Journal of Atomic, Molecular, Condensed Matter & Nano Physics
Vol. 8, No. 1, pp. 45–61, 2021
ISSN 2582-8215
Published by RGN Publications

http://www.rgnpublications.com

DOI: 10.26713/jamcnp.v8i1.1482

Research Article

Energy Levels and Oscillator Strengths of Ca V

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Received: November 8, 2020 **Accepted:** December 4, 2020

Communicated by: Arun Goel

Abstract. We report an extensive and elaborate theoretical study of excitation energies and radiative data for the lowest 148 fine-structure levels of Sulphur-like Ca using Configuration Interaction Method (CIV3). We have included the relativistic effects using Breit-Pauli approximation by adding mass-correction, Darwin and Spin-Orbit terms to the non-relativistic Hamiltonian. Dipole allowed transitions are fined tuned by adjusting diagonal elements of the Hamiltonian Matrix.The exact identification of many levels becomes tedious due to the strong mixing between several fine-structure levels. We have compared our calculated values of energywith the data compiled by National Institute of standard and Technology (NIST) and found good agreement. We have reported data for many new levels which are not in the NIST database.

Keywords. Atomic structure; Excitation energies; Oscillator strengths

PACS. 32.70 Cs

1. Introduction

Fine structure energy levels and radiative data of highly charged ions is of significant interest for both pure atomic physics and astrophysicsfor a long time. An accurate atomic data is helpful for recognizing highly ionized impurity ions in fusion reactors [1, 4]. It is beneficial in understanding astrophysical plasmas like density, temperature and chemical composition.

The Sulphur isoelectronic sequence has been the subject of attention due to its applications in astrophysical plasmas. Several authors have performed the relativistic estimations for energy levels of Sulphur like ions [2, 10–12]. Biemont et al. [2] presented the energy levels in the ground state configuration of Sulphur like ions. Chou et al. [3] calculated theoretical energy levels for 47 low lying levels of S-like ions for $Z > 18$. In this paper, two independent Atomic Structure Codes namely LOS Alamos National Laboratory code (LANL) and the Configuration Interaction Method were used. These both codes are based on relativistic Hartree Fock method [6]. There has been experimental and theoretical work in past years about the atomic properties of Ca V ion, which is a reasonable sign of their significance in the astrophysics and atomic physics [7].

In our current work, we report energy levels and oscillator strengths for electric dipole allowed transitions with the low-lying fine structure energy levels of Ca V. We have reported the energy values of Ca V belonging to the configurations ($1s^2 2s^2 2p^6$) $3s^2 3p^4$, $3s^1 3p^5$, $3p^6$, $3s^2 3p^3 3d$, $3s3p^4 3d$, $3s^1 3p^3 3d^2$, $3s^2 3p^3 4s^1$ and $3s^2 3p^3 4d$. The energies for the vast majority of the fine structure levels belonging to the $3s^1 3p^3 3d^2$and $3s^1 3p^4 3d^1$ are reported. These results are accounted for the first time, to the best of our knowledge. These levels are essential for finding the spectra acquired by Hinode spacecraft [15], which was observed the transitions having a place with these levels. We also fine tune the configuration interaction coefficients using the experimental energies. The relativistic effects are included in the Breit-Pauli Hamiltonian [8]. The Darwin and mass correction terms move the energies of levels while the Spin-orbit term presents fine-structure splitting. Our presented energies are in acceptable concurrence with the NIST,giving its credit to the accuracyof our CI wave functions.

2. Theoretical Methods

In our calculations we have used the configuration interation code CIV3 of Hibbert [8] to obtain the wave functions which describe the atomic states included in these calculations. The configuration interaction wave functions are represented

$$\psi_i(LSJ) = \sum_{i=1}^{M} a_i \phi_i(\alpha_i LSJ), \tag{2.1}$$

where φ_i refers to single configuration function which came from one-electron orbital's having α_i as angular momentum which is coupling forms total angular momentum L and S common for all M configurations. The coefficients α_i are obtained as eigen vector components from diagonalized Hamiltonian [8]. Here we take the Hamiltonian to be the Schrödinger Hamiltonian adds the mass-correction term, Darwin term and modified Spin-orbit term.

$$H_{SO} = \frac{1}{2}\alpha^2 \sum_{i=1}^{N} \frac{Z\xi_i}{r_i^3} l_i s_i \,. \tag{2.2}$$

In equation (2.2), where summation is for all the electrons and the parameter ξ_i depend on l value of the electron involved in the interaction. Radial function which is used in the CI method can be expressed as summation over all normalized Slater-Type orbitals [9].

$$P_{nl}(r) = \sum_{j=1}^{K} C_{jnl} \left[\frac{(2\xi_{jnl})^{I_{jnl}+\frac{1}{2}}}{((2I_{jnl})!)^{\frac{1}{2}}} \right] \left(r^{I_{jnl}} \exp(-\xi_{jnl} r) \right) I_{jnl} \tag{2.3}$$

I_{jnl} are fixed integers but ξ_{jnl} and C_{jnl} may be considered as variational parameters depending on orthonormality conditions [9].

$$\int_0^\infty P_{nl}P_{n'l'}dr = \delta_{nn'}; \quad l < n' \leq n. \tag{2.4}$$

If $\langle\phi_i|H|\phi_f\rangle$ is a Hamiltonian matrix whose eigenvectors give the Configuration Interaction coefficients a_i in equation (2.1) and corresponding eigen values from upper bounds to the energies of different states with a particular symmetry ($LSJ\pi$). This upper bound property of the variational principle and eigenvaluesprovide a set of conditions to enable us to optimize the radial parameters in equation (2.3).

If once we are able to determine wavefunction in form (2.1), can be used later for transitions between initial state Ψ_i with energy E_i to final state Ψ_f with energy E_f and find absorption oscillator strengths in the form of length (f_l) and velocity (f_v).

$$f_l = \frac{2\delta E}{3g_i}\left|\left\langle \Psi_i \left| \sum_{p=1}^{N} r_p \right| \Psi_f \right\rangle\right|^2, \tag{2.5}$$

$$f_v = \frac{2\delta E}{3g_i}\left|\left\langle \Psi_i \left| \sum_{p=1}^{N} \nabla_p \right| \Psi_f \right\rangle\right|^2, \tag{2.6}$$

$$\delta E = E_f - E_i \quad \text{and} \quad g_i = (2L_i+1)(2S_i+1),$$

where g_i is the statistical weight of the (Ψ_i)lower state.For exact wave functions, identical results are obtained using (2.5) and (2.6), while for approximate wave functions the two expressions may yield various outcomes. The reliability of either depends not just on the closeness of the two qualities yet additionally on their stability as more configurations are included into (2.1). Such convergence might be all the more immediately accomplished in one type of the oscillator strength than in other.

We have taken non-relativistic Hamiltonian for optimization of orbitals. The $1s$, $2s$, $2p$, $3s$ and $3p$ orbitals are taken Hartree-Fock orbitals of Ca V from Clemmenti and Roetti [5], while $3p$ and $3s$ orbitals reoptimized on $3s^2 3p^4$ to obtainaccurate results of ground states. Similarly, $3d$ orbital to $7s$ orbital optimized on different states and the optimized parameters of the radial wavefunctions are reported in Table 1.

Table 1. Radial wave-functions parameter of Ca V

Ca orbitals	Expansion coefficients	Power of r	Exponents
3s	0.10748	1	19.37410
	0.00041	1	28.25440
	−0.35455	2	8.41156
	0.05299	2	17.04380
	0.68504	3	3.84010
	0.47718	3	2.92181
	−0.22645	3	7.47541

Contd. Table 1

Ca orbitals	Expansion coefficients	Power of *r*	Exponents
3p	−0.28779	2	8.23810
	−0.02532	2	14.70990
	0.50161	3	3.81644
	0.61835	3	2.67703
	−0.11471	3	6.70743
3d	0.99550	3	2.60894
	0.00596	3	4.61970
4s	0.07444	1	15.12083
	−0.27115	2	7.01843
	0.70269	3	3.38423
	−1.17620	4	1.86414
4p	0.18431	2	8.23308
	−0.62039	3	3.16453
	1.13689	4	1.68751
4d	0.42929	3	3.27744
	−1.01846	4	1.28981
4f	0.99796	3	1.31174
	0.00267	3	2.14659
5s	0.04436	1	15.69514
	−0.20308	2	6.32845
	0.37833	3	3.99725
	1.86086	4	1.18022
	−1.61366	5	2.11505
5p	0.00026	2	0.60000
	−1.02122	3	0.11221
	0.00142	4	1.10000
	0.08194	5	0.54542
5d	13.04284	3	0.98948
	−21.18670	4	1.33771
	8.25363	5	1.64765
5f	0.50389	4	0.78012
	1.82033	4	0.64650
	1.28633	5	1.10929
	−4.07925	5	0.82273
5g	0.99929	5	1.00174
	0.00093	5	1.57077

