2.611−14	2.61−14
5	$2s^22p^43s$	$^2P_{3/2}$	621.8872	621.8796	4.306−15	4.343−15	4.346−15	4.34−15
6	$2s^22p^43s$	$^2S_{1/2}$	625.8602	625.8603	8.686−15	8.753−15	8.761−15	8.76−15
7	$2s^22p^4(^3P)3p$	$^4P^0_{3/2}$	631.2412	631.2407	1.641−12	1.695−12	1.694−12	4.75−11
8	$2s^22p^4(^3P)3p$	$^2D^0_{5/2}$	631.3863	631.3844	5.693−13	5.792−13	5.796−13	7.44−11
9	$2s^22p^4(^1S)3p$	$^2P^0_{1/2}$	635.7706	635.7751	6.923−13	7.030−13	7.043−13	1.25−11
10	$2s^22p^4(^3P)3p$	$^4P^0_{5/2}$	659.8776	659.8754	4.762−13	4.781−13	4.785−13	1.19−12
11	$2s^22p^4(^3P)3p$	$^2S^0_{1/2}$	659.9483	659.9464	4.781−13	4.886−13	4.888−13	1.20−11
12	$2s^22p^4(^3P)3p$	$^4D^0_{7/2}$	659.8778	659.8753	4.742−13	4.759−13	4.763−13	6.13−13
13	$2s^22p^4(^3P)3p$	$^2P^0_{3/2}$	663.5191	663.5196	2.564−13	2.631−13	2.633−13	6.38−12
14	$2s^22p^4(^1S)3p$	$^2P^0_{3/2}$	665.4119	665.4188	5.199−13	5.170−13	5.173−13	2.63−09
15	$2s^22p^4(^1D)3d$	$^2P_{3/2}$	670.7106	670.7140	4.125−14	4.133−14	4.132−14	4.36−14
16	$2s^22p^4(^3P)3d$	$^4D_{5/2}$	670.8819	670.8850	1.320−14	1.330−14	1.332−14	1.35−14
17	$2s^22p^4(^3P)3d$	$^4P_{1/2}$	671.1548	671.1567	2.857−15	2.862−15	2.863−15	2.87−15
18	$2s^22p^4(^3P)3d$	$^2F_{7/2}$	670.9368	670.9401	8.388−13	8.375−13	8.385−13	8.41−13
19	$2s^22p^4(^1S)3d$	$^2D_{3/2}$	675.3983	675.4067	1.566−13	1.563−13	1.555−13	1.94−13
20	$2s^22p^4(^3P)3d$	$^4D_{7/2}$	677.3681	677.3713	4.171−12	4.173−12	4.177−12	9.36−10
21	$2s^22p^4(^3P)3d$	$^4F_{9/2}$	677.4136	677.4175	7.795−12	7.811−12	7.827−12	7.82−12
22	$2s^22p^4(^3P)3d$	$^2P_{1/2}$	678.4637	678.4638	1.267−15	1.272−15	1.271−15	1.27−15
23	$2s^22p^4(^3P)3d$	$^2D_{5/2}$	680.2619	680.2594	6.140−16	6.162−16	6.173−16	6.16−16
24	$2s^22p^4(^3P)3d$	$^2P_{3/2}$	680.3604	680.3573	4.950−16	5.004−16	5.005−16	5.01−16
25	$2s^22p^4(^1S)3d$	$^2D_{5/2}$	682.9582	682.9646	8.968−16	9.163−16	9.142−16	9.17−16
26	$2s^22p^43s$	$^4P_{3/2}$	723.6503	723.6366	4.500−14	4.551−14	4.561−14	4.97−14
27	$2s^22p^43s$	$^2P_{1/2}$	724.3699	724.3534	4.774−15	4.812−15	4.815−15	1.96−14
28	$2s^22p^43s$	$^2D_{5/2}$	725.1435	725.1301	2.403−14	2.412−14	2.415−14	2.41−14
29	$2s^22p^43s$	$^2D_{3/2}$	725.6072	725.5919	5.647−15	5.685−15	5.688−15	5.06−14
30	$2s^22p^4(^3P)3p$	$^4P^0_{1/2}$	733.4481	733.4395	1.025−11	1.006−11	1.006−11	2.17−10
31	$2s^22p^4(^3P)3p$	$^4D^0_{3/2}$	733.9249	733.9161	1.447−12	1.493−12	1.492−12	1.31−11
32	$2s^22p^4(^1D)3p$	$^2F^0_{5/2}$	734.9602	734.9512	9.538−13	9.643−13	9.649−13	1.51−10
33	$2s^22p^4(^1D)3p$	$^2P^0_{3/2}$	738.0971	738.0933	6.761−13	7.436−13	7.427−13	1.19−12
34	$2s2p^5(^3P)3s$	$^4P^0_{5/2}$	754.0331		9.574−14	9.485−14	9.463−14	
35	$2s2p^5(^3P)3s$	$^2P^0_{3/2}$	756.1273		6.259−15	6.303−15	6.329−15	
36	$2s2p^5(^1P)3s$	$^2P^0_{1/2}$	760.3957		8.121−15	8.225−15	8.197−15	
37	$2s2p^5(^1P)3s$	$^2P^0_{3/2}$	761.3648		5.081−14	5.101−14	5.080−14	
38	$2s^22p^4(^3P)3p$	$^4D^0_{5/2}$	762.5396	762.5287	3.750−13	3.772−13	3.774−13	2.80−12
39	$2s^22p^4(^3P)3p$	$^2D^0_{3/2}$	762.8995	762.8885	2.467−13	2.482−13	2.515−13	7.46−10
40	$2s^22p^4(^3P)3p$	$^2P^0_{1/2}$	763.3791	763.3714	1.376−14	1.369−14	1.381−14	1.61−14
41	$2s^22p^4(^1D)3p$	$^2F^0_{7/2}$	763.6864	763.6761	3.517−13	3.556−13	3.559−13	1.47−09
42	$2s2p^5(^3P)3p$	$^4S_{3/2}$	764.7496		4.425−15	4.445−15	4.458−15	

