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Transition rates and radiative lifetimes of Ca I

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ABSTRACT

We tabulate spontaneous emission rates for all possible 811 electric-dipole-allowed transitions between the 75 lowest-energy states of Ca I. These involve the 4s*n*s (n = 4–8), 4s*n*p (n = 4–7), 4s*n*d (n = 3–6), 4s*n*f (n = 4–6), $3d^2$, $4p^2$, 3d4p, and 4s5g electronic configurations. We compile the transition rates by carrying out *ab initio* relativistic calculations using the combined method of configuration interaction and many-body perturbation theory. The results are compared to the available literature values. The tabulated rates can be useful in various applications, such as optimizing laser cooling in magneto-optical traps, estimating various systematic effects in optical clocks and evaluating static or dynamic polarizabilities and long-range atom–atom interaction coefficients and related atomic properties.

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Contents

1. Introduction

Alkaline-earth atoms and divalent-like atoms (such as Yb and Hg) became a subject of interest to the cold atom community in the past decade. These atoms possess two valence electrons outside a tightly bound core and in the LS coupling scheme, the atomic states can be classified by being either singlet or triplet states. The availability of relatively wide spin-allowed and narrow spin-forbidden electric-dipole (E1) transitions enables stacking laser cooling on both types of transitions, with the spin-allowed transitions used for the initial rapid cooling and spin-forbidden transitions—for reaching much lower Doppler-limit temperatures. Moreover, the narrow inter-combination transitions, such as the $4s^2\ {}^1S_0 - 4s4p\ {}^3P_1$ transition, can be used as an optical frequency Refs. [1,2]. The highly-forbidden $4s^2\ {}^1S_0 - 4s4p\ {}^3P_0$ transition can be potentially used for an optical lattice clock scheme [3]. However, due to peculiarities of its electronic structure, Ca, unlike other alkaline-earth atoms, has a relatively short lifetime in conventional magneto-optical traps (MOT). To improve the MOT efficiency, several re-pumping schemes were proposed and demonstrated [4]. That work required reliable electric-dipole transition data for many transitions between the 75 lowest energy states of neutral Ca. Here, we compile the results of our computational work that served as a basis of the MOT performance analysis [4]. We anticipate that the tabulated data will be useful in multiple other contexts, such as estimating various systematic effects in optical clocks and computing static or dynamic polarizabilities and long-range inter-atomic interaction coefficients.

There have been a number of atomic-structure calculations for neutral calcium. The earlier work includes multi-configuration Hartree–Fock (MCHF) calculation [5] and semi-empirical model-potential calculations [6–9]. These computations provide oscillator strengths for spin-allowed transitions for levels up to 4s10s, 4s9p and 4s6d. Most of them are non-relativistic with very limited numbers of low-lying levels treated with *ab initio* relativistic methods. In particular, Fisher and Tachiev [10] reported energies and E1 transition rates for levels below 3d4p ${}^1F_3$. Porsev et al. [11] and Savukov and Johnson [12] computed the $4s^2 - 4s4p$, $4s4p - 3d4s$, and $4s4p - 4s5s$ transition rates using a combination of configuration-interaction (CI) and many-body perturbation theory (MBPT) (referred to as the CI+MBPT method). The CI+MBPT method results were in excellent agreement with high-precision experimental values. This fact partially motivated our use of the relativistic CI+MBPT method for the present work.

2. Computational details

The CI+MBPT method employs a systematic formalism that combines advantages of both configuration interaction (CI) method and many-body perturbation theory (MBPT) [13]. This method has been used extensively for evaluation of atomic properties (see, e.g., review [14] for optical lattice clock applications and references therein). Relativistic effects are included exactly as the formalism starts from the Dirac equation and employs relativistic bi-spinor wave functions throughout the entire calculation. In our treatment, the CI model space is limited to excitations of the two valence electrons. Contributions involving virtual excitations of core orbitals are treated within the MBPT. In this approach, we first solve for the valence electron orbitals and energies in the field of core electrons. The one-electron effective potential includes both the frozen-cored Dirac–Hartree– Fock (DHF V^{N-2}) and self-energy (core-polarization) potentials. The self-energy correction is computed using second-order MBPT diagrams involving virtual core excitations. At the next step, the computed one-electron valence orbitals are used to diagonalize the atomic Hamiltonian in the model space of two valence electrons within the CI method. The CI model-space Hamiltonian includes the residual (beyond DHF) Coulomb interaction between the valence electrons and also their core-polarization-mediated interaction. The latter was computed in the second-order MBPT. This step yields two-electron wave-functions and energies. Finally, with the obtained wave-functions we calculated the required electric-dipole matrix elements. In calculations of transition rates we used experimental energy intervals and the computed CI+MBPT matrix elements.

We used two independent CI+MBPT implementations: (i) by the Reno group (see the description of the earlier version in Ref. [15]) and (ii) the recently published package [16]. The practical goal of the calculations was not reaching the best possible accuracy, but rather the generation of massive amounts of reliable data for the transition array involving 75 lowest-energy levels. The Reno code was run on a large basis set but without including core-polarization-mediated interaction in the CI Hamiltonian due to considerable computational costs. The production runs with package [16] employed a smaller basis set (due to code limitations) but treated the correlation problem more fully.

While using the package [16] we employed the one-electron basis set that included the 1s−17s, 2p−17p, 3d−17d, 4f−17f, and 5g−17g orbitals, where the core and 4s, . . . , 6f orbitals are DHF ones, while the remaining orbitals were represented by a B-spline basis set. The Reno code used the dual-kinetic-balance basis set generated in the DHF V^{N-2} potential using spherical cavity of 75 Bohr radius [17]. The basis included orbitals with orbital angular momentum ℓ up to 6. The total number of positive-energy (in the Dirac sense) orbitals per partial wave was 40 with the 35 lowest-energy orbitals used in the calculations.

For most states, the values of transition rates obtained with package [16] were in close agreement with the NIST recommended values due to more complete treatment of the correlation problem. The level of agreement was degraded for states with the 4s6f electron configuration which was traced to our use of small basis set due to package [16] limitations. For these 4s6f states, the values of transition rates obtained with the Reno code displayed a better agreement with the NIST data because of the larger basis set. In addition, due to the restriction on the number of eigenvalues in the package [16], we were not able to compute the states arising from the 4s8s configuration. Our final values combine the outputs of the two codes. While the bulk of the results comes from the package [16], rates for states involving the 4s6f and 4s8s configurations are taken from the Reno code output in our tabulation. The rates for $4s7p\ ^1P_1$ to $4s^2\ ^1S_0$, $4s7s\ ^1S_0$ to $4s4p\ ^1P_1$, and $4s6d\ ^1D_2$ to $4s4p\ ^1P_1$ transitions are taken from Reno code.

The spontaneous emission rate A_{if} from the upper (initial) state i to the lower (final) state f was calculated as

$$A_{if} = 2.02613 \times 10^{18} \frac{|\langle i \| D \| f \rangle|^2}{(2J_i+1)\lambda^3}\ \mathrm{s}^{-1}, \tag{1}$$

where $\langle i \| D \| f \rangle$ is the reduced matrix element of the electric-dipole operator in atomic units, the transition wavelength λ is expressed in Å, and J_i is the total angular momentum of the upper (initial) state. The emission rate can be converted into the weighted oscillator strength using [18]

$$\begin{aligned} gf &= (2J_f+1)f_{fi} = -(2J_i+1)f_{if} \\ &= 1.499 \times 10^{-16} A_{if} \lambda^2 (2J_i+1), \end{aligned} \tag{2}$$

where gf is weighted oscillator strength, f_{if} is the emission oscillator strength (usually taken to be negative), f_{fi} is the adsorption oscillator strength, and J_f is the total angular momentum of the lower (final) state. We determined λ from the NIST recommended energy values [19]. Finally, the total transition rate A_{total} from a given initial state is a sum of A_{if} over all E1-allowed final states, with the resulting initial state lifetime $\tau = 1/A_{\mathrm{total}}$.

3. Results and discussion

We summarize the lifetime of the 75 states in Table 1 and compare with the available theoretical and experimental values. Our data show better agreement with the experimental values, as compared with the other theoretical data. The computed spontaneous emission rates are compiled in Tables 2–6. For completeness, we list values obtained with the electric dipole operator in both the length and velocity forms (gauges) in columns marked L and V, respectively. Generally, the length and velocity gauges agree at a few percent level, except for some occasional large discrepancies for weak transitions. The length form values are in better overall agreement with the available literature data and therefore we recommend using the length-form values.

We further assessed the quality of our calculation by comparing our values with other theoretical data [9–11] and with the NIST recommended values [19] in Table 7. The other theoretical data are taken primarily from three sources. The first source is the non-relativistic semi-empirical calculation by Hansen et al. [9]. They used the model potential and CI (MPCI) method to determine rates for the LS allowed E1 transitions for levels up to 4s10s. From a comparison with other semi-empirical work [6,7], Hansen et al. concluded that their data are more accurate because they have used larger basis size, larger cut-off radius, and more accurate model potential. In Table 7 we compare 80 transition rates with Hansen's results [9]. For comparison, their weighted oscillator strength gf values are converted to A_{if} (in 1/s) as $A_{if} = 6.67 \times 10^{15} gf/[(2J_i+1)\lambda^2]$, where λ is in Å. The difference between our's and the Hansen's results is better than 1% for the $4s4p\ ^1P_1 - 4s^2\ ^1S_0$ and $4s4p\ ^3P_1 - 4s^2\ ^1S_0$ transitions and better than 50% for majority of other transitions. There are a few cases where the discrepancy between our's and Hansen's data is worse than 50% for some specific transitions decaying from highly excited states like 4sns with $n = 6-8$, 4s7p, 4s6d, and 4s5d. The second source is the *ab initio* relativistic MCHF calculations by Fischer et al. [10]. They report the transition rates between levels below $3d4p\ ^1F_3$, both allowed and spin forbidden. In Table 7, we compared 13 spin forbidden singlet–triplet transition rates with their results. Our values are in better agreement with the NIST data than the MCHF results, for example, for the $4s4p\ ^3P_1 - 4s^2\ ^1S_0$, $3d4p\ ^1D_2 - 3d4s\ ^3D_1$, $3d4p\ ^1D_2 - 3d4s\ ^3D_2$ transitions. The third source is the CI+MBPT calculation [11]. These authors reported rates for the spin-allowed $4s^2-4s4p$, $4s4p-3d4s$ transitions, and for the spin-forbidden $4s4p\ ^1P_1-4s5s\ ^3S_1$ and $4s4p\ ^3P_{1,2}-3d4s\ ^1D_2$ transitions. We find excellent agreement with their CI+MBPT results [11]. Finally, we compared 99 transition rates with the NIST Atomic Spectra Database [19] in Table 7. In most cases, the discrepancy is better than 50%. There are some instances when the discrepancy is worse than 50%. In particular, for the $4s6f\ ^1F_0 - 3d4s\ ^1D_2$, $4s5p\ ^1P_1 - 4s^2\ ^1S_0$, and $4s4f\ ^1F_3 - 3d4s\ ^1D_2$ transitions, our data show good agreement with the MPCI theoretical data, but display large differences with the NIST recommended values.

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Explanation of Tables

In Table 1, we compile radiative E1 lifetimes of the 74 lowest-energy excited states of Ca I. In Tables 2–6, we tabulate our theoretical data for spontaneous emission rates of all possible 811 E1-allowed transitions between the 75 lowest-energy states of Ca I. A comparison with other literature values is presented in Table 7.

Table 1. **Radiative electric-dipole decay rates A_{total} and lifetimes τ of Ca I.**

First column	States.
Second and third columns	Energies in cm^{-1}, our CI+MBPT and the NIST values.
Fourth column	Difference between our CI+MBPT and NIST energies in %.
Fifth column	Total spontaneous emission rates A_{total} in 10^8 s^{-1} for the state.
Sixth and seventh columns	Lifetime of the state, our and the literature values.
MPCI	Model Potential Configuration Interaction method.
MCHF	Multi-Configuration Hartree–Fock method.
Exp.	Experimental values.

Table 2. **Spontaneous emission rates of transitions originating from the 4*s*n*s* (n = 4–8) states of Ca I.**

First and Second columns	Transition levels, the upper (initial) and the lower (final) level.
Third column	Transition wavelength λ, in nm.
Fourth and Fifth columns	Our values of spontaneous emission rates A_{if} in 10^8 s^{-1} in length (L) and velocity (V) forms of the E1 operator.
Sixth column	Difference between the L and V column values defined as $(L-V)/L$ in %.
Seventh column	Branching ratio (BR) in %, defined as A_{if}/A_{total}.

Table 3. **Spontaneous emission rates of transitions originating from the 4*s*n*p* (n = 4–7) states of Ca I.**

First and Second columns	Transition levels, the upper (initial) and the lower (final) level.
Third column	Transition wavelength λ, in nm.
Fourth and Fifth columns	Our values of spontaneous emission rates A_{if} in 10^8 s^{-1} in length (L) and velocity (V) forms of the E1 operator.
Sixth column	Difference between the L and V column values defined as $(L-V)/L$ in %.
Seventh column	Branching ratio (BR) in %, defined as A_{if}/A_{total}.

Table 4. **Spontaneous emission rates of transitions originating from the 4*s*n*d* (n = 3–6) states of Ca I.**

First and Second columns	Transition levels, the upper (initial) and the lower (final) level.
Third column	Transition wavelength λ, in nm.
Fourth and Fifth columns	Our values of spontaneous emission rates A_{if} in 10^8 s^{-1} in length (L) and velocity (V) forms of the E1 operator.
Sixth column	Difference between the L and V column values defined as $(L-V)/L$ in %.
Seventh column	Branching ratio (BR) in %, defined as A_{if}/A_{total}.

Table 5. **Spontaneous emission rates of transitions originating from the 4*s*n*f* (n = 4–6) states of Ca I.**

First and Second columns	Transition levels, the upper (initial) and the lower (final) level.
Third column	Transition wavelength λ, in nm.
Fourth and Fifth columns	Our values of spontaneous emission rates A_{if} in 10^8 s^{-1} in length (L) and velocity (V) forms of the E1 operator.
Sixth column	Difference between the L and V column values defined as $(L-V)/L$ in %.
Seventh column	Branching ratio (BR) in %, defined as A_{if}/A_{total}.

Table 6. **Spontaneous emission rates of transitions originating from the $3d^2$, $4p^2$, 3d4p, and 4s5g states of Ca I.**

First and Second columns	Transition levels, the upper (initial) and the lower (final) level.
Third column	Transition wavelength λ, in nm.
Fourth and Fifth columns	Our values of spontaneous emission rates A_{if} in 10^8 s^{-1} in length (L) and velocity (V) forms of the E1 operator.
Sixth column	Difference between the L and V column values defined as $(L-V)/L$ in %.
Seventh column	Branching ratio (BR) in %, defined as A_{if}/A_{total}.