Contd. Table 1

Ca orbitals	Expansion coefficients	Power of r	Exponents
6s	0.03180	1	15.60825
	−0.14194	2	6.40869
	0.27245	3	3.95349
	4.37132	4	0.90591
	−1.39965	5	2.10206
	−4.06689	6	1.03684
6p	0.08355	2	26.42731
	3.85276	3	8.16738
	−4.70651	4	8.96996
	8.08007	5	3.47620
	−7.63696	6	3.90000
6d	6.13038	3	0.50948
	0.00898	3	2.57064
	0.00004	4	9.92947
	0.12826	4	5.89824
	−5.90105	5	0.67106
	−1.60050	6	2.09726
6f	0.02068	4	2.60227
	2.81005	4	0.97527
	0.01016	5	3.46074
	−4.74416	5	0.97397
	−4.74416	6	0.79993
6g	1.78684	5	0.87305
	0.27225	5	0.97854
	−2.45328	6	0.82455
7s	0.67717	1	0.17066
	−5.68319	2	0.37485
	2.78074	3	1.45357
	−1.07929	4	2.76503
	−4.96649	5	0.96321
	8.89785	6	1.02660
	−0.00375	7	74.81913

3. Results and Discussion

Table 2 lists the parameters of the optimized orbitals of Fe XI. The lowest 148 fine-structure levels of Ca V with respect to ground level are shown in Table 3, where theoretical results compared with the experimental energies which are compiled in the NIST database from reference [13, 14]. There is a decent arrangement of our tabulated results with data listed in NIST data and other accessible results. Our results concur inside 0.8% deviation from the NIST data with the exception of the level $3s^23p^4(^3P_2)$ with 2.2%, $3s^13p^5(^1P_1)$ with 2.0%,$3s^23p^3(^2P)3d(^3P_2)$ with 1.4% and $3s^23p^33d(^1P_1)$ with 1.5% deviations as appeared in the Table 3. That implies the levels of agreement with the NIST data were found to relies upon the level of mixing configurations between many levels. From this table titled "Leading percentage", we first give the rate of the premise state relating to the level's name. Next, the second-biggest rate along with related that premise state and so on. The greater part of the levels show solid blending in our calculations. For example, we found that the solid blending is available in $^3D_3$ levels of $3s^23p^3(^2P)3d$ with 58% of the $3s^23p^3(^2D)3d(^3D_3)$ level. That levels belonging to the $3s^23p^3(^4S)3d$ configurations have been introduced for the first time. This spectrum belonging to the configuration has so numerous more grounded blending. Two ^3P symmetries are belonging to the configuration, one is expected to $3s^23p^3(^4S)3d(^3D)$ (level 14-16) and other because of $3s^2$3p3(2P)3d(3D) (level 27-28). That implies ^3D symmetry (level 14-16) of $3s^23p^3(^4S)3d(^3D)$ has a solid blending in with ^3D symmetry of $3s^23p^3(^2P)3d(^3D)$ (level 27-28) i.e. it is difficult to perceive the levels. So, the spectrum belonging to $3s^23p^33d$ configuration is extremely expounded and needs further investigation.

Accurate oscillator strengths are important for determining modeling, radiation loss and Astrophysical plasmas. We have also presented the oscillator strengths in transitions of the states of Ca V as appeared in the Table 4. We introduced the oscillator strength in both the velocity and length formations. One can see that there is a nearby understanding between the length and velocity forms in the majority of our outcomes. A little difference among velocity and length forms for few transitions, can be due to possible cancellations of dipole integrals and oversight of very faraway configurations.

Table 2. Optmization (Ca)

Orbitals	Eeigenvalue minimized	Term	Configuration
3p	$3s^23p^4$	^1S	$3s^23p^4$
3p	$3s^23p^4$	^1S	$3s^23p^4$
3d	$3s^23p^33d$	^1S	$3s^23p^4$, $2p^63p^6$, $3s^23p^23d^2$, $3s3p^43d$
4s	$3s^23p^34s$	^1D	$3s^23p^34s$
4p	$3s^23p^34p$	^1S	$3s^23p^4$, $2p^63p^6$, $3s^23p^24s^2$,$3s^23p^24p^2$, $3s3p^34s4p$, $3s^23p^34p$
4d	$3s^23p^34d$	^1D	$3s^23p^33d$,$3s^23p^34d$,$3s^23p^34s$
4f	$3s^23p^34f$	^3F	$3s^23p^34f$
5s	$3s^23p^35s$	^1D	$3s^23p^34s$,$3s^23p^35s$
5p	$3s^23p^35p$	^1S	$3s^23p^4$,$2p^63p^6$,$3p^24s^2$,$3p^24p^2$,$3s3p^34s4p$,$3p^34p$,$3p^35p$
5d	$3s^23p^35d$	^1D	$3s^23p^33d$,$3s^23p^34d$,$3s^23p^34d$,$3s^23p^35d$
5f	$3s^23p^35f$	^3D	$3s^23p^34f$, $3s^23p^35f$
5g	$3s^23p^35g$	^3D	$3s^23p^35g$
6s	$3s^23p^36s$	^1D	$3s^23p^34s$,$3s^23p^35s$,$3s^23p^36s$
6p	$3s^23p^36p$	^1S	$3s^23p^4$,$2p^63p^6$,$3p^24s^2$,$3s^23p^24p^2$,$3s3p^34s4p$,$3p^34p$,$3p^35p$,$3p^36p$
6d	$3s^23p^36d$	^1D	$3s^23p^33d$,$3s^23p^34d$,$3s^23p^34s$,$3s^23p^35d$,$3s^23p^36d$
6f	$3s^23p^36f$	^3F	$3s^23p^34f$,$3s^23p^35f$,$3s^23p^36f$
6g	$3s^23p^36g$	^3D	$3s^23p^33d$, $3s^23p^35g$, $3s^23p^36g$
7s	$3s^23p^37s$	^1D	$3s^23p^34s$,$3s^23p^35s$,$3s^23p^36s$,$3s^23p^37s$

Table 3

Index	Configuration	Term	NIST(RYD)	CIV3(RYD)	Percentage
1	$3s^2(^1S)3p^4$	$^3P_2$	0.0000	0.000000	97
2	$3s^2(^1S)3p^4$	$^3P_1$	0.021913	0.021412	97
3	$3s^2(^1S)3p^4$	$^3P_0$	0.029849	0.029165	97
4	$3s^2(^1S)3p^4$	$^1D_2$	0.171549	0.172919	97
5	$3s^2(^1S)3p^4$	$^1S_0$	0.399468	0.399215	96
6	$3s^1(^2S)3p^5$	$^3P_2$	1.409464	1.401400	80
7	$3s^1(^2S)3p^5$	$^3P_1$	1.428504	1.420667	80
8	$3s^1(^2S)3p^5$	$^3P_0$	1.438895	1.430307	80
9	$3s^1(^2S)3p^5$	$^1P_1$	1.802892	1.766260	55
10	$3s^23p^3(^4S)3d^1$	$^5D_0$		2.064214	97
11	$3s^23p^3(^4S)3d^1$	$^5D_1$		2.089270	96
12	$3s^23p^3(^4S)3d^1$	$^5D_2$		2.089820	96
13	$3s^23p^3(^4S)3d^1$	$^5D_3$		2.090295	96
14	$3s^23p^3(^4S)3d^1$	$^3D_3$		2.187900	48
15	$3s^23p^3(^4S)3d^1$	$^3D_2$		2.204611	49
16	$3s^23p^3(^4S)3d^1$	$^3D_1$		2.206122	49
17	$3s^23p^3(^2D)3d^1$	$^1S_0$		2.292309	96
18	$3s^23p^3(^2D)3d^1$	$^3F_3$		2.319226	66
19	$3s^23p^3(^2D)3d^1$	$^3F_2$		2.343948	81
20	$3s^23p^3(^2D)3d^1$	$^3tt_3$		2.496952	95
21	$3s^23p^3(^2P)3d^1$	$^1D_2$		2.558217	72
22	$3s^23p^3(^2P)3d^1$	$^3D_3$		2.572205	58
23	$3s^23p^3(^2P)3d^1$	$^3F_3$		2.592395	59
24	$3s^23p^3(^2P)3d^1$	$^3P_0$		2.655123	61
25	$3s^23p^3(^2P)3d^1$	$^3P_1$		2.662644	61
26	$3s^23p^3(^2P)3d^1$	$^3P_2$	2.71753	2.680115	62
27	$3s^23p^3(^2P)3d^1$	$^3D_1$		2.681654	49
28	$3s^23p^3(^2P)3d^1$	$^3D_2$		2.692301	46
29	$3s^23p^3(^2P)3d^1$	$^3F_2$		2.700227	74
30	$3s^23p^3(^2P)3d^1$	$^1F_3$		2.710032	68
31	$3s^23p^3(^2D)3d^1$	$^1P_1$	2.75370	2.795583	55
32	$3s^23p^3(^2D)3d^1$	$^3P_2$		2.928559	50
33	$3s^23p^3(^2D)3d^1$	$^3S_1$		2.937350	50
34	$3s^23p^3(^2D)3d^1$	$^3S_1$		2.950618	44
35	$3s^23p^3(^2D)3d^1$	$^3P_0$		2.951618	49
36	$3s^23p^3(^4S)3d^1$	$^3D_3$		3.060005	44
37	$3s^23p^3(^4S)4s^1$	$^5S_2$		3.080712	96
38	$3s^23p^3(^2P)3d^1$	$^3D_2$		3.143465	40
39	$3s^23p^3(^2P)3d^1$	$^3D_1$		3.152430	40
40	$3s^23p^3(^4S)4s^1$	$^3S_1$	3.19776	3.196724	92
41	$3s^23p^3(^2D)3d^1$	$^1D_2$		3.219380	68
42	$3s^23p^3(^2D)3d^1$	$^1F_3$		3.237211	66
43	$(^1S)3p^6$	$^1S_0$		3.276070	60
44	$3s^23p^3(^2D)4s^1$	$^3D_1$	3.36800	3.368357	94
45	$3s^23p^3(^2D)4s^1$	$^3D_2$	3.36892	3.369308	94
46	$3s^23p^3(^2D)4s^1$	$^3D_3$	3.37131	3.371372	96
47	$3s^13p^4(^4P)3d^1$	$^5D_2$		3.396156	99
48	$3s^13p^4(^4P)3d^1$	$^5D_1$		3.397528	99

