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Atomic structure and transition parameters of the V XVIII carbon-like ion

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Abstract. The atomic and transition parameters of carbon-like ions are significant for many important astrophysical researches, such as the modeling of stellar atmospheres, the determination of stellar abundance, the analysis of spectral lines for laboratory plasmas or astronomical objects. In this contribution, we calculated the energy levels and lifetimes of the carbon-like vanadium ion (V XVIII) using the atomic structure codes AUTOSTRUCTURE and GRASP2018. Weighted oscillator strengths and transition probabilities are also calculated for the allowed transitions between the energy levels considered. The calculations were carried out for the first 17 configurations: $2s^22p^2$, $2p^4$, $2s^22p3p$, $2s2p^23s$, $2s2p^23d$, $2p^33p$, $2s^22p4p$, $2s^23d^2$, $2s2p^3$, $2s^22p3s$, $2s^22p3d$, $2s2p^23p$, $2p^33s$, $2p^33d$, $2s^22p4s$, $2s^22p4d$ and $2s2p3d^2$.

Key words: energy levels – lifetimes – oscillator strengths – transition probabilities – AUTOSTRUCTURE – GRASP2018

1. Introduction

A wide variety of astrophysical plasmas show emission lines resulting from transitions involving carbon-like (C-like) ions, such as planetary nebulae (Aller, 1987) and the solar corona (Widing et al., 1986; Widing & Cook, 1987) as well as being observed in the laboratory (Keenan et al., 1988). For this reason, many theoretical and experimental investigations of the spectra of C-like ions have been performed. In the Opacity Project, atomic data for photoabsorption from a large number of bound states; energy levels, oscillator strengths and photoionisation cross sections are computed for carbon like ions (Luo & Pradhan, 1989). Fawcett (1987) used the HartreeFock pseudo-relativistic (HFR) code of Cowan (1981) to calculate oscillator strengths and energy levels in C-like ions between F IV and Ni XXIII. Bhatia & Doschek (1993), used the SUPERSTRUCTURE (SS) code to calculate electron impact collision strengths and spontaneous radiative decay rates for the C-like ion, Si IX. Zhang & Sampson (1996) and Zhang & Sampson (1996) calculated values for a large number of states using GRASP (General purpose Relativistic Atomic Structure Program). Aggarwal et al. (1997), Aggarwal (1998) and Aggarwal et al. (2001) have obtained rates between low-lying states using the CIV3 code for a number of C-like ions. Froese Fischer & Tachiev (2004) calculated energy levels and transition rates for low-lying states using multi-configuration BreitPauli wave-functions. Jönsson et al. (2011) used the relativistic configuration interaction (RCI) method to obtain energy levels, transition rates, hyperfine structure parameters and Landé gJ values in carbon like ions. Recently, Li et al. (2022) performed a large-scale Multi-Configuration Dirac-Hartree-Fock (MCDHF) calculations for the n $\leq$ 5 states in C-like ions from O III to Mg VII.

Vanadium is an important element in physics laboratories and in technology. The first C-like spectra of V XVIII in the range 16-22 Å are reported by Goldsmith et al. (1972). Jönsson et al. (2011) used MCDHF to calculate energies, electric dipole, magnetic dipole, and electric quadrupole transition rates, hyperfine structures, and Landé gJ factors from relativistic configuration interaction calculations for the states of the $(1s^2)2s^22p^2$, $2s2p^3$, and $2p^4$ configurations in all C-like ions between F IV and Ni XXIII. Ekman et al. (2014) have performed Self-consistent MCDHF and subsequent RCI calculations using the GRASP2K program suite in the carbon isoelectronic sequence from Ar XIII to Zn XXV. Most recently, Wu et al. (2022) presented a theoretical study of the transition energies and the oscillator strengths gf for the C-like ions (with Z from 14-36) subject to plasma environment for atomic transitions.

In a first work concerning the atomic structure in the C-like ions (Al-Modlej et al., 2018), we calculated excitation energies and oscillator strengths for the $2s^22p^2$, $2s2p^3$, $2s^22p3s$, $2s^22p3p$, $2s^22p3d$, $2s^22p4s$, $2s^22p4p$, and $2s^22p5s$ configurations in C-like ions from N II to Ne V, using the three different codes: Cowan (Cowan, 1981), SUPERSTRUCTURE (Eissner et al., 1974), and AU-

TOSTRUCTURE (Badnell, 1986). The two latest codes use the Thomas-Fermi-Dirac-Amaldi (TFDA) potential method.

After this purely *ab initio* calculations, we extended the same methods (HFR and TFDA methods) to calculate *ab initio* and semi-empirical values in the C-like sequence from Na VI to Ar XIII (Almodlej et al., 2021). We added the calculation of the transition probabilities of these C-like ions. We also calculated atomic structure and transition parameters of the Ca XIV C-like ion (Alwadie et al., 2020). The calculated parameters are produced by the suite of atomic structure codes of GRASP2018 (Froese Fischer et al., 2019). The configuration expansion of the basis set used consists of 4 even parity configurations: $2s^2$ $2p^2$ and $2s^2$ 2p np (n = 3 - 5) and 5 odd parity configurations: 2s $2p^3$, $2s^2$ 2p ns (n = 3 - 5) and $2s^2$ 2p 3d. The calculated values of energy levels and oscillator strengths obtained with the GRASP2018 code have been compared with other theoretical methods and with data from NIST database (Kramida et al., 2021).

In this work, we extend our previous works to study the atomic structure and transition parameters of the C-like ion V XVIII using the TFDA and MCDHF methods. In section 2, we present briefly the two methods of calculation used for this work. In section 3, we present the results and discussion, and we finish by concluding in section 4

2. Theoretical methods

We will use two completely different methods TFDA and MCDHF:

2.1. Thomas-Fermi-Dirac-Amaldi (TFDA) potential method

In this method approximate Thomas-Fermi-Dirac-Amaldi (TFDA) potential used in the Hamiltonian of the system. This potential is given as follows:

$$V(r) = \frac{Z_{eff}(\lambda_{nl}, r)}{r} = -\frac{Z}{r}\varphi(x) \tag{1}$$

where

$$\varphi(x) = e^{-\frac{Zr}{2}} + \lambda_{nl}\left(1 - e^{-\frac{Zr}{2}}\right), x = \frac{r}{\mu}$$

and

$$\mu = \frac{1}{4}\left(\frac{N}{N-1}\right)^{2/3}\left(\frac{9\pi^2}{2Z}\right)^{1/3} \approx 0.8853\left(\frac{N}{N-1}\right)^{2/3}(Z)^{-1/3}$$

where Z is the atomic number and N the number of electrons. Z_{eff} is the effective charge function depending on λ_{nl} and r. λ_{nl} are the orbital scaling parameters.

This theoretical method is used by the AUTOSTRUCTURE (AS) atomic structure code (Badnell, 2011, 2022) .

A configuration C is defined by a set of one-particle orbitals $n_i\ell_i$. It can be represented by Eissner et al. (1974):

$$C \equiv \prod_{\gamma=1}^{m} (n_\gamma \ell_\gamma)^{q_\gamma} = (n_1\ell_1)^{q_1}(n_2\ell_2)^{q_2}\dots(n_m\ell_m)^{q_m}, \sum_{\gamma=1}^{m} q_\gamma = N \tag{2}$$

Each configuration gives rise to a set of terms ΓSLM_SM_L which defines a solution ψ of the system.

The TFDA potential is included in the Hamiltonian in any of the two coupling models, Russell-Saunders (LS) or intermediate (LSJ). It is diagonalized to obtain eigenvalues and eigenvectors:

In LS coupling, the wave functions of an N electrons atom or ion, can be written as:

$$\psi = \psi(\Gamma SM_SLM_L\,|x_1, \dots x_N) \tag{3}$$

which are eigenvectors with the corresponding eigenvalues in this state $E(LS)$.

In intermediate coupling, the wave functions of an N electrons atom or ion, can be written as:

$$\psi = \psi(\Gamma SLJM_J\,|x_1, \dots x_N) \tag{4}$$

which are eigenvectors with the corresponding eigenvalues in this state $E(LSJ)$.

2.2. Multi-Configuration Dirac-Hartree-Fock (MCDHF) method

The fully relativistic multiconfiguration Dirac-Hartree-Fock (MCDHF) method described by Fischer et al. (2016) for computing the atomic structures and radiative parameters is used for C-like V XVIII ion, with the latest version of GRASP (General Relativistic Atomic Structure Program), i.e. GRASP2018 (Froese Fischer et al., 2019). In this approach, the atomic state functions (ASFs), Ψ, are represented by a superposition of configuration state functions (CSFs), Φ, with the same parity, P, total angular momentum, and total magnetic quantum numbers, J and M :

$$\psi(\gamma PJM) = \sum_{j=1}^{N_{CSF}} c_j \Phi(\gamma_j PJM), \tag{5}$$

where the label γ_j represents all the other quantum numbers needed to univoquely specify CSFs that are jj-coupled Slater determinants built from one-electron spinorbitals. The configuration mixing coefficients c_j are obtained through the diagonalisation of the Dirac-Coulomb Hamiltonian

$$H_{DC} = \sum_{i=1}^{N} \left[c\alpha_i.\mathbf{p}_i + (\beta_i - 1)\,c^2 + V\,(r_i)\right] + \sum_{i>j}^{N} \frac{1}{r_{ij}} \tag{6}$$

where $V(r)$ is the monopole part of the electron-nucleus interaction. Finally, the high-order relativistic effects, i.e. the Breit interaction, QED self-energy and vacuum polarization effects are incorporated in the relativistic configuration interaction (RCI) step of the GRASP2018 package. In the present work, we optimize the wave functions and the corresponding energy levels by gradually increasing the basis of CSFs, and thus taking into account more correlated orbitals.

In the present work valence, corevalence, and corecore correlation effects were included, and the configuration expansions were obtained by single/double-excitations to active sets with principal quantum numbers n from 3 to 8 and orbital quantum numbers ℓ = 0,1,2,3 (i.e., angular symmetries s, p, d, f) from all shells belongs to multireference (MR) configurations of ($1s^2$) $2s^2$ $2p^2$, $2s2p^3$, $2p^4$, $2s^2$ $3d^2$, 2s 2p $3d^2$, $2s^2$ 2p 3ℓ, 2s $2p^2$ 3ℓ, $2p^3$ 3ℓ and $2s^2$ 2p 4ℓ (ℓ= s,p,d,f).

The multireference was chosen based on the criteria that it should contain the configurations that had the largest weights in the preceding self-consistent field calculations (Jnsson et al., 2011). Among the states generated by single/double-excitations from the multireference set, only those interacting with the multireference states were kept. The self-consistent field calculations for each layer of orbitals were followed by RCI calculations, including the Breit interaction. The leading QED effects vacuum polarization and self-energy were included in the final multireference RCI calculations. The total number of CSFs that are included in the calculations in the different layers is shown in Tab. 1

Table 1. The total number of CSFs that are included in the calculations in the different layers of V XVIII.

Parity	n	$2J_{min}$	$2J_{max}$	No. of CSF
Even	MR	0	10	139
	4			9730
	5			27894
	6			55573
	7			92767
	8			139476
Odd	MR	0	12	222
	4			12239
	5			36725
	6			74141
	7			124646
	8			188222

3. Results and discussion

We used the v28.46.9 version of AS (Badnell, 2022) and the GRASP2018 (Froese Fischer et al., 2019) of the GRASP atomic structure codes. The two codes are applied to study the atomic structure (energy levels and lifetimes) and transition parameters (oscillator strengths and transition probabilities) for the vanadium C-like ion (V XVIII).