Table 1 (*Continued*)

43	$2s^22p^4(^1D)3p$	$^2D^0_{3/2}$	764.6368	764.6281	8.337−14	8.170−14	8.194−14	2.49−13
44	$2s2p^5(^3P)3p$	$^2D_{5/2}$	764.8120	764.6376	1.651−15	1.664−15	1.668−15	1.24−11
45	$2s^22p^4(^1D)3p$	$^2D^0_{5/2}$	764.6501		2.801−13	2.840−13	2.842−13	
46	$2s^22p^4(^1D)3p$	$^2P^0_{1/2}$	768.7551	768.7536	1.632−13	1.552−13	1.563−13	4.17−13
47	$2s2p^5(^1P)3p$	$^2P_{1/2}$	770.8143		1.056−15	1.057−15	1.061−15	
48	$2s2p^5(^1P)3p$	$^2D_{3/2}$	771.0121		1.792−15	1.793−15	1.800−15	
49	$2s^22p^4(^3P)3d$	$^4D_{1/2}$	772.7321	772.7272	2.294−14	2.298−14	2.305−14	6.08−13
50	$2s^22p^4(^3P)3d$	$^4D_{3/2}$	773.6008	773.5953	1.544−14	1.553−14	1.552−14	2.85−13
51	$2s^22p^4(^3P)3d$	$^4F_{5/2}$	774.0316	774.0254	2.967−15	2.985−15	2.991−15	3.00−15
52	$2s^22p^4(^1D)3d$	$^2G_{7/2}$	774.5477	774.5434	8.267−13	8.275−13	8.284−13	1.54−09
53	$2s^22p^4(^1D)3d$	$^2S_{1/2}$	776.1650	776.1573	7.493−16	7.562−16	7.544−16	7.80−16
54	$2s^22p^4(^1D)3d$	$^2F_{5/2}$	776.2201	776.2118	7.554−16	7.752−16	7.740−16	7.76−16
55	$2s^22p^4(^1D)3d$	$^2D_{3/2}$	776.6317	776.6228	6.662−16	6.799−16	6.788−16	6.89−16
56	$2s^22p^4(^3P)3d$	$^4F_{7/2}$	779.7930	779.7869	4.364−12	4.317−12	4.321−12	4.09−07
57	$2s^22p^4(^3P)3d$	$^2F_{5/2}$	780.8165	780.8088	3.207−12	3.216−12	3.221−12	1.85−11
58	$2s^22p^4(^3P)3d$	$^4P_{3/2}$	780.8796	780.8718	9.657−15	9.552−15	9.590−15	6.67−12
59	$2s^22p^4(^1D)3d$	$^2G_{9/2}$	781.2936	781.2890	7.065−12	7.088−12	7.100−12	3.82−09
60	$2s^22p^4(^1D)3d$	$^2D_{5/2}$	781.9634	781.9558	2.757−12	2.917−12	2.915−12	2.64−11
61	$2s^22p^4(^1D)3d$	$^2F_{7/2}$	782.4471	782.4398	5.584−12	5.496−12	5.504−12	9.81−10
62	$2s^22p^4(^3P)3d$	$^2D_{3/2}$	784.1419	784.1285	3.466−16	3.510−16	3.509−16	5.98−14
63	$2s^22p^4(^1D)3d$	$^2P_{1/2}$	784.6003	784.5867	3.221−16	3.254−16	3.253−16	3.55−14
64	$2s2p^5(^3P)3p$	$^4D_{7/2}$	793.1551		8.336−14	8.385−14	8.375−14	
65	$2s2p^5(^3P)3p$	$^2P_{3/2}$	793.7276		2.920−15	2.942−15	2.957−15	