Contd. Table 3

Index	Configuration	Term	NIST(RYD)	CIV3(RYD)	Percentage
49	$3s^1 3p^4(^4P)3d^1$	$^5D_0$		3.398299	99
50	$3s^1 3p^4(^4P)3d^1$	$^5D_3$		3.413320	99
51	$3s^2 3p^3(^2P)3d^1$	$^1P_1$		3.415249	87
52	$3s^2 3p^3(^2D)4s^1$	$^1D_2$		3.416623	91
53	$3s^2 3p^3(^4S)4p^1$	$^5P_1$		3.474806	94
54	$3s^2 3p^3(^4S)4p^1$	$^5P_2$		3.476891	94
55	$3s^2 3p^3(^4S)4p^1$	$^5P_3$		3.480285	94
56	$3s^2 3p^3(^2P)4s^1$	$^3P_0$	3.52696	3.528670	95
57	$3s^2 3p^3(^2P)4s^1$	$^3P_1$	3.52866	3.530551	94
58	$3s^2 3p^3(^2P)4s^1$	$^3P_2$	3.53254	3.534694	93
59	$3s^2 3p^3(^4S)4p^1$	$^3P_2$		3.563750	84
60	$3s^2 3p^3(^4S)4p^1$	$^3P_1$		3.563809	84
61	$3s^2 3p^3(^4S)4p^1$	$^3P_0$		3.565041	84
62	$3s^1 3p^4(^4P)3d^1$	$^5F_3$		3.582701	98
63	$3s^1 3p^4(^4P)3d^1$	$^5F_2$		3.586451	99
64	$3s^1 3p^4(^4P)3d^1$	$^5F_1$		3.588899	99
65	$3s^2 3p^3(^2P)4s^1$	$^1P_1$		3.589926	91
66	$3s^1 3p^4(^4P)3d^1$	$^5P_1$		3.685876	98
67	$3s^1 3p^4(^4P)3d^1$	$^5P_2$		3.691614	98
68	$3s^1 3p^4(^4P)3d^1$	$^5P_3$		3.699995	98
69	$3s^2 3p^3(^2D)4p^1$	$^1P_1$		3.733524	69
70	$3s^2 3p^3(^2D)4p^1$	$^3D_2$		3.753807	87
71	$3s^2 3p^3(^2D)4p^1$	$^3D_1$		3.754678	74
72	$3s^2 3p^3(^2D)4p^1$	$^3D_3$		3.759372	88
73	$3s^2 3p^3(^2D)4p^1$	$^3F_2$		3.779657	92
74	$3s^2 3p^3(^2D)4p^1$	$^3F_3$		3.782527	90
75	$3s^2 3p^3(^2D)4p^1$	$^1F_3$		3.800042	95
76	$3s^1 3p^4(^4P)3d^1$	$^3P_0$		3.889887	38
77	$3s^2 3p^3(^2D)4p^1$	$^3P_1$		3.892515	39
78	$3s^2 3p^3(^2D)4p^1$	$^3P_2$		3.899716	68
79	$3s^2 3p^3(^2D)4p^1$	$^3P_0$		3.922390	55
80	$3s^2 3p^3(^2D)4p^1$	$^3P_1$		3.922435	40
81	$3s^1 3p^4(^4P)3d^1$	$^3F_3$		3.935224	90
82	$3s^1 3p^4(^4P)3d^1$	$^3P_2$		3.939001	47
83	$3s^1 3p^4(^4P)3d^1$	$^3F_2$		3.943910	90
84	$3s^2 3p^3(^2P)4p^1$	$^3D_2$		3.950843	77
85	$3s^2 3p^3(^2P)4p^1$	$^3D_1$		3.951830	84
86	$3s^2 3p^3(^2P)4p^1$	$^3S_1$		3.955567	88
87	$3s^2 3p^3(^2D)4p^1$	$^1D_2$		3.973633	68
88	$3s^2 3p^3(^2P)4p^1$	$^3D_3$		3.974150	76
89	$3s^1 3p^4(^4P)3d^1$	$^3D_1$		4.007282	30
90	$3s^2 3p^3(^2P)4p^1$	$^1P_1$		4.008061	56
91	$3s^1 3p^4(^2D)3d^1$	$^3D_3$		4.010113	40
92	$3s^1 3p^4(^4P)3d^1$	$^3D_2$		4.011998	42
93	$3s^2 3p^3(^2P)4p^1$	$^3P_0$		4.032693	92
94	$3s^2 3p^3(^2P)4p^1$	$^3P_1$		4.034633	89
95	$3s^2 3p^3(^2P)4p^1$	$^3P_2$		4.038219	87
96	$3s^2 3p^3(^2P)4p^1$	$^1D_2$		4.075562	73
97	$3s^1 3p^4(^2D)3d^1$	$^3tt_3$		4.095509	98
98	$3s^2 3p^3(^4S)4d^1$	$^5D_0$		4.138577	96

Contd. Table 3

Index	Configuration	Term	NIST(RYD)	CIV3(RYD)	Percentage
99	$3s^2 3p^3(^4S)4d^1$	$^5D_1$		4.163467	96
100	$3s^2 3p^3(^4S)4d^1$	$^5D_2$		4.163646	96
101	$3s^2 3p^3(^4S)4d^1$	$^5D_3$		4.163918	96
102	$3s^2 3p^3(^4S)4d^1$	$^3D_3$		4.230207	92
103	$3s^2 3p^3(^4S)4d^1$	$^3D_2$		4.230331	91
104	$3s^2 3p^3(^4S)4d^1$	$^3D_1$		4.230545	91
105	$3s^2 3p^3(^2P)4p^1$	$^1S_0$		4.256207	95
106	$3s^1 3p^4(^2D)3d^1$	$^3F_2$		4.294934	92
107	$3s^1 3p^4(^2D)3d^1$	$^3F_3$		4.296887	92
108	$3s^1 3p^4(^2D)3d^1$	$^1P_1$		4.412172	72
109	$3s^2 3p^3(^2D)4d^1$	$^3F_2$		4.439248	92
110	$3s^2 3p^3(^2D)4d^1$	$^3F_3$		4.442008	91
111	$3s^2 3p^3(^2D)4d^1$	$^1S_0$		4.444921	96
112	$3s^2 3p^3(^2D)4d^1$	$^3tt_3$		4.457678	94
113	$3s^1 3p^4(^2D)3d^1$	$^1D_2$		4.462769	69
114	$3s^2 3p^3(^2D)4d^1$	$^1P_1$		4.467917	51
115	$3s^2 3p^3(^2D)4d^1$	$^3D_3$		4.468974	91
116	$3s^2 3p^3(^2D)4d^1$	$^3D_2$		4.470672	91
117	$3s^2 3p^3(^2D)4d^1$	$^3D_1$		4.473820	55
118	$3s^2 3p^3(^2D)4d^1$	$^3P_2$		4.482864	89
119	$3s^2 3p^3(^2D)4d^1$	$^3P_1$		4.489023	86
120	$3s^2 3p^3(^2D)4d^1$	$^3P_0$		4.489893	93
121	$3s^1 3p^4(^2P)3d^1$	$^3D_3$		4.492264	50
122	$3s^2 3p^3(^2D)4d^1$	$^3S_1$		4.500353	91
123	$3s^2 3p^3(^2D)4d^1$	$^1D_2$		4.511250	86
124	$3s^1 3p^4(^4P)4s^1$	$^5P_3$		4.531537	89
125	$3s^2 3p^3(^2D)4d^1$	$^1F_3$		4.541135	94
126	$3s^2 3p^3(^2P)4d^1$	$^3P_0$		4.649539	93
127	$3s^2 3p^3(^2P)4d^1$	$^3F_3$		4.673150	90
128	$3s^2 3p^3(^2P)4d^1$	$^3F_2$		4.673660	89
129	$3s^2 3p^3(^2P)4d^1$	$^3P_1$		4.676102	92
130	$3s^2 3p^3(^2P)4d^1$	$^3P_2$		4.682080	89
131	$3s^2 3p^3(^2P)4d^1$	$^3D_2$		4.687166	63
132	$3s^2 3p^3(^2P)4d^1$	$^3D_1$		4.688352	94
133	$3s^2 3p^3(^2P)4d^1$	$^3D_3$		4.692685	90
134	$3s^2 3p^3(^2P)4d^1$	$^1D_2$		4.696321	55
135	$3s^2 3p^3(^2P)4d^1$	$^1F_3$		4.709614	94
136	$3s^2 3p^3(^2P)4d^1$	$^1P_1$		4.772934	89
137	$3s^1 3p^4(^4P)4p^1$	$^5P_3$		4.959976	88
138	$3s^1 3p^4(^4P)4p^1$	$^5P_2$		4.963666	87
139	$3s^1 3p^4(^4P)4p^1$	$^5P_1$		4.968599	89
140	$3s^1 3p^4(^4P)4p^1$	$^5D_0$		5.000456	88
141	$3s^1 3p^4(^4P)4p^1$	$^5D_3$		5.016514	86
142	$3s^1 3p^4(^4P)4p^1$	$^5D_2$		5.021153	87
143	$3s^1 3p^4(^4P)4p^1$	$^3D_3$		5.083698	87
144	$3s^1 3p^4(^4P)4p^1$	$^5S_2$		5.092274	84
145	$3s^1 3p^4(^4P)4p^1$	$^3D_2$		5.095331	79
146	$3s^1 3p^4(^4P)4p^1$	$^3P_2$		5.113334	67
147	$3s^1 3p^4(^2D)4p^1$	$^3F_3$		5.377104	78
148	$3s^1 3p^4(^2D)4p^1$	$^1F_3$		5.424084	77