3.1. Atomic structure of the V XVIII ion

Table 2. Energy levels calculated by AS code (E_{ab}(AS) for ab initio and E_{fit}(AS) fitted calculated values) and E(GRASP) for GRASP2018 code calculated values, compared with NIST database values E(NIST). All energies are in cm^{-1}

No.	Level	E(NIST)	E_{ab}(AS)	E_{fit}(AS)	E(GRASP)
1	$2s^22p^2(^3_2P)\ ^3P_0$	0	0	0	0
2	$2s^22p^2(^3_2P)\ ^3P_1$	37960	38494	38194	37771
3	$2s^22p^2(^3_2P)\ ^3P_2$	68190	69636	67897	68088
4	$2s^22p^2(^1_2D)\ ^1D_2$	160910	166591	161667	161161
5	$2s^22p^2(^1_0S)\ ^1S_0$	269000	272384	269025	268878
6	$2s2p^3(^4_3S)\ ^5S_2$	366870	355786	366944	366708
7	$2s2p^3(^2_3D)\ ^3D_2$	623860	625808	624102	625018
8	$2s2p^3(^2_3D)\ ^3D_1$	625040	627032	625194	626316
9	$2s2p^3(^2_3D)\ ^3D_3$	634950	637632	635238	636125
10	$2s2p^3(^2_1P)\ ^3P_0$	731870	733749	732154	733015
11	$2s2p^3(^2_1P)\ ^3P_1$	735420	737632	735618	736611
12	$2s2p^3(^2_1P)\ ^3P_2$	743350	746031	743584	744581
13	$2s2p^3(^4_3S)\ ^3S_1$	897330	905012	897336	901381
14	$2s2p^3(^2_3D)\ ^1D_2$	908420	920421	909045	911791
15	$2s2p^3(^2_1P)\ ^1P_1$	1014420	1026011	1015243	1017964
16	$2p^4\ ^3P_2$	1358710	1363958	1358599	1362046
17	$2p^4\ ^3P_1$	1410770	1416810	1411126	1413939
18	$2p^4\ ^3P_0$	1416110	1422576	1415929	1419409
19	$2p^4\ ^1D_2$	1480330	1492832	1481175	1483705
20	$2p^4\ ^1S_0$	1668300	1683630	1669640	1671963
21	$2s^22p^2P\ 3s\ ^3P_0$		5741747	5726678	5727408
22	$2s^22p^2P\ 3s\ ^3P_1$	5726000	5749002	5742005	5734362
23	$2s^22p^2P\ 3s\ ^3P_2$	5786000	5808065	5787164	5795086
24	$2s^22p^2P\ 3s\ ^1P_1$	5805000	5830422	5806629	5816030
25	$2s^22p^2P\ 3p\ ^3D_1$		5893348	5893638	5879738

Table 2. Continued.

No.	Level	E(NIST)	E_{ab}(AS)	E_{fit}(AS)	E(GRASP)
26	$2s^22p^2P\ 3p\ ^1P_1$		5977494	5977784	5916694
27	$2s^22p^2P\ 3p\ ^3D_2$		5930946	5931236	5918275
28	$2s^22p^2P\ 3p\ ^3P_0$		5949954	5950244	5937593
29	$2s^22p^2P\ 3p\ ^3P_1$		5928975	5929265	5966188
30	$2s^22p^2P\ 3p\ ^3D_3$		5980661	5980931	5969441
31	$2s^22p^2P\ 3p\ ^3S_1$		5994329	5994619	5983123
32	$2s^22p^2P\ 3p\ ^3P_2$		6000027	6000317	5988688
33	$2s^22p^2P\ 3p\ ^1D_2$		6050362	6050652	6036511
34	$2s2p^2(\frac{3}{2}P)\ ^4P\ 3s\ ^5P_1$		6070076	6070367	6068096
35	$2s^22p^2P\ 3d\ ^3F_2$	6073000	6089405	6076514	6074663
36	$2s^22p^2P\ 3p\ ^1S_0$		6105286	6100963	6091781
37	$2s2p^2(\frac{3}{2}P)\ ^4P\ 3s\ ^5P_2$		6097022	6097312	6095391
38	$2s^22p^2P\ 3d\ ^3F_3$		6114466	6105576	6099769
39	$2s^22p^2P\ 3d\ ^1D_2$:a		6122010	6112204	6106912
40	$2s^22p^2P\ 3d\ ^3D_1$	6100000	6140364	6137252	6124638
41	$2s2p^2(\frac{3}{2}P)\ ^4P\ 3s\ ^5P_3$		6127021	6115589	6125534
42	$2s^22p^2P\ 3d\ ^3F_4$		6158858	6159148	6145669
43	$2s2p^2(\frac{3}{2}P)\ ^4P\ 3s\ ^3P_0$		6160881	6161166	6154005
44	$2s^22p^2P\ 3d\ ^1D_2$:b		6122010	6112204	6154936
45	$2s^22p^2P\ 3d\ ^3D_3$	6157000	6187577	6182368	6173056
46	$2s2p^2(\frac{3}{2}P)\ ^4P\ 3s\ ^3P_1$	6174000	6182078	6176765	6176182
47	$2s^22p^2P\ 3d\ ^3P_2$		6197672	6187899	6183871
48	$2s^22p^2P\ 3d\ ^3P_1$		6199099	6196301	6185563
49	$2s^22p^2P\ 3d\ ^3P_0$	6188000	6200763	6201012	6187517
50	$2s2p^2(\frac{3}{2}P)\ ^4P\ 3s\ ^3P_2$	6195000	6214599	6214889	6208761
51	$2s2p^2(\frac{3}{2}P)\ ^4P\ 3p\ ^5D_0$		6228663	6227959	6228586
52	$2s2p^2(\frac{3}{2}P)\ ^4P\ 3p\ ^5D_1$		6230644	6230657	6230282
53	$2s^22p^2P\ 3d\ ^1F_3$		6250984	6249822	6233066
54	$2s^22p^2P\ 3d\ ^1P_1$		6247647	6231339	6234691
55	$2s2p^2(\frac{3}{2}P)\ ^4P\ 3p\ ^3S_1$		6251025	6249834	6249320
56	$2s2p^2(\frac{3}{2}P)\ ^4P\ 3p\ ^5D_2$	6226000	6249551	6235938	6250264
57	$2s2p^2(\frac{3}{2}P)\ ^4P\ 3p\ ^5D_3$		6273475	6273762	6274627
58	$2s2p^2(\frac{3}{2}P)\ ^4P\ 3p\ ^5P_1$	6234000	6280441	6280680	6281143
59	$2s2p^2(\frac{3}{2}P)\ ^4P\ 3p\ ^5P_2$		6281544	6281822	6282258
60	$2s2p^2(\frac{3}{2}P)\ ^4P\ 3p\ ^5D_4$		6301934	6302224	6303229
61	$2s2p^2(\frac{3}{2}P)\ ^4P\ 3p\ ^5P_3$		6302997	6303373	6303696
62	$2s2p^2(\frac{3}{2}P)\ ^4P\ 3p\ ^3D_1$		6309608	6309867	6306719
63	$2s2p^2(\frac{3}{2}P)\ ^4P\ 3p\ ^3D_2$		6328832	6326594	6326082

Table 2. Continued.

No.	Level	E(NIST)	E$_{ab}$(AS)	E$_{fit}$(AS)	E(GRASP)
64	2s2p^2($^1_2$D) ^{2}D 3s ^{3}D$_1$		6355744	6351092	6343261
65	2s2p^2($^1_2$D) ^{2}D 3s ^{3}D$_2$		6358922	6359212	6346527
66	2s2p^2($^1_2$D) ^{2}D 3s ^{3}D$_3$		6363171	6363006	6350738
67	2s2p^2($^3_2$P) ^{4}P 3p ^{5}S$_2$		6350807	6329120	6350784
68	2s2p^2($^3_2$P) ^{4}P 3p ^{3}P$_0$		6356557	6356034	6353947
69	2s2p^2($^3_2$P) ^{4}P 3p ^{3}D$_3$		6359071	6360638	6356703
70	2s2p^2($^3_2$P) ^{4}P 3p ^{3}P$_1$		6369204	6369478	6366732
71	2s2p^2($^3_2$P) ^{4}P 3p ^{3}P$_2$		6374857	6375142	6371960
72	2s2p^2($^1_2$D) ^{2}D 3s ^{1}D$_2$		6414931	6415220	6401195
73	2s2p^2($^3_2$P) ^{4}P 3d ^{5}F$_1$		6403691	6403981	6402335
74	2s2p^2($^3_2$P) ^{4}P 3d ^{5}F$_2$	6323300	6409095	6409385	6407843
75	2s2p^2($^3_2$P) ^{4}P 3d ^{5}F$_3$		6419356	6419642	6418241
76	2s2p^2($^3_2$P) ^{4}P 3d ^{5}F$_4$		6438472	6438762	6437440
77	2s2p^2($^3_2$P) ^{4}P 3d ^{5}D$_0$		6449489	6448385	6449838
78	2s2p^2($^3_2$P) ^{4}P 3d ^{5}D$_1$		6450163	6450453	6450333
79	2s2p^2($^3_2$P) ^{4}P 3d ^{5}D$_2$		6451499	6451788	6451253
80	2s2p^2($^3_2$P) ^{4}P 3d ^{5}D$_3$		6455729	6455984	6455234
81	2s2p^2($^3_2$P) ^{4}P 3d ^{5}F$_5$		6462921	6463211	6461691
82	2s2p^2($^1_0$S) ^{2}S 3s ^{3}S$_1$		6478695	6478985	6468148
83	2s2p^2($^3_2$P) ^{4}P 3d ^{5}D$_4$		6475251	6475541	6475040
84	2s2p^2($^3_2$P) ^{2}P 3s ^{3}P$_0$		6492936	6490852	6479653
85	2s2p^2($^3_2$P) ^{4}P 3d ^{3}P$_2$		6483543	6483831	6480330
86	2s2p^2($^3_2$P) ^{4}P 3d ^{5}P$_3$		6495315	6495523	6494621
87	2s2p^2($^3_2$P) ^{4}P 3d ^{3}F$_2$		6506799	6504788	6500486
88	2s2p^2($^1_2$D) ^{2}D 3p ^{3}F$_2$		6515149	6510532	6503533
89	2s2p^2($^3_2$P) ^{4}P 3d ^{5}P$_2$		6504472	6504762	6503941
90	2s2p^2($^3_2$P) ^{4}P 3d ^{3}P$_1$		6510244	6509439	6507239
91	2s2p^2($^3_2$P) ^{4}P 3d ^{5}P$_1$		6509149	6507089	6508631
92	2s2p^2($^1_2$D) ^{2}D 3p ^{3}F$_3$		6531204	6531606	6520173
93	2s2p^2($^3_2$P) ^{4}P 3d ^{3}F$_3$		6526407	6515383	6520278
94	2s2p^2($^3_2$P) ^{4}P 3d ^{3}P$_0$	6500000	6527315	6526697	6524579
95	2s2p^2($^1_2$D) ^{2}D 3p ^{1}D$_2$		6540057	6540316	6528886
96	2s2p^2($^1_2$D) ^{2}D 3p ^{3}F$_4$		6543104	6543394	6532562
97	2s2p^2($^1_2$D) ^{2}D 3p ^{3}D$_1$		6546646	6546921	6535757
98	2s2p^2($^3_2$P) ^{2}P 3s ^{3}P$_1$		6548950	6549240	6537337
99	2s2p^2($^1_2$D) ^{2}D 3p ^{1}F$_3$	6674000	6555647	6557588	6543959
100	2s2p^2($^1_2$D) ^{2}D 3p ^{3}D$_2$		6557312	6564823	6546739
101	2s2p^2($^3_2$P) ^{4}P 3d ^{3}F$_4$		6554550	6554840	6548724

Table 2. Continued.