66	$2s2p^5(^3P)3p$	$^4P_{5/2}$	794.2004		4.455−15	4.501−15	4.513−15	
67	$2s2p^5(^3P)3p$	$^2P_{1/2}$	795.8038		2.122−15	2.141−15	2.149−15	
68	$2s2p^5(^1P)3p$	$^2D_{5/2}$	799.7800		3.539−15	3.540−15	3.548−15	
69	$2s2p^5(^1P)3p$	$^2P_{3/2}$	800.2864		5.631−15	5.686−15	5.681−15	
70	$2s2p^5(^3P)3p$	$^2S_{1/2}$	802.5328		2.209−14	2.204−14	2.202−14	
71	$2s2p^5(^3P)3d$	$^4P^0_{1/2}$	803.4929		2.775−14	2.781−14	2.788−14	
72	$2s2p^5(^3P)3d$	$^4P^0_{3/2}$	804.1891		1.209−14	1.214−14	1.218−14	
73	$2s2p^5(^3P)3d$	$^2F^0_{7/2}$	804.3974		5.838−14	6.013−14	6.013−14	
74	$2s2p^5(^3P)3d$	$^4D^0_{5/2}$	804.7064		7.001−14	7.280−14	7.283−14	
75	$2s2p^5(^1P)3d$	$^2P^0_{1/2}$	810.4719		1.039−14	1.021−14	1.020−14	
76	$2s2p^5(^1P)3d$	$^2F^0_{5/2}$	810.3798		3.879−14	4.024−14	4.016−14	
77	$2s2p^5(^1P)3d$	$^2D^0_{3/2}$	810.6739		2.017−14	2.074−14	2.078−14	
78	$2s2p^5(^3P)3d$	$^4F^0_{9/2}$	810.2333		9.542−14	1.004−13	1.003−13	
79	$2s2p^5(^3P)3d$	$^4D^0_{7/2}$	811.7811		6.573−14	6.771−14	6.774−14	
80	$2s2p^5(^3P)3d$	$^2D^0_{5/2}$	811.8840		4.485−14	4.551−14	4.566−14	
81	$2s2p^5(^3P)3d$	$^2P^0_{3/2}$	813.3103		1.241−15	1.253−15	1.258−15	
82	$2s2p^5(^3P)3d$	$^2P^0_{1/2}$	814.7743		3.470−16	3.514−16	3.526−16	
83	$2s2p^5(^1P)3d$	$^2F^0_{7/2}$	817.4226		2.963−14	3.040−14	3.039−14	
84	$2s2p^5(^1P)3d$	$^2D^0_{5/2}$	818.0069		3.210−14	3.311−14	3.309−14	
85	$2s2p^5(^1P)3d$	$^2P^0_{3/2}$	819.0259		4.533−16	4.587−16	4.597−16	
86	$2s^22p^43s$	$^4P_{1/2}$	829.7354	829.7138	1.955−14	1.966−14	1.969−14	8.87−11
87	$2s^22p^4(^3P)3p$	$^4D^0_{1/2}$	840.8018	840.7876	1.340−12	1.365−12	1.359−12	2.28−12
88	$2s2p^5(^3P)3s$	$^4P^0_{1/2}$	858.3681		2.269−14	2.263−14	2.264−14	
89	$2s2p^5(^3P)3s$	$^4P^0_{3/2}$	860.6983		1.575−14	1.574−14	1.573−14	
90	$2s2p^5(^3P)3s$	$^2P^0_{1/2}$	862.9096		3.035−14	3.075−14	3.093−14	
91	$2s2p^5(^3P)3p$	$^4D_{1/2}$	868.3439		5.079−15	5.095−15	5.099−15	
92	$2s^22p^4(^3P)3p$	$^4S^0_{3/2}$	868.6480	868.6295	1.009−13	1.022−13	1.025−13	1.78−13