Table 4. Energy levels of Ca V related to the ground state

LowerConf.	Terms	UpperConf.	Terms	wavelength	f_L	f_v	f_L/f_v
$3s^2(^1S)3p^4$	$^3P_2$	$3s^23p^3(^2D)4s^1$	$^3D_1$	5.2132239	$0.58696D-03$	$0.61579D-03$	0.95
$3s^2(^1S)3p^4$	$^3P_2$	$3s^23p^3(^2P)4s^1$	$^3P_1$	4.9737274	$0.71041D-02$	$0.72466D-02$	0.98
$3s^2(^1S)3p^4$	$^1D_2$	$3s^23p^3(^2P)3d^1$	$^3P_1$	7.0529882	$0.20289D-02$	$0.21258D-02$	0.95
$3s^2(^1S)3p^4$	$^1D_2$	$3s^23p^3(^2D)3d^1$	$^1P_1$	6.6954812	$0.65371D+00$	$0.62870D+00$	1.04
$3s^23p^3(^4S)4p^1$	$^3P_2$	$3s^23p^3(^4S)4d^1$	$^3D_1$	26.3349094	$0.88919D-02$	$0.92663D-02$	0.96
$3s^23p^3(^4S)4p^1$	$^3P_2$	$3s^23p^3(^2D)4d^1$	$^3S_1$	18.7485926	$0.13546D-01$	$0.13618D-01$	0.99
$3s^13p^4(^4P)3d^1$	$^5P_2$	$3s^23p^3(^2P)4d^1$	$^3D_1$	17.6174763	$0.21722D-06$	$0.20863D-06$	1.04
$3s^23p^3(^4S)4s^1$	$^3S_1$	$3s^23p^3(^2D)4p^1$	$^3D_2$	31.5213698	$0.10307D-03$	$0.10509D-03$	0.98
$3s^23p^3(^2D)4p^1$	$^3D_2$	$3s^23p^3(^2P)4d^1$	$^3P_1$	19.0394514	$0.50320D-02$	$0.48260D-02$	1.04
$3s^1(^2S)3p^5$	$^1P_1$	$3s^23p^3(^2D)4p^1$	$^3F_2$	8.7215789	$0.18275D-04$	$0.18851D-04$	0.97
$3s^23p^3(^2D)4s^1$	$^3D_1$	$3s^23p^3(^2D)4p^1$	$^3F_2$	42.6939135	$0.39625D+00$	$0.38914D+00$	1.02
$3s^23p^3(^2D)4p^1$	$^3F_2$	$3s^23p^3(^2D)4d^1$	$^3S_1$	24.3653235	$0.76467D-04$	$0.77148D-04$	0.99
$3s^23p^3(^2D)4p^1$	$^3F_2$	$3s^23p^3(^2P)4d^1$	$^3P_1$	19.5884825	$0.16949D-03$	$0.16179D-03$	1.05
$3s^23p^3(^2D)4p^1$	$^3P_2$	$3s^23p^3(^2P)4d^1$	$^3P_1$	22.6176214	$0.18667D-02$	$0.18232D-02$	1.02
$3s^23p^3(^2P)4s^1$	$^3P_1$	$3s^23p^3(^2P)4p^1$	$^3D_2$	41.7805218	$0.26390D+00$	$0.25335D+00$	1.04
$3s^23p^3(^2P)4p^1$	$^3D_2$	$3s^23p^3(^2P)4d^1$	$^3P_1$	24.2120315	$0.34166D-02$	$0.33901D-02$	1.01
$3s^23p^3(^2P)4p^1$	$^3P_2$	$3s^23p^3(^2P)4d^1$	$^3P_1$	27.5285775	$0.62722D-01$	$0.60831D-01$	1.03
$3s^23p^3(^2D)3d^1$	$^1P_1$	$3s^23p^3(^2P)4p^1$	$^1D_2$	13.7189825	$0.18615D-01$	$0.18714D-01$	0.99
$3s^23p^3(^2P)4s^1$	$^3P_1$	$3s^13p^4(^2D)3d^1$	$^3F_2$	22.9727817	$0.19455D-04$	$0.19258D-04$	1.01
$3s^1(^2S)3p^5$	$^3P_1$	$3s^13p^4(^2D)3d^1$	$^1D_2$	5.7723243	$0.80010D-02$	$0.83329D-02$	0.96
$3s^13p^4(^2D)3d^1$	$^1D_2$	$3s^13p^4(^4P)4p^1$	$^5P_1$	34.7152125	$0.21843D-06$	$0.22258D-06$	0.98
$3s^2(^1S)3p^4$	$^3P_2$	$3s^23p^3(^2D)3d^1$	$^3F_2$	7.4916349	$0.14219D-04$	$0.13905D-04$	1.02
$3s^2(^1S)3p^4$	$^3P_2$	$3s^23p^3(^2P)4s^1$	$^3P_2$	4.9678974	$0.22149D-01$	$0.23125D-01$	0.96
$3s^2(^1S)3p^4$	$^3P_2$	$3s^13p^4(^4P)4p^1$	$^5P_2$	3.5377074	$0.23656D-04$	$0.24078D-04$	0.98
$3s^2(^1S)3p^4$	$^1D_2$	$3s^23p^3(^2P)3d^1$	$^3D_2$	6.9699630	$0.60096D-04$	$0.59552D-04$	1.01
$3s^23p^3(^4S)4p^1$	$^5P_2$	$3s^23p^3(^2D)4d^1$	$^3D_2$	17.6698865	$0.86178D-05$	$0.90571D-05$	0.95
$3s^23p^3(^4S)4p^1$	$^5P_2$	$3s^13p^4(^4P)4p^1$	$^5D_2$	11.3711298	$0.24299D-01$	$0.23509D-01$	1.03
$3s^23p^3(^4S)4p^1$	$^3P_2$	$3s^23p^3(^4S)4d^1$	$^3D_2$	26.3433506	$0.13355D+00$	$0.13938D+00$	0.96
$3s^23p^3(^4S)4p^1$	$^3P_2$	$3s^13p^4(^4P)4p^1$	$^3P_2$	11.3320738	$0.25065D-01$	$0.24311D-01$	1.03
$3s^1(^2S)3p^5$	$^3P_2$	$3s^13p^4(^4P)3d^1$	$^5P_2$	7.6674039	$0.65739D-05$	$0.68177D-05$	0.96
$3s^13p^4(^4P)3d^1$	$^5P_2$	$3s^23p^3(^2P)4d^1$	$^3D_2$	17.6384597	$0.77829D-06$	$0.76830D-06$	1.01
$3s^23p^3(^2D)4p^1$	$^3D_2$	$3s^23p^3(^4S)4d^1$	$^5D_2$	42.8460063	$0.10794D-04$	$0.10456D-04$	1.03
$3s^23p^3(^4S)4s^1$	$^5S_2$	$3s^23p^3(^2D)4p^1$	$^3F_2$	25.1235759	$0.13204D-06$	$0.13356D-06$	0.99
$3s^23p^3(^2D)4p^1$	$^3F_2$	$3s^23p^3(^2D)4d^1$	$^3P_2$	24.9712881	$0.24770D-03$	$0.25130D-03$	0.99
$3s^23p^3(^2D)4p^1$	$^3F_2$	$3s^23p^3(^2D)4d^1$	$^1D_2$	24.0024140	$0.22179D-03$	$0.22465D-03$	0.99
$3s^23p^3(^2D)4p^1$	$^3F_2$	$3s^23p^3(^2P)4d^1$	$^3F_2$	19.6419947	$0.54423D-02$	$0.52306D-02$	1.04
$3s^23p^3(^2D)4p^1$	$^3F_2$	$3s^23p^3(^2P)4d^1$	$^3P_2$	19.4587112	$0.13221D-03$	$0.12838D-03$	1.03
$3s^23p^3(^2D)4p^1$	$^3F_2$	$3s^23p^3(^2P)4d^1$	$^3D_2$	19.3496666	$0.38185D-03$	$0.39589D-03$	0.96
$3s^23p^3(^2D)4p^1$	$^3P_2$	$3s^23p^3(^2D)4d^1$	$^1D_2$	28.7146874	$0.76361D-03$	$0.76347D-03$	1.00
$3s^23p^3(^2D)4p^1$	$^3P_2$	$3s^23p^3(^2P)4d^1$	$^3P_2$	22.4447886	$0.43532D-02$	$0.44667D-02$	0.97
$3s^13p^4(^4P)3d^1$	$^3F_2$	$3s^23p^3(^2P)4d^1$	$^3P_2$	23.7885285	$0.14778D-04$	$0.15352D-04$	0.96
$3s^23p^3(^2P)4s^1$	$^3P_2$	$3s^23p^3(^2P)4p^1$	$^3D_2$	42.1964960	$0.50659D-01$	$0.50318D-01$	1.01
$3s^23p^3(^4S)3d^1$	$^5D_2$	$3s^23p^3(^2D)4p^1$	$^1D_2$	9.3215216	$0.23616D-06$	$0.24382D-06$	0.97
$3s^23p^3(^2P)4s^1$	$^3P_2$	$3s^23p^3(^2D)4p^1$	$^1D_2$	40.0056363	$0.25977D-02$	$0.26224D-02$	0.99
$3s^23p^3(^2D)4p^1$	$^1D_2$	$3s^13p^4(^4P)4p^1$	$^3D_2$	15.6548352	$0.69390D-03$	$0.71268D-03$	0.97
$3s^13p^4(^4P)3d^1$	$^3D_2$	$3s^23p^3(^2P)4d^1$	$^3D_2$	26.0083406	$0.58496D-02$	$0.58441D-02$	1.00
$3s^13p^4(^4P)3d^1$	$^3D_2$	$3s^23p^3(^2P)4d^1$	$^1D_2$	25.6603996	$0.39750D-02$	$0.39279D-02$	1.01