No.	Level	E(NIST)	E_{ab}(AS)	E_{fit}(AS)	E(GRASP)
102	$2s2p^2(^3_2P)\ ^2P\ 3s\ ^3P_2$		6565500	6565789	6551335
103	$2s2p^2(^1_2D)\ ^2D\ 3p\ ^3D_3$		6565719	6569280	6555082
104	$2s2p^2(^1_2D)\ ^2D\ 3p\ ^1P_1$		6569041	6578319	6557794
105	$2s2p^2(^3_2P)\ ^2P\ 3s\ ^1P_1$		6581583	6583350	6566792
106	$2s2p^2(^1_0S)\ ^2S\ 3s\ ^1S_0$		6578032	6581873	6568288
107	$2s2p^2(^1_2D)\ ^2D\ 3p\ ^3P_0$		6584368	6587912	6573693
108	$2s2p^2(^1_2D)\ ^2D\ 3p\ ^3P_1$		6587703	6588169	6577037
109	$2s2p^2(^3_2P)\ ^4P\ 3d\ ^3D_1$		6583060	6583486	6577834
110	$2s2p^2(^3_2P)\ ^4P\ 3d\ ^3D_2$		6587880	6593843	6582363
111	$2s2p^2(^1_2D)\ ^2D\ 3p\ ^3P_2$		6594511	6634065	6584159
112	$2s2p^2(^3_2P)\ ^4P\ 3d\ ^3D_3$		6593554	6594717	6587788
113	$2s2p^2(^3_2P)\ ^2P\ 3p\ ^3P_0$:a		6633798	6655454	6622129
114	$2s2p^2(^3_2P)\ ^2P\ 3p\ ^3D_1$		6655212	6669332	6643916
115	$2s2p^2(^3_2P)\ ^2P\ 3p\ ^3D_2$		6669119	6669376	6658714
116	$2s2p^2(^3_2P)\ ^2P\ 3p\ ^3P_1$		6670171	6670339	6660018
117	$2s2p^2(^1_2D)\ ^2D\ 3d\ ^3G_3$		6700514	6700804	6687925
118	$2s2p^2(^3_2P)\ ^2P\ 3p\ ^1S_0$		6699942	6700164	6690409
119	$2s2p^2(^1_2D)\ ^2D\ 3d\ ^3G_4$		6705961	6706251	6693160
120	$2s2p^2(^1_2D)\ ^2D\ 3d\ ^3G_5$		6712503	6712793	6699723
121	$2s2p^2(^1_2D)\ ^2D\ 3d\ ^3F_2$		6718777	6719067	6703787
122	$2s2p^2(^1_2D)\ ^2D\ 3d\ ^3F_3$		6722518	6722808	6707516
123	$2s2p^2(^1_2D)\ ^2D\ 3d\ ^3F_4$		6725204	6725494	6709918
124	$2s2p^2(^1_0S)\ ^2S\ 3p\ ^1P_1$		6723434	6723640	6713721
125	$2s2p^2(^1_2D)\ ^2D\ 3d\ ^3D_1$		6724936	6725226	6713897
126	$2s2p^2(^1_0S)\ ^2S\ 3p\ ^3P_2$		6725654	6725867	6716788
127	$2s2p^2(^1_2D)\ ^2D\ 3d\ ^3D_2$		6728114	6728404	6717197
128	$2s2p^2(^3_2P)\ ^2P\ 3p\ ^3D_3$		6730742	6731273	6718506
129	$2s2p^2(^1_2D)\ ^2D\ 3d\ ^3D_3$		6730983	6734379	6719585
130	$2s2p^2(^1_2D)\ ^2D\ 3d\ ^1F_3$		6743017	6743307	6730355
131	$2s2p^2(^3_2P)\ ^2P\ 3p\ ^3P_2$		6725654	6725867	6730377
132	$2s2p^2(^3_2P)\ ^2P\ 3p\ ^3S_1$		6741704	6741964	6731167
133	$2s2p^2(^3_2P)\ ^2P\ 3p\ ^3P_0$:b		6742834	6742515	6731869
134	$2s2p^2(^1_0S)\ ^2S\ 3p\ ^3P_1$		6745641	6745885	6736397
135	$2s2p^2(^1_2D)\ ^2D\ 3d\ ^1G_4$		6760536	6760826	6745195
136	$2s2p^2(^1_2D)\ ^2D\ 3d\ ^3P_0$		6759391	6759566	6745372
137	$2s2p^2(^1_2D)\ ^2D\ 3d\ ^3P_1$		6761523	6761813	6747918
138	$2s2p^2(^1_2D)\ ^2D\ 3d\ ^3P_2$		6763993	6764281	6750371
139	$2s2p^2(^1_2D)\ ^2D\ 3d\ ^3S_1$		6773976	6774266	6762330

Table 2. Continued.

No.	Level	E(NIST)	E$_{ab}$(AS)	E$_{fit}$(AS)	E(GRASP)
140	2s2p^2(${}^1_2$D) ^{2}D 3d ^{1}D$_2$		6786475	6786751	6770475
141	2s2p^2(${}^1_2$D) ^{2}D 3d ^{1}P$_1$		6791180	6791470	6778053
142	2s2p^2(${}^3_2$P) ^{2}P 3p ^{1}D$_2$		6795469	6795742	6778329
143	2p^3${}^4_3$S) 3s ^{5}S$_2$		6791745	6792010	6797008
144	2s2p^2(${}^1_2$D) ^{2}D 3d ^{1}S$_0$		6828378	6828554	6811372
145	2s2p^2(${}^3_2$P) ^{2}P 3p ^{1}P$_1$		6832720	6832844	6816537
146	2s2p^2(${}^3_2$P) ^{2}P 3d ^{3}F$_2$		6836989	6837279	6822060
147	2s2p^2(${}^3_2$P) ^{2}P 3d ^{3}F$_3$		6897901	6898190	6827253
148	2s2p^2(${}^1_0$S) ^{2}S 3d ^{3}D$_1$		6840140	6840430	6827349
149	2s2p^2(${}^1_0$S) ^{2}S 3d ^{3}D$_2$		6855839	6856129	6842158
150	2p^3(${}^4_3$S) 3s ^{3}S$_1$		6890278	6890499	6885290
151	2s2p^2(${}^1_0$S) ^{2}S 3d ^{3}D$_3$		6923450	6923739	6885411
152	2s2p^2(${}^3_2$P) ^{2}P 3d ^{3}F$_4$		6901606	6901896	6885667
153	2s2p^2(${}^3_2$P) ^{2}P 3d ^{3}D$_2$		6912061	6912351	6898769
154	2s2p^2(${}^3_2$P) ^{2}P 3d ^{1}P$_1$		6912138	6912428	6898869
155	2s2p^2(${}^3_2$P) ^{2}P 3d ^{3}D$_3$		6923450	6923739	6907325
156	2s2p^2(${}^3_2$P) ^{2}P 3d ^{3}D$_1$		6927015	6927305	6912222
157	2s2p^2(${}^1_0$S) ^{2}S 3d ^{1}D$_2$		6928253	6928542	6915637
158	2s2p^2(${}^3_2$P) ^{2}P 3d ^{3}P$_2$		6940380	6940669	6924457
159	2s2p^2(${}^3_2$P) ^{2}P 3d ^{3}P$_0$		6953789	6953815	6935785
160	2s2p^2(${}^3_2$P) ^{2}P 3d ^{3}P$_1$		6954920	6955208	6936294
161	2p^3(${}^2_3$D) 3s ^{3}D$_1$		6950261	6950503	6940370
162	2p^3(${}^2_3$D) 3s ^{3}D$_2$		6951940	6952169	6941806
163	2p^3(${}^4_3$S) 3p ^{5}P$_1$		6943746	6944036	6950681
164	2s2p^2(${}^3_2$P) ^{2}P 3d ^{1}F$_3$		6971686	6971976	6950784
165	2p^3(${}^2_3$D) 3s ^{3}D$_3$		6962318	6962641	6952252
166	2p^3(${}^4_3$S) 3p ^{5}P$_2$		6950971	6951261	6954357
167	2p^3(${}^4_3$S) 3p ^{5}P$_3$		6959208	6959440	6965811
168	2p^3(${}^2_3$D) 3s ^{1}D$_2$		6992832	6993090	6981197
169	2s2p^2(${}^3_2$P) ^{2}P 3d ^{1}D$_2$		7018949	7019237	6992640
170	2p^3(${}^4_3$S) 3p ^{3}P$_1$		6999757	7000047	7001672
171	2p^3(${}^4_3$S) 3p ^{3}P$_2$		7003762	7004051	7009236
172	2p^3(${}^4_3$S) 3p ^{3}P$_0$		7010694	7010775	7013325
173	2p^3(${}^2_3$D) 3p ^{3}D$_1$		7074853	7075143	7067415
174	2p^3(${}^2_1$P) 3s ^{3}P$_0$		7083881	7084124	7074533
175	2p^3(${}^2_1$P) 3s ^{3}P$_1$		7090002	7089744	7080633
176	2p^3(${}^2_3$D) 3p ^{3}D$_2$		7090247	7090537	7081966
177	2p^3(${}^2_3$D) 3p ^{3}D$_3$		7101254	7101544	7092984

Table 2. Continued.

No.	Level	E(NIST)	E$_{ab}$(AS)	E$_{fit}$(AS)	E(GRASP)
178	$2p^3({}^2_3D)\ 3p\ {}^3F_2$		7104662	7104952	7095870
179	$2p^3({}^2_1P)\ 3s\ {}^3P_2$		7110085	7109885	7101083
180	$2p^3({}^2_3D)\ 3p\ {}^1P_1$		7109363	7109653	7102443
181	$2p^3({}^2_3D)\ 3p\ {}^3F_3$		7115091	7115381	7106652
182	$2p^3({}^2_3D)\ 3p\ {}^1F_3$		7123559	7123849	7113829
183	$2p^3({}^2_3D)\ 3p\ {}^3F_4$		7124032	7124322	7115274
184	$2p^3({}^4_3S)\ 3d\ {}^5D_0$		7118129	7118419	7123530
185	$2p^3({}^4_3S)\ 3d\ {}^5D_1$		7118329	7118615	7123677
186	$2p^3({}^4_3S)\ 3d\ {}^5D_2$		7118574	7118849	7123824
187	$2p^3({}^4_3S)\ 3d\ {}^5D_3$		7118952	7119232	7124015
188	$2p^3({}^4_3S)\ 3d\ {}^5D_4$		7120699	7120989	7125760
189	$2p^3({}^2_1P)\ 3s\ {}^1P_1$		7137295	7137044	7127552
190	$2p^3({}^2_3D)\ 3p\ {}^3P_0$		7179087	7179371	7167848
191	$2p^3({}^2_3D)\ 3p\ {}^3P_1$		7186048	7186337	7176347
192	$2p^3({}^4_3S)\ 3d\ {}^3D_2$		7178450	7178719	7177011
193	$2p^3({}^2_3D)\ 3p\ {}^3P_2$		7192508	7192797	7182120
194	$2p^3({}^4_3S)\ 3d\ {}^3D_3$		7188146	7188428	7187396
195	$2p^3({}^4_3S)\ 3d\ {}^3D_1$		7188421	7188703	7187939
196	$2p^3({}^2_3D)\ 3p\ {}^1D_2$		7224525	7224812	7211136
197	$2p^3({}^2_1P)\ 3p\ {}^3D_1$		7235122	7235412	7225340
198	$2p^3({}^2_1P)\ 3p\ {}^3S_1$		7248516	7248806	7241695
199	$2p^3({}^2_3D)\ 3d\ {}^3F_2$		7251687	7251937	7243328
200	$2p^3({}^2_1P)\ 3p\ {}^3D_2$		7252630	7252920	7243842
201	$2p^3({}^2_3D)\ 3d\ {}^3F_3$		7258935	7259219	7250333
202	$2p^3({}^2_3D)\ 3d\ {}^3G_4$		7267143	7267433	7258224
203	$2p^3({}^2_3D)\ 3d\ {}^1S_0$		7267287	7267577	7258336
204	$2p^3({}^2_3D)\ 3d\ {}^3G_3$		7269033	7269312	7260016
205	$2p^3({}^2_1P)\ 3p\ {}^3D_3$		7268773	7269062	7260930
206	$2p^3({}^2_1P)\ 3p\ {}^1P_1$		7274720	7275010	7265566
207	$2p^3({}^2_3D)\ 3d\ {}^3F_4$		7276654	7276944	7267758
208	$2p^3({}^2_3D)\ 3d\ {}^3G_5$		7281367	7281657	7272356
209	$2p^3({}^2_3D)\ 3d\ {}^1G_4$		7284361	7284651	7274780
210	$2p^3({}^2_1P)\ 3p\ {}^3P_0$		7293324	7293601	7282919
211	$2p^3({}^2_3D)\ 3d\ {}^3D_1$		7290736	7290979	7283196
212	$2p^3({}^2_1P)\ 3p\ {}^3P_1$		7300121	7300411	7290418
213	$2p^3({}^2_1P)\ 3p\ {}^3P_2$		7304161	7304451	7295131
214	$2p^3({}^2_1P)\ 3p\ {}^1D_2$		7323328	7323616	7310062
215	$2p^3({}^2_3D)\ 3d\ {}^3D_2$		7318862	7319113	7310196