Table 7. **Comparison of transition probabilities with literature values.**

First and Second columns	Transition levels, the upper (initial) and the lower (final) level.
Third column	Spontaneous emission rates A_{if} in units of 10^8 s^{-1} using the L-form of the E1 operator.
Forth and Fifth columns	Other theoretical A_{if} values and the % difference between this work and other theoretical data, calculated as the difference of the third and forth column values divided by the third column value.
Sixth and Seventh columns	NIST recommended A_{if} value and the % difference between this work and NIST data, computed as the difference between the third and sixth column values divided by the third column value.
L	Length form of the electric-dipole operator.
MPCI	Model Potential Configuration Interaction method.
MCHF	Multi-Configuration Hartree–Fock method.
CI+MBPT	Configuration Interaction with Many-Body Perturbation Theory method.
NIST	NIST recommended values.

Table 1
Radiative electric-dipole decay rates A_{total} and lifetimes τ of Ca I.

State	Energy (cm^{-1})		Diff. (%)	A_{total}(10^8 s^{-1})	τ (ns)	
	This work	NIST			This work	Refs.
$4s4p\ ^3P_0$	15125.730	15157.900	0.2	0.0	∞	
$4s4p\ ^3P_1$	15179.500	15210.060	0.2	2.74×10^{-5}	3.65×10^5	$(3.4\pm0.2)\times10^5$ Exp. [20]
$4s4p\ ^3P_2$	15289.530	15315.940	0.2	0.0	∞	
$3d4s\ ^3D_1$	20822.630	20335.360	2.4	8.68×10^{-3}	1.15×10^3	
$3d4s\ ^3D_2$	20840.440	20349.260	2.4	8.50×10^{-3}	1.18×10^3	
$3d4s\ ^3D_3$	20868.160	20371.000	2.4	8.24×10^{-3}	1.21×10^3	
$3d4s\ ^1D_2$	22449.920	21849.630	2.7	4.88×10^{-6}	2.05×10^6	$2.3(5)\times10^6$ Exp. [21] $1.71(3)\times10^6$ Exp. [22]
$4s4p\ ^1P_1$	23491.350	23652.300	0.7	2.17	4.61	4.535(28) Exp. [23]
$4s5s\ ^3S_1$	31729.740	31539.500	0.6	0.823	12.1	12.4 MPCI [9]
$4s5s\ ^1S_0$	33465.560	33317.260	0.4	0.229	43.6	
$3d4p\ ^3F_2$	36235.100	35730.450	1.4	0.401	24.9	
$3d4p\ ^3F_3$	36332.400	35818.710	1.4	0.381	26.2	
$3d4p\ ^1D_2$	36350.570	35835.410	1.4	0.446	22.4	
$3d4p\ ^3F_4$	36419.600	35896.890	1.5	0.385	26.0	
$4s5p\ ^3P_0$	36513.680	36547.690	0.1	0.176	57.0	
$4s5p\ ^3P_1$	36521.570	36554.750	0.1	0.176	56.9	
$4s5p\ ^3P_2$	36543.800	36575.120	0.1	0.177	56.5	
$4s5p\ ^1P_1$	36708.430	36731.620	0.1	0.163	61.5	57.6 MPCI [9]
$4s4d\ ^1D_2$	37660.590	37298.290	1.0	0.161	62.3	64.9 MPCI [9]
$4s4d\ ^3D_1$	38013.550	37748.200	0.7	0.786	12.7	13.0(5) Exp. [24]
$4s4d\ ^3D_2$	38017.720	37751.870	0.7	0.784	12.8	13.0(5) Exp. [24]
$4s4d\ ^3D_3$	38023.990	37757.450	0.7	0.781	12.8	13.0(5) Exp. [24]
$3d4p\ ^3D_1$	38787.640	38192.390	1.6	0.689	14.5	
$3d4p\ ^3D_2$	38819.160	38219.120	1.6	0.690	14.5	
$3d4p\ ^3D_3$	38866.410	38259.120	1.6	0.692	14.5	
$4p^2\ ^3P_0$	38858.080	38417.540	1.1	1.83	5.48	6.9(4) Exp. [24]
$4p^2\ ^3P_1$	38908.680	38464.810	1.2	1.83	5.46	6.9(4) Exp. [24]
$4p^2\ ^3P_2$	39001.360	38551.560	1.2	1.83	5.45	6.9(4) Exp. [24]
$3d4p\ ^3P_0$	39871.870	39333.380	1.4	0.781	12.8	
$3d4p\ ^3P_1$	39875.220	39335.320	1.4	0.781	12.8	
$3d4p\ ^3P_2$	39883.770	39340.080	1.4	0.779	12.8	
$4s6s\ ^3S_1$	40664.630	40474.240	0.5	0.327	30.6	
$3d4p\ ^1F_3$	41100.840	40537.890	1.4	0.073	137	
$4s6s\ ^1S_0$	40942.640	40690.440	0.6	0.070	142	113.0 MPCI [9]
$4p^2\ ^1D_2$	41182.450	40719.850	1.1	0.593	16.9	15.2 MPCI [9] 16.3 Exp. [24]
$4s6p\ ^1P_1$	41787.870	41679.010	0.3	0.361	27.7	
$4p^2\ ^1S_0$	42336.930	41786.280	1.3	0.792	12.6	12.5 MPCI [9] 14.4(7) Exp. [24]
$4s4f\ ^3F_2$	42078.450	42170.210	0.2	0.261	38.4	
$4s4f\ ^3F_3$	42078.850	42170.560	0.2	0.261	38.4	
$4s4f\ ^3F_4$	42079.380	42171.030	0.2	0.261	38.3	
$4s4f\ ^1F_3$	42392.680	42343.590	0.1	0.378	26.4	28.8 MPCI [9]
$4s6p\ ^3P_0$	42479.440	42514.850	0.1	0.005	0.020	
$4s6p\ ^3P_1$	42483.640	42518.710	0.1	0.005	0.020	
$4s6p\ ^3P_2$	42492.270	42526.590	0.1	0.005	0.019	
$4s5d\ ^3D_1$	42979.530	42743.000	0.6	0.406	24.7	
$4s5d\ ^3D_2$	42981.440	42744.720	0.6	0.405	24.7	
$4s5d\ ^3D_3$	42984.390	42747.390	0.6	0.403	24.8	
$4s5d\ ^1D_2$	43227.380	42919.050	0.7	0.511	19.6	22.8 MPCI [9]
$3d^2\ ^3F_2$	44231.820	43474.830	1.7	0.007	0.015	
$3d^2\ ^3F_3$	44251.410	43489.120	1.8	0.007	0.015	
$3d^2\ ^3F_4$	44277.650	43508.090	1.8	0.007	0.015	
$4snp\ ^1P_1$	44382.940	43933.480	1.0	0.757	13.2	
$4s7s\ ^3S_1$	44707.350	43980.770	1.7	0.223	44.9	
$4s7s\ ^1S_0$	45215.430	44276.540	2.1	0.248	40.4	73.2 MPCI [9] 45.7 MCHF [5]
$4s5f\ ^3F_2$	44796.860	44762.620	0.1	0.170	58.8	
$4s5f\ ^3F_3$	44797.140	44762.840	0.1	0.170	588	
$4s5f\ ^3F_4$	44797.520	44763.120	0.1	0.171	58.6	
$4s5f\ ^1F_3$	44870.500	44804.880	0.1	0.231	43.3	56.5 MPCI [9]
$4s5g\ ^3G_5$	45191.910	44874.860	0.7	0.005	195	
$4s5g\ ^1G_4$	45191.510	44875.950	0.7	0.007	147	
$4s7p\ ^3P_0$	45997.520	44955.670	2.3	0.002	550	
$4s7p\ ^3P_1$	46001.620	44957.660	2.3	0.002	546	
$4s7p\ ^3P_2$	46010.100	44961.760	2.3	0.002	539	
$4s6d\ ^1D_2$	45815.480	44989.830	1.8	0.206	48.6	76.3 MPCI [9] 58.9 Exp. [25]
$4s6d\ ^3D_1$	45890.620	45049.070	1.9	0.378	26.5	

(continued on next page)

Table 1 (*continued*)

State	Energy (cm^{-1})		Diff. (%)	$A_{total}(10^8\ s^{-1})$	τ (ns)	
	This work	NIST			This work	Refs.
$4s6d\ ^3D_2$	45893.340	45050.420	1.9	0.377	26.5	
$4s6d\ ^3D_3$	45897.080	45052.370	1.9	0.376	26.6	
$4s7p\ ^1P_1$	46975.130	45425.360	3.4	0.407	24.5	
$4s8s\ ^3S_1$		45738.680		0.009	105	149 MPCI [9] 118.3(6.3) Exp. [25]
$4s8s\ ^1S_0$		45887.200		0.006	157	
$4s6f\ ^3F_2$	47711.820	46164.640	3.4	0.227	112.7	
$4s6f\ ^3F_3$	47712.420	46164.790	3.4	0.228	113.7	
$4s6f\ ^3F_4$	47713.200	46164.970	3.4	0.228	121.9	
$4s6f\ ^1F_3$	47768.330	46182.400	3.4	0.291	96.7	

Table 2
Spontaneous emission rates of transitions originating from the 4sns ($n = 4$–8) states of Ca I.

Transition		λ (nm)	A_{if} (10^8 s^{-1})		Diff. (%)	BR. (%)
Initial	Final		L	V		
4s5s $^3S_1$	4s4p $^3P_0$	610.441	9.246E−02	9.001E−02	2.65	11.23
4s5s $^3S_1$	4s4p $^3P_1$	612.391	2.759E−01	2.685E−01	2.67	33.51
4s5s $^3S_1$	4s4p $^3P_2$	616.388	4.549E−01	4.426E−01	2.71	55.26
4s5s $^3S_1$	4s4p $^1P_1$	1267.877	5.911E−06	6.068E−06	−2.66	0.00
4s5s $^1S_0$	4s4p $^3P_1$	552.267	1.694E−05	1.826E−05	−7.78	0.01
4s5s $^1S_0$	4s4p $^1P_1$	1034.665	2.293E−01	2.217E−01	3.34	99.99
4s6s $^3S_1$	3d4p $^3F_2$	2108.019	2.378E−05	2.360E−05	0.77	0.01
4s6s $^3S_1$	3d4p $^1D_2$	2155.716	1.673E−04	1.664E−04	0.53	0.05
4s6s $^3S_1$	4s5p $^3P_0$	2546.765	9.152E−03	9.132E−03	0.22	2.80
4s6s $^3S_1$	4s5p $^3P_1$	2551.352	2.714E−02	2.708E−02	0.21	8.30
4s6s $^3S_1$	4s5p $^3P_2$	2564.681	4.537E−02	4.528E−02	0.21	13.88
4s6s $^3S_1$	4s5p $^1P_1$	2671.925	2.703E−04	2.697E−04	0.24	0.08
4s6s $^3S_1$	4s4p $^3P_0$	395.002	2.621E−02	2.500E−02	4.60	8.01
4s6s $^3S_1$	3d4p $^3D_1$	4382.409	5.498E−07	4.698E−07	14.55	0.00
4s6s $^3S_1$	3d4p $^3D_2$	4434.354	1.660E−06	1.531E−06	7.76	0.00
4s6s $^3S_1$	3d4p $^3P_0$	8765.317	1.184E−04	1.166E−04	1.53	0.04
4s6s $^3S_1$	4s4p $^3P_1$	395.817	7.994E−02	7.638E−02	4.46	24.45
4s6s $^3S_1$	3d4p $^3P_1$	8780.248	3.539E−04	3.462E−04	2.19	0.11
4s6s $^3S_1$	3d4p $^3P_2$	8817.098	5.849E−04	5.674E−04	2.99	0.18
4s6s $^3S_1$	4s4p $^3P_2$	397.483	1.377E−01	1.319E−01	4.20	42.10
4s6s $^3S_1$	4s4p $^1P_1$	594.462	1.172E−06	1.231E−06	−5.01	0.00
4s6s $^1S_0$	4s5p $^3P_1$	2417.976	5.790E−04	5.636E−04	2.67	0.82
4s6s $^1S_0$	4s5p $^1P_1$	2526.005	5.484E−02	5.299E−02	3.37	77.90
4s6s $^1S_0$	3d4p $^3D_1$	4003.122	8.321E−06	8.418E−06	−1.17	0.01
4s6s $^1S_0$	4s4p $^3P_1$	392.459	7.678E−04	8.401E−04	−9.42	1.09
4s6s $^1S_0$	3d4p $^3P_1$	7379.420	1.071E−06	8.795E−07	17.85	0.00
4s6s $^1S_0$	4s4p $^1P_1$	586.919	1.420E−02	2.181E−02	−53.58	20.17
4s7s $^3S_1$	3d4p $^3F_2$	1212.074	9.204E−06	9.121E−06	0.90	0.00
4s7s $^3S_1$	3d4p $^1D_2$	1227.693	6.343E−05	6.312E−05	0.48	0.03
4s7s $^3S_1$	4s5p $^3P_0$	1345.337	4.039E−03	4.043E−03	−0.12	1.81
4s7s $^3S_1$	4s5p $^3P_1$	1346.616	1.196E−02	1.197E−02	−0.13	5.37
4s7s $^3S_1$	4s5p $^3P_2$	1350.320	1.990E−02	1.994E−02	−0.16	8.94
4s7s $^3S_1$	4s5p $^1P_1$	1379.472	1.143E−04	1.145E−04	−0.22	0.05
4s7s $^3S_1$	4s4p $^3P_0$	346.947	1.873E−02	1.773E−02	5.35	8.41
4s7s $^3S_1$	3d4p $^3D_1$	1727.599	2.534E−08	1.214E−08	52.10	0.00
4s7s $^3S_1$	3d4p $^3D_2$	1735.614	6.215E−08	4.375E−08	29.61	0.00
4s7s $^3S_1$	3d4p $^3P_0$	2151.745	6.592E−05	5.724E−05	13.17	0.03
4s7s $^3S_1$	4s4p $^3P_1$	347.576	5.630E−02	5.330E−02	5.32	25.27
4s7s $^3S_1$	3d4p $^3P_1$	2152.644	2.023E−04	1.771E−04	12.49	0.09
4s7s $^3S_1$	3d4p $^3P_2$	2154.852	3.557E−04	3.143E−04	11.64	0.16
4s7s $^3S_1$	4s6p $^1P_1$	4344.502	3.555E−08	2.421E−08	31.91	0.00
4s7s $^3S_1$	4s4f $^3F_2$	5523.153	1.611E−13	1.419E−13	11.93	0.00
4s7s $^3S_1$	4s4p $^3P_2$	348.860	9.417E−02	8.923E−02	5.24	42.28
4s7s $^3S_1$	4s6p $^3P_0$	6821.655	1.886E−03	1.631E−03	13.50	0.85
4s7s $^3S_1$	4s6p $^3P_1$	6839.665	5.634E−03	4.869E−03	13.58	2.53
4s7s $^3S_1$	4s6p $^3P_2$	6876.728	9.311E−03	8.031E−03	13.75	4.18
4s7s $^3S_1$	4snp $^1P_1$	211461.197	6.064E−12	3.709E−10	−6016.54	0.00
4s7s $^3S_1$	4s4p $^1P_1$	491.921	7.761E−07	8.123E−07	−4.67	0.00
4s7s $^1S_0$	4s5p $^3P_1$	1295.037	4.787E−04	4.881E−04	−1.97	0.19
4s7s $^1S_0$	4s5p $^1P_1$	1325.395	4.599E−02	4.680E−02	−1.75	18.57
4s7s $^1S_0$	3d4p $^3D_1$	1643.615	1.933E−06	2.372E−06	−22.69	0.00
4s7s $^1S_0$	4s4p $^3P_1$	344.039	3.318E−06	3.419E−06	−3.03	0.00
4s7s $^1S_0$	3d4p $^3P_1$	2023.792	2.553E−08	4.952E−08	−93.96	0.00
4s7s $^1S_0$	4s6p $^1P_1$	3849.811	2.243E−02	1.991E−02	11.25	9.06
4s7s $^1S_0$	4s6p $^3P_1$	5688.832	3.489E−08	5.111E−08	−46.48	0.00
4s7s $^1S_0$	4snp $^1P_1$	29149.420	3.074E−04	9.826E−05	68.03	0.12
4s7s $^1S_0$	4s4p $^1P_1$	484.866	6.836E−02			72.05
4s8s $^3S_1$	3d4p $^3F_2$	999.178	7.736E−09			0.00
4s8s $^3S_1$	3d4p $^1D_2$	1009.767	7.664E−07			0.00
4s8s $^3S_1$	4s5p $^3P_0$	1088.022	1.542E−03			1.63
4s8s $^3S_1$	4s5p $^3P_1$	1088.858	4.577E−03			4.83
4s8s $^3S_1$	4s5p $^3P_2$	1091.279	7.690E−03			8.11
4s8s $^3S_1$	4s5p $^1P_1$	1110.240	4.267E−05			0.05
4s8s $^3S_1$	3d4p $^3D_1$	1325.154	5.676E−08			0.00
4s8s $^3S_1$	3d4p $^3D_2$	1329.865	2.426E−07			0.00
4s8s $^3S_1$	4s4p $^3P_0$	327.003	7.436E−03			7.85
4s8s $^3S_1$	3d4p $^3P_0$	1561.207	4.073E−05			0.04
4s8s $^3S_1$	3d4p $^3P_1$	1561.680	1.174E−04			0.12
4s8s $^3S_1$	3d4p $^3P_2$	1562.842	1.793E−04			0.19
4s8s $^3S_1$	4s4p $^3P_1$	327.561	2.225E−02			23.47