Contd. Table 4

LowerConf.	Terms	UpperConf.	Terms	wavelength	f_L	f_v	$\frac{fL}{fv}$
$3s^23p^3(^2P)4p^1$	$^3P_2$	$3s^23p^3(^2P)4d^1$	$^3P_2$	27.2729663	0.16957D+00	0.16356D+00	1.04
$3s^23p^3(^2P)4p^1$	$^3P_2$	$3s^23p^3(^2P)4d^1$	$^3D_2$	27.0592368	0.10068D+00	0.95895D − 01	1.05
$3s^23p^3(^2P)4p^1$	$^3P_2$	$3s^23p^3(^2P)4d^1$	$^1D_2$	26.6828133	0.29919D − 01	0.28851D − 01	1.04
$3s^23p^3(^4S)3d^1$	$^5D_2$	$3s^23p^3(^2P)4p^1$	$^1D_2$	8.8430431	0.76208D − 08	0.78899D − 08	0.97
$3s^1(^2S)3p^5$	$^3P_2$	$3s^13p^4(^2D)3d^1$	$^1D_2$	5.7359960	0.18746D − 02	0.19033D − 02	0.98
$3s^23p^3(^4S)3d^1$	$^5D_2$	$3s^13p^4(^2D)3d^1$	$^1D_2$	7.4000759	0.60492D − 05	0.58015D − 05	1.04
$3s^13p^4(^2D)3d^1$	$^1D_2$	$3s^13p^4(^4P)4p^1$	$^3P_2$	26.9919247	0.69344D − 04	0.69833D − 04	0.99
$3s^2(^1S)3p^4$	$^3P_2$	$3s^13p^4(^4P)4p^1$	$^5D_3$	3.5004389	0.17714D − 03	0.17458D − 03	1.01
$3s^2(^1S)3p^4$	$^1D_2$	$3s^13p^4(^4P)4p^1$	$^5D_3$	3.6254066	0.35870D − 06	0.34715D − 06	1.03
$3s^23p^3(^4S)4p^1$	$^5P_2$	$3s^13p^4(^4P)4p^1$	$^5D_3$	11.4053917	0.26186D − 01	0.25902D − 01	1.01
$3s^23p^3(^2P)3d^1$	$^3D_3$	$3s^23p^3(^4S)4p^1$	$^3P_2$	17.7097398	0.34573D − 03	0.33193D − 03	1.04
$3s^23p^3(^4S)4p^1$	$^3P_2$	$3s^23p^3(^4S)4d^1$	$^3D_3$	26.3482568	0.75384D+00	0.78516D+00	0.96
$3s^23p^3(^4S)4p^1$	$^3P_2$	$3s^13p^4(^2D)4p^1$	$^1F_3$	9.4391654	0.56769D − 04	0.56582D − 04	1.00
$3s^23p^3(^4S)3d^1$	$^3D_3$	$3s^13p^4(^4P)3d^1$	$^5P_2$	11.6777509	0.53627D − 04	0.51756D − 04	1.04
$3s^13p^4(^4P)3d^1$	$^5P_2$	$3s^13p^4(^2D)4p^1$	$^3F_3$	10.4183393	0.97090D − 06	0.10114D − 05	0.96
$3s^23p^3(^2D)4p^1$	$^3D_2$	$3s^23p^3(^2D)4d^1$	$^3D_3$	24.5537019	0.29004D − 01	0.28148D − 01	1.03
$3s^23p^3(^2D)4p^1$	$^3D_2$	$3s^13p^4(^2D)4p^1$	$^3F_3$	10.8174900	0.10046D − 01	0.10176D − 01	0.99
$3s^23p^3(^2D)4p^1$	$^3D_2$	$3s^13p^4(^2D)4p^1$	$^1F_3$	10.5132260	0.29836D − 03	0.29634D − 03	1.01
$3s^23p^3(^2D)4p^1$	$^3F_2$	$3s^23p^3(^4S)4d^1$	$^3D_3$	38.9745451	0.44764D − 04	0.43508D − 04	1.03
$3s^23p^3(^2D)4p^1$	$^3F_2$	$3s^23p^3(^2P)4d^1$	$^3D_3$	19.2326988	0.17254D − 03	0.17552D − 03	0.98
$3s^23p^3(^2D)4p^1$	$^3F_2$	$3s^13p^4(^2D)4p^1$	$^3F_3$	10.9925417	0.86670D − 02	0.86075D − 02	1.01
$3s^23p^3(^2D)4p^1$	$^3P_2$	$3s^23p^3(^2P)4d^1$	$^3F_3$	22.7039599	0.37607D − 03	0.39419D − 03	0.95
$3s^13p^4(^4P)3d^1$	$^3F_2$	$3s^23p^3(^2D)4d^1$	$^3tt_3$	34.1788246	0.76372D − 02	0.73431D − 02	1.04
$3s^13p^4(^4P)3d^1$	$^3F_2$	$3s^23p^3(^2P)4d^1$	$^3F_3$	24.0798626	0.25985D − 02	0.25375D − 02	1.02
$3s^23p^3(^4S)3d^1$	$^5D_3$	$3s^23p^3(^2P)4p^1$	$^3D_2$	9.4380816	0.10185D − 04	0.10062D − 04	1.01
$3s^23p^3(^4S)3d^1$	$^3D_3$	$3s^23p^3(^2P)4p^1$	$^3D_2$	9.9606186	0.22896D − 03	0.23308D − 03	0.98
$3s^23p^3(^2D)4s^1$	$^3D_3$	$3s^23p^3(^2P)4p^1$	$^3D_2$	30.3035113	0.22493D − 02	0.22378D − 02	1.01
$3s^23p^3(^2P)4p^1$	$^3D_2$	$3s^13p^4(^2D)4p^1$	$^3F_3$	12.3119133	0.10283D − 01	0.10399D − 01	0.99
$3s^23p^3(^2D)3d^1$	$^3tt_3$	$3s^13p^4(^4P)3d^1$	$^3D_2$	11.5904055	0.70347D − 04	0.71170D − 04	0.99
$3s^23p^3(^2P)4p^1$	$^3P_2$	$3s^23p^3(^2P)4d^1$	$^3F_3$	27.6565859	0.94822D − 02	0.94192D − 02	1.01
$3s^23p^3(^2P)4p^1$	$^3P_2$	$3s^23p^3(^2P)4d^1$	$^3D_3$	26.8310420	0.56871D+00	0.54221D+00	1.05
$3s^23p^3(^4S)3d^1$	$^5D_3$	$3s^23p^3(^2P)4p^1$	$^1D_2$	8.8451596	0.18162D − 06	0.17940D − 06	1.01
$3s^23p^3(^2D)3d^1$	$^3F_3$	$3s^13p^4(^2D)3d^1$	$^3F_2$	8.8879537	0.16488D − 02	0.16796D − 02	0.98
$3s^23p^3(^2D)3d^1$	$^3tt_3$	$3s^13p^4(^2D)3d^1$	$^3F_2$	9.7665036	0.46224D − 01	0.44248D − 01	1.04
$3s^13p^4(^2D)3d^1$	$^3F_2$	$3s^23p^3(^2D)4d^1$	$^3F_3$	119.3959011	0.21157D − 03	0.20156D − 03	1.05
$3s^23p^3(^2D)3d^1$	$^3F_3$	$3s^13p^4(^2D)3d^1$	$^1D_2$	8.1920467	0.10565D − 01	0.10769D − 01	0.98
$3s^2(^1S)3p^4$	$^3P_1$	$3s^23p^3(^2P)4s^1$	$^3P_0$	5.0067607	0.11500D − 01	0.11979D − 01	0.96
$3s^23p^3(^4S)4p^1$	$^5P_1$	$3s^13p^4(^4P)4p^1$	$^5D_0$	11.5098471	0.12259D − 01	0.12120D − 01	1.01
$3s^23p^3(^2D)4p^1$	$^1P_1$	$3s^23p^3(^2P)4d^1$	$^3P_0$	19.1699898	0.48052D − 03	0.48948D − 03	0.98
$3s^23p^3(^2D)4p^1$	$^3D_1$	$3s^23p^3(^2P)4d^1$	$^3P_0$	19.6231458	0.37416D − 02	0.36501D − 02	1.03
$3s^23p^3(^2D)3d^1$	$^3P_0$	$3s^23p^3(^2D)4p^1$	$^3P_1$	18.0878520	0.17853D − 02	0.17035D − 02	1.05
$3s^23p^3(^2P)4s^1$	$^3P_0$	$3s^23p^3(^2P)4p^1$	$^3D_1$	41.4973392	0.40422D+00	0.39096D+00	1.03
$3s^23p^3(^2P)4p^1$	$^3D_1$	$3s^23p^3(^2D)4d^1$	$^3P_0$	32.6355707	0.51980D−02	0.50917D−02	1.02
$3s^23p^3(^2P)4p^1$	$^3P_1$	$3s^23p^3(^2P)4d^1$	$^3P_0$	28.5571864	0.70245D−01	0.73317D−01	0.96
$3s^2(^1S)3p^4$	$^3P_1$	$3s^1(^2S)3p^5$	$^1P_1$	10.0639161	0.17794D−04	0.17270D−04	1.03
$3s^2(^1S)3p^4$	$^3P_1$	$3s^23p^3(^2D)3d^1$	$^1P_1$	6.3298186	0.18071D−02	0.17429D−02	1.04