Table 2. Continued.

No.	Level	E(NIST)	E_{ab}(AS)	E_{fit}(AS)	E(GRASP)
216	$2p^3(^2_3D)$ 3d $^1P_1$		7319556	7319836	7311015
217	$2p^3(^2_3D)$ 3d $^3D_3$		7326383	7326665	7315245
218	$2p^3(^2_3D)$ 3d $^3P_2$		7332437	7332706	7324495
219	$2p^3(^2_3D)$ 3d $^3P_0$		7334573	7334863	7326757
220	$2p^3{}^2_3D)$ 3d $^3P_1$		7337715	7337987	7329772
221	$2p^3(^2_3D)$ 3d $^1D_2$		7348934	7349205	7337502
222	$2p^3(^2_3D)$ 3d $^3S_1$		7359484	7359750	7346647
223	$2p^3(^2_3D)$ 3d $^1F_3$		7380513	7381084	7366579
224	$2p^3(^2_1P)$ 3d $^3F_2$		7411647	7411611	7402549
225	$2p^3(^2_1P)$ 3d $^3F_3$		7416885	7417141	7407777
226	$2p^3(^2_1P)$ 3p $^1S_0$		7427895	7428172	7409852
227	$2p^3(^2_1P)$ 3d $^3F_4$		7426969	7427259	7418490
228	$2p^3(^2_1P)$ 3d $^3P_2$		7436573	7436651	7427040
229	$2p^3(^2_1P)$ 3d $^3P_0$		7436818	7437108	7430308
230	$2p^3(^2_1P)$ 3d $^3P_1$		7439845	7440051	7431960
231	$2p^3(^2_1P)$ 3d $^1D_2$		7486657	7486822	7440360
232	$2p^3(^2_1P)$ 3d $^3D_1$		7465372	7465633	7452683
233	$2p^3{}^2_1P)$ 3d $^3D_3$		7466444	7466518	7456489
234	$2p^3(^2_1P)$ 3d $^3D_2$		7451816	7451960	7472850
235	$2p^3(^2_1P)$ 3d $^1F_3$		7493789	7493772	7478909
236	$2p^3(^2_1P)$ 3d $^1P_1$		7561443	7561290	7543791
237	$2s^22p^2P$ 4s $^3P_0$		7795381	7795670	7749456
238	$2s^22p^2P$ 4s $^3P_1$		7797987	7798268	7752082
239	$2s^22p^2P$ 4p $^3D_1$		7858690	7858980	7812720
240	$2s^22p^2P$ 4s $^3P_2$		7863544	7863823	7817484
241	$2s^22p^2P$ 4s $^1P_1$		7869822	7870105	7823822
242	$2s^22p^2P$ 4p $^3P_1$		7873758	7874048	7828846
243	$2s^22p^2P$ 4p $^3D_2$		7875543	7875833	7830393
244	$2s^22p^2P$ 4p $^3P_0$		7880856	7881146	7836188
245	$2s^22p^2P$ 4d $^3F_2$		7931974	7932255	7885404
246	$2s^22p^2P$ 4p $^1P_1$		7931877	7932167	7886477
247	$2s^22p^2P$ 4p $^3D_3$		7934743	7935033	7889498
248	$2s^22p^2P$ 4p $^3P_2$		7938902	7939192	7893544
249	$2s^22p^2P$ 4p $^3S_1$		7939643	7939933	7894058
250	$2s^22p^2P$ 4d $^3P_2$:a		8013799	8014088	7898263
251	$2s^22p^2P$ 4d $^3F_3$		7944931	7945220	7898372
252	$2s^22p^2P$ 4d $^3D_1$		7950293	7950582	7904345
253	$2s^22p^2P$ 4p $^1D_2$		7955151	7955441	7909857

Table 2. Continued.

No.	Level	E(NIST)	E_{ab}(AS)	E_{fit}(AS)	E(GRASP)
254	$2s^22p^2P\ 4p\ ^1S_0$		7974259	7974549	7928738
255	$2s^22p^2P\ 4f\ ^3G_3$		7980672	7980962	7937815
256	$2s^22p^2P\ 4f\ ^3F_2$		7982863	7983153	7939610
257	$2s^22p^2P\ 4f\ ^3G_4$		7982588	7982878	7939891
258	$2s^22p^2P\ 4d\ ^3F_4$		8001725	8002015	7955060
259	$2s^22p^2P\ 4d\ ^1D_2$		8003031	8003319	7956528
260	$2s^22p^2P\ 4d\ ^3D_3$		8009038	8009327	7962650
261	$2s^22p^2P\ 4d\ ^3P_2$:b		8013799	8014088	7967552
262	$2s^22p^2P\ 4d\ ^3P_1$		8014529	8014819	7968190
263	$2s^22p^2P\ 4d\ ^3P_0$		8015398	8015688	7968989
264	$2s^22p^2P\ 4d\ ^1F_3$		8030100	8030388	7982900
265	$2s^22p^2P\ 4d\ ^1P_1$		8031033	8031320	7985215
266	$2s^22p^2P\ 4f\ ^3F_4$		8047872	8048162	8005173
267	$2s^22p^2P\ 4f\ ^3D_2$		8050954	8051244	8007598
268	$2s^22p^2P\ 4f\ ^3D_1$		8055435	8055725	8012289
269	$2s^22p^2P\ 4f\ ^1D_2$		8057313	8057603	8013991
270	$2s2p^2(^3_2P)\ ^4P\ 4s\ ^3P_0$		8111191	8111481	8109236
271	$2s2p^2(^3_2P)\ ^4P\ 4p\ ^5D_0$		8152227	8152517	8151980
272	$2s2p^2(^3_2P)\ ^4P\ 4p\ ^5D_1$		8153548	8153838	8152944
273	$2s2p^2(^3_2P)\ ^4P\ 4p\ ^5D_2$:a		8162997	8163287	8163322
274	$2s2p^2(^3_2P)\ ^4P\ 4p\ ^3S_1$		8176073	8176363	8174042
275	$2s2p^2(^3_2P)\ ^4P\ 4p\ ^5P_1$		8183623	8183913	8183504
276	$2s2p^2(^3_2P)\ ^4P\ 4p\ ^5D_3$		8187668	8187958	8188402
277	$2s2p^2(^3_2P)\ ^4P\ 4p\ ^5D_2$:b		8162997	8163287	8189522
278	$2s2p^2(^3_2P)\ ^4P\ 4p\ ^3D_1$		8199262	8199552	8198102
279	$2s2p^2(^3_2P)\ ^4P\ 4p\ ^3D_2$		8208095	8208385	8207330
280	$2s2p^2(^3_2P)\ ^4P\ 4p\ ^5P_3$		8216544	8216834	8217080
281	$2s2p^2(^3_2P)\ ^4P\ 4p\ ^3P_0$		8218277	8218564	8217719
282	$2s2p^2(^3_2P)\ ^4P\ 4p\ ^5D_4$		8217578	8217868	8218590
283	$2s2p^2(^3_2P)\ ^4P\ 4p\ ^5S_2$		8226239	8226529	8227146
284	$2s2p^2(^3_2P)\ ^4P\ 4p\ ^3P_1$		8239826	8240116	8238638
285	$2s2p^2(^3_2P)\ ^4P\ 4p\ ^3D_3$		8239693	8239983	8239229
286	$2s2p^2(^3_2P)\ ^4P\ 4p\ ^3P_2$		8245703	8245993	8244974
287	$2s2p^2(^3_2P)\ ^4P\ 4d\ ^5D_0$		8253408	8253698	8254194
288	$2s2p^2(^3_2P)\ ^4P\ 4f\ ^5G_2$		8267517	8267807	8267688
289	$2s2p^2(^3_2P)\ ^4P\ 4f\ ^5G_3$:a		8268250	8268540	8268616
290	$2s2p^2(^3_2P)\ ^4P\ 4f\ ^5D_4$		8269290	8269580	8270118
291	$2s2p^2(^3_2P)\ ^4P\ 4f\ ^3G_3$:a		8272585	8272875	8272482

Table 2. Continued.