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Table 2 (*continued*)

Transition		λ (nm)	A_{if} (10^8 s^{-1})		Diff. (%)	BR. (%)
Initial	Final		L	V		
$4s8s\,^3S_1$	$4s6p\,^1P_1$	2463.254	2.019E−08			0.00
$4s8s\,^3S_1$	$4s4f\,^3F_2$	2802.321	8.155E−13			0.00
$4s8s\,^3S_1$	$4s4p\,^3P_2$	328.701	3.693E−02			38.96
$4s8s\,^3S_1$	$4s6p\,^3P_0$	3101.901	8.286E−04			0.87
$4s8s\,^3S_1$	$4s6p\,^3P_1$	3105.619	2.469E−03			2.61
$4s8s\,^3S_1$	$4s6p\,^3P_2$	3113.238	4.063E−03			4.29
$4s8s\,^3S_1$	$4snp\,^1P_1$	5539.552	1.078E−08			0.00
$4s8s\,^3S_1$	$4s5f\,^3F_2$	10245.272	2.432E−13			0.00
$4s8s\,^3S_1$	$4s7p\,^3P_0$	12771.229	7.410E−04			0.78
$4s8s\,^3S_1$	$4s7p\,^3P_1$	12803.769	2.215E−03			2.34
$4s8s\,^3S_1$	$4s7p\,^3P_2$	12871.338	3.664E−03			3.87
$4s8s\,^3S_1$	$4s7p\,^1P_1$	31916.252	2.029E−08			0.00
$4s8s\,^3S_1$	$4s4p\,^1P_1$	452.768	2.558E−07			0.00
$4s8s\,^1S_0$	$4s5p\,^3P_1$	1071.530	1.821E−04			0.29
$4s8s\,^1S_0$	$4s5p\,^1P_1$	1092.230	1.964E−02			30.78
$4s8s\,^1S_0$	$3d4p\,^3D_1$	1299.577	9.657E−06			0.02
$4s8s\,^1S_0$	$3d4p\,^3P_1$	1526.279	7.658E−07			0.00
$4s8s\,^1S_0$	$4s4p\,^3P_1$	325.976	6.115E−08			0.00
$4s8s\,^1S_0$	$4s6p\,^1P_1$	2376.319	6.149E−03			9.63
$4s8s\,^1S_0$	$4s6p\,^3P_1$	2968.689	1.757E−07			0.00
$4s8s\,^1S_0$	$4snp\,^1P_1$	5118.441	7.344E−05			0.12
$4s8s\,^1S_0$	$4s7p\,^3P_1$	10758.009	5.245E−07			0.00
$4s8s\,^1S_0$	$4s7p\,^1P_1$	21652.520	2.071E−03			3.25
$4s8s\,^1S_0$	$4s4p\,^1P_1$	449.743	3.569E−02			55.93

Table 3
Spontaneous emission rates of transitions originating from the 4s*n*p ($n = 4$–7) states of Ca I.

Transition		λ (nm)	A_{if} (10^8 s^{-1})		Diff. (%)	BR. (%)
Initial	Final		*L*	*V*		
$4s4p\,^3P_1$	$4s^2\,^1S_0$	657.460	2.738E−05	3.531E−05	−28.98	100.00
$4s4p\,^1P_1$	$4s^2\,^1S_0$	422.792	2.170E+00	2.327E+00	−7.20	100.00
$4s4p\,^1P_1$	$3d4s\,^3D_1$	3014.827	3.767E−08	4.832E−08	−28.27	0.00
$4s4p\,^1P_1$	$3d4s\,^3D_2$	3027.514	1.000E−07	3.825E−07	−282.52	0.00
$4s4p\,^1P_1$	$3d4s\,^1D_2$	5547.327	5.341E−05	2.287E−06	95.72	0.00
$4s5p\,^3P_0$	$4s5s\,^3S_1$	1996.729	7.103E−02	7.143E−02	−0.55	40.46
$4s5p\,^3P_0$	$3d4s\,^3D_1$	616.814	1.045E−01	1.102E−01	−5.38	59.54
$4s5p\,^3P_1$	$4s5s\,^3S_1$	1993.919	7.055E−02	7.096E−02	−0.58	40.15
$4s5p\,^3P_1$	$4s^2\,^1S_0$	273.562	2.340E−06	4.425E−05	−1790.81	0.00
$4s5p\,^3P_1$	$4s5s\,^1S_0$	3088.813	2.055E−04	2.050E−04	0.24	0.12
$4s5p\,^3P_1$	$3d4s\,^3D_1$	616.546	2.532E−02	2.667E−02	−5.34	14.41
$4s5p\,^3P_1$	$3d4s\,^3D_2$	617.075	7.859E−02	8.296E−02	−5.55	44.73
$4s5p\,^3P_1$	$3d4s\,^1D_2$	680.035	1.051E−03	1.177E−03	−11.99	0.60
$4s5p\,^3P_2$	$4s5s\,^3S_1$	1985.853	7.180E−02	7.223E−02	−0.60	40.59
$4s5p\,^3P_2$	$3d4s\,^3D_1$	615.773	6.273E−04	6.834E−04	−8.93	0.35
$4s5p\,^3P_2$	$3d4s\,^3D_2$	616.300	1.558E−02	1.638E−02	−5.14	8.81
$4s5p\,^3P_2$	$3d4s\,^3D_3$	617.127	8.710E−02	9.206E−02	−5.69	49.24
$4s5p\,^3P_2$	$3d4s\,^1D_2$	679.095	1.792E−03	2.000E−03	−11.62	1.01
$4s5p\,^1P_1$	$4s5s\,^3S_1$	1925.996	7.950E−04	7.974E−04	−0.30	0.49
$4s5p\,^1P_1$	$4s^2\,^1S_0$	272.245	7.505E−03	1.833E−02	−144.27	4.62
$4s5p\,^1P_1$	$4s5s\,^1S_0$	2928.807	2.361E−02	2.339E−02	0.95	14.52
$4s5p\,^1P_1$	$3d4s\,^3D_1$	609.895	3.978E−04	4.252E−04	−6.88	0.24
$4s5p\,^1P_1$	$3d4s\,^3D_2$	610.413	2.354E−04	2.298E−04	2.38	0.14
$4s5p\,^1P_1$	$3d4s\,^1D_2$	671.953	1.301E−01	1.446E−01	−11.19	79.98
$4s6p\,^1P_1$	$4s5s\,^3S_1$	986.241	5.599E−08	5.809E−08	−3.74	0.00
$4s6p\,^1P_1$	$4s^2\,^1S_0$	239.929	9.182E−02	8.164E−02	11.09	25.41
$4s6p\,^1P_1$	$4s5s\,^1S_0$	1195.922	1.516E−02	1.561E−02	−2.92	4.20
$4s6p\,^1P_1$	$4s4d\,^1D_2$	2282.730	1.407E−02	1.541E−02	−9.50	3.89
$4s6p\,^1P_1$	$4s4d\,^3D_1$	2544.005	2.339E−09	9.781E−09	−318.22	0.00
$4s6p\,^1P_1$	$4s4d\,^3D_2$	2546.382	1.725E−06	2.001E−06	−16.02	0.00
$4s6p\,^1P_1$	$4p^2\,^3P_0$	3066.102	2.017E−06	1.819E−06	9.82	0.00
$4s6p\,^1P_1$	$4p^2\,^3P_1$	3111.194	5.703E−09	4.304E−09	24.53	0.00
$4s6p\,^1P_1$	$4p^2\,^3P_2$	3197.493	7.016E−06	6.775E−06	3.43	0.00
$4s6p\,^1P_1$	$4s6s\,^3S_1$	8300.339	1.476E−08	1.402E−08	5.02	0.00
$4s6p\,^1P_1$	$4s6s\,^1S_0$	10115.622	1.605E−03	1.577E−03	1.75	0.44
$4s6p\,^1P_1$	$4p^2\,^1D_2$	10425.789	7.877E−04	6.658E−04	15.47	0.22
$4s6p\,^1P_1$	$3d4s\,^3D_1$	468.523	6.442E−07	1.470E−07	77.18	0.00
$4s6p\,^1P_1$	$3d4s\,^3D_2$	468.829	2.073E−05	2.677E−05	−29.15	0.01
$4s6p\,^1P_1$	$3d4s\,^1D_2$	504.302	2.379E−01	2.744E−01	−15.35	65.83
$4s6p\,^3P_0$	$4s5s\,^3S_1$	911.133	7.945E−03	8.043E−03	−1.23	15.61
$4s6p\,^3P_0$	$4s4d\,^3D_1$	2097.909	7.984E−03	7.472E−03	6.42	15.69
$4s6p\,^3P_0$	$4p^2\,^3P_1$	2469.111	4.647E−06	1.928E−06	58.52	0.01
$4s6p\,^3P_0$	$4s6s\,^3S_1$	4900.495	1.618E−02	1.650E−02	−1.97	31.79
$4s6p\,^3P_0$	$3d4s\,^3D_1$	450.867	1.878E−02	2.995E−02	−59.42	36.90
$4s6p\,^3P_1$	$4s5s\,^3S_1$	910.812	8.107E−03	8.203E−03	−1.19	15.85
$4s6p\,^3P_1$	$4s^2\,^1S_0$	235.191	1.122E−08	4.799E−08	−327.69	0.00
$4s6p\,^3P_1$	$4s5s\,^1S_0$	1086.785	1.281E−08	3.164E−08	−146.98	0.00
$4s6p\,^3P_1$	$4s4d\,^1D_2$	1915.555	2.977E−07	2.213E−07	25.66	0.00
$4s6p\,^3P_1$	$4s4d\,^3D_1$	2096.212	1.976E−03	1.848E−03	6.49	3.86
$4s6p\,^3P_1$	$4s4d\,^3D_2$	2097.826	5.964E−03	5.579E−03	6.45	11.66
$4s6p\,^3P_1$	$4p^2\,^3P_0$	2438.329	2.340E−08	6.862E−08	−193.25	0.00
$4s6p\,^3P_1$	$4p^2\,^3P_1$	2466.760	6.170E−07	1.982E−07	67.88	0.00
$4s6p\,^3P_1$	$4p^2\,^3P_2$	2520.701	1.270E−06	3.888E−07	69.38	0.00
$4s6p\,^3P_1$	$4s6s\,^3S_1$	4891.243	1.625E−02	1.657E−02	−1.96	31.78
$4s6p\,^3P_1$	$4s6s\,^1S_0$	5469.652	2.777E−08	3.211E−08	−15.61	0.00
$4s6p\,^3P_1$	$4p^2\,^1D_2$	5559.076	9.162E−09	5.895E−09	35.66	0.00
$4s6p\,^3P_1$	$4p^2\,^1S_0$	13653.182	5.670E−10	3.303E−10	41.75	0.00
$4s6p\,^3P_1$	$3d4s\,^3D_1$	450.789	4.808E−03	7.627E−03	−58.62	9.40
$4s6p\,^3P_1$	$3d4s\,^3D_2$	451.071	1.403E−02	2.241E−02	−59.70	27.43
$4s6p\,^3P_1$	$3d4s\,^1D_2$	483.814	2.442E−06	2.156E−06	11.73	0.00
$4s6p\,^3P_2$	$4s5s\,^3S_1$	910.159	8.442E−03	8.542E−03	−1.18	16.34
$4s6p\,^3P_2$	$4s4d\,^1D_2$	1912.668	1.141E−07	1.298E−07	−13.73	0.00
$4s6p\,^3P_2$	$4s4d\,^3D_1$	2092.755	7.728E−05	7.217E−05	6.62	0.15
$4s6p\,^3P_2$	$4s4d\,^3D_2$	2094.364	1.168E−03	1.091E−03	6.57	2.26
$4s6p\,^3P_2$	$4s4d\,^3D_3$	2096.814	6.602E−03	6.170E−03	6.54	12.78
$4s6p\,^3P_2$	$4p^2\,^3P_1$	2461.975	9.452E−07	1.747E−06	−84.89	0.00
$4s6p\,^3P_2$	$4p^2\,^3P_2$	2515.704	1.001E−08	4.894E−07	−4791.12	0.00
$4s6p\,^3P_2$	$4s6s\,^3S_1$	4872.463	1.638E−02	1.671E−02	−1.99	31.71
$4s6p\,^3P_2$	$4p^2\,^1D_2$	5534.831	1.361E−08	1.069E−08	21.42	0.00
$4s6p\,^3P_2$	$3d4s\,^3D_1$	450.628	2.012E−04	3.163E−04	−57.22	0.39

(*continued on next page*)

Table 3 (*continued*)