Contd. Table 4

LowerConf.	Terms	UpperConf.	Terms	wavelength	f_L	f_v	$\frac{f_L}{f_V}$
$3s^23p^3(^4S)4p^1$	$^3P_1$	$3s^23p^3(^4S)4d^1$	$^3D_1$	26.3372624	0.22387D+00	0.23425D+00	0.96
$3s^13p^4(^4P)3d^1$	$^5P_1$	$3s^23p^3(^2P)4d^1$	$^3D_1$	17.5166283	0.33707D − 06	0.33824D − 06	1.00
$3s^23p^3(^4S)4s^1$	$^3S_1$	$3s^23p^3(^2D)4p^1$	$^1P_1$	32.7123531	0.19960D − 03	0.19636D − 03	1.02
$3s^23p^3(^2D)4p^1$	$^3D_1$	$3s^23p^3(^2D)4d^1$	$^1P_1$	24.6200859	0.11542D − 01	0.11404D − 01	1.01
$3s^23p^3(^2P)4s^1$	$^3P_1$	$3s^23p^3(^2P)4p^1$	$^3D_1$	41.6826439	0.97575D − 01	0.95738D − 01	1.02
$3s^23p^3(^2P)4p^1$	$^3D_1$	$3s^23p^3(^2D)4d^1$	$^3P_1$	32.6884399	0.28776D − 02	0.27664D − 02	1.04
$3s^23p^3(^2P)4p^1$	$^3D_1$	$3s^23p^3(^2P)4d^1$	$^1P_1$	21.3858392	0.16584D − 02	0.16122D − 02	1.03
$3s^23p^3(^2P)4s^1$	$^1P_1$	$3s^23p^3(^2P)4p^1$	$^3S_1$	48.0252550	0.46535D − 03	0.46435D − 03	1.00
$3s^23p^3(^2P)4p^1$	$^3S_1$	$3s^23p^3(^2D)4d^1$	$^3P_1$	32.9174531	0.21769D − 01	0.21014D − 01	1.04
$3s^1(^2S)3p^5$	$^1P_1$	$3s^13p^4(^4P)3d^1$	$^3D_1$	7.8357090	0.11784D − 02	0.12102D − 02	0.97
$3s^13p^4(^4P)3d^1$	$^3D_1$	$3s^23p^3(^2P)4d^1$	$^3D_1$	25.7829838	0.10679D − 01	0.11070D − 01	0.96
$3s^13p^4(^4P)3d^1$	$^3D_1$	$3s^23p^3(^2P)4d^1$	$^1P_1$	22.9347222	0.76316D − 01	0.78348D − 01	0.97
$3s^23p^3(^2P)4p^1$	$^1P_1$	$3s^23p^3(^2P)4d^1$	$^1P_1$	22.9580790	0.17505D+00	0.18015D+00	0.97
$3s^23p^3(^2P)4p^1$	$^3P_1$	$3s^23p^3(^2P)4d^1$	$^3P_1$	27.3746656	0.42497D − 01	0.40840D − 01	1.04
$3s^23p^3(^2P)4p^1$	$^3P_1$	$3s^23p^3(^2P)4d^1$	$^3D_1$	26.8617021	0.18487D+00	0.17909D+00	1.03
$3s^23p^3(^2P)4p^1$	$^3P_1$	$3s^23p^3(^2P)4d^1$	$^1P_1$	23.7843447	0.95684D − 02	0.98452D − 02	0.97
$3s^23p^3(^2P)3d^1$	$^3D_1$	$3s^13p^4(^2D)3d^1$	$^1P_1$	10.1472531	0.94032D − 04	0.95589D − 04	0.98
$3s^23p^3(^4S)4p^1$	$^5P_1$	$3s^13p^4(^4P)4p^1$	$^5D_2$	11.3557975	0.14190D − 01	0.13840D − 01	1.03
$3s^23p^3(^4S)4p^1$	$^5P_1$	$3s^13p^4(^4P)4p^1$	$^3P_2$	10.7169389	0.13931D − 03	0.13998D − 03	1.00
$3s^23p^3(^4S)4p^1$	$^3P_1$	$3s^23p^3(^4S)4d^1$	$^3D_2$	26.3457052	0.67676D+00	0.70580D+00	0.96
$3s^23p^3(^2D)4s^1$	$^1D_2$	$3s^13p^4(^4P)3d^1$	$^5P_1$	65.2174745	0.71099D − 07	0.69677D − 07	1.02
$3s^13p^4(^4P)3d^1$	$^5P_1$	$3s^23p^3(^2P)4d^1$	$^3D_2$	17.5373720	0.12080D − 06	0.11758D − 06	1.03
$3s^23p^3(^2D)4p^1$	$^1P_1$	$3s^13p^4(^4P)4p^1$	$^5S_2$	12.9236456	0.23660D − 05	0.24751D − 05	0.96
$3s^23p^3(^2D)4p^1$	$^3D_1$	$3s^23p^3(^2P)4d^1$	$^3P_2$	18.9346036	0.34477D − 03	0.35547D − 03	0.97
$3s^23p^3(^2D)4p^1$	$^3P_1$	$3s^13p^4(^4P)4p^1$	$^3P_2$	14.3837879	0.23587D − 01	0.24804D − 01	0.95
$3s^23p^3(^2D)4p^1$	$^3P_1$	$3s^23p^3(^2D)4d^1$	$^1D_2$	29.8226324	0.96346D − 04	0.10140D − 03	0.95
$3s^23p^3(^2P)4s^1$	$^3P_2$	$3s^23p^3(^2P)4p^1$	$^3D_1$	42.0966617	0.36566D − 02	0.36361D − 02	1.01
$3s^23p^3(^2P)4p^1$	$^3D_1$	$3s^23p^3(^2P)4d^1$	$^3P_2$	24.0465335	0.15847D − 03	0.16451D − 03	0.96
$3s^23p^3(^2P)4p^1$	$^3S_1$	$3s^23p^3(^2P)4d^1$	$^3D_2$	24.0022192	0.62994D − 02	0.65351D − 02	0.96
$3s^23p^3(^2P)4p^1$	$^3S_1$	$3s^23p^3(^2P)4d^1$	$^1D_2$	23.7055780	0.13605D − 02	0.14181D − 02	0.96
$3s^23p^3(^2D)3d^1$	$^3F_2$	$3s^13p^4(^4P)3d^1$	$^3D_1$	10.5571041	0.18224D − 01	0.18245D − 01	1.00
$3s^23p^3(^2P)4p^1$	$^1P_1$	$3s^23p^3(^2P)4d^1$	$^3P_2$	26.0526758	0.34467D − 02	0.33552D − 02	1.03
$3s^23p^3(^2P)4p^1$	$^3P_1$	$3s^23p^3(^2P)4d^1$	$^3F_2$	27.4792869	0.61096D − 02	0.62239D − 02	0.98
$3s^23p^3(^2P)4p^1$	$^3P_1$	$3s^23p^3(^2P)4d^1$	$^3P_2$	27.1218915	0.15927D+00	0.15255D+00	1.04
$3s^23p^3(^2P)4p^1$	$^3P_1$	$3s^23p^3(^2P)4d^1$	$^3D_2$	26.9105141	0.24902D+00	0.24472D+00	1.02
$3s^23p^3(^2P)4p^1$	$^3P_1$	$3s^23p^3(^2P)4d^1$	$^1D_2$	26.5381886	0.25228D+00	0.24311D+00	1.04
$3s^23p^3(^2P)4p^1$	$^3P_1$	$3s^13p^4(^4P)4p^1$	$^5D_2$	17.7999484	0.41240D − 04	0.41185D − 04	1.00
$3s^23p^3(^4S)4p^1$	$^5P_3$	$3s^23p^3(^2D)4d^1$	$^3P_2$	17.5148240	0.37314D − 05	0.36441D − 05	1.02
$3s^23p^3(^4S)4p^1$	$^5P_3$	$3s^23p^3(^2P)4d^1$	$^3D_2$	14.5499035	0.29376D − 06	0.28437D − 06	1.03
$3s^23p^3(^4S)4p^1$	$^5P_3$	$3s^13p^4(^4P)4p^1$	$^5D_2$	11.3961777	0.32005D − 02	0.30724D − 02	1.04
$3s^23p^3(^2D)4s^1$	$^3D_2$	$3s^13p^4(^4P)3d^1$	$^5P_3$	53.1015845	0.83491D − 07	0.80037D − 07	1.04
$3s^13p^4(^4P)3d^1$	$^5P_3$	$3s^23p^3(^2P)4d^1$	$^3D_2$	17.7882040	0.28690D − 06	0.27823D − 06	1.03
$3s^23p^3(^2D)4p^1$	$^3D_3$	$3s^23p^3(^2P)4d^1$	$^3P_2$	19.0309207	0.68163D − 02	0.65549D − 02	1.04
$3s^23p^3(^2D)4p^1$	$^3D_3$	$3s^13p^4(^4P)4p^1$	$^5S_2$	13.1742560	0.68444D − 04	0.65901D − 04	1.04
$3s^23p^3(^2D)4s^1$	$^3D_2$	$3s^23p^3(^2D)4p^1$	$^3F_3$	42.4956359	0.34283D+00	0.33363D+00	1.03
$3s^23p^3(^2D)4p^1$	$^3F_3$	$3s^23p^3(^2D)4d^1$	$^3P_2$	25.0736245	0.24986D−02	0.24099D−02	1.04