No.	Level	E(NIST)	E$_{ab}$(AS)	E$_{fit}$(AS)	E(GRASP)
292	2s2p^2($^3_2$P) ^{4}P 4f ^{5}G$_3$:b		8268250	8268540	8295909
293	2s2p^2($^3_2$P) ^{4}P 4f ^{5}G$_4$		8295260	8295550	8296354
294	2s2p^2($^3_2$P) ^{4}P 4f ^{5}F$_2$		8297149	8297439	8297743
295	2s2p^2($^3_2$P) ^{4}P 4f ^{5}G$_5$		8298122	8298412	8299557
296	2s2p^2($^3_2$P) ^{4}P 4f ^{3}G$_3$:b		8272585	8272875	8299785
297	2s2p^2($^3_2$P) ^{4}P 4f ^{5}F$_1$		8300261	8300551	8301019
298	2s2p^2($^3_2$P) ^{4}P 4f ^{3}G$_4$		8301129	8301419	8301612
299	2s2p^2($^3_2$P) ^{4}P 4f ^{3}F$_2$		8304031	8304321	8304478
300	2s2p^2($^3_2$P) ^{4}P 4f ^{5}D$_0$		8327198	8327488	8328229
301	2s2p^2($^3_2$P) ^{4}P 4f ^{5}D$_1$		8328019	8328309	8328907
302	2s2p^2($^3_2$P) ^{4}P 4f ^{5}G$_6$		8327343	8327633	8330148
303	2s2p^2($^3_2$P) ^{4}P 4f ^{5}D$_2$		8329593	8329883	8330524
304	2s2p^2($^3_2$P) ^{4}P 4f ^{3}G$_5$		8333112	8333402	8331132
305	2s2p^2($^3_2$P) ^{4}P 4f ^{5}F$_3$		8331046	8331336	8332023
306	2s2p^2($^3_2$P) ^{4}P 4f ^{3}D$_1$		8331600	8331890	8332356
307	2s2p^2($^3_2$P) ^{4}P 4f ^{5}F$_4$		8331715	8332005	8333061
308	2s2p^2($^3_2$P) ^{4}P 4f ^{5}F$_5$		8329609	8329899	8334663
309	2s2p^2($^3_2$P) ^{4}P 4f ^{3}D$_2$		8334495	8334785	8335018
310	2s2p^2($^3_2$P) ^{4}P 4f ^{3}F$_3$		8336429	8336719	8336780
311	2s2p^2($^3_2$P) ^{4}P 4f ^{3}F$_4$		8336641	8336931	8337257
312	2s2p^2($^1_2$D) ^{2}D 4p ^{3}F$_2$		8432436	8432725	8422797
313	2s2p^2($^1_2$D) ^{2}D 4p ^{3}F$_3$		8439354	8439644	8430659
314	2s2p^2($^1_2$D) ^{2}D 4p ^{3}D$_1$		8439923	8440213	8431188
315	2s2p^2($^1_2$D) ^{2}D 4p ^{3}D$_2$		8443704	8443994	8434788
316	2s2p^2($^1_2$D) ^{2}D 4p ^{3}F$_4$		8446787	8447077	8438803
317	2s2p^2($^1_2$D) ^{2}D 4p ^{1}D$_2$		8450342	8450632	8439411
318	2s2p^2($^1_2$D) ^{2}D 4p ^{1}F$_3$		8449473	8449772	8439531
319	2s2p^2($^1_2$D) ^{2}D 4p ^{3}D$_3$		8448117	8448416	8440871
320	2s2p^2($^1_2$D) ^{2}D 4p ^{3}P$_1$		8453637	8453926	8443308
321	2s2p^2($^1_2$D) ^{2}D 4p ^{3}P$_0$		8453845	8454128	8443942
322	2s2p^2($^1_2$D) ^{2}D 4p ^{3}P$_2$		8463127	8463416	8453012
323	2s2p^2($^1_2$D) ^{2}D 4p ^{1}P$_1$		8464465	8464754	8453409
324	2s2p^2($^1_2$D) ^{2}D 4f ^{3}G$_3$		8539625	8539915	8532346
325	2s2p^2($^1_2$D) ^{2}D 4f ^{3}G$_4$		8540911	8541201	8534340
326	2s2p^2($^1_2$D) ^{2}D 4f ^{3}F$_2$		8543073	8543360	8535458
327	2s2p^2($^1_2$D) ^{2}D 4f ^{3}F$_3$		8544386	8544676	8537297
328	2s2p^2($^1_2$D) ^{2}D 4f ^{3}H$_4$		8545576	8545866	8538613
329	2s2p^2($^1_2$D) ^{2}D 4f ^{3}G$_5$		8545639	8545929	8541462

Table 2. Continued.

No.	Level	E(NIST)	E$_{ab}$(AS)	E$_{fit}$(AS)	E(GRASP)
330	2s2p^2($^1_0$S) ^{2}S 4p ^{3}P$_0$		8550727	8551016	8541948
331	2s2p^2($^1_2$D) ^{2}D 4f ^{3}F$_4$		8549385	8549675	8542672
332	2s2p^2($^1_2$D) ^{2}D 4f ^{1}F$_3$		8550932	8551223	8543483
333	2s2p^2($^1_2$D) ^{2}D 4f ^{3}D$_1$		8551576	8551866	8543758
334	2s2p^2($^1_2$D) ^{2}D 4f ^{1}G$_4$		8551605	8551895	8544719
335	2s2p^2($^1_2$D) ^{2}D 4f ^{3}D$_2$		8552597	8552883	8545004
336	2s2p^2($^1_2$D) ^{2}D 4f ^{3}H$_5$		8551201	8551491	8546910
337	2s2p^2($^3_2$P) ^{2}P 4p ^{3}D$_1$:a		8629504	8629794	8548860
338	2s2p^2($^1_2$D) ^{2}D 4f ^{3}D$_3$		8556110	8556398	8548931
339	2s2p^2($^1_2$D) ^{2}D 4f ^{1}D$_2$		8557008	8557297	8549291
340	2s2p^2($^1_2$D) ^{2}D 4f ^{1}H$_5$		8557193	8557483	8552539
341	2s2p^2($^1_2$D) ^{2}D 4f ^{3}P$_2$		8561243	8561531	8554302
342	2s2p^2($^1_2$D) ^{2}D 4f ^{3}P$_1$		8562383	8562670	8554490
343	2s2p^2($^1_2$D) ^{2}D 4f ^{3}H$_6$		8556169	8556459	8556266
344	2s2p^2($^1_2$D) ^{2}D 4f ^{3}P$_0$		8564100	8564390	8556516
345	2s2p^2($^1_0$S) ^{2}S 4p ^{3}P$_2$:a		8564356	8564643	8557699
346	2s2p^2($^1_2$D) ^{2}D 4f ^{1}P$_1$:a		8565732	8566017	8557866
347	2s2p^2($^1_2$D) ^{2}D 4f ^{1}P$_1$:b		8565732	8566017	8559474
348	2s2p^2($^3_2$P) ^{2}P 4p ^{1}S$_0$		8622972	8623260	8617089
349	2s2p^2($^3_2$P) ^{2}P 4p ^{3}D$_1$:b		8629504	8629794	8622145
350	2s2p^2($^1_0$S) ^{2}S 4p ^{3}P$_2$:b		8649315	8649603	8624138
351	2s2p^2($^3_2$P) ^{2}P 4p ^{3}P$_1$		8638664	8638953	8629689
352	2s2p^2($^3_2$P) ^{2}P 4p ^{3}P$_2$		8649315	8649603	8633308
353	2s2p^2($^3_2$P) ^{2}P 4p ^{3}D$_3$		8646398	8646687	8633453
354	2s2p^2($^3_2$P) ^{2}P 4p ^{1}D$_2$		8660102	8660392	8647410
355	2s2p^2($^3_2$P) ^{2}P 4f ^{3}G$_3$		8736401	8736690	8660666
356	2s2p^2($^1_0$S) ^{2}S 4f ^{3}F$_4$:a		8665287	8665577	8662200
357	2s2p^2($^1_0$S) ^{2}S 4f ^{1}F$_3$		8666624	8666913	8662705
358	2s2p^2($^1_0$S) ^{2}S 4f ^{3}F$_3$		8758923	8759212	8732041
359	2s2p^2($^1_0$S) ^{2}S 4f ^{3}F$_4$:b		8760381	8760671	8733179
360	2s2p^2($^3_2$P) ^{2}P 4f ^{1}G$_4$		8753252	8753542	8744359
361	2s2p^2($^3_2$P) ^{2}P 4f ^{3}G$_5$		8752933	8753223	8745053

In Tab. 2, we present the calculated energy levels and compared to the NIST database values. There are only 34 energy levels in the NIST database and the corresponding *ab initio* and fitted AS values and GRASP values differ from the NIST values by 0.81 % , 0.25 % and 0.31 % respectively. For all 361 energy levels calculated by the TFDA and the MCDHF methods, the average difference between them is only 0.19 %.

Table 3. Lifetimes (τ_l in s. in the length form) calculated by AS code $\tau_l(AS)$ and by GRASP2018 code $\tau_l(GRASP)$ for *V XVIII*

No.	Level	$\tau_l(GRASP)$	$\tau_l(AS)$
1	2s^{2}2p^{2}P 3s ^{3}P$_0$	8.147E-13	8.246E-13
2	2s^{2}2p^{2}P 3s ^{3}P$_1$	7.090E-13	7.325E-13
3	2s^{2}2p^{2}P 3s ^{3}P$_2$	7.773E-13	8.102E-13
4	2s^{2}2p^{2}P 3s ^{1}P$_1$	5.094E-13	5.243E-13
5	2s^{2}2p^{2}P 3p ^{3}D$_1$	3.581E-11	2.963E-11
6	2s^{2}2p^{2}P 3p ^{1}P$_1$	1.344E-11	7.594E-12
7	2s^{2}2p^{2}P 3p ^{3}D$_2$	2.643E-11	2.227E-11
8	2s^{2}2p^{2}P 3p ^{3}P$_0$	5.564E-12	4.513E-12
9	2s^{2}2p^{2}P 3p ^{3}P$_1$	9.245E-12	1.092E-11
10	2s^{2}2p^{2}P 3p ^{3}D$_3$	3.189E-11	2.719E-11
11	2s^{2}2p^{2}P 3p ^{3}S$_1$	7.738E-12	6.269E-12
12	2s^{2}2p^{2}P 3p ^{3}P$_2$	6.233E-12	4.996E-12
13	2s^{2}2p^{2}P 3p ^{1}D$_2$	1.283E-11	1.135E-11
14	2s2p^2($\frac{3}{2}$P) ^{4}P 3s ^{5}P$_1$	1.076E-12	1.100E-12
15	2s^{2}2p^{2}P 3d ^{3}F$_2$	7.397E-13	1.053E-12
16	2s^{2}2p^{2}P 3p ^{1}S$_0$	4.580E-12	3.896E-12
17	2s2p^2($\frac{3}{2}$P) ^{4}P 3s ^{5}P$_2$	1.042E-12	1.074E-12
18	2s^{2}2p^{2}P 3d ^{3}F$_3$	4.029E-13	3.183E-13
19	2s^{2}2p^{2}P 3d ^{1}D$_2$a	1.386E-13	1.269E-13
20	2s^{2}2p^{2}P 3d ^{3}D$_1$	7.826E-14	7.927E-14
21	2s2p^2($\frac{3}{2}$P) ^{4}P 3s ^{5}P$_3$	9.827E-13	1.078E-12
22	2s^{2}2p^{2}P 3d ^{3}F$_4$	8.721E-10	8.278E-10
23	2s2p^2($\frac{3}{2}$P) ^{4}P 3s ^{3}P$_0$	6.832E-13	7.158E-13
24	2s^{2}2p^{2}P 3d ^{1}D$_2$b	1.277E-13	1.269E-13
25	2s^{2}2p^{2}P 3d ^{3}D$_3$	8.248E-14	8.720E-14
26	2s2p^2($\frac{3}{2}$P) ^{4}P 3s ^{3}P$_1$	6.260E-13	6.448E-13
27	2s^{2}2p^{2}P 3d ^{3}P$_2$	9.776E-14	1.010E-13
28	2s^{2}2p^{2}P 3d ^{3}P$_1$	1.078E-13	1.051E-13
29	2s^{2}2p^{2}P 3d ^{3}P$_0$	1.259E-13	1.243E-13
30	2s2p^2($\frac{3}{2}$P) ^{4}P 3s ^{3}P$_2$	6.142E-13	6.324E-13
31	2s2p^2($\frac{3}{2}$P) ^{4}P 3p ^{5}D$_0$	1.578E-10	3.426E-10
32	2s2p^2($\frac{3}{2}$P) ^{4}P 3p ^{5}D$_1$	9.416E-13	2.254E-13
33	2s^{2}2p^{2}P 3d ^{1}F$_3$	5.733E-14	5.773E-14
34	2s^{2}2p^{2}P 3d ^{1}P$_1$	9.543E-14	1.360E-13

Table 3. Continued.