Transition		λ (nm)	A_{if} (10^8 s^{-1})		Diff. (%)	BR. (%)
Initial	Final		*L*	*V*		
$4s6p\,^3P_2$	$3d4s\,^3D_2$	450.911	2.942E−03	4.653E−03	−58.15	5.69
$4s6p\,^3P_2$	$3d4s\,^3D_3$	451.353	1.585E−02	2.530E−02	−59.67	30.67
$4s6p\,^3P_2$	$3d4s\,^1D_2$	483.630	3.466E−06	4.781E−06	−37.96	0.01
$4snp\,^1P_1$	$4s5s\,^3S_1$	806.843	1.985E−07	1.391E−07	29.94	0.00
$4snp\,^1P_1$	$4s^2\,^1S_0$	227.617	3.246E−01	3.466E−01	−6.80	42.88
$4snp\,^1P_1$	$4s5s\,^1S_0$	941.955	3.895E−02	4.001E−02	−2.71	5.15
$4snp\,^1P_1$	$4s4d\,^1D_2$	1507.116	1.273E−02	1.509E−02	−18.48	1.68
$4snp\,^1P_1$	$4s4d\,^3D_1$	1616.742	6.691E−09	2.113E−08	−215.79	0.00
$4snp\,^1P_1$	$4s4d\,^3D_2$	1617.702	1.500E−06	1.628E−06	−8.50	0.00
$4snp\,^1P_1$	$4p^2\,^3P_0$	1812.928	5.659E−08	2.200E−08	61.12	0.00
$4snp\,^1P_1$	$4p^2\,^3P_1$	1828.598	6.298E−09	1.871E−08	−197.07	0.00
$4snp\,^1P_1$	$4p^2\,^3P_2$	1858.073	1.206E−06	1.524E−06	−26.37	0.00
$4snp\,^1P_1$	$4s6s\,^3S_1$	2890.808	8.702E−08	1.053E−07	−21.02	0.00
$4snp\,^1P_1$	$4s6s\,^1S_0$	3083.527	6.961E−03	7.698E−03	−10.59	0.92
$4snp\,^1P_1$	$4p^2\,^1D_2$	3111.746	7.630E−04	8.518E−04	−11.63	0.10
$4snp\,^1P_1$	$4p^2\,^1S_0$	4657.228	3.175E−03	3.202E−03	−0.85	0.42
$4snp\,^1P_1$	$4s5d\,^3D_1$	8399.973	1.344E−08	1.665E−08	−23.86	0.00
$4snp\,^1P_1$	$4s5d\,^3D_2$	8412.127	2.373E−07	1.846E−07	22.23	0.00
$4snp\,^1P_1$	$4s5d\,^1D_2$	9857.753	2.552E−03	2.015E−03	21.02	0.34
$4snp\,^1P_1$	$3d^2\,^3F_2$	21803.118	2.171E−08	1.501E−08	30.87	0.00
$4snp\,^1P_1$	$3d4s\,^3D_1$	423.763	7.516E−07	2.790E−07	62.87	0.00
$4snp\,^1P_1$	$3d4s\,^3D_2$	424.012	5.665E−06	5.933E−06	−4.74	0.00
$4snp\,^1P_1$	$3d4s\,^1D_2$	452.820	3.673E−01	4.427E−01	−20.53	48.52
$4s7p\,^3P_0$	$4s5s\,^3S_1$	745.369	1.781E−03	1.925E−03	−8.08	9.79
$4s7p\,^3P_0$	$4s4d\,^3D_1$	1387.449	5.557E−03	5.436E−03	2.17	30.55
$4s7p\,^3P_0$	$4p^2\,^3P_1$	1540.628	3.888E−06	3.340E−06	14.10	0.02
$4s7p\,^3P_0$	$4s6s\,^3S_1$	2231.431	2.027E−03	1.651E−03	18.56	11.14
$4s7p\,^3P_0$	$4s5d\,^3D_1$	4519.427	4.666E−03	2.823E−03	39.50	25.66
$4s7p\,^3P_0$	$3d4s\,^3D_1$	406.169	1.349E−03	3.243E−03	−140.39	7.42
$4s7p\,^3P_0$	$4s7s\,^3S_1$	10257.462	2.804E−03	4.161E−03	−48.38	15.42
$4s7p\,^3P_1$	$4s5s\,^3S_1$	745.259	1.866E−03	2.014E−03	−7.91	10.19
$4s7p\,^3P_1$	$4s^2\,^1S_0$	222.432	2.344E−07	3.119E−08	86.69	0.00
$4s7p\,^3P_1$	$4s5s\,^1S_0$	859.077	7.106E−08	3.350E−08	52.85	0.00
$4s7p\,^3P_1$	$4s4d\,^1D_2$	1305.590	4.279E−07	3.715E−07	13.17	0.00
$4s7p\,^3P_1$	$4s4d\,^3D_1$	1387.066	1.376E−03	1.346E−03	2.22	7.52
$4s7p\,^3P_1$	$4s4d\,^3D_2$	1387.773	4.153E−03	4.062E−03	2.19	22.68
$4s7p\,^3P_1$	$4p^2\,^3P_0$	1529.024	5.358E−08	2.853E−08	46.76	0.00
$4s7p\,^3P_1$	$4p^2\,^3P_1$	1540.156	5.720E−07	4.865E−07	14.96	0.00
$4s7p\,^3P_1$	$4p^2\,^3P_2$	1561.012	1.080E−06	8.977E−07	16.87	0.01
$4s7p\,^3P_1$	$4s6s\,^3S_1$	2230.440	2.065E−03	1.684E−03	18.47	11.28
$4s7p\,^3P_1$	$4s6s\,^1S_0$	2343.446	5.201E−09	7.345E−09	−41.23	0.00
$4s7p\,^3P_1$	$4p^2\,^1D_2$	2359.709	6.693E−09	1.793E−08	−167.98	0.00
$4s7p\,^3P_1$	$4p^2\,^1S_0$	3153.201	1.366E−07	1.495E−07	−9.47	0.00
$4s7p\,^3P_1$	$4s5d\,^3D_1$	4515.366	1.159E−03	7.005E−04	39.58	6.33
$4s7p\,^3P_1$	$4s5d\,^3D_2$	4518.875	3.489E−03	2.109E−03	39.57	19.05
$4s7p\,^3P_1$	$4s5d\,^1D_2$	4905.303	9.373E−08	7.250E−08	22.64	0.00
$4s7p\,^3P_1$	$3d^2\,^3F_2$	6743.861	1.526E−11	2.413E−13	98.42	0.00
$4s7p\,^3P_1$	$3d4s\,^3D_1$	406.136	3.506E−04	8.310E−04	−137.01	1.91
$4s7p\,^3P_1$	$4s7s\,^3S_1$	10236.567	2.815E−03	4.179E−03	−48.48	15.37
$4s7p\,^3P_1$	$4s7s\,^1S_0$	14681.701	6.269E−08	8.214E−08	−31.03	0.00
$4s7p\,^3P_1$	$3d4s\,^3D_2$	406.365	1.029E−03	2.465E−03	−139.62	5.62
$4s7p\,^3P_1$	$3d4s\,^1D_2$	432.750	4.981E−06	5.234E−06	−5.06	0.03
$4s7p\,^3P_2$	$4s5s\,^3S_1$	745.031	2.047E−03	2.203E−03	−7.63	11.03
$4s7p\,^3P_2$	$4s4d\,^1D_2$	1304.892	8.304E−08	9.558E−08	−15.10	0.00
$4s7p\,^3P_2$	$4s4d\,^3D_1$	1386.278	5.391E−05	5.267E−05	2.30	0.29
$4s7p\,^3P_2$	$4s4d\,^3D_2$	1386.984	8.143E−04	7.958E−04	2.27	4.39
$4s7p\,^3P_2$	$4s4d\,^3D_3$	1388.058	4.603E−03	4.500E−03	2.24	24.81
$4s7p\,^3P_2$	$4p^2\,^3P_1$	1539.184	4.980E−07	5.495E−07	−10.35	0.00
$4s7p\,^3P_2$	$4p^2\,^3P_2$	1560.014	1.123E−08	4.110E−10	96.34	0.00
$4s7p\,^3P_2$	$4s6s\,^3S_1$	2228.402	2.145E−03	1.752E−03	18.29	11.56
$4s7p\,^3P_2$	$4p^2\,^1D_2$	2357.429	6.802E−09	7.577E−09	−11.39	0.00
$4s7p\,^3P_2$	$4s5d\,^3D_1$	4507.022	4.580E−05	2.759E−05	39.75	0.25
$4s7p\,^3P_2$	$4s5d\,^3D_2$	4510.519	6.890E−04	4.152E−04	39.74	3.71
$4s7p\,^3P_2$	$4s5d\,^3D_3$	4515.957	3.876E−03	2.337E−03	39.71	20.89
$4s7p\,^3P_2$	$4s5d\,^1D_2$	4895.458	1.470E−07	8.716E−08	40.69	0.00
$4s7p\,^3P_2$	$3d^2\,^3F_2$	6725.266	1.161E−13	2.007E−12	−1627.75	0.00
$4s7p\,^3P_2$	$3d4s\,^3D_1$	406.068	1.509E−05	3.487E−05	−131.15	0.08
$4s7p\,^3P_2$	$3d^2\,^3F_3$	6790.526	3.141E−15	1.968E−11		0.00
$4s7p\,^3P_2$	$4s7s\,^3S_1$	10193.784	2.836E−03	4.219E−03	−48.74	15.29
$4s7p\,^3P_2$	$3d4s\,^3D_2$	406.298	2.219E−04	5.176E−04	−133.28	1.20
$4s7p\,^3P_2$	$3d4s\,^3D_3$	406.657	1.204E−03	2.852E−03	−136.81	6.49

(*continued on next page*)

Table 3 (*continued*)

Transition		λ (nm)	A_{if} (10^8 s^{-1})		Diff. (%)	BR. (%)
Initial	Final		*L*	*V*		
$4s7p\ ^3P_2$	$3d4s\ ^1D_2$	432.673	7.948E−08	2.350E−07	−195.65	0.00
$4s7p\ ^1P_1$	$4s5s\ ^3S_1$	720.157	1.497E−06	1.062E−06	29.07	0.00
$4s7p\ ^1P_1$	$4s^2\ ^1S_0$	220.141	1.295E−01			55.13
$4s7p\ ^1P_1$	$4s5s\ ^1S_0$	825.893	1.135E−02	1.209E−02	−6.49	2.79
$4s7p\ ^1P_1$	$4s4d\ ^1D_2$	1230.456	4.083E−03	5.034E−03	−23.28	1.00
$4s7p\ ^1P_1$	$4s4d\ ^3D_1$	1302.565	1.678E−09	1.352E−08	−705.49	0.00
$4s7p\ ^1P_1$	$4s4d\ ^3D_2$	1303.188	2.058E−07	2.067E−07	−0.45	0.00
$4s7p\ ^1P_1$	$4p^2\ ^3P_0$	1426.977	5.766E−07	4.382E−07	24.01	0.00
$4s7p\ ^1P_1$	$4p^2\ ^3P_1$	1436.668	3.708E−08	1.279E−07	−245.02	0.00
$4s7p\ ^1P_1$	$4p^2\ ^3P_2$	1454.799	2.469E−07	1.081E−06	−337.68	0.00
$4s7p\ ^1P_1$	$4s6s\ ^3S_1$	2019.745	7.975E−07	6.883E−07	13.69	0.00
$4s7p\ ^1P_1$	$4s6s\ ^1S_0$	2111.968	4.763E−03	4.261E−03	10.53	1.17
$4s7p\ ^1P_1$	$4p^2\ ^1D_2$	2125.168	1.349E−03	1.870E−03	−38.60	0.33
$4s7p\ ^1P_1$	$4p^2\ ^1S_0$	2747.947	7.203E−07	5.423E−05	−7429.71	0.00
$4s7p\ ^1P_1$	$4s5d\ ^3D_1$	3728.060	5.631E−09	4.271E−10	92.42	0.00
$4s7p\ ^1P_1$	$4s5d\ ^3D_2$	3730.452	1.906E−10	3.758E−09	−1872.01	0.00
$4s7p\ ^1P_1$	$4s5d\ ^1D_2$	3989.929	7.689E−04	1.177E−04	84.70	0.19
$4s7p\ ^1P_1$	$3d^2\ ^3F_2$	5126.812	3.402E−07	1.639E−07	51.81	0.00
$4s7p\ ^1P_1$	$3d4s\ ^3D_1$	398.565	1.918E−09	3.078E−08	−1504.30	0.00
$4s7p\ ^1P_1$	$4s7s\ ^3S_1$	6922.379	2.786E−07	5.027E−07	−80.46	0.00
$4s7p\ ^1P_1$	$4s7s\ ^1S_0$	8704.584	2.597E−03	4.065E−03	−56.57	0.64
$4s7p\ ^1P_1$	$3d4s\ ^3D_2$	398.786	1.169E−05	1.428E−05	−22.12	0.00
$4s7p\ ^1P_1$	$4s6d\ ^1D_2$	22960.531	4.250E−04	1.325E−04	68.83	0.10
$4s7p\ ^1P_1$	$4s6d\ ^3D_1$	26575.248	6.286E−09	3.545E−09	43.61	0.00
$4s7p\ ^1P_1$	$4s6d\ ^3D_2$	26670.934	6.608E−07	1.930E−07	70.80	0.00
$4s7p\ ^1P_1$	$3d4s\ ^1D_2$	424.165	1.575E−01	1.942E−01	−23.35	38.64

Table 4
Spontaneous emission rates of transitions originating from the 4s*n*d ($n = 3$–6) states of Ca I.