Contd. Table 4

LowerConf.	Terms	UpperConf.	Terms	wavelength	f_L	f_v	$\frac{f_L}{f_v}$
$3s^23p^3(^4S)4p^1$	$^3P_1$	$3s^23p^3(^4S)4d^1$	$^3D_1$	26.3372624	0.22387D+00	0.23425D+00	0.96
$3s^13p^4(^4P)3d^1$	$^5P_1$	$3s^23p^3(^2P)4d^1$	$^3D_1$	17.5166283	0.33707D − 06	0.33824D − 06	1.00
$3s^23p^3(^4S)4s^1$	$^3S_1$	$3s^23p^3(^2D)4p^1$	$^1P_1$	32.7123531	0.19960D − 03	0.19636D − 03	1.02
$3s^23p^3(^2D)4p^1$	$^3D_1$	$3s^23p^3(^2D)4d^1$	$^1P_1$	24.6200859	0.11542D − 01	0.11404D − 01	1.01
$3s^23p^3(^2P)4s^1$	$^3P_1$	$3s^23p^3(^2P)4p^1$	$^3D_1$	41.6826439	0.97575D − 01	0.95738D − 01	1.02
$3s^23p^3(^2P)4p^1$	$^3D_1$	$3s^23p^3(^2D)4d^1$	$^3P_1$	32.6884399	0.28776D − 02	0.27664D − 02	1.04
$3s^23p^3(^2P)4p^1$	$^3D_1$	$3s^23p^3(^2P)4d^1$	$^1P_1$	21.3858392	0.16584D − 02	0.16122D − 02	1.03
$3s^23p^3(^2P)4s^1$	$^1P_1$	$3s^23p^3(^2P)4p^1$	$^3S_1$	48.0252550	0.46535D − 03	0.46435D − 03	1.00
$3s^23p^3(^2P)4p^1$	$^3S_1$	$3s^23p^3(^2D)4d^1$	$^3P_1$	32.9174531	0.21769D − 01	0.21014D − 01	1.04
$3s^1(^2S)3p^5$	$^1P_1$	$3s^13p^4(^4P)3d^1$	$^3D_1$	7.8357090	0.11784D − 02	0.12102D − 02	0.97
$3s^13p^4(^4P)3d^1$	$^3D_1$	$3s^23p^3(^2P)4d^1$	$^3D_1$	25.7829838	0.10679D − 01	0.11070D − 01	0.96
$3s^13p^4(^4P)3d^1$	$^3D_1$	$3s^23p^3(^2P)4d^1$	$^1P_1$	22.9347222	0.76316D − 01	0.78348D − 01	0.97
$3s^23p^3(^2P)4p^1$	$^1P_1$	$3s^23p^3(^2P)4d^1$	$^1P_1$	22.9580790	0.17505D+00	0.18015D+00	0.97
$3s^23p^3(^2P)4p^1$	$^3P_1$	$3s^23p^3(^2P)4d^1$	$^3P_1$	27.3746656	0.42497D − 01	0.40840D − 01	1.04
$3s^23p^3(^2P)4p^1$	$^3P_1$	$3s^23p^3(^2P)4d^1$	$^3D_1$	26.8617021	0.18487D+00	0.17909D+00	1.03
$3s^23p^3(^2P)4p^1$	$^3P_1$	$3s^23p^3(^2P)4d^1$	$^1P_1$	23.7843447	0.95684D − 02	0.98452D − 02	0.97
$3s^23p^3(^2P)3d^1$	$^3D_1$	$3s^13p^4(^2D)3d^1$	$^1P_1$	10.1472531	0.94032D − 04	0.95589D − 04	0.98
$3s^23p^3(^4S)4p^1$	$^5P_1$	$3s^13p^4(^4P)4p^1$	$^5D_2$	11.3557975	0.14190D − 01	0.13840D − 01	1.03
$3s^23p^3(^4S)4p^1$	$^5P_1$	$3s^13p^4(^4P)4p^1$	$^3P_2$	10.7169389	0.13931D − 03	0.13998D − 03	1.00
$3s^23p^3(^4S)4p^1$	$^3P_1$	$3s^23p^3(^4S)4d^1$	$^3D_2$	26.3457052	0.67676D+00	0.70580D+00	0.96
$3s^23p^3(^2D)4s^1$	$^1D_2$	$3s^13p^4(^4P)3d^1$	$^5P_1$	65.2174745	0.71099D − 07	0.69677D − 07	1.02
$3s^13p^4(^4P)3d^1$	$^5P_1$	$3s^23p^3(^2P)4d^1$	$^3D_2$	17.5373720	0.12080D − 06	0.11758D − 06	1.03
$3s^23p^3(^2D)4p^1$	$^1P_1$	$3s^13p^4(^4P)4p^1$	$^5S_2$	12.9236456	0.23660D − 05	0.24751D − 05	0.96
$3s^23p^3(^2D)4p^1$	$^3D_1$	$3s^23p^3(^2P)4d^1$	$^3P_2$	18.9346036	0.34477D − 03	0.35547D − 03	0.97
$3s^23p^3(^2D)4p^1$	$^3P_1$	$3s^13p^4(^4P)4p^1$	$^3P_2$	14.3837879	0.23587D − 01	0.24804D − 01	0.95
$3s^23p^3(^2D)4p^1$	$^3P_1$	$3s^23p^3(^2D)4d^1$	$^1D_2$	29.8226324	0.96346D − 04	0.10140D − 03	0.95
$3s^23p^3(^2P)4s^1$	$^3P_2$	$3s^23p^3(^2P)4p^1$	$^3D_1$	42.0966617	0.36566D − 02	0.36361D − 02	1.01
$3s^23p^3(^2P)4p^1$	$^3D_1$	$3s^23p^3(^2P)4d^1$	$^3P_2$	24.0465335	0.15847D − 03	0.16451D − 03	0.96
$3s^23p^3(^2P)4p^1$	$^3S_1$	$3s^23p^3(^2P)4d^1$	$^3D_2$	24.0022192	0.62994D − 02	0.65351D − 02	0.96
$3s^23p^3(^2P)4p^1$	$^3S_1$	$3s^23p^3(^2P)4d^1$	$^1D_2$	23.7055780	0.13605D − 02	0.14181D − 02	0.96
$3s^23p^3(^2D)3d^1$	$^3F_2$	$3s^13p^4(^4P)3d^1$	$^3D_1$	10.5571041	0.18224D − 01	0.18245D − 01	1.00
$3s^23p^3(^2P)4p^1$	$^1P_1$	$3s^23p^3(^2P)4d^1$	$^3P_2$	26.0526758	0.34467D − 02	0.33552D − 02	1.03
$3s^23p^3(^2P)4p^1$	$^3P_1$	$3s^23p^3(^2P)4d^1$	$^3F_2$	27.4792869	0.61096D − 02	0.62239D − 02	0.98
$3s^23p^3(^2P)4p^1$	$^3P_1$	$3s^23p^3(^2P)4d^1$	$^3P_2$	27.1218915	0.15927D+00	0.15255D+00	1.04
$3s^23p^3(^2P)4p^1$	$^3P_1$	$3s^23p^3(^2P)4d^1$	$^3D_2$	26.9105141	0.24902D+00	0.24472D+00	1.02
$3s^23p^3(^2P)4p^1$	$^3P_1$	$3s^23p^3(^2P)4d^1$	$^1D_2$	26.5381886	0.25228D+00	0.24311D+00	1.04
$3s^23p^3(^2P)4p^1$	$^3P_1$	$3s^13p^4(^4P)4p^1$	$^5D_2$	17.7999484	0.41240D − 04	0.41185D − 04	1.00
$3s^23p^3(^4S)4p^1$	$^5P_3$	$3s^23p^3(^2D)4d^1$	$^3P_2$	17.5148240	0.37314D − 05	0.36441D − 05	1.02
$3s^23p^3(^4S)4p^1$	$^5P_3$	$3s^23p^3(^2P)4d^1$	$^3D_2$	14.5499035	0.29376D − 06	0.28437D − 06	1.03
$3s^23p^3(^4S)4p^1$	$^5P_3$	$3s^13p^4(^4P)4p^1$	$^5D_2$	11.3961777	0.32005D − 02	0.30724D − 02	1.04
$3s^23p^3(^2D)4s^1$	$^3D_2$	$3s^13p^4(^4P)3d^1$	$^5P_3$	53.1015845	0.83491D − 07	0.80037D − 07	1.04
$3s^13p^4(^4P)3d^1$	$^5P_3$	$3s^23p^3(^2P)4d^1$	$^3D_2$	17.7882040	0.28690D − 06	0.27823D − 06	1.03
$3s^23p^3(^2D)4p^1$	$^3D_3$	$3s^23p^3(^2P)4d^1$	$^3P_2$	19.0309207	0.68163D − 02	0.65549D − 02	1.04
$3s^23p^3(^2D)4p^1$	$^3D_3$	$3s^13p^4(^4P)4p^1$	$^5S_2$	13.1742560	0.68444D − 04	0.65901D − 04	1.04
$3s^23p^3(^2D)4s^1$	$^3D_2$	$3s^23p^3(^2D)4p^1$	$^3F_3$	42.4956359	0.34283D+00	0.33363D+00	1.03
$3s^23p^3(^2D)4p^1$	$^3F_3$	$3s^23p^3(^2D)4d^1$	$^3P_2$	25.0736245	0.24986D−02	0.24099D−02	1.04