No.	Level	$\tau_l(GRASP)$	$\tau_l(AS)$
35	2s2p^2($^3_2$P) ^{4}P 3p ^{3}S$_1$	5.074E-13	4.956E-13
36	2s2p^2($^3_2$P) ^{4}P 3p ^{5}D$_2$	2.270E-10	2.284E-10
37	2s2p^2($^3_2$P) ^{4}P 3p ^{5}D$_3$	1.662E-10	1.120E-10
38	2s2p^2($^3_2$P) ^{4}P 3p ^{5}P$_1$	9.980E-13	9.738E-13
39	2s2p^2($^3_2$P) ^{4}P 3p ^{5}P$_2$	4.438E-12	5.307E-12
40	2s2p^2($^3_2$P) ^{4}P 3p ^{5}D$_4$	6.430E-10	4.333E-10
41	2s2p^2($^3_2$P) ^{4}P 3p ^{5}P$_3$	2.856E-12	3.599E-12
42	2s2p^2($^3_2$P) ^{4}P 3p ^{3}D$_1$	3.021E-13	2.871E-13
43	2s2p^2($^3_2$P) ^{4}P 3p ^{3}D$_2$	3.092E-13	2.948E-13
44	2s2p^2($^1_2$D) ^{2}D 3s ^{3}D$_1$	5.347E-13	5.264E-13
45	2s2p^2($^1_2$D) ^{2}D 3s ^{3}D$_2$	5.334E-13	5.256E-13
46	2s2p^2($^1_2$D) ^{2}D 3s ^{3}D$_3$	5.142E-13	5.114E-13
47	2s2p^2($^3_2$P) ^{4}P 3p ^{5}S$_2$	7.317E-12	9.195E-12
48	2s2p^2($^3_2$P) ^{4}P 3p ^{3}P$_0$	3.010E-13	3.029E-13
49	2s2p^2($^3_2$P) ^{4}P 3p ^{3}D$_3$	3.229E-13	3.057E-13
50	2s2p^2($^3_2$P) ^{4}P 3p ^{3}P$_1$	2.954E-13	2.895E-13
51	2s2p^2($^3_2$P) ^{4}P 3p ^{3}P$_2$	3.083E-13	2.993E-13
52	2s2p^2($^1_2$D) ^{2}D 3s ^{1}D$_2$	1.132E-12	1.096E-12
53	2s2p^2($^3_2$P) ^{4}P 3d ^{5}F$_1$	1.142E-11	1.126E-11
54	2s2p^2($^3_2$P) ^{4}P 3d ^{5}F$_2$	3.905E-12	3.867E-12
55	2s2p^2($^3_2$P) ^{4}P 3d ^{5}F$_3$	1.648E-12	1.618E-12
56	2s2p^2($^3_2$P) ^{4}P 3d ^{5}F$_4$	1.696E-11	1.839E-11
57	2s2p^2($^3_2$P) ^{4}P 3d ^{5}D$_0$	6.379E-12	2.805E-12
58	2s2p^2($^3_2$P) ^{4}P 3d ^{5}D$_1$	1.146E-12	1.194E-12
59	2s2p^2($^3_2$P) ^{4}P 3d ^{5}D$_2$	4.356E-13	4.541E-13
60	2s2p^2($^3_2$P) ^{4}P 3d ^{5}D$_3$	2.253E-13	2.310E-13
61	2s2p^2($^3_2$P) ^{4}P 3d ^{5}F$_5$	1.104E-09	1.029E-09
62	2s2p^2($^1_0$S) ^{2}S 3s ^{3}S$_1$	5.928E-13	5.799E-13
63	2s2p^2($^3_2$P) ^{4}P 3d ^{5}D$_4$	5.981E-10	6.915E-10
64	2s2p^2($^3_2$P) ^{2}P 3s ^{3}P$_0$	6.013E-13	7.158E-13
65	2s2p^2($^3_2$P) ^{4}P 3d ^{3}P$_2$	2.100E-13	2.022E-13
66	2s2p^2($^3_2$P) ^{4}P 3d ^{5}P$_3$	9.302E-14	9.035E-14
67	2s2p^2($^3_2$P) ^{4}P 3d ^{3}F$_2$	1.972E-13	1.893E-13
68	2s2p^2($^1_2$D) ^{2}D 3p ^{3}F$_2$	7.139E-13	7.233E-13
69	2s2p^2($^3_2$P) ^{4}P 3d ^{5}P$_2$	7.559E-14	7.408E-14
70	2s2p^2($^3_2$P) ^{4}P 3d ^{3}P$_1$	1.729E-13	1.364E-13
71	2s2p^2($^3_2$P) ^{4}P 3d ^{5}P$_1$	6.909E-14	7.538E-14
72	2s2p^2($^1_2$D) ^{2}D 3p ^{3}F$_3$	6.413E-12	8.862E-12

Table 3. Continued.

No.	Level	$\tau_l(GRASP)$	$\tau_l(AS)$
73	2s2p^2(${}^3_2$P) ^{4}P 3d ^{3}F$_3$	2.029E-13	1.942E-13
74	2s2p^2(${}^3_2$P) ^{4}P 3d ^{3}P$_0$	2.042E-13	3.095E-13
75	2s2p^2(${}^1_2$D) ^{2}D 3p ^{1}D$_2$	3.421E-13	3.345E-13
76	2s2p^2(${}^1_2$D) ^{2}D 3p ^{3}F$_4$	1.817E-10	1.701E-10
77	2s2p^2(${}^1_2$D) ^{2}D 3p ^{3}D$_1$	6.621E-13	6.871E-13
78	2s2p^2(${}^3_2$P) ^{2}P 3s ^{3}P$_1$	6.664E-13	6.660E-13
79	2s2p^2(${}^1_2$D) ^{2}D 3p ^{1}F$_3$	2.739E-13	2.256E-13
80	2s2p^2(${}^1_2$D) ^{2}D 3p ^{3}D$_2$	1.978E-12	1.903E-12
81	2s2p^2(${}^3_2$P) ^{4}P 3d ^{3}F$_4$	2.011E-13	1.941E-13
82	2s2p^2(${}^3_2$P) ^{2}P 3s ^{3}P$_2$	7.563E-13	7.215E-13
83	2s2p^2(${}^1_2$D) ^{2}D 3p ^{3}D$_3$	1.394E-12	7.735E-13
84	2s2p^2(${}^1_2$D) ^{2}D 3p ^{1}P$_1$	2.620E-13	2.524E-13
85	2s2p^2(${}^3_2$P) ^{2}P 3s ^{1}P$_1$	3.369E-13	2.763E-13
86	2s2p^2(${}^1_0$S) ^{2}S 3s ^{1}S$_0$	9.777E-13	9.234E-13
87	2s2p^2(${}^1_2$D) ^{2}D 3p ^{3}P$_0$	4.036E-12	4.776E-12
88	2s2p^2(${}^1_2$D) ^{2}D 3p ^{3}P$_1$	1.951E-12	1.908E-12
89	2s2p^2(${}^3_2$P) ^{4}P 3d ^{3}D$_1$	1.323E-13	1.363E-13
90	2s2p^2(${}^3_2$P) ^{4}P 3d ^{3}D$_2$	1.319E-13	1.265E-13
91	2s2p^2(${}^1_2$D) ^{2}D 3p ^{3}P$_2$	1.256E-12	1.285E-12
92	2s2p^2(${}^3_2$P) ^{4}P 3d ^{3}D$_3$	1.172E-13	1.122E-13
93	2s2p^2(${}^3_2$P) ^{2}P 3p ^{3}P$_0$a	1.254E-12	1.277E-12
94	2s2p^2(${}^3_2$P) ^{2}P 3p ^{3}D$_1$	8.528E-13	8.534E-13
95	2s2p^2(${}^3_2$P) ^{2}P 3p ^{3}D$_2$	1.891E-12	1.903E-12
96	2s2p^2(${}^3_2$P) ^{2}P 3p ^{3}P$_1$	7.336E-13	6.853E-13
97	2s2p^2(${}^1_2$D) ^{2}D 3d ^{3}G$_3$	9.146E-12	1.000E-11
98	2s2p^2(${}^3_2$P) ^{2}P 3p ^{1}S$_0$	3.905E-12	4.538E-12
99	2s2p^2(${}^1_2$D) ^{2}D 3d ^{3}G$_4$	1.430E-12	1.889E-12
100	2s2p^2(${}^1_2$D) ^{2}D 3d ^{3}G$_5$	2.761E-10	2.600E-10
101	2s2p^2(${}^1_2$D) ^{2}D 3d ^{3}F$_2$	7.954E-14	7.758E-14
102	2s2p^2(${}^1_2$D) ^{2}D 3d ^{3}F$_3$	8.212E-14	8.076E-14
103	2s2p^2(${}^1_2$D) ^{2}D 3d ^{3}F$_4$	8.064E-14	7.720E-14
104	2s2p^2(${}^1_0$S) ^{2}S 3p ^{1}P$_1$	3.932E-13	3.921E-13
105	2s2p^2(${}^1_2$D) ^{2}D 3d ^{3}D$_1$	8.086E-14	7.919E-14
106	2s2p^2(${}^1_0$S) ^{2}S 3p ^{3}P$_2$	2.022E-12	1.836E-12
107	2s2p^2(${}^1_2$D) ^{2}D 3d ^{3}D$_2$	8.141E-14	7.982E-14
108	2s2p^2(${}^3_2$P) ^{2}P 3p ^{3}D$_3$	1.016E-12	7.735E-13
109	2s2p^2(${}^1_2$D) ^{2}D 3d ^{3}D$_3$	1.130E-13	9.191E-14
110	2s2p^2(${}^1_2$D) ^{2}D 3d ^{1}F$_3$	1.622E-13	1.760E-13

Table 3. Continued.

No.	Level	$\tau_l(GRASP)$	$\tau_l(AS)$
111	2s2p^2($^3_2$P) ^{2}P 3p ^{3}P$_2$	9.197E-13	9.316E-13
112	2s2p^2($^3_2$P) ^{2}P 3p ^{3}S$_1$	5.032E-13	4.956E-13
113	2s2p^2($^3_2$P) ^{2}P 3p ^{3}P$_0$b	2.835E-12	2.341E-12
114	2s2p^2($^1_0$S) ^{2}S 3p ^{3}P$_1$	7.738E-13	6.853E-13
115	2s2p^2($^1_2$D) ^{2}D 3d ^{1}G$_4$	5.452E-13	5.450E-13
116	2s2p^2($^1_2$D) ^{2}D 3d ^{3}P$_0$	9.886E-14	9.521E-14
117	2s2p^2($^1_2$D) ^{2}D 3d ^{3}P$_1$	1.980E-13	9.681E-14
118	2s2p^2($^1_2$D) ^{2}D 3d ^{3}P$_2$	1.024E-13	9.965E-14
119	2s2p^2($^1_2$D) ^{2}D 3d ^{3}S$_1$	1.464E-13	1.370E-13
120	2s2p^2($^1_2$D) ^{2}D 3d ^{1}D$_2$	9.973E-14	9.658E-14
121	2s2p^2($^1_2$D) ^{2}D 3d ^{1}P$_1$	2.227E-13	2.202E-13
122	2s2p^2($^3_2$P) ^{2}P 3p ^{1}D$_2$	2.309E-12	2.855E-12
123	2p^3($^4_3$S) 3s ^{5}S$_2$	1.251E-11	4.884E-12
124	2s2p^2($^1_2$D) ^{2}D 3d ^{1}S$_0$	1.665E-13	1.592E-13
125	2s2p^2($^3_2$P) ^{2}P 3p ^{1}P$_1$	1.244E-12	1.269E-12
126	2s2p^2($^3_2$P) ^{2}P 3d ^{3}F$_2$	1.867E-13	1.893E-13
127	2s2p^2($^3_2$P) ^{2}P 3d ^{3}F$_3$	1.598E-13	1.942E-13
128	2s2p^2($^1_0$S) ^{2}S 3d ^{3}D$_1$	2.448E-13	2.332E-13
129	2s2p^2($^1_0$S) ^{2}S 3d ^{3}D$_2$	2.822E-13	2.952E-13
130	2p^3($^4_3$S) 3s ^{3}S$_1$	4.721E-13	4.714E-13
131	2s2p^2($^1_0$S) ^{2}S 3d ^{3}D$_3$	2.292E-13	1.516E-13
132	2s2p^2($^3_2$P) ^{2}P 3d ^{3}F$_4$	4.453E-13	4.182E-13
133	2s2p^2($^3_2$P) ^{2}P 3d ^{3}D$_2$	1.467E-13	1.568E-13
134	2s2p^2($^3_2$P) ^{2}P 3d ^{1}P$_1$	1.061E-13	1.000E-13
135	2s2p^2($^3_2$P) ^{2}P 3d ^{3}D$_3$	4.140E-13	3.757E-13
136	2s2p^2($^3_2$P) ^{2}P 3d ^{3}D$_1$	1.410E-13	1.427E-13
137	2s2p^2($^1_0$S) ^{2}S 3d ^{1}D$_2$	3.722E-13	3.201E-13
138	2s2p^2($^3_2$P) ^{2}P 3d ^{3}P$_2$	8.993E-14	9.749E-14
139	2s2p^2($^3_2$P) ^{2}P 3d ^{3}P$_0$	7.422E-14	7.086E-14
140	2s2p^2($^3_2$P) ^{2}P 3d ^{3}P$_1$	7.817E-14	8.123E-14
141	2p^3($^2_3$D) 3s ^{3}D$_1$	9.982E-13	9.609E-13
142	2p^3($^2_3$D) 3s ^{3}D$_2$	1.045E-12	1.500E-12
143	2p^3($^4_3$S) 3p ^{5}P$_1$	5.943E-13	3.712E-13
144	2s2p^2($^3_2$P) ^{2}P 3d ^{1}F$_3$	5.335E-14	5.031E-14
145	2p^3($^2_3$D) 3s ^{3}D$_3$	1.013E-12	9.875E-13
146	2p^3($^4_3$S) 3p ^{5}P$_2$	6.503E-13	2.944E-13
147	2p^3($^4_3$S) 3p ^{5}P$_3$	6.118E-13	6.364E-13
148	2p^3($^2_3$D) 3s ^{1}D$_2$	5.038E-13	4.865E-13