Transition		λ (nm)	A_{if} (10^8 s^{-1})		Diff. (%)	BR. (%)
Initial	Final		*L*	*V*		
$3d4s\ ^3D_1$	$4s4p\ ^3P_0$	1931.449	4.891E−03	4.940E−03	−0.99	56.36
$3d4s\ ^3D_1$	$4s4p\ ^3P_1$	1951.105	3.564E−03	3.604E−03	−1.11	41.06
$3d4s\ ^3D_1$	$4s4p\ ^3P_2$	1992.262	2.239E−04	2.271E−04	−1.46	2.58
$3d4s\ ^3D_2$	$4s4p\ ^3P_1$	1945.828	6.467E−03	6.537E−03	−1.07	76.09
$3d4s\ ^3D_2$	$4s4p\ ^3P_2$	1986.760	2.032E−03	2.060E−03	−1.37	23.91
$3d4s\ ^3D_3$	$4s4p\ ^3P_2$	1978.216	8.240E−03	8.340E−03	−1.22	100.00
$3d4s\ ^1D_2$	$4s4p\ ^3P_1$	1506.122	4.059E−06	3.854E−06	5.05	83.12
$3d4s\ ^1D_2$	$4s4p\ ^3P_2$	1530.529	8.245E−07	4.298E−07	47.87	16.88
$4s4d\ ^1D_2$	$3d4p\ ^3F_2$	6378.202	1.341E−05	4.334E−06	67.69	0.01
$4s4d\ ^1D_2$	$3d4p\ ^3F_3$	6758.675	2.997E−12	9.405E−10		0.00
$4s4d\ ^1D_2$	$3d4p\ ^1D_2$	6835.831	2.778E−05	7.399E−06	73.37	0.02
$4s4d\ ^1D_2$	$4s5p\ ^3P_1$	13449.176	3.410E−06	3.878E−06	−13.75	0.00
$4s4d\ ^1D_2$	$4s5p\ ^3P_2$	13828.007	3.794E−08	1.751E−08	53.85	0.00
$4s4d\ ^1D_2$	$4s5p\ ^1P_1$	17646.955	1.270E−04	1.479E−04	−16.46	0.08
$4s4d\ ^1D_2$	$4s4p\ ^3P_1$	452.730	4.043E−06	2.354E−06	41.76	0.00
$4s4d\ ^1D_2$	$4s4p\ ^3P_2$	454.910	2.657E−04	2.853E−04	−7.37	0.17
$4s4d\ ^1D_2$	$4s4p\ ^1P_1$	732.816	1.601E−01	1.521E−01	5.04	99.73
$4s4d\ ^3D_1$	$3d4p\ ^3F_2$	4956.015	8.657E−05	3.087E−04	−256.62	0.01
$4s4d\ ^3D_1$	$3d4p\ ^1D_2$	5227.965	2.133E−05	9.554E−05	−347.94	0.00
$4s4d\ ^3D_1$	$4s5p\ ^3P_0$	8329.793	8.753E−04	8.950E−04	−2.25	0.11
$4s4d\ ^3D_1$	$4s5p\ ^3P_1$	8379.069	6.389E−04	6.531E−04	−2.23	0.08
$4s4d\ ^3D_1$	$4s5p\ ^3P_2$	8524.568	4.144E−05	4.311E−05	−4.02	0.01
$4s4d\ ^3D_1$	$4s5p\ ^1P_1$	9836.904	4.067E−06	4.195E−06	−3.15	0.00
$4s4d\ ^3D_1$	$4s4p\ ^3P_0$	442.668	4.415E−01	4.444E−01	−0.66	56.18
$4s4d\ ^3D_1$	$4s4p\ ^3P_1$	443.692	3.223E−01	3.239E−01	−0.50	41.01
$4s4d\ ^3D_1$	$4s4p\ ^3P_2$	445.787	2.034E−02	2.038E−02	−0.19	2.59
$4s4d\ ^3D_1$	$4s4p\ ^1P_1$	709.426	1.472E−05	1.545E−05	−4.93	0.00
$4s4d\ ^3D_2$	$3d4p\ ^3F_2$	4947.017	4.947E−06	2.471E−05	−399.44	0.00
$4s4d\ ^3D_2$	$3d4p\ ^3F_3$	5172.878	9.036E−05	3.505E−04	−287.87	0.01
$4s4d\ ^3D_2$	$3d4p\ ^1D_2$	5217.954	1.436E−05	3.049E−05	−112.32	0.00
$4s4d\ ^3D_2$	$4s5p\ ^3P_1$	8353.381	1.159E−03	1.185E−03	−2.32	0.15
$4s4d\ ^3D_2$	$4s5p\ ^3P_2$	8497.982	3.700E−04	3.778E−04	−2.11	0.05
$4s4d\ ^3D_2$	$4s5p\ ^1P_1$	9801.519	8.902E−06	9.008E−06	−1.20	0.00
$4s4d\ ^3D_2$	$4s4p\ ^3P_1$	443.620	5.939E−01	5.979E−01	−0.66	75.78
$4s4d\ ^3D_2$	$4s4p\ ^3P_2$	445.714	1.882E−01	1.889E−01	−0.38	24.01
$4s4d\ ^3D_2$	$4s4p\ ^1P_1$	709.241	5.037E−05	4.876E−05	3.20	0.01
$4s4d\ ^3D_3$	$3d4p\ ^3F_2$	4933.399	4.148E−06	6.231E−06	−50.22	0.00
$4s4d\ ^3D_3$	$3d4p\ ^3F_3$	5157.989	8.396E−06	3.183E−05	−279.06	0.00
$4s4d\ ^3D_3$	$3d4p\ ^1D_2$	5202.805	1.347E−05	1.265E−05	6.12	0.00
$4s4d\ ^3D_3$	$3d4p\ ^3F_4$	5374.726	8.476E−05	3.470E−04	−309.41	0.01
$4s4d\ ^3D_3$	$4s5p\ ^3P_2$	8457.876	1.506E−03	1.542E−03	−2.44	0.19
$4s4d\ ^3D_3$	$4s4p\ ^3P_2$	445.603	7.793E−01	7.841E−01	−0.62	99.79
$4s5d\ ^3D_1$	$3d4p\ ^3F_2$	1426.015	5.674E−04	9.580E−04	−68.85	0.14
$4s5d\ ^3D_1$	$3d4p\ ^1D_2$	1447.683	2.901E−04	4.608E−04	−58.87	0.07
$4s5d\ ^3D_1$	$4s5p\ ^3P_0$	1614.124	2.721E−02	2.712E−02	0.35	6.71
$4s5d\ ^3D_1$	$4s5p\ ^3P_1$	1615.966	2.024E−02	2.017E−02	0.34	4.99
$4s5d\ ^3D_1$	$4s5p\ ^3P_2$	1621.303	1.351E−03	1.341E−03	0.71	0.33
$4s5d\ ^3D_1$	$4s5p\ ^1P_1$	1663.512	2.278E−04	2.272E−04	0.29	0.06
$4s5d\ ^3D_1$	$4s4p\ ^3P_0$	362.515	1.927E−01	1.949E−01	−1.17	47.50
$4s5d\ ^3D_1$	$3d4p\ ^3D_1$	2197.508	3.832E−04	3.482E−04	9.15	0.09
$4s5d\ ^3D_1$	$3d4p\ ^3D_2$	2210.492	1.230E−04	1.118E−04	9.10	0.03
$4s5d\ ^3D_1$	$3d4p\ ^3P_0$	2932.878	3.953E−03	4.409E−03	−11.52	0.97
$4s5d\ ^3D_1$	$4s4p\ ^3P_1$	363.201	1.452E−01	1.469E−01	−1.17	35.80
$4s5d\ ^3D_1$	$3d4p\ ^3P_1$	2934.548	2.947E−03	3.285E−03	−11.49	0.73
$4s5d\ ^3D_1$	$3d4p\ ^3P_2$	2938.653	1.943E−04	2.166E−04	−11.48	0.05
$4s5d\ ^3D_1$	$4s6p\ ^1P_1$	9398.585	7.140E−09	1.133E−08	−58.67	0.00
$4s5d\ ^3D_1$	$4s4f\ ^3F_2$	17458.405	4.014E−04	3.943E−04	1.77	0.10
$4s5d\ ^3D_1$	$4s4p\ ^3P_2$	364.603	9.773E−03	9.890E−03	−1.20	2.41
$4s5d\ ^3D_1$	$4s6p\ ^3P_0$	43830.813	2.419E−05	3.547E−05	−46.67	0.01
$4s5d\ ^3D_1$	$4s6p\ ^3P_1$	44585.135	1.724E−05	2.545E−05	−47.63	0.00
$4s5d\ ^3D_1$	$4s6p\ ^3P_2$	46208.586	1.033E−06	1.547E−06	−49.79	0.00
$4s5d\ ^3D_1$	$4s4p\ ^1P_1$	523.815	4.670E−06	5.065E−06	−8.45	0.00
$4s5d\ ^3D_2$	$3d4p\ ^3F_2$	1425.665	1.123E−04	1.667E−04	−48.50	0.03
$4s5d\ ^3D_2$	$3d4p\ ^3F_3$	1443.833	7.112E−04	1.197E−03	−68.34	0.18
$4s5d\ ^3D_2$	$3d4p\ ^1D_2$	1447.323	1.035E−06	3.266E−07	68.44	0.00
$4s5d\ ^3D_2$	$4s5p\ ^3P_1$	1615.517	3.645E−02	3.632E−02	0.36	9.01
$4s5d\ ^3D_2$	$4s5p\ ^3P_2$	1620.851	1.231E−02	1.227E−02	0.27	3.04
$4s5d\ ^3D_2$	$4s5p\ ^1P_1$	1663.036	2.945E−04	2.945E−04	0.02	0.07
$4s5d\ ^3D_2$	$3d4p\ ^3D_1$	2196.677	4.749E−05	4.072E−05	14.27	0.01
$4s5d\ ^3D_2$	$3d4p\ ^3D_2$	2209.652	3.503E−04	3.173E−04	9.44	0.09

(*continued on next page*)

Table 4 (*continued*)

Transition		λ (nm)	A_{if} (10^8 s^{-1})		Diff. (%)	BR. (%)
Initial	Final		L	V		
$4s5d\,^3D_2$	$3d4p\,^3D_3$	2229.356	7.036E−05	6.352E−05	9.73	0.02
$4s5d\,^3D_2$	$4s4p\,^3P_1$	363.179	2.593E−01	2.624E−01	−1.18	64.09
$4s5d\,^3D_2$	$3d4p\,^3P_1$	2933.067	5.367E−03	5.986E−03	−11.54	1.33
$4s5d\,^3D_2$	$3d4p\,^3P_2$	2937.168	1.768E−03	1.971E−03	−11.51	0.44
$4s5d\,^3D_2$	$3d4p\,^1F_3$	4531.387	1.324E−07	1.016E−07	23.28	0.00
$4s5d\,^3D_2$	$4s6p\,^1P_1$	9383.416	3.239E−07	3.478E−07	−7.38	0.00
$4s5d\,^3D_2$	$4s4f\,^3F_2$	17406.137	4.516E−05	4.435E−05	1.79	0.01
$4s5d\,^3D_2$	$4s4f\,^3F_3$	17416.748	3.588E−04	3.525E−04	1.76	0.09
$4s5d\,^3D_2$	$4s4p\,^3P_2$	364.581	8.734E−02	8.839E−02	−1.20	21.59
$4s5d\,^3D_2$	$4s4f\,^1F_3$	24929.574	1.528E−08	1.641E−08	−7.36	0.00
$4s5d\,^3D_2$	$4s6p\,^3P_1$	44245.830	3.176E−05	4.678E−05	−47.29	0.01
$4s5d\,^3D_2$	$4s6p\,^3P_2$	45844.221	9.520E−06	1.422E−05	−49.42	0.00
$4s5d\,^3D_2$	$4s4p\,^1P_1$	523.768	2.267E−05	2.414E−05	−6.45	0.01
$4s5d\,^3D_3$	$3d4p\,^3F_2$	1425.123	1.057E−05	8.168E−06	22.72	0.00
$4s5d\,^3D_3$	$3d4p\,^3F_3$	1443.276	6.712E−05	1.117E−04	−66.44	0.02
$4s5d\,^3D_3$	$3d4p\,^1D_2$	1446.763	1.651E−04	1.682E−04	−1.83	0.04
$4s5d\,^3D_3$	$3d4p\,^3F_4$	1459.747	7.044E−04	1.199E−03	−70.24	0.17
$4s5d\,^3D_3$	$4s5p\,^3P_2$	1620.149	4.895E−02	4.878E−02	0.36	12.15
$4s5d\,^3D_3$	$3d4p\,^3D_2$	2208.349	2.401E−05	1.934E−05	19.47	0.01
$4s5d\,^3D_3$	$3d4p\,^3D_3$	2228.030	3.871E−04	3.443E−04	11.04	0.10
$4s5d\,^3D_3$	$3d4p\,^3P_2$	2934.867	7.191E−03	8.024E−03	−11.59	1.78
$4s5d\,^3D_3$	$3d4p\,^1F_3$	4525.911	1.350E−08	1.565E−08	−15.96	0.00
$4s5d\,^3D_3$	$4s4f\,^3F_2$	17325.618	9.287E−07	9.121E−07	1.79	0.00
$4s5d\,^3D_3$	$4s4f\,^3F_3$	17336.130	3.247E−05	3.190E−05	1.77	0.01
$4s5d\,^3D_3$	$4s4p\,^3P_2$	364.545	3.451E−01	3.494E−01	−1.23	85.62
$4s5d\,^3D_3$	$4s4f\,^3F_4$	17350.267	3.751E−04	3.686E−04	1.74	0.09
$4s5d\,^3D_3$	$4s4f\,^1F_3$	24764.735	1.063E−11	4.116E−14	99.61	0.00
$4s5d\,^3D_3$	$4s6p\,^3P_2$	45289.855	3.953E−05	5.883E−05	−48.82	0.01
$4s5d\,^1D_2$	$3d4p\,^3F_2$	1391.091	3.178E−04	5.393E−04	−69.70	0.06
$4s5d\,^1D_2$	$3d4p\,^3F_3$	1408.383	1.842E−07	9.196E−08	50.07	0.00
$4s5d\,^1D_2$	$3d4p\,^1D_2$	1411.704	6.727E−04	1.171E−03	−74.00	0.13
$4s5d\,^1D_2$	$4s5p\,^3P_1$	1571.265	2.494E−04	2.510E−04	−0.64	0.05
$4s5d\,^1D_2$	$4s5p\,^3P_2$	1576.310	1.835E−07	7.977E−07	−334.59	0.00
$4s5d\,^1D_2$	$4s5p\,^1P_1$	1616.180	3.302E−02	3.328E−02	−0.79	6.46
$4s5d\,^1D_2$	$3d4p\,^3D_1$	2115.659	6.374E−06	6.799E−06	−6.66	0.00
$4s5d\,^1D_2$	$3d4p\,^3D_2$	2127.691	2.942E−07	2.245E−07	23.69	0.00
$4s5d\,^1D_2$	$3d4p\,^3D_3$	2145.955	1.764E−08	5.117E−08	−190.06	0.00
$4s5d\,^1D_2$	$4s4p\,^3P_1$	360.894	4.989E−06	5.512E−06	−10.48	0.00
$4s5d\,^1D_2$	$3d4p\,^3P_1$	2790.389	2.158E−06	2.145E−06	0.61	0.00
$4s5d\,^1D_2$	$3d4p\,^3P_2$	2794.100	5.239E−07	7.264E−07	−38.65	0.00
$4s5d\,^1D_2$	$3d4p\,^1F_3$	4199.634	1.274E−03	9.537E−04	25.14	0.25
$4s5d\,^1D_2$	$4s6p\,^1P_1$	8064.256	4.324E−03	4.715E−03	−9.06	0.85
$4s5d\,^1D_2$	$4s4f\,^3F_2$	13353.988	1.317E−08	1.371E−08	−4.12	0.00
$4s5d\,^1D_2$	$4s4f\,^3F_3$	13360.232	7.626E−08	7.525E−08	1.33	0.00
$4s5d\,^1D_2$	$4s4p\,^3P_2$	362.278	9.190E−06	1.055E−05	−14.76	0.00
$4s5d\,^1D_2$	$4s4f\,^1F_3$	17377.402	3.433E−04	3.685E−04	−7.32	0.07
$4s5d\,^1D_2$	$4s6p\,^3P_1$	24978.768	2.028E−08	2.336E−08	−15.19	0.00
$4s5d\,^1D_2$	$4s6p\,^3P_2$	25480.304	8.673E−09	9.809E−09	−13.10	0.00
$4s5d\,^1D_2$	$4s4p\,^1P_1$	519.029	4.710E−01	4.953E−01	−5.16	92.13
$4s6d\,^1D_2$	$3d4p\,^3F_2$	1079.986	6.757E−06	8.174E−05	−1109.68	0.00
$4s6d\,^1D_2$	$3d4p\,^3F_3$	1090.379	1.109E−05	1.180E−05	−6.38	0.01
$4s6d\,^1D_2$	$3d4p\,^1D_2$	1092.368	5.667E−05	3.284E−04	−479.57	0.03
$4s6d\,^1D_2$	$4s5p\,^3P_1$	1185.525	9.629E−04	9.650E−04	−0.22	0.47
$4s6d\,^1D_2$	$4s5p\,^3P_2$	1188.395	2.516E−05	3.142E−05	−24.89	0.01
$4s6d\,^1D_2$	$4s5p\,^1P_1$	1210.916	5.046E−02	5.069E−02	−0.45	24.53
$4s6d\,^1D_2$	$3d4p\,^3D_1$	1471.142	2.112E−06	2.190E−06	−3.69	0.00
$4s6d\,^1D_2$	$3d4p\,^3D_2$	1476.950	6.605E−06	6.655E−06	−0.75	0.00
$4s6d\,^1D_2$	$3d4p\,^3D_3$	1485.727	6.257E−06	7.255E−06	−15.94	0.00
$4s6d\,^1D_2$	$4s4p\,^3P_1$	335.798	4.997E−04	5.146E−04	−2.98	0.24
$4s6d\,^1D_2$	$3d4p\,^3P_1$	1768.500	6.652E−08	9.571E−08	−43.88	0.00
$4s6d\,^1D_2$	$3d4p\,^3P_2$	1769.990	3.555E−08	2.483E−08	30.16	0.00
$4s6d\,^1D_2$	$3d4p\,^1F_3$	2246.212	1.202E−03	1.889E−03	−57.15	0.58
$4s6d\,^1D_2$	$4s6p\,^1P_1$	3020.400	7.402E−03	9.236E−03	−24.76	3.60
$4s6d\,^1D_2$	$4s4f\,^3F_2$	3546.577	2.016E−09	1.129E−11	99.44	0.00
$4s6d\,^1D_2$	$4s4f\,^3F_3$	3547.017	2.270E−08	1.627E−09	92.83	0.00
$4s6d\,^1D_2$	$4s4p\,^3P_2$	336.997	1.545E−04	1.594E−04	−3.17	0.08
$4s6d\,^1D_2$	$4s4f\,^1F_3$	3778.947	3.857E−06	2.326E−05	−502.93	0.00
$4s6d\,^1D_2$	$4s6p\,^3P_1$	4046.748	1.297E−05	1.768E−05	−36.33	0.01
$4s6d\,^1D_2$	$4s6p\,^3P_2$	4059.694	4.392E−06	5.752E−06	−30.98	0.00
$4s6d\,^1D_2$	$4snp\,^1P_1$	9466.559	2.409E−03	4.866E−03	−102.02	1.17
$4s6d\,^1D_2$	$4s5f\,^3F_2$	44012.147	1.136E−08	5.438E−09	52.12	0.00