GRASP1: Present results with the GRASP code from 11 configurations and 113 levels;

GRASP2: Present results with the GRASP code from 23 configurations and 359 levels;

GRASP3: Present results with the GRASP code from 38 configurations and 501 levels;

GRASP4: Earlier results of SA[2] with the GRASP code from 23 configurations and 359 levels.

3. Lifetimes

The lifetime τ of a level j is determined as $\tau_j = 1/\sum_i A_{ji}$, i.e., the summation is over *all* types of transitions from lower levels i to higher j. In Table 1, we list our calculated τ from GRASP1, GRASP2, and GRASP3 calculations, along with those of SA (GRASP4) for a ready comparison. However, results are listed for only the lowest 92 levels, because beyond those the intermixing of the levels of the $2s^2 2p^4 4s$ configuration affect the calculations of τ. However, our calculated τ for the last two levels of SA, namely $(2s^2 2p^4 3d)\ ^4F_{3/2}$ and $^2F_{5/2}$, not included in our Table 1, are 8.119×10^{-16} and 2.195×10^{-12} s, respectively, and correspond to levels 101 and 106 listed in Table 8 of Aggarwal and Keenan.[3] For these two levels the respective τ by SA are 8.65×10^{-10} and 1.00×10^{-11} s, i.e., differing by up to 6 orders of magnitude.

It is clear from Table 1 that all three calculations, namely GRASP1, GRASP2, and GRASP3, determine values of τ within a satisfactory agreement, and the discrepancy, if any, is below 10% — see level 33 for example. Therefore, as stated above, the effect of additional CI included in GRASP2 and GRASP3 calculations is nominal on the determination of atomic parameters. On the other hand, the τ results of SA are invariably *higher*, by up to 6 orders of magnitude for several levels – see for example 14, 41, 52, 56, and 59. Since SA included the same CI as in our GRASP2 calculations, his results for τ should have been comparable with ours. Unfortunately, this is not the case, and the discrepancy cannot be understood because of the limited listing of A-values by SA. In this short communication it is not possible for us to list A-values for all transitions, but in Table 2 we list all those A-values which contribute to over 20% to $\sum_i A_{ji}$. This will help us to understand the differences between ours and the τ of SA. We also note that for level 60 $(2s^2 2p^4 3d\ ^2D_{5/2})$, several transitions make substantial contributions but are individually below 20% of the sum total. Therefore, for this level those transitions are listed which contribute to over 10%. Finally, all A-values for a wide range of transitions are provided in a separate paper.[3]

Table 2. Total and dominant A-values (in unit s^{-1}) for the lowest 92 levels of W LXVI ($a \pm b \equiv a \times 10^{\pm b}$).