Table 3. Continued.

No.	Level	$\tau_l(GRASP)$	$\tau_l(AS)$
149	$\mathrm{2s2p^2({}^3_2P)\ {}^2P\ 3d\ {}^1D_2}$	6.177E-14	5.877E-14
150	$\mathrm{2p^3({}^4_3S)\ 3p\ {}^3P_1}$	3.788E-13	3.745E-13
151	$\mathrm{2p^3({}^4_3S)\ 3p\ {}^3P_2}$	2.373E-13	2.251E-13
152	$\mathrm{2p^3({}^4_3S)\ 3p\ {}^3P_0}$	3.868E-13	3.899E-13
153	$\mathrm{2p^3({}^2_3D)\ 3p\ {}^3D_1}$	4.781E-13	4.631E-13
154	$\mathrm{2p^3({}^2_1P)\ 3s\ {}^3P_0}$	9.518E-13	9.070E-13
155	$\mathrm{2p^3({}^2_1P)\ 3s\ {}^3P_1}$	8.375E-13	8.100E-13
156	$\mathrm{2p^3({}^2_3D)\ 3p\ {}^3D_2}$	6.467E-13	6.529E-13
157	$\mathrm{2p^3({}^2_3D)\ 3p\ {}^3D_3}$	6.636E-13	6.713E-13
158	$\mathrm{2p^3({}^2_3D)\ 3p\ {}^3F_2}$	6.739E-13	7.354E-13
159	$\mathrm{2p^3({}^2_1P)\ 3s\ {}^3P_2}$	7.907E-13	7.678E-13
160	$\mathrm{2p^3({}^2_3D)\ 3p\ {}^1P_1}$	4.257E-13	3.917E-13
161	$\mathrm{2p^3({}^2_3D)\ 3p\ {}^3F_3}$	6.157E-13	6.521E-13
162	$\mathrm{2p^3({}^2_3D)\ 3p\ {}^1F_3}$	6.900E-13	7.957E-13
163	$\mathrm{2p^3({}^2_3D)\ 3p\ {}^3F_4}$	7.624E-13	8.423E-13
164	$\mathrm{2p^3({}^4_3S)\ 3d\ {}^5D_0}$	1.100E-11	1.022E-11
165	$\mathrm{2p^3({}^4_3S)\ 3d\ {}^5D_1}$	6.802E-12	8.466E-12
166	$\mathrm{2p^3({}^4_3S)\ 3d\ {}^5D_2}$	1.050E-11	1.092E-11
167	$\mathrm{2p^3({}^4_3S)\ 3d\ {}^5D_3}$	1.989E-11	1.993E-11
168	$\mathrm{2p^3({}^4_3S)\ 3d\ {}^5D_4}$	2.957E-11	2.721E-11
169	$\mathrm{2p^3({}^2_1P)\ 3s\ {}^1P_1}$	4.840E-13	4.508E-13
170	$\mathrm{2p^3({}^2_3D)\ 3p\ {}^3P_0}$	5.332E-13	5.769E-13
171	$\mathrm{2p^3({}^2_3D)\ 3p\ {}^3P_1}$	4.967E-13	5.318E-13
172	$\mathrm{2p^3({}^4_3S)\ 3d\ {}^3D_2}$	4.649E-13	3.931E-13
173	$\mathrm{2p^3({}^2_3D)\ 3p\ {}^3P_2}$	3.808E-13	4.800E-13
174	$\mathrm{2p^3({}^4_3S)\ 3d\ {}^3D_3}$	3.687E-13	3.220E-13
175	$\mathrm{2p^3({}^4_3S)\ 3d\ {}^3D_1}$	3.441E-13	3.016E-13
176	$\mathrm{2p^3({}^2_3D)\ 3p\ {}^1D_2}$	5.182E-13	5.803E-13
177	$\mathrm{2p^3({}^2_1P)\ 3p\ {}^3D_1}$	5.454E-13	5.592E-13
178	$\mathrm{2p^3({}^2_1P)\ 3p\ {}^3S_1}$	4.966E-13	4.912E-13
179	$\mathrm{2p^3({}^2_3D)\ 3d\ {}^3F_2}$	3.083E-12	3.120E-12
180	$\mathrm{2p^3({}^2_1P)\ 3p\ {}^3D_2}$	6.335E-13	6.529E-13
181	$\mathrm{2p^3({}^2_3D)\ 3d\ {}^3F_3}$	3.315E-12	3.519E-12
182	$\mathrm{2p^3({}^2_3D)\ 3d\ {}^3G_4}$	7.633E-11	7.700E-11
183	$\mathrm{2p^3({}^2_3D)\ 3d\ {}^1S_0}$	3.132E-11	2.790E-11
184	$\mathrm{2p^3({}^2_3D)\ 3d\ {}^3G_3}$	3.783E-12	3.885E-12
185	$\mathrm{2p^3({}^2_1P)\ 3p\ {}^3D_3}$	6.197E-13	6.459E-13
186	$\mathrm{2p^3({}^2_1P)\ 3p\ {}^1P_1}$	4.084E-13	3.917E-13

Table 3. Continued.

No.	Level	$\tau_l(GRASP)$	$\tau_l(AS)$
187	$2p^3({}^2_3D)$ 3d $^3F_4$	7.424E-11	6.771E-11
188	$2p^3({}^2_3D)$ 3d $^3G_5$	8.321E-11	7.752E-11
189	$2p^3({}^2_3D)$ 3d $^1G_4$	9.254E-11	8.679E-11
190	$2p^3({}^2_1P)$ 3p $^3P_0$	3.710E-13	3.759E-13
191	$2p^3({}^2_3D)$ 3d $^3D_1$	1.848E-13	1.769E-13
192	$2p^3({}^2_1P)$ 3p $^3P_1$	3.789E-13	3.745E-13
193	$2p^3({}^2_1P)$ 3p $^3P_2$	5.799E-13	6.125E-13
194	$2p^3({}^2_1P)$ 3p $^1D_2$	3.253E-13	3.162E-13
195	$2p^3({}^2_3D)$ 3d $^3D_2$	1.212E-13	1.131E-13
196	$2p^3({}^2_3D)$ 3d $^1P_1$	1.640E-13	1.612E-13
197	$2p^3({}^2_3D)$ 3d $^3D_3$	8.239E-14	7.955E-14
198	$2p^3({}^2_3D)$ 3d $^3P_2$	7.729E-14	7.696E-14
199	$2p^3({}^2_3D)$ 3d $^3P_0$	1.486E-13	1.412E-13
200	$2p^3({}^2_3D)$ 3d $^3P_1$	1.180E-13	1.123E-13
201	$2p^3({}^2_3D)$ 3d $^1D_2$	1.622E-13	1.572E-13
202	$2p^3({}^2_3D)$ 3d $^3S_1$	7.458E-14	7.800E-14
203	$2p^3({}^2_3D)$ 3d $^1F_3$	9.480E-14	9.268E-14
204	$2p^3({}^2_1P)$ 3d $^3F_2$	1.145E-12	1.194E-12
205	$2p^3({}^2_1P)$ 3d $^3F_3$	1.439E-12	1.155E-12
206	$2p^3({}^2_1P)$ 3p $^1S_0$	3.390E-13	3.579E-13
207	$2p^3({}^2_1P)$ 3d $^3F_4$	3.437E-11	3.125E-11
208	$2p^3({}^2_1P)$ 3d $^3P_2$	1.965E-13	2.524E-13
209	$2p^3({}^2_1P)$ 3d $^3P_0$	1.368E-13	1.356E-13
210	$2p^3({}^2_1P)$ 3d $^3P_1$	1.576E-13	1.538E-13
211	$2p^3({}^2_1P)$ 3d $^1D_2$	2.042E-13	1.572E-13
212	$2p^3({}^2_1P)$ 3d $^3D_1$	7.814E-14	7.121E-14
213	$2p^3({}^2_1P)$ 3d $^3D_3$	2.707E-13	2.520E-13
214	$2p^3({}^2_1P)$ 3d $^3D_2$	9.484E-14	1.131E-13
215	$2p^3({}^2_1P)$ 3d $^1F_3$	6.558E-14	5.779E-14
216	$2p^3({}^2_1P)$ 3d $^1P_1$	5.725E-14	5.220E-14

216 lifetimes are reported in Tab. 3. There is no values to compare with, but from the two different methods (TFDA and MCDHF), the difference is less than 10 %.