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Table 4 (*continued*)

Transition		λ (nm)	$A_{if}(10^8\ s^{-1})$		Diff. (%)	BR. (%)
Initial	Final		L	V		
$4s6d\ ^1D_2$	$4s5f\ ^3F_3$	44054.804	9.300E−08	4.405E−08	52.63	0.00
$4s6d\ ^1D_2$	$4s5f\ ^1F_3$	54068.667	3.250E−05	1.512E−05	53.47	0.02
$4s6d\ ^1D_2$	$4s7p\ ^3P_1$	310848.617	2.924E−10	1.492E−11	94.90	0.00
$4s6d\ ^1D_2$	$4s7p\ ^3P_2$	356252.227	4.427E−11	1.051E−12	97.63	0.00
$4s6d\ ^1D_2$	$4s4p\ ^1P_1$	468.658	5.757E−02			69.25
$4s6d\ ^3D_1$	$3d4p\ ^3F_2$	1073.120	3.603E−03	4.349E−03	−20.72	0.95
$4s6d\ ^3D_1$	$3d4p\ ^1D_2$	1085.345	1.577E−03	1.884E−03	−19.46	0.42
$4s6d\ ^3D_1$	$4s5p\ ^3P_0$	1176.280	2.879E−02	2.872E−02	0.24	7.62
$4s6d\ ^3D_1$	$4s5p\ ^3P_1$	1177.257	2.135E−02	2.131E−02	0.22	5.65
$4s6d\ ^3D_1$	$4s5p\ ^3P_2$	1180.087	1.379E−03	1.372E−03	0.53	0.36
$4s6d\ ^3D_1$	$4s5p\ ^1P_1$	1202.292	2.353E−04	2.346E−04	0.26	0.06
$4s6d\ ^3D_1$	$4s4p\ ^3P_0$	334.547	1.707E−01	1.759E−01	−3.04	45.16
$4s6d\ ^3D_1$	$3d4p\ ^3D_1$	1458.432	2.695E−03	2.616E−03	2.94	0.71
$4s6d\ ^3D_1$	$3d4p\ ^3D_2$	1464.140	9.003E−04	8.734E−04	2.99	0.24
$4s6d\ ^3D_1$	$3d4p\ ^3P_0$	1749.570	7.835E−05	1.128E−04	−44.03	0.02
$4s6d\ ^3D_1$	$4s4p\ ^3P_1$	335.132	1.280E−01	1.319E−01	−3.03	33.86
$4s6d\ ^3D_1$	$3d4p\ ^3P_1$	1750.164	4.797E−05	7.106E−05	−48.13	0.01
$4s6d\ ^3D_1$	$3d4p\ ^3P_2$	1751.623	1.974E−06	3.170E−06	−60.57	0.00
$4s6d\ ^3D_1$	$4s6p\ ^1P_1$	2967.306	3.408E−09	2.205E−10	93.53	0.00
$4s6d\ ^3D_1$	$4s4f\ ^3F_2$	3473.597	4.555E−07	5.349E−06	−1074.42	0.00
$4s6d\ ^3D_1$	$4s4p\ ^3P_2$	336.325	8.498E−03	8.754E−03	−3.01	2.25
$4s6d\ ^3D_1$	$4s6p\ ^3P_0$	3945.987	5.568E−03	7.494E−03	−34.58	1.47
$4s6d\ ^3D_1$	$4s6p\ ^3P_1$	3952.007	4.186E−03	5.630E−03	−34.50	1.11
$4s6d\ ^3D_1$	$4s6p\ ^3P_2$	3964.353	2.794E−04	3.753E−04	−34.34	0.07
$4s6d\ ^3D_1$	$4snp\ ^1P_1$	8963.867	3.648E−08	6.193E−08	−69.79	0.00
$4s6d\ ^3D_1$	$4s5f\ ^3F_2$	34910.106	1.213E−04	6.145E−05	49.33	0.03
$4s6d\ ^3D_1$	$4s7p\ ^3P_0$	107066.381	2.278E−06	4.384E−07	80.75	0.00
$4s6d\ ^3D_1$	$4s7p\ ^3P_1$	109397.221	1.601E−06	2.851E−07	82.18	0.00
$4s6d\ ^3D_1$	$4s7p\ ^3P_2$	114534.418	9.254E−08	1.398E−08	84.89	0.00
$4s6d\ ^3D_1$	$4s4p\ ^1P_1$	467.360	3.252E−06	3.641E−06	−11.96	0.00
$4s6d\ ^3D_2$	$3d4p\ ^3F_2$	1072.965	5.600E−04	6.729E−04	−20.16	0.15
$4s6d\ ^3D_2$	$3d4p\ ^3F_3$	1083.223	4.395E−03	5.317E−03	−20.97	1.17
$4s6d\ ^3D_2$	$3d4p\ ^1D_2$	1085.186	2.603E−05	3.473E−05	−33.42	0.01
$4s6d\ ^3D_2$	$4s5p\ ^3P_1$	1177.070	3.799E−02	3.790E−02	0.26	10.08
$4s6d\ ^3D_2$	$4s5p\ ^3P_2$	1179.899	1.291E−02	1.289E−02	0.21	3.43
$4s6d\ ^3D_2$	$4s5p\ ^1P_1$	1202.096	8.279E−04	8.295E−04	−0.19	0.22
$4s6d\ ^3D_2$	$3d4p\ ^3D_1$	1458.145	4.962E−04	4.780E−04	3.67	0.13
$4s6d\ ^3D_2$	$3d4p\ ^3D_2$	1463.850	2.428E−03	2.353E−03	3.08	0.64
$4s6d\ ^3D_2$	$3d4p\ ^3D_3$	1472.472	5.408E−04	5.232E−04	3.26	0.14
$4s6d\ ^3D_2$	$4s4p\ ^3P_1$	335.117	2.294E−01	2.365E−01	−3.06	60.89
$4s6d\ ^3D_2$	$3d4p\ ^3P_1$	1749.751	1.170E−04	1.661E−04	−41.91	0.03
$4s6d\ ^3D_2$	$3d4p\ ^3P_2$	1751.209	2.603E−05	3.915E−05	−50.36	0.01
$4s6d\ ^3D_2$	$3d4p\ ^1F_3$	2216.052	1.595E−06	2.762E−06	−73.16	0.00
$4s6d\ ^3D_2$	$4s6p\ ^1P_1$	2966.118	1.247E−05	1.536E−05	−23.22	0.00
$4s6d\ ^3D_2$	$4s4f\ ^3F_2$	3471.969	3.633E−08	6.501E−07	−1689.24	0.00
$4s6d\ ^3D_2$	$4s4f\ ^3F_3$	3472.391	2.941E−07	5.183E−06	−1662.09	0.00
$4s6d\ ^3D_2$	$4s4p\ ^3P_2$	336.310	7.651E−02	7.884E−02	−3.04	20.31
$4s6d\ ^3D_2$	$4s4f\ ^1F_3$	3694.358	1.691E−11	8.874E−08		0.00
$4s6d\ ^3D_2$	$4s6p\ ^3P_1$	3949.899	7.509E−03	1.011E−02	−34.60	1.99
$4s6d\ ^3D_2$	$4s6p\ ^3P_2$	3962.232	2.517E−03	3.383E−03	−34.43	0.67
$4s6d\ ^3D_2$	$4snp\ ^1P_1$	8953.032	5.585E−06	1.077E−05	−92.89	0.00
$4s6d\ ^3D_2$	$4s5f\ ^3F_2$	34746.352	1.366E−05	6.933E−06	49.23	0.00
$4s6d\ ^3D_2$	$4s5f\ ^3F_3$	34772.933	1.088E−04	5.521E−05	49.23	0.03
$4s6d\ ^3D_2$	$4s5f\ ^1F_3$	40726.562	1.239E−07	6.247E−08	49.57	0.00
$4s6d\ ^3D_2$	$4s7p\ ^3P_1$	107805.088	3.007E−06	5.644E−07	81.23	0.00
$4s6d\ ^3D_2$	$4s7p\ ^3P_2$	112790.435	8.756E−07	1.398E−07	84.03	0.00
$4s6d\ ^3D_2$	$4s4p\ ^1P_1$	467.331	3.448E−04	3.640E−04	−5.57	0.09
$4s6d\ ^3D_3$	$3d4p\ ^3F_2$	1072.740	3.034E−06	1.988E−06	34.49	0.00
$4s6d\ ^3D_3$	$3d4p\ ^3F_3$	1082.994	4.090E−04	4.943E−04	−20.86	0.11
$4s6d\ ^3D_3$	$3d4p\ ^1D_2$	1084.956	2.059E−04	2.089E−04	−1.46	0.05
$4s6d\ ^3D_3$	$3d4p\ ^3F_4$	1092.242	4.385E−03	5.331E−03	−21.58	1.17
$4s6d\ ^3D_3$	$4s5p\ ^3P_2$	1179.628	5.147E−02	5.134E−02	0.25	13.70
$4s6d\ ^3D_3$	$3d4p\ ^3D_2$	1463.432	3.365E−04	3.216E−04	4.42	0.09
$4s6d\ ^3D_3$	$3d4p\ ^3D_3$	1472.049	2.951E−03	2.848E−03	3.46	0.79
$4s6d\ ^3D_3$	$3d4p\ ^3P_2$	1750.611	1.644E−04	2.315E−04	−40.83	0.04
$4s6d\ ^3D_3$	$3d4p\ ^1F_3$	2215.095	1.731E−07	1.819E−07	−5.07	0.00
$4s6d\ ^3D_3$	$4s4f\ ^3F_2$	3469.620	4.376E−10	1.488E−08	−3300.03	0.00
$4s6d\ ^3D_3$	$4s4f\ ^3F_3$	3470.041	1.504E−08	5.199E−07	−3357.32	0.00
$4s6d\ ^3D_3$	$4s4p\ ^3P_2$	336.288	3.055E−01	3.149E−01	−3.10	81.33
$4s6d\ ^3D_3$	$4s4f\ ^3F_4$	3470.607	1.790E−07	6.017E−06	−3261.02	0.00
$4s6d\ ^3D_3$	$4s4f\ ^1F_3$	3691.699	5.711E−09	6.355E−09	−11.27	0.00

(*continued on next page*)

Table 4 (*continued*)

Transition		λ (nm)	A_{if} (10^8 s^{-1})		Diff. (%)	BR. (%)
Initial	Final		*L*	*V*		
$4s6d\ ^3D_3$	$4s6p\ ^3P_2$	3959.173	1.005E−02	1.353E−02	−34.57	2.68
$4s6d\ ^3D_3$	$4s5f\ ^3F_2$	34512.511	2.834E−07	1.443E−07	49.09	0.00
$4s6d\ ^3D_3$	$4s5f\ ^3F_3$	34538.735	9.918E−06	5.048E−06	49.10	0.00
$4s6d\ ^3D_3$	$4s5f\ ^3F_4$	34572.169	1.145E−04	5.826E−05	49.11	0.03
$4s6d\ ^3D_3$	$4s5f\ ^1F_3$	40405.673	1.512E−12	1.608E−13	89.36	0.00
$4s6d\ ^3D_3$	$4s7p\ ^3P_2$	110363.095	3.748E−06	6.449E−07	82.79	0.00

Table 5
Spontaneous emission rates of transitions originating from the 4snf (n = 4–6) states of Ca I.