Index	Configuration	Level	$\sum_i A_{ji}$	Dominant A_{ji}
1	$2s^2 2p^5$	$^2P^0_{3/2}$	–	
2	$2s^2 2p^5$	$^2P^0_{1/2}$	2.417+10	1 – 2 M1: 2.396+10
3	$2s2p^6$	$^2S_{1/2}$	2.233+13	1 – 3 E1: 2.216+13
4	$2s^2 2p^4 3s$	$^4P_{5/2}$	3.831+13	1 – 4 E1: 3.830+13
5	$2s^2 2p^4 3s$	$^2P_{3/2}$	2.301+14	1 – 5 E1: 2.301+14
6	$2s^2 2p^4 3s$	$^2S_{1/2}$	1.141+14	1 – 6 E1: 1.141+14
7	$2s^2 2p^4(^3P)3p$	$^4P^0_{3/2}$	5.902+11	1 – 7 E2: 4.955+11
8	$2s^2 2p^4(^3P)3p$	$^2D^0_{5/2}$	1.725+12	1 – 8 E2: 1.692+12
9	$2s^2 2p^4(^1S)3p$	$^2P^0_{1/2}$	1.420+12	1 – 9 E2: 1.291+12
10	$2s^2 2p^4(^3P)3p$	$^4P^0_{5/2}$	2.090+12	1 – 10 E2: 5.174+11, 4 – 10 E1: 8.411+11, 5 – 10 E1: 7.228+11
11	$2s^2 2p^4(^3P)3p$	$^2S^0_{1/2}$	2.046+12	1 – 11 E2: 4.393+11, 5 – 11 E1: 1.503+12
12	$2s^2 2p^4(^3P)3p$	$^4D^0_{7/2}$	2.100+12	1 – 12 E2: 4.686+11, 4 – 12 E1: 1.631+12
13	$2s^2 2p^4(^3P)3p$	$^2P^0_{3/2}$	3.799+12	1 – 13 E2: 1.626+12, 5 – 13 E1: 1.419+12
14	$2s^2 2p^4(^1S)3p$	$^2P^0_{3/2}$	1.933+12	6 – 14 E1: 1.476+12
15	$2s^2 2p^4(^1D)3d$	$^2P_{3/2}$	2.420+13	1 – 15 E1: 2.295+13
16	$2s^2 2p^4(^3P)3d$	$^4D_{5/2}$	7.506+13	1 – 16 E1: 7.388+13
17	$2s^2 2p^4(^3P)3d$	$^4P_{1/2}$	3.493+14	1 – 17 E1: 3.480+14
18	$2s^2 2p^4(^3P)3d$	$^2F_{7/2}$	1.193+12	8 – 18 E1: 1.187+12
19	$2s^2 2p^4(^1S)3d$	$^2D_{3/2}$	6.429+12	1 – 19 E1: 5.193+12
20	$2s^2 2p^4(^3P)3d$	$^4D_{7/2}$	2.394+11	1 – 20 M2: 1.118+11,10 – 20 E1: 9.891+10
21	$2s^2 2p^4(^3P)3d$	$^4F_{9/2}$	1.278+11	12 – 21 E1: 1.276+11
22	$2s^2 2p^4(^3P)3d$	$^2P_{1/2}$	7.865+14	1 – 22 E1: 7.862+14
23	$2s^2 2p^4(^3P)3d$	$^2D_{5/2}$	1.620+15	1 – 23 E1: 1.620+15
24	$2s^2 2p^4(^3P)3d$	$^2P_{3/2}$	1.998+15	1 – 24 E1: 1.998+15
25	$2s^2 2p^4(^1S)3d$	$^2D_{5/2}$	1.094+15	1 – 25 E1: 1.094+15
26	$2s^2 2p^4 3s$	$^4P_{3/2}$	2.192+13	1 – 26 E1: 2.007+13
27	$2s^2 2p^4 3s$	$^2P_{1/2}$	2.077+14	1 – 27 E1: 5.106+13, 2 – 27 E1: 1.566+14
28	$2s^2 2p^4 3s$	$^2D_{5/2}$	4.141+13	1 – 28 E1: 4.139+13
29	$2s^2 2p^4 3s$	$^2D_{3/2}$	1.758+14	2 – 29 E1: 1.560+14
30	$2s^2 2p^4(^3P)3p$	$^4P^0_{1/2}$	9.945+10	2 – 30 M1: 3.243+10, 7 – 30 M1: 2.043+10, 26 – 30 E1: 2.074+10
31	$2s^2 2p^4(^3P)3p$	$^4D^0_{3/2}$	6.703+11	2 – 31 E2: 5.151+11