3.2. Transition parameters of the V XVIII ion

Table 4. Weighted oscillator strengths and transition probabilities calculated by the AS code ($gf(AS)$ and $gA(AS)$) and by the GRASP2018 code ($gf(GRASP)$ and $gA(GRASP)$), compared with NIST database values $gf(NIST)$ and $gA(NIST)$

No.	L	U	gf ($GRASP$)	gf (AS)	gA ($GRASP$)	gA (AS)	gf ($NIST$)	gA ($NIST$)
1	1	22	5.55E-02	5.26E-02	1.22E+12	1.15E+12		
2	1	24	1.84E-03	1.78E-03	4.15E+10	4.00E+10		
3	1	40	1.25E+00	1.25E+00	3.14E+13	3.13E+13		
4	1	48	4.27E-03	6.02E-04	1.09E+11	1.54E+10		
5	1	55	4.49E-02	4.79E-02	1.17E+12	1.25E+12		
6	1	58	7.92E-02	7.27E-02	2.08E+12	1.91E+12		
7	1	62	2.06E-01	2.23E-01	5.46E+12	5.92E+12		
8	1	70	4.43E-02	4.49E-02	1.20E+12	1.22E+12		
9	1	97	2.73E-02	2.84E-02	7.77E+11	8.13E+11		
10	1	114	1.11E-02	2.84E-02	3.26E+11	8.13E+11		
11	1	116	5.98E-02	4.49E-02	1.77E+12	1.22E+12		
12	2	21	5.68E-02	5.59E-02	1.23E+12	1.21E+12		
13	2	22	3.36E-02	3.28E-02	7.28E+11	7.08E+11		
14	2	23	7.51E-02	7.11E-02	1.66E+12	1.57E+12		
15	2	24	7.95E-03	7.46E-03	1.77E+11	1.66E+11		
16	2	35	1.32E-02	3.30E-02	3.21E+11	8.02E+11		
17	2	39	1.05E+00	1.10E+00	2.59E+13	2.75E+13		
18	2	40	2.58E-01	2.16E-01	6.37E+12	5.36E+12		
19	2	44	1.19E+00	1.10E+00	2.98E+13	2.75E+13		
20	2	47	2.36E-01	1.76E-01	5.94E+12	4.45E+12		
21	2	48	6.86E-01	7.22E-01	1.73E+13	1.83E+13	6.90E-01	1.70E+13
22	2	49	3.15E-01	3.18E-01	7.94E+12	8.05E+12		
23	2	51	1.69E-04	8.00E-07	4.33E+09	2.04E+07		
24	2	52	4.15E-02	4.01E-02	1.06E+12	1.67E+12		
25	2	54	1.30E-02	9.79E-04	3.32E+11	2.51E+10		
26	2	55	7.49E-02	7.86E-02	1.93E+12	2.02E+12		
27	2	58	1.45E-02	2.12E-02	3.77E+11	5.50E+11		
28	2	59	4.27E-02	3.53E-02	1.11E+12	9.18E+11		
29	2	62	1.62E-01	1.64E-01	4.25E+12	4.29E+12		
30	2	63	5.68E-01	5.95E-01	1.50E+13	1.57E+13		
31	2	67	4.79E-03	3.81E-03	1.27E+11	1.01E+11		
32	2	68	1.23E-01	1.23E-01	3.27E+12	3.24E+12		
33	2	70	6.91E-02	7.21E-02	1.85E+12	1.93E+12		
34	2	71	6.08E-02	6.13E-02	1.63E+12	1.64E+12		
35	2	88	3.52E-03	3.49E-03	9.82E+10	9.76E+10		
36	2	95	6.79E-03	6.19E-03	1.91E+11	1.75E+11		

Table 4. Continued.

No.	L	U	gf $(GRASP)$	gf (AS)	gA $(GRASP)$	gA (AS)	gf $(NIST)$	gA $(NIST)$
37	2	97	2.57E-02	2.67E-02	7.23E+11	7.56E+11		
38	2	114	3.77E-02	2.67E-02	1.10E+12	7.56E+11		
39	2	116	2.84E-02	7.21E-02	8.29E+11	1.93E+12		
40	2	126	6.93E-02	6.13E-02	2.06E+12	1.64E+12		
41	2	132	4.84E-03	2.04E-04	1.45E+11	2.90E+10		
42	2	134	2.63E-02	7.21E-02	7.87E+11	1.93E+12		
43	3	22	9.14E-02	8.99E-02	1.96E+12	1.92E+12		
44	3	23	1.90E-01	1.82E-01	4.15E+12	3.98E+12		
45	3	24	1.68E-03	1.59E-03	3.70E+10	3.48E+10		
46	3	35	1.29E-01	8.89E-02	3.09E+12	2.14E+12		
47	3	38	6.60E-01	8.48E-01	1.60E+13	2.07E+13		
48	3	39	1.37E-01	1.56E-01	3.34E+12	3.87E+12		
49	3	40	9.38E-03	1.54E-02	2.30E+11	3.78E+11		
50	3	44	7.28E-02	1.56E-01	1.80E+12	3.87E+12		
51	3	45	3.33E+00	3.10E+00	8.28E+13	7.72E+13	3.10E+00	7.70E+13
52	3	47	1.42E+00	1.35E+00	3.54E+13	3.37E+13		
53	3	48	3.67E-01	3.58E-01	9.17E+12	8.97E+12	3.45E-01	8.70E+12
54	3	52	3.19E-02	2.61E-02	8.08E+11	6.61E+11		
55	3	53	1.24E-01	1.45E-01	3.16E+12	3.67E+12		
56	3	55	8.58E-02	8.98E-02	2.19E+12	2.29E+12		
57	3	56	5.13E-04	2.87E-04	1.31E+10	7.32E+09		
58	3	57	1.12E-03	1.87E-03	2.89E+10	4.81E+10		
59	3	58	1.50E-02	1.77E-02	3.86E+11	4.55E+11		
60	3	61	8.58E-02	6.64E-02	2.23E+12	1.72E+12		
61	3	62	2.36E-03	1.80E-03	6.13E+10	4.69E+10		
62	3	63	4.23E-02	4.47E-02	1.10E+12	1.17E+12		
63	3	67	1.92E-02	1.49E-02	5.06E+11	3.91E+11		
64	3	69	7.73E-01	7.91E-01	2.04E+13	2.09E+13		
65	3	70	2.49E-01	2.50E-01	6.59E+12	6.63E+12		
66	3	71	5.22E-01	5.34E-01	1.38E+13	1.42E+13		
67	3	88	4.45E-02	4.52E-02	1.23E+12	1.25E+12		
68	3	92	1.73E-02	2.24E-02	4.81E+11	6.23E+11		
69	3	95	4.76E-02	5.19E-02	1.33E+12	1.45E+12		
70	3	97	2.99E-02	2.87E-02	8.33E+11	8.03E+11		
71	3	100	3.21E-02	4.47E-02	8.99E+11	1.17E+12		
72	3	103	3.22E-02	4.45E-03	9.03E+11	1.99E+11		
73	3	115	2.07E-02	4.47E-02	5.98E+11	1.17E+12		
74	3	132	1.01E-01	8.98E-02	3.00E+12	2.29E+12		
75	3	142	1.02E-02	3.89E-03	3.06E+11	1.73E+11		
76	4	22	1.24E-02	1.23E-02	2.57E+11	2.54E+11		
77	4	23	2.92E-02	2.98E-02	6.18E+11	6.28E+11		

Table 4. Continued.

No.	L	U	gf $(GRASP)$	gf (AS)	gA $(GRASP)$	gA (AS)	gf $(NIST)$	gA $(NIST)$
78	4	24	1.99E-01	1.95E-01	4.25E+12	4.14E+12		
79	4	35	1.43E-01	7.71E-02	3.34E+12	1.80E+12		
80	4	38	5.67E-02	5.56E-02	1.33E+12	1.31E+12		
81	4	39	2.89E-01	3.34E-01	6.81E+12	8.02E+12		
82	4	40	2.07E-03	3.09E-03	4.90E+10	7.36E+10		
83	4	44	3.18E-01	3.34E-01	7.60E+12	8.02E+12		
84	4	45	8.63E-02	1.27E-01	2.08E+12	3.05E+12		
85	4	47	4.05E-01	4.70E-01	9.79E+12	1.14E+13		
86	4	48	4.75E-02	4.81E-02	1.15E+12	1.17E+12		
87	4	52	6.84E-03	1.77E-03	1.68E+11	7.16E+10		
88	4	53	4.84E+00	4.78E+00	1.19E+14	1.18E+14		
89	4	54	5.00E-02	2.72E-02	1.23E+12	6.67E+11		
90	4	55	2.75E-03	3.80E-03	6.80E+10	9.39E+10		
91	4	57	9.66E-05	1.40E-04	2.41E+09	3.48E+09		
92	4	58	3.68E-04	5.36E-04	9.19E+09	1.34E+10		
93	4	59	1.07E-04	1.67E-04	2.67E+09	4.16E+09		
94	4	61	8.29E-03	8.05E-03	2.09E+11	2.02E+11		
95	4	62	4.79E-04	5.07E-04	1.21E+10	1.28E+10		
96	4	63	1.83E-03	2.36E-03	4.65E+10	5.98E+10		
97	4	67	7.98E-04	7.32E-04	2.04E+10	1.87E+10		
98	4	69	4.90E-02	7.65E-02	1.25E+12	1.96E+12		
99	4	70	1.35E-02	1.52E-02	3.47E+11	3.90E+11		
100	4	71	1.92E-02	2.29E-02	4.94E+11	5.90E+11		
101	4	88	2.09E-01	2.03E-01	5.60E+12	5.48E+12		
102	4	92	2.09E-02	4.31E-03	5.62E+11	1.17E+11		
103	4	95	4.79E-01	4.84E-01	1.30E+13	1.31E+13		
104	4	97	7.37E-02	6.54E-02	2.00E+12	1.78E+12		
105	4	100	5.10E-03	2.36E-03	1.39E+11	5.98E+10		
106	4	103	1.47E-01	7.65E-02	4.02E+12	1.96E+12		
107	4	108	1.59E-02	1.52E-02	4.36E+11	3.90E+11		
108	4	111	8.75E-02	2.29E-02	2.41E+12	5.90E+11		
109	4	114	3.09E-02	1.45E-02	8.67E+11	2.70E+11		
110	4	115	8.03E-04	2.36E-03	2.26E+10	5.98E+10		
111	4	128	7.01E-02	7.65E-02	2.01E+12	1.96E+12		
112	4	131	6.86E-02	2.29E-02	1.97E+12	5.90E+11		
113	4	132	4.01E-02	3.80E-03	1.16E+12	9.39E+10		
114	5	22	3.52E-03	3.14E-03	7.01E+10	6.24E+10		
115	5	24	6.74E-02	6.57E-02	1.38E+12	1.34E+12		
116	5	40	1.28E-02	1.11E-02	2.92E+11	4.28E+11		
117	5	48	4.95E-03	4.98E-03	1.16E+11	1.17E+11		
118	5	52	2.19E-02	1.53E-02	5.20E+11	6.04E+11		

Table 4. Continued.

No.	L	U	gf $(GRASP)$	gf (AS)	gA $(GRASP)$	gA (AS)	gf $(NIST)$	gA $(NIST)$
119	5	54	1.25E+00	8.55E-01	2.97E+13	2.03E+13		
120	5	55	2.26E-02	1.55E-02	5.40E+11	3.70E+11		
121	5	58	5.42E-03	5.18E-03	1.31E+11	1.25E+11		
122	5	62	5.36E-03	6.55E-03	1.30E+11	1.59E+11		
123	5	70	6.48E-04	8.26E-04	1.61E+10	2.05E+10		
124	5	97	2.85E-03	3.02E-03	7.47E+10	7.94E+10		
125	5	114	3.93E-02	6.55E-03	1.06E+12	1.59E+11		
126	5	116	3.85E-02	8.26E-04	1.05E+12	2.05E+10		
127	5	132	1.67E-02	1.55E-02	4.66E+11	3.70E+11		
128	5	134	6.56E-02	8.26E-04	1.83E+12	2.05E+10		

Oscillator strengths and transition probabilities are presented in Tab. 4. The differences between the calculated values and the NIST database values are less than 5 %. In average the AS and GRASP oscillator strengths and transition probabilities values differ by about 30 %.

Comparing our results of energy values, lifetimes, oscillator strengths and transition probabilities using the TFDA and MCDHF methods with available values, we recommend our MCDHF data calculated using the GRASP atomic structure code. The TFDA method gives data which are near the MCDHF results.

4. Conclusions

In this work, we calculated energy levels of the vanadium carbon-like ion V XVIII using two different methods: The TFDA and the fully relativistic MCDHF methods using the AS and the GRASP2018 atomic structure codes. We obtained good values of energy levels, new lifetime values, weighted oscillator strengths and transition probabilities for transitions from the fundamental configurations levels. Our results are interesting for plasma and astrophysical applications.

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