Contd. Table 4

LowerConf.	Terms	UpperConf.	Terms	wavelength	f_L	f_v	$\frac{f_L}{f_v}$
$3s^23p^3(^2D)4p^1$	$^3F_3$	$3s^23p^3(^2P)4d^1$	$^3F_2$	19.7052562	$0.77055D-03$	$0.74529D-03$	1.03
$3s^23p^3(^2D)4p^1$	$^3F_3$	$3s^23p^3(^2P)4d^1$	$^3D_2$	19.4110562	$0.28549D-03$	$0.27762D-03$	1.03
$3s^23p^3(^2D)4s^1$	$^1D_2$	$3s^23p^3(^2D)4p^1$	$^1F_3$	45.7984457	$0.33690D+00$	$0.34902D+00$	0.97
$3s^23p^3(^2D)3d^1$	$^3F_2$	$3s^13p^4(^2D)3d^1$	$^3F_3$	8.9915725	$0.57788D-02$	$0.60231D-02$	0.96
$3s^13p^4(^2D)3d^1$	$^3F_3$	$3s^23p^3(^2D)4d^1$	$^1D_2$	81.9172753	$0.32659D-04$	$0.31592D-04$	1.03
$3s^1(^2S)3p^5$	$^3P_2$	$3s^13p^4(^2P)3d^1$	$^3D_3$	5.6812580	$0.19313D+00$	$0.19632D+00$	0.98
$3s^23p^3(^2D)3d^1$	$^3F_2$	$3s^13p^4(^2P)3d^1$	$^3D_3$	8.1738405	$0.79107D-03$	$0.76599D-03$	1.03
$3s^23p^3(^4S)4p^1$	$^5P_3$	$3s^13p^4(^4P)4p^1$	$^5D_3$	11.4305909	$0.18254D-01$	$0.17871D-01$	1.02
$3s^23p^3(^2D)4s^1$	$^3D_3$	$3s^13p^4(^4P)3d^1$	$^5P_3$	53.4350840	$0.64776D-05$	$0.62760D-05$	1.03
$3s^13p^4(^4P)3d^1$	$^5P_3$	$3s^23p^3(^2D)4d^1$	$^1F_3$	20.8764321	$0.21444D-06$	$0.20850D-06$	1.03
$3s^23p^3(^2D)4p^1$	$^3D_3$	$3s^23p^3(^4S)4d^1$	$^5D_3$	43.4066578	$0.18802D-04$	$0.19316D-04$	0.97
$3s^23p^3(^2D)4p^1$	$^3D_3$	$3s^23p^3(^2D)4d^1$	$^1F_3$	22.4620408	$0.27939D-03$	$0.28444D-03$	0.98
$3s^23p^3(^2D)4p^1$	$^3D_3$	$3s^13p^4(^2D)4p^1$	$^3F_3$	10.8547024	$0.66453D-02$	$0.64330D-02$	1.03
$3s^23p^3(^2D)4p^1$	$^1F_3$	$3s^23p^3(^2D)4d^1$	$^3F_3$	27.3534792	$0.18145D-02$	$0.18819D-02$	0.96
$3s^23p^3(^2D)4p^1$	$^1F_3$	$3s^23p^3(^2D)4d^1$	$^3D_3$	26.2508102	$0.13182D-02$	$0.12712D-02$	1.04
$3s^23p^3(^2D)4p^1$	$^1F_3$	$3s^23p^3(^2D)4d^1$	$^1F_3$	23.6947323	$0.22155D+00$	$0.21204D+00$	1.04
$3s^23p^3(^2D)4p^1$	$^1F_3$	$3s^13p^4(^2D)4p^1$	$^1F_3$	10.8125305	$0.38254D-01$	$0.37264D-01$	1.03
$3s^23p^3(^2P)4p^1$	$^3D_3$	$3s^23p^3(^2D)4d^1$	$^3tt_3$	36.3164497	$0.20859D-04$	$0.20274D-04$	1.03
$3s^13p^4(^2D)3d^1$	$^3D_3$	$3s^23p^3(^2D)4d^1$	$^1F_3$	33.0683440	$0.20396D-04$	$0.21421D-04$	0.95
$3s^23p^3(^2D)3d^1$	$^3F_3$	$3s^13p^4(^2D)3d^1$	$^3F_3$	8.8791752	$0.33725D-01$	$0.34172D-01$	0.99
$3s^23p^3(^2D)4s^1$	$^3D_3$	$3s^13p^4(^2D)3d^1$	$^3F_3$	18.9732121	$0.15614D-03$	$0.16414D-03$	0.95
$3s^23p^3(^4S)3d^1$	$^5D_3$	$3s^13p^4(^2P)3d^1$	$^3D_3$	7.3106679	$0.35500D-03$	$0.36272D-03$	0.98
$3s^23p^3(^2D)3d^1$	$^3F_3$	$3s^13p^4(^2P)3d^1$	$^3D_3$	8.0808516	$0.19483D-01$	$0.18998D-01$	1.03
$3s^23p^3(^2D)3d^1$	$^3tt_3$	$3s^13p^4(^2P)3d^1$	$^3D_3$	8.8006257	$0.11674D-03$	$0.11634D-03$	1.00
$3s^23p^3(^2D)3d^1$	$^3F_3$	$3s^13p^4(^4P)4s^1$	$^5P_3$	7.9374018	$0.57568D-06$	$0.57425D-06$	1.00
$3s^13p^4(^4P)4s^1$	$^5P_3$	$3s^13p^4(^2D)4p^1$	$^1F_3$	19.6740439	$0.19510D-06$	$0.20322D-06$	0.96
$3s^2(^1S)3p^4$	$^3P_0$	$3s^23p^3(^2D)3d^1$	$^1P_1$	6.3475560	$0.54289D-02$	$0.52148D-02$	1.04
$3s^2(^1S)3p^4$	$^1S_0$	$3s^23p^3(^2D)3d^1$	$^1P_1$	7.3277530	$0.16030D+00$	$0.16144D+00$	0.99
$3s^23p^3(^4S)4p^1$	$^3P_0$	$3s^23p^3(^4S)4d^1$	$^3D_1$	26.3860301	$0.90088D+00$	$0.94405D+00$	0.95
$3s^23p^3(^4S)4s^1$	$^3S_1$	$3s^13p^4(^4P)3d^1$	$^3P_0$	25.3331425	$0.49319D-02$	$0.50086D-02$	0.98
$3s^23p^3(^2P)4p^1$	$^3P_0$	$3s^23p^3(^2P)4d^1$	$^3P_1$	27.2921262	$0.26047D+00$	$0.25102D+00$	1.04
$3s^23p^3(^2P)4p^1$	$^3P_0$	$3s^23p^3(^2P)4d^1$	$^3D_1$	26.7822226	$0.70813D+00$	$0.69490D+00$	1.02

4. Conclusions

In this paper we have employed extensive CI technique to calculate excitation energies, oscillator strength and transition probabilities for Ca V using the CIV3 program of Hibbert [9]. The lowest 148 fine-structure levels listed in Table 3 have been considered. In most of the cases, our tabulated energy levels agree well with the NIST data, although some energy levels show discrepancies. Energies for the vast majority of the levels belonging to $3s3p^4 3d$ and $3s3p^3 3d^2$ configurations determined for the first time. The arrangement among length and velocity forms of oscillator strength reflect the quality of wavefunction for present estimations. We examine our new expected data by using Configuration Interaction technique, where no theoretical and experimental results are accessible, which will form a basis for future work.

Acknowledgements

F. Yadav and P. C. Bhowmick are thankful to UGC and CSIR, Government of India for their Junior Research Fellowship. The authors are thankful to Shyam Lal College and Department of Physics and Astrophysics, University of Delhi for providing computational facilities.

Competing Interests

The authors declare that they have no competing interests.

Authors' Contributions

All the authors contributed significantly in writing this article. The authors read and approved the final manuscript.

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