Table 2 (*Continued*)

32	$2s^22p^4(^1D)3p$	$^2F^0_{5/2}$	1.036+12	2 – 32 E2: 9.909+11
33	$2s^22p^4(^1D)3p$	$^2P^0_{3/2}$	1.346+12	2 – 33 E2: 4.710+11, 3 – 33 E1: 6.239+11
34	$2s2p^5(^3P)3s$	$^4P^0_{5/2}$	1.057+13	4 – 34 E1: 9.820+12
35	$2s2p^5(^3P)3s$	$^2P^0_{3/2}$	1.580+14	3 – 35 E1: 1.467+14
36	$2s2p^5(^1P)3s$	$^2P^0_{1/2}$	1.220+14	3 – 36 E1: 1.044+14
37	$2s2p^5(^1P)3s$	$^2P^0_{3/2}$	1.968+13	4 – 37 E1: 1.012+13, 6 – 37 E1: 4.484+12
38	$2s^22p^4(^3P)3p$	$^4D^0_{5/2}$	2.649+12	26 – 38 E1: 1.711+12
39	$2s^22p^4(^3P)3p$	$^2D^0_{3/2}$	3.976+12	1 – 39 E2: 1.102+12
40	$2s^22p^4(^3P)3p$	$^2P^0_{1/2}$	7.241+13	3 – 40 E1: 6.132+13
41	$2s^22p^4(^1D)3p$	$^2F^0_{7/2}$	2.810+12	1 – 41 E2: 1.205+12, 28 – 41 E1: 1.590+12
42	$2s2p^5(^3P)3p$	$^4S_{3/2}$	2.243+14	1 – 42 E1: 2.131+14
43	$2s^22p^4(^1D)3p$	$^2D^0_{3/2}$	1.220+13	3 – 43 E1: 4.034+12, 4 – 43 E1: 4.041+12
44	$2s2p^5(^3P)3p$	$^2D_{5/2}$	5.996+14	1 – 44 E1: 5.881+14
45	$2s^22p^4(^1D)3p$	$^2D^0_{5/2}$	3.519+12	1 – 45 E2: 7.593+11, 2 – 45 E2: 8.964+11, 28 – 45 E1: 9.669+11, 29 – 45 E1: 7.800+11
46	$2s^22p^4(^1D)3p$	$^2P^0_{1/2}$	6.397+12	3 – 46 E1: 2.358+12, 29 – 46 E1: 2.004+12
47	$2s2p^5(^1P)3p$	$^2P_{1/2}$	9.426+14	1 – 47 E1: 9.142+14
48	$2s2p^5(^1P)3p$	$^2D_{3/2}$	5.556+14	1 – 48 E1: 5.289+14
49	$2s^22p^4(^3P)3d$	$^4D_{1/2}$	4.339+13	2 – 49 E1: 4.062+13
50	$2s^22p^4(^3P)3d$	$^4D_{3/2}$	6.442+13	2 – 50 E1: 5.933+13
51	$2s^22p^4(^3P)3d$	$^4F_{5/2}$	3.344+14	1 – 51 E1: 3.330+14
52	$2s^22p^4(^1D)3d$	$^2G_{7/2}$	1.207+12	32 – 52 E1: 1.185+12
53	$2s^22p^4(^1D)3d$	$^2S_{1/2}$	1.326+15	1 – 53 E1: 1.286+15
54	$2s^22p^4(^1D)3d$	$^2F_{5/2}$	1.292+15	1 – 54 E1: 1.290+15
55	$2s^22p^4(^1D)3d$	$^2D_{3/2}$	1.473+15	1 – 55 E1: 1.454+15
56	$2s^22p^4(^3P)3d$	$^4F_{7/2}$	2.314+11	38 – 56 E1: 1.074+11
57	$2s^22p^4(^3P)3d$	$^2F_{5/2}$	3.105+11	2 – 57 M2: 6.951+10, 39 –57 E1: 9.236+10
58	$2s^22p^4(^3P)3d$	$^4P_{3/2}$	1.043+14	2 – 58 E1: 1.038+14