Transition		λ (nm)	A_{if} (10^8 s^{-1})		Diff. (%)	BR. (%)
Initial	Final		L	V		
$4s4f\ ^3F_2$	$4s5s\ ^3S_1$	940.671	2.802E−13	1.357E−13	51.58	0.00
$4s4f\ ^3F_2$	$4s4d\ ^1D_2$	2052.579	1.385E−06	1.352E−06	2.37	0.00
$4s4f\ ^3F_2$	$4s4d\ ^3D_1$	2261.415	8.393E−02	8.413E−02	−0.23	32.22
$4s4f\ ^3F_2$	$4s4d\ ^3D_2$	2263.293	1.559E−02	1.562E−02	−0.21	5.98
$4s4f\ ^3F_2$	$4s4d\ ^3D_3$	2266.155	4.422E−04	4.429E−04	−0.18	0.17
$4s4f\ ^3F_2$	$4p^2\ ^3P_1$	2698.764	2.194E−06	2.208E−06	−0.60	0.00
$4s4f\ ^3F_2$	$4p^2\ ^3P_2$	2763.462	6.099E−07	6.172E−07	−1.21	0.00
$4s4f\ ^3F_2$	$4s6s\ ^3S_1$	5896.331	2.241E−13	2.165E−13	3.39	0.00
$4s4f\ ^3F_2$	$4p^2\ ^1D_2$	6894.840	3.576E−09	4.377E−09	−22.40	0.00
$4s4f\ ^3F_2$	$3d4s\ ^3D_1$	457.983	1.348E−01	1.346E−01	0.12	51.72
$4s4f\ ^3F_2$	$3d4s\ ^3D_2$	458.275	2.508E−02	2.506E−02	0.11	9.63
$4s4f\ ^3F_2$	$3d4s\ ^3D_3$	458.732	7.142E−04	7.134E−04	0.11	0.27
$4s4f\ ^3F_2$	$3d4s\ ^1D_2$	492.112	9.191E−06	9.248E−06	−0.62	0.00
$4s4f\ ^3F_3$	$4s4d\ ^1D_2$	2052.431	1.173E−05	1.187E−05	−1.17	0.00
$4s4f\ ^3F_3$	$4s4d\ ^3D_2$	2263.114	8.863E−02	8.885E−02	−0.24	34.02
$4s4f\ ^3F_3$	$4s4d\ ^3D_3$	2265.976	1.106E−02	1.108E−02	−0.22	4.24
$4s4f\ ^3F_3$	$4p^2\ ^3P_2$	2763.194	3.435E−06	3.449E−06	−0.39	0.00
$4s4f\ ^3F_3$	$4p^2\ ^1D_2$	6893.176	4.241E−09	3.877E−09	8.59	0.00
$4s4f\ ^3F_3$	$3d4s\ ^3D_2$	458.268	1.429E−01	1.427E−01	0.12	54.84
$4s4f\ ^3F_3$	$3d4s\ ^3D_3$	458.725	1.791E−02	1.789E−02	0.11	6.87
$4s4f\ ^3F_3$	$3d4s\ ^1D_2$	492.103	3.396E−05	3.360E−05	1.07	0.01
$4s4f\ ^3F_4$	$4s4d\ ^3D_3$	2265.734	9.963E−02	9.990E−02	−0.26	38.13
$4s4f\ ^3F_4$	$3d4s\ ^3D_3$	458.715	1.617E−01	1.615E−01	0.13	61.87
$4s4f\ ^1F_3$	$4s4d\ ^1D_2$	1982.043	6.368E−02	6.694E−02	−5.12	16.83
$4s4f\ ^1F_3$	$4s4d\ ^3D_2$	2177.833	4.902E−06	5.192E−06	−5.92	0.00
$4s4f\ ^1F_3$	$4s4d\ ^3D_3$	2180.483	6.505E−08	5.181E−08	20.35	0.00
$4s4f\ ^1F_3$	$4p^2\ ^3P_2$	2637.110	2.345E−05	2.319E−05	1.10	0.01
$4s4f\ ^1F_3$	$4p^2\ ^1D_2$	6158.621	2.920E−03	2.690E−03	7.88	0.77
$4s4f\ ^1F_3$	$3d4s\ ^3D_2$	454.663	5.336E−05	4.883E−05	8.49	0.01
$4s4f\ ^1F_3$	$3d4s\ ^3D_3$	455.112	1.616E−05	1.754E−05	−8.50	0.00
$4s4f\ ^1F_3$	$3d4s\ ^1D_2$	487.949	3.116E−01	2.919E−01	6.32	82.37
$4s5f\ ^3F_2$	$4s5s\ ^3S_1$	756.251	4.042E−13	2.396E−13	40.73	0.00
$4s5f\ ^3F_2$	$4s4d\ ^1D_2$	1339.705	2.099E−07	1.973E−07	6.00	0.00
$4s5f\ ^3F_2$	$4s4d\ ^3D_1$	1425.635	1.131E−02	1.132E−02	−0.08	6.65
$4s5f\ ^3F_2$	$4s4d\ ^3D_2$	1426.381	2.086E−03	2.087E−03	−0.03	1.23
$4s5f\ ^3F_2$	$4s4d\ ^3D_3$	1427.517	5.888E−05	5.885E−05	0.06	0.03
$4s5f\ ^3F_2$	$4p^2\ ^3P_1$	1587.854	4.242E−08	4.323E−08	−1.91	0.00
$4s5f\ ^3F_2$	$4p^2\ ^3P_2$	1610.031	7.211E−09	7.895E−09	−9.48	0.00
$4s5f\ ^3F_2$	$4s6s\ ^3S_1$	2331.883	1.295E−12	1.288E−12	0.51	0.00
$4s5f\ ^3F_2$	$4p^2\ ^1D_2$	2473.552	1.699E−08	1.574E−08	7.38	0.00
$4s5f\ ^3F_2$	$4s5d\ ^3D_1$	4951.427	2.095E−02	2.217E−02	−5.80	12.31
$4s5f\ ^3F_2$	$4s5d\ ^3D_2$	4955.647	3.886E−03	4.110E−03	−5.78	2.28
$4s5f\ ^3F_2$	$4s5d\ ^3D_3$	4962.213	1.106E−04	1.170E−04	−5.78	0.06
$4s5f\ ^3F_2$	$4s5d\ ^1D_2$	5424.258	5.316E−07	5.810E−07	−9.30	0.00
$4s5f\ ^3F_2$	$3d^2\ ^3F_2$	7765.241	3.178E−08	5.672E−07	−1684.76	0.00
$4s5f\ ^3F_2$	$3d4s\ ^3D_1$	409.379	1.106E−01	1.122E−01	−1.51	64.99
$4s5f\ ^3F_2$	$3d^2\ ^3F_3$	7852.375	4.424E−09	7.138E−08	−1513.46	0.00
$4s5f\ ^3F_2$	$4s7s\ ^3S_1$	12790.177	2.412E−14	3.985E−14	−65.24	0.00
$4s5f\ ^3F_2$	$3d4s\ ^3D_2$	409.612	2.057E−02	2.088E−02	−1.51	12.09
$4s5f\ ^3F_2$	$3d4s\ ^3D_3$	409.977	5.884E−04	5.973E−04	−1.50	0.35
$4s5f\ ^3F_2$	$3d4s\ ^1D_2$	436.434	6.474E−06	6.582E−06	−1.66	0.00
$4s5f\ ^3F_3$	$4s4d\ ^1D_2$	1339.665	1.773E−06	1.806E−06	−1.85	0.00
$4s5f\ ^3F_3$	$4s4d\ ^3D_2$	1426.336	1.192E−02	1.193E−02	−0.12	7.00
$4s5f\ ^3F_3$	$4s4d\ ^3D_3$	1427.472	1.475E−03	1.476E−03	−0.03	0.87
$4s5f\ ^3F_3$	$4p^2\ ^3P_2$	1609.974	4.163E−08	4.164E−08	−0.03	0.00
$4s5f\ ^3F_3$	$4p^2\ ^1D_2$	2473.417	5.270E−08	5.376E−08	−2.01	0.00
$4s5f\ ^3F_3$	$4s5d\ ^3D_2$	4955.107	2.214E−02	2.342E−02	−5.80	13.01
$4s5f\ ^3F_3$	$4s5d\ ^3D_3$	4961.671	2.764E−03	2.925E−03	−5.80	1.62
$4s5f\ ^3F_3$	$4s5d\ ^1D_2$	5423.611	2.734E−06	2.905E−06	−6.27	0.00
$4s5f\ ^3F_3$	$3d^2\ ^3F_2$	7763.915	3.583E−09	4.521E−08	−1161.85	0.00
$4s5f\ ^3F_3$	$3d^2\ ^3F_3$	7851.019	2.904E−08	5.463E−07	−1781.01	0.00
$4s5f\ ^3F_3$	$3d^2\ ^3F_4$	7969.715	3.279E−09	5.241E−08	−1498.50	0.00
$4s5f\ ^3F_3$	$3d4s\ ^3D_2$	409.608	1.172E−01	1.189E−01	−1.50	68.84
$4s5f\ ^3F_3$	$3d4s\ ^3D_3$	409.973	1.471E−02	1.493E−02	−1.50	8.64
$4s5f\ ^3F_3$	$3d4s\ ^1D_2$	436.429	3.280E−05	3.278E−05	0.06	0.02
$4s5f\ ^3F_4$	$4s4d\ ^3D_3$	1427.415	1.333E−02	1.335E−02	−0.14	7.82
$4s5f\ ^3F_4$	$4s5d\ ^3D_3$	4960.982	2.489E−02	2.634E−02	−5.82	14.59
$4s5f\ ^3F_4$	$3d^2\ ^3F_3$	7849.294	3.028E−09	3.428E−08	−1031.94	0.00
$4s5f\ ^3F_4$	$3d^2\ ^3F_4$	7967.937	3.248E−08	6.179E−07	−1802.55	0.00
$4s5f\ ^3F_4$	$3d4s\ ^3D_3$	409.968	1.323E−01	1.343E−01	−1.51	77.59

(continued on next page)

Table 5 (*continued*)

Transition		λ (nm)	A_{if} (10^8 s^{-1})		Diff. (%)	BR. (%)
Initial	Final		*L*	*V*		
$4s5f\ ^1F_3$	$4s4d\ ^1D_2$	1332.163	1.783E−02	1.829E−02	−2.58	7.72
$4s5f\ ^1F_3$	$4s4d\ ^3D_2$	1417.834	7.599E−07	7.848E−07	−3.28	0.00
$4s5f\ ^1F_3$	$4s4d\ ^3D_3$	1418.957	2.190E−10	9.774E−11	55.36	0.00
$4s5f\ ^1F_3$	$4p^2\ ^3P_2$	1599.151	9.537E−07	9.462E−07	0.78	0.00
$4s5f\ ^1F_3$	$4p^2\ ^1D_2$	2447.962	5.935E−03	6.158E−03	−3.76	2.57
$4s5f\ ^1F_3$	$4s5d\ ^3D_2$	4853.992	2.822E−06	3.029E−06	−7.36	0.00
$4s5f\ ^1F_3$	$4s5d\ ^3D_3$	4860.291	1.191E−09	8.065E−10	32.30	0.00
$4s5f\ ^1F_3$	$4s5d\ ^1D_2$	5302.705	1.878E−02	2.032E−02	−8.20	8.13
$4s5f\ ^1F_3$	$3d^2\ ^3F_2$	7518.514	4.818E−07	5.906E−07	−22.59	0.00
$4s5f\ ^1F_3$	$3d^2\ ^3F_3$	7600.170	1.378E−10	1.242E−09	−801.12	0.00
$4s5f\ ^1F_3$	$3d^2\ ^3F_4$	7711.349	1.617E−10	7.512E−10	−364.55	0.00
$4s5f\ ^1F_3$	$3d4s\ ^3D_2$	408.904	3.547E−05	3.541E−05	0.17	0.02
$4s5f\ ^1F_3$	$3d4s\ ^3D_3$	409.268	3.427E−07	3.977E−07	−16.05	0.00
$4s5f\ ^1F_3$	$3d4s\ ^1D_2$	435.630	1.884E−01	1.866E−01	0.95	81.57
$4s6f\ ^3F_2$	$4s5s\ ^3S_1$	23476.383	3.096E−11			0.00
$4s6f\ ^3F_2$	$4s4d\ ^1D_2$	683.754	7.751E−09			0.00
$4s6f\ ^3F_2$	$4s4d\ ^3D_1$	1127.860	2.663E−03			3.00
$4s6f\ ^3F_2$	$4s4d\ ^3D_2$	1188.151	4.872E−04			0.55
$4s6f\ ^3F_2$	$4s4d\ ^3D_3$	1188.669	1.364E−05			0.02
$4s6f\ ^3F_2$	$4p^2\ ^3P_1$	1189.458	1.919E−07			0.00
$4s6f\ ^3F_2$	$4p^2\ ^3P_2$	1298.730	2.903E−08			0.00
$4s6f\ ^3F_2$	$4s6s\ ^3S_1$	1313.529	6.059E−13			0.00
$4s6f\ ^3F_2$	$4p^2\ ^1D_2$	1757.346	1.426E−08			0.00
$4s6f\ ^3F_2$	$4s5d\ ^3D_1$	1836.618	6.585E−03			7.42
$4s6f\ ^3F_2$	$4s5d\ ^3D_2$	2922.575	1.215E−03			1.37
$4s6f\ ^3F_2$	$4s5d\ ^3D_3$	2924.045	3.456E−05			0.04
$4s6f\ ^3F_2$	$4s5d\ ^1D_2$	2926.330	4.574E−07			0.00
$4s6f\ ^3F_2$	$3d^2\ ^3F_2$	3081.104	5.369E−07			0.00
$4s6f\ ^3F_2$	$3d^2\ ^3F_3$	3717.735	6.821E−08			0.00
$4s6f\ ^3F_2$	$4s7s\ ^3S_1$	387.158	5.704E−14			0.00
$4s6f\ ^3F_2$	$3d4s\ ^3D_1$	3737.591	5.931E−02			66.82
$4s6f\ ^3F_2$	$3d4s\ ^3D_2$	4579.027	1.101E−02			12.40
$4s6f\ ^3F_2$	$4s6d\ ^1D_2$	387.366	1.013E−06			0.00
$4s6f\ ^3F_2$	$4s6d\ ^3D_1$	8512.015	5.860E−03			6.60
$4s6f\ ^3F_2$	$4s6d\ ^3D_2$	8964.027	1.089E−03			1.23
$4s6f\ ^3F_2$	$4s6d\ ^3D_3$	8974.888	1.648E−04			0.19
$4s6f\ ^3F_2$	$4s8s\ ^3S_1$	8990.623	1.511E−12			0.00
$4s6f\ ^3F_2$	$3d4s\ ^3D_3$	387.692	3.166E−04			0.36
$4s6f\ ^3F_2$	$3d4s\ ^1D_2$	411.269	1.067E−05			0.01
$4s6f\ ^3F_3$	$4s4d\ ^1D_2$	1127.841	7.618E−08			0.00
$4s6f\ ^3F_3$	$4s4d\ ^3D_2$	1188.648	2.806E−03			3.19
$4s6f\ ^3F_3$	$4s4d\ ^3D_3$	1189.437	3.444E−04			0.39
$4s6f\ ^3F_3$	$4p^2\ ^3P_2$	1313.503	1.671E−07			0.00
$4s6f\ ^3F_3$	$4p^2\ ^1D_2$	1836.568	1.285E−07			0.00
$4s6f\ ^3F_3$	$4s5d\ ^3D_2$	2923.917	6.950E−03			7.90
$4s6f\ ^3F_3$	$4s5d\ ^3D_3$	2926.201	8.652E−04			0.98
$4s6f\ ^3F_3$	$4s5d\ ^1D_2$	3080.962	4.168E−06			0.00
$4s6f\ ^3F_3$	$3d^2\ ^3F_2$	3717.527	1.031E−08			0.00
$4s6f\ ^3F_3$	$3d^2\ ^3F_3$	3737.382	4.362E−07			0.00
$4s6f\ ^3F_3$	$3d^2\ ^3F_4$	3764.068	4.538E−08			0.00
$4s6f\ ^3F_3$	$4s5g\ ^1G_4$	387.364	5.031E−10			0.00
$4s6f\ ^3F_3$	$4s6d\ ^1D_2$	7758.915	4.900E−06			0.01
$4s6f\ ^3F_3$	$3d4s\ ^3D_2$	8510.928	6.277E−02			71.37
$4s6f\ ^3F_3$	$4s6d\ ^3D_2$	8973.680	6.224E−03			7.08
$4s6f\ ^3F_3$	$4s6d\ ^3D_3$	8989.410	1.029E−05			0.01
$4s6f\ ^3F_3$	$3d4s\ ^3D_3$	387.690	7.898E−03			8.98
$4s6f\ ^3F_3$	$3d4s\ ^1D_2$	411.266	7.556E−05			0.09
$4s6f\ ^3F_4$	$4s4d\ ^3D_3$	1189.411	3.132E−03			3.82
$4s6f\ ^3F_4$	$4s5d\ ^3D_3$	2926.047	7.799E−03			9.50
$4s6f\ ^3F_4$	$3d^2\ ^3F_3$	3737.130	3.533E−08			0.00
$4s6f\ ^3F_4$	$3d^2\ ^3F_4$	3763.813	4.728E−07			0.00
$4s6f\ ^3F_4$	$4s5g\ ^3G_5$	7751.277	2.433E−04			0.30
$4s6f\ ^3F_4$	$4s5g\ ^1G_4$	7757.832	6.584E−12			0.00
$4s6f\ ^3F_4$	$4s6d\ ^3D_3$	8987.956	1.238E−07			0.00
$4s6f\ ^3F_4$	$3d4s\ ^3D_3$	387.688	7.088E−02			86.38
$4s6f\ ^1F_3$	$4s4d\ ^1D_2$	1125.605	5.391E−03			5.21
$4s6f\ ^1F_3$	$4s4d\ ^3D_2$	1186.165	1.504E−11			0.00
$4s6f\ ^1F_3$	$4s4d\ ^3D_3$	1186.951	1.325E−08			0.00
$4s6f\ ^1F_3$	$4p^2\ ^3P_2$	1310.472	3.967E−07			0.00
$4s6f\ ^1F_3$	$4p^2\ ^1D_2$	1830.647	2.969E−03			2.87
$4s6f\ ^1F_3$	$4s5d\ ^3D_2$	2908.939	5.057E−06			0.00