59	$2s^22p^4(^1D)3d$	$^2G_{9/2}$	1.408+11	41 – 59 E1: 1.278+11
60	$2s^22p^4(^1D)3d$	$^2D_{5/2}$	3.430+11	1 – 60 E1: 3.845+10, 2 – 60 M2: 6.058+10, 43 – 60 E1: 4.924+10, 45 – 60 E1: 4.317+10
61	$2s^22p^4(^1D)3d$	$^2F_{7/2}$	1.817+11	45 – 61 E1: 9.946+10
62	$2s^22p^4(^3P)3d$	$^2D_{3/2}$	2.850+15	2 – 62 E1: 2.833+15
63	$2s^22p^4(^1D)3d$	$^2P_{1/2}$	3.074+15	2 – 63 E1: 3.045+15
64	$2s2p^5(^3P)3p$	$^4D_{7/2}$	1.194+13	12 – 64 E1: 8.936+12
65	$2s2p^5(^3P)3p$	$^2P_{3/2}$	3.382+14	1 – 65 E1: 3.239+14
66	$2s2p^5(^3P)3p$	$^4P_{5/2}$	2.216+14	1 – 66 E1: 2.081+14
67	$2s2p^5(^3P)3p$	$^2P_{1/2}$	4.654+14	1 – 67 E1: 4.502+14
68	$2s2p^5(^1P)3p$	$^2D_{5/2}$	2.819+14	1 – 68 E1: 2.536+14
69	$2s2p^5(^1P)3p$	$^2P_{3/2}$	1.760+14	1 – 69 E1: 1.455+14
70	$2s2p^5(^3P)3p$	$^2S_{1/2}$	4.541+13	1 – 70 E1: 1.216+13, 14 – 70 E1: 1.380+13
71	$2s2p^5(^3P)3d$	$^4P^0_{1/2}$	3.587+13	3 – 71 E1: 2.379+13
72	$2s2p^5(^3P)3d$	$^4P^0_{3/2}$	8.209+13	3 – 72 E1: 6.951+13
73	$2s2p^5(^3P)3d$	$^2F^0_{7/2}$	1.663+13	1 – 73 E2: 5.508+12, 18 – 73 E1: 8.687+12
74	$2s2p^5(^3P)3d$	$^4D^0_{5/2}$	1.373+13	16 – 74 E1: 6.176+12
75	$2s2p^5(^1P)3d$	$^2P^0_{1/2}$	9.807+13	3 – 75 E1: 6.424+13
76	$2s2p^5(^1P)3d$	$^2F^0_{5/2}$	2.490+13	18 – 76 E1: 1.437+13, 19 – 76 E1: 5.022+12
77	$2s2p^5(^1P)3d$	$^2D^0_{3/2}$	4.811+13	3 – 77 E1: 2.378+13, 16 – 77 E1: 9.757+12
78	$2s2p^5(^3P)3d$	$^4F^0_{9/2}$	9.967+12	21 – 78 E1: 8.177+12
79	$2s2p^5(^3P)3d$	$^4D^0_{7/2}$	1.476+13	1 – 79 E2: 4.504+12, 20 – 79 E1: 4.450+12
80	$2s2p^5(^3P)3d$	$^2D^0_{5/2}$	2.190+13	1 – 80 E2: 8.730+12, 20 – 80 E1: 6.393+12
81	$2s2p^5(^3P)3d$	$^2P^0_{3/2}$	7.950+14	3 – 81 E1: 7.656+14
82	$2s2p^5(^3P)3d$	$^2P^0_{1/2}$	2.836+15	3 – 82 E1: 2.816+15
83	$2s2p^5(^1P)3d$	$^2F^0_{7/2}$	3.290+13	1 – 83 E2: 7.486+12, 21 – 83 E1: 1.473+13
84	$2s2p^5(^1P)3d$	$^2D^0_{5/2}$	3.022+13	20 – 84 E1: 7.795+12, 23 – 84 E1: 9.119+12
85	$2s2p^5(^1P)3d$	$^2P^0_{3/2}$	2.176+15	3 – 85 E1: 2.151+15

Table 2 (*Continued*)

86	$2s^22p^43s$	$^4P_{1/2}$	5.080+13	2 – 86 E1: 5.066+13
87	$2s^22p^4(^3P)3p$	$^4D^0_{1/2}$	7.361+11	3 – 87 E1: 4.424+11
88	$2s2p^5(^3P)3s$	$^4P^0_{1/2}$	4.417+13	3 – 88 E1: 2.222+13, 26 – 88 E1: 1.676+13
89	$2s2p^5(^3P)3s$	$^4P^0_{3/2}$	6.357+13	3 – 89 E1: 4.063+13, 28 – 89 E1: 1.730+13
90	$2s2p^5(^3P)3s$	$^2P^0_{1/2}$	3.233+13	3 – 90 E1: 1.051+13, 29 – 90 E1: 1.674+13
91	$2s2p^5(^3P)3p$	$^4D_{1/2}$	1.961+14	2 – 91 E1: 1.745+14
92	$2s^22p^4(^3P)3p$	$^4S^0_{3/2}$	9.760+12	3 – 92 E1: 5.596+12

SA mentioned the calculations for M2 transitions (only in the abstract but not in the text of the paper), and nothing about E2 and M1. Additionally, he presented no results for any other types except E1. However, it is clear from Table 2 that for the determination of τ for level 2, the 1–2 M1 transition dominates. Since there is no discrepancy between the two sets of results for this level (see Table 1), he *must* have included the contributions of M1 transitions. However, he did not calculate A-values for E2 transitions, because for 7–9 levels, their A-values clearly dominate, hence the discrepancies between the GRASP2 and GRASP4 results for τ. On the other hand, for level 20 the 1–20 M2 and 10–20 E1 transitions contribute almost equally. As there is a discrepancy of over an order of magnitude in τ for this level, it is clear that he made no calculations for M2 transitions. However, the 10–20 E1 A-value (9.891×10^{10} s^{-1}) should give $\tau = 1.01\times10^{-11}$ s and not 9.36×10^{-10} s, as listed by him. This is because, his calculation is based on A-value (1.068×10^{9} s^{-1}) for the 8–20 E1 transition alone. Among the E1 transitions, the one which dominates is 12–20 with $A = 2.747\times10^{10}$ s^{-1}, not listed in Table 2. Therefore, apart from the omissions of E2 and M2 transitions by him, there are other reasons too. We discuss this further.

For level 14, the 6–14 E1 A-value (1.476×10^{12} s^{-1}) contributes to over 76%, but the τ of SA is perhaps based on 3–14 ($A = 3.80\times10^{9}$ s^{-1}) alone, and hence the discrepancy of four orders of magnitude. Similarly, for level 56 the A-value for the 38–56 E1 transition contributes to about half, but the calculation of SA is probably based on the A-value for the 8–56 E1 ($A = 2.446\times10^{6}$ s^{-1}) transition alone. Therefore, it is apparent that his calculations are totally random and hence highly unreliable. It may be worth noting here that W LXVI is not the only ion for which we have found discrepancies, errors and anomalies in his (and the group members) reported work. Several of their calculations have been demonstrated as unreliable — see for example W XL,[5], W LVIII,[6] and W LXII.[7]

4. Conclusions

In this work, we have calculated energy levels, radiative rates and lifetimes for the lowest 501 levels/transitions of F-like tungsten, i.e., W LXVI, by adopting the widely used GRASP code. However, results are presented here only for the lowest 92 levels to make comparisons with the recent work of SA,[2] who has reported similar results. His results for energy levels and A-values, only for limited levels/transitions, are found to be correct, but the corresponding values of τ have large errors, of up to 6 orders of magnitude, for several levels. This is because he has randomly selected transitions for the calculations, which are not always the most contributing ones. Therefore, for the benefit of users (mainly experimentalists) as well as for future workers, we have listed the correct values of τ, and have also explained the reasons for the discrepancies.

Since SA[2] reported A-values only for E1 transitions from the ground levels, these are insufficient for applications, because a *complete* set of data for *all* transitions is required for any modelling application. Additionally, he did not consider all levels of the calculations as several are missing (see Table 1). Furthermore, there is scope for improvement in his work by including additional CI in the calculations. Therefore, an improved set of complete data for all transitions of W LXVI are reported in a separate paper.[3]

References

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