(*continued on next page*)

Table 5 (*continued*)

Transition		λ (nm)	A_{if} (10^8 s^{-1})		Diff. (%)	BR. (%)
Initial	Final		*L*	*V*		
$4s6f\ ^1F_3$	$4s5d\ ^3D_3$	2911.200	7.052E−09			0.00
$4s6f\ ^1F_3$	$4s5d\ ^1D_2$	3064.336	5.037E−03			4.87
$4s6f\ ^1F_3$	$3d^2\ ^3F_2$	3693.349	2.889E−05			0.03
$4s6f\ ^1F_3$	$3d^2\ ^3F_3$	3712.945	3.051E−10			0.00
$4s6f\ ^1F_3$	$3d^2\ ^3F_4$	3739.282	1.498E−09			0.00
$4s6f\ ^1F_3$	$4s5g\ ^1G_4$	387.100	7.996E−05			0.08
$4s6f\ ^1F_3$	$4s6d\ ^1D_2$	7654.330	5.901E−03			5.71
$4s6f\ ^1F_3$	$4s6d\ ^3D_2$	8385.252	6.309E−06			0.01
$4s6f\ ^1F_3$	$4s6d\ ^3D_3$	8834.078	6.540E−11			0.00
$4s6f\ ^1F_3$	$3d4s\ ^3D_2$	8849.323	9.069E−05			0.09
$4s6f\ ^1F_3$	$3d4s\ ^3D_3$	387.426	7.248E−08			0.00
$4s6f\ ^1F_3$	$3d4s\ ^1D_2$	410.968	8.390E−02			81.13

Table 6
Spontaneous emission rates of transitions originating from the $3d^2$, $4p^2$, 3d4p, and 4s5g states of Ca I.

Transition		λ (nm)	A_{if} (10^8 s^{-1})		Diff. (%)	BR. (%)
Initial	Final		L	V		
$3d4p\ ^3F_2$	$4s5s\ ^3S_1$	2386.094	1.489E−05	1.490E−05	−0.06	0.00
$3d4p\ ^3F_2$	$3d4s\ ^3D_1$	649.558	2.250E−01	2.062E−01	8.37	56.13
$3d4p\ ^3F_2$	$3d4s\ ^3D_2$	650.145	4.840E−02	4.514E−02	6.74	12.07
$3d4p\ ^3F_2$	$3d4s\ ^3D_3$	651.065	7.591E−04	6.482E−04	14.60	0.19
$3d4p\ ^3F_2$	$3d4s\ ^1D_2$	720.419	1.267E−01	1.435E−01	−13.25	31.61
$3d4p\ ^3F_3$	$3d4s\ ^3D_2$	646.435	3.367E−01	3.086E−01	8.36	88.32
$3d4p\ ^3F_3$	$3d4s\ ^3D_3$	647.345	4.447E−02	4.113E−02	7.51	11.67
$3d4p\ ^3F_3$	$3d4s\ ^1D_2$	715.867	5.039E−05	4.493E−05	10.83	0.01
$3d4p\ ^1D_2$	$4s5s\ ^3S_1$	2327.796	1.115E−04	1.118E−04	−0.28	0.02
$3d4p\ ^1D_2$	$3d4s\ ^3D_1$	645.159	9.127E−02	8.382E−02	8.16	20.46
$3d4p\ ^1D_2$	$3d4s\ ^3D_2$	645.738	1.210E−02	1.073E−02	11.31	2.71
$3d4p\ ^1D_2$	$3d4s\ ^3D_3$	646.646	1.798E−03	1.857E−03	−3.30	0.40
$3d4p\ ^1D_2$	$3d4s\ ^1D_2$	715.012	3.408E−01	3.840E−01	−12.67	76.40
$3d4p\ ^3F_4$	$3d4s\ ^3D_3$	644.085	3.850E−01	3.530E−01	8.30	100.00
$3d4p\ ^3D_1$	$4s5s\ ^3S_1$	1503.106	2.929E−06	2.599E−06	11.27	0.00
$3d4p\ ^3D_1$	$4s^2\ ^1S_0$	261.832	7.250E−05	9.235E−05	−27.38	0.01
$3d4p\ ^3D_1$	$4s5s\ ^1S_0$	2051.227	8.697E−06	9.073E−06	−4.33	0.00
$3d4p\ ^3D_1$	$4s4d\ ^1D_2$	11184.431	1.313E−07	1.517E−07	−15.48	0.00
$3d4p\ ^3D_1$	$4s4d\ ^3D_1$	22512.889	4.675E−07	8.653E−07	−85.10	0.00
$3d4p\ ^3D_1$	$4s4d\ ^3D_2$	22700.445	2.167E−07	3.977E−07	−83.57	0.00
$3d4p\ ^3D_1$	$3d4s\ ^3D_1$	560.004	5.100E−01	5.685E−01	−11.48	74.03
$3d4p\ ^3D_1$	$3d4s\ ^3D_2$	560.440	1.788E−01	2.002E−01	−12.00	25.95
$3d4p\ ^3D_1$	$3d4s\ ^1D_2$	611.892	1.973E−05	1.650E−05	16.35	0.00
$3d4p\ ^3D_2$	$4s5s\ ^3S_1$	1497.091	5.606E−06	5.337E−06	4.80	0.00
$3d4p\ ^3D_2$	$4s4d\ ^1D_2$	10859.768	9.848E−11	6.034E−10	−512.78	0.00
$3d4p\ ^3D_2$	$4s4d\ ^3D_1$	21235.029	1.139E−07	2.015E−07	−76.85	0.00
$3d4p\ ^3D_2$	$4s4d\ ^3D_2$	21401.819	4.939E−07	9.157E−07	−85.39	0.00
$3d4p\ ^3D_2$	$4s4d\ ^3D_3$	21660.493	1.881E−07	3.420E−07	−81.77	0.00
$3d4p\ ^3D_2$	$3d4s\ ^3D_1$	559.167	1.062E−01	1.181E−01	−11.22	15.39
$3d4p\ ^3D_2$	$3d4s\ ^3D_2$	559.601	4.691E−01	5.232E−01	−11.51	67.98
$3d4p\ ^3D_2$	$3d4s\ ^3D_3$	560.283	1.146E−01	1.288E−01	−12.37	16.61
$3d4p\ ^3D_2$	$3d4s\ ^1D_2$	610.893	1.438E−04	1.689E−04	−17.46	0.02
$3d4p\ ^3D_3$	$4s4d\ ^1D_2$	10407.668	3.897E−08	2.840E−08	27.12	0.00
$3d4p\ ^3D_3$	$4s4d\ ^3D_2$	19714.145	1.103E−07	1.898E−07	−72.05	0.00
$3d4p\ ^3D_3$	$4s4d\ ^3D_3$	19933.422	8.589E−07	1.569E−06	−82.62	0.00
$3d4p\ ^3D_3$	$3d4s\ ^3D_2$	558.352	8.072E−02	8.971E−02	−11.14	11.66
$3d4p\ ^3D_3$	$3d4s\ ^3D_3$	559.030	6.113E−01	6.825E−01	−11.65	88.33
$3d4p\ ^3D_3$	$3d4s\ ^1D_2$	609.403	1.765E−07	8.340E−07	−372.51	0.00
$4p^2\ ^3P_0$	$4s5p\ ^3P_1$	5368.292	6.316E−07	3.988E−06	−531.44	0.00
$4p^2\ ^3P_0$	$4s5p\ ^1P_1$	5931.480	6.195E−07	5.585E−07	9.85	0.00
$4p^2\ ^3P_0$	$3d4p\ ^3D_1$	44414.835	3.804E−07	1.233E−06	−224.19	0.00
$4p^2\ ^3P_0$	$4s4p\ ^3P_1$	430.896	1.826E+00	2.020E+00	−10.65	99.98
$4p^2\ ^3P_0$	$4s4p\ ^1P_1$	677.266	2.992E−04	3.512E−04	−17.40	0.02
$4p^2\ ^3P_1$	$3d4p\ ^3F_2$	3657.163	1.577E−08	8.457E−09	46.38	0.00
$4p^2\ ^3P_1$	$3d4p\ ^1D_2$	3803.149	6.818E−09	2.776E−09	59.28	0.00
$4p^2\ ^3P_1$	$4s5p\ ^3P_0$	5216.158	1.346E−06	3.461E−06	−157.02	0.00
$4p^2\ ^3P_1$	$4s5p\ ^3P_1$	5235.438	2.798E−07	1.248E−06	−345.96	0.00
$4p^2\ ^3P_1$	$4s5p\ ^3P_2$	5291.873	1.654E−09	6.758E−07		0.00
$4p^2\ ^3P_1$	$4s5p\ ^1P_1$	5769.708	1.410E−09	6.768E−10	51.99	0.00
$4p^2\ ^3P_1$	$4s4p\ ^3P_0$	429.057	6.116E−01	6.765E−01	−10.62	33.42
$4p^2\ ^3P_1$	$3d4p\ ^3D_1$	36708.024	1.646E−07	7.103E−07	−331.44	0.00
$4p^2\ ^3P_1$	$3d4p\ ^3D_2$	40701.697	3.709E−07	1.379E−06	−271.81	0.00
$4p^2\ ^3P_1$	$4s4p\ ^3P_1$	430.020	4.633E−01	5.123E−01	−10.56	25.32
$4p^2\ ^3P_1$	$4s4p\ ^3P_2$	431.987	7.551E−01	8.358E−01	−10.69	41.26
$4p^2\ ^3P_1$	$4s4p\ ^1P_1$	675.105	4.708E−06	6.010E−06	−27.64	0.00
$4p^2\ ^3P_2$	$3d4p\ ^3F_2$	3544.704	2.188E−08	7.096E−08	−224.26	0.00
$4p^2\ ^3P_2$	$3d4p\ ^3F_3$	3659.184	4.339E−08	1.008E−08	76.78	0.00
$4p^2\ ^3P_2$	$3d4p\ ^1D_2$	3681.682	1.422E−07	2.910E−07	−104.66	0.00
$4p^2\ ^3P_2$	$4s5p\ ^3P_1$	5007.988	9.858E−07	2.596E−06	−163.32	0.00
$4p^2\ ^3P_2$	$4s5p\ ^3P_2$	5059.602	3.420E−07	2.677E−06	−682.95	0.00
$4p^2\ ^3P_2$	$4s5p\ ^1P_1$	5494.687	2.137E−06	2.192E−06	−2.59	0.00
$4p^2\ ^3P_2$	$3d4p\ ^3D_1$	27841.969	1.472E−08	1.770E−07	−1102.26	0.00
$4p^2\ ^3P_2$	$3d4p\ ^3D_2$	30080.616	1.749E−07	1.156E−06	−560.76	0.00
$4p^2\ ^3P_2$	$3d4p\ ^3D_3$	34195.049	6.898E−07	3.349E−06	−385.57	0.00
$4p^2\ ^3P_2$	$4s4p\ ^3P_1$	428.421	4.571E−01	5.055E−01	−10.59	24.93
$4p^2\ ^3P_2$	$4s4p\ ^3P_2$	430.374	1.376E+00	1.522E+00	−10.59	75.05
$4p^2\ ^3P_2$	$4s4p\ ^1P_1$	671.174	3.911E−04	4.160E−04	−6.39	0.02
$3d4p\ ^3P_0$	$4s5s\ ^3S_1$	1283.058	5.926E−03	5.734E−03	3.24	0.76
$3d4p\ ^3P_0$	$4s4d\ ^3D_1$	6308.432	7.123E−04	9.429E−04	−32.38	0.09

(continued on next page)

Table 6 (*continued*)

Transition		λ (nm)	A_{if} (10^8 s^{-1})		Diff. (%)	BR. (%)
Initial	Final		L	V		
$3d4p\ ^3P_0$	$4p^2\ ^3P_1$	11513.177	1.430E−07	1.807E−06	−1163.46	0.00
$3d4p\ ^3P_0$	$3d4s\ ^3D_1$	526.371	7.748E−01	9.561E−01	−23.40	99.15
$3d4p\ ^3P_1$	$4s5s\ ^3S_1$	1282.739	5.936E−03	5.734E−03	3.41	0.76
$3d4p\ ^3P_1$	$4s^2\ ^1S_0$	254.224	8.447E−05	9.012E−05	−6.69	0.01
$3d4p\ ^3P_1$	$4s5s\ ^1S_0$	1661.665	8.536E−06	8.572E−06	−0.42	0.00
$3d4p\ ^3P_1$	$4s4d\ ^1D_2$	4909.108	1.481E−06	1.789E−06	−20.79	0.00
$3d4p\ ^3P_1$	$4s4d\ ^3D_1$	6300.721	1.806E−04	2.392E−04	−32.43	0.02
$3d4p\ ^3P_1$	$4s4d\ ^3D_2$	6315.324	5.308E−04	7.037E−04	−32.58	0.07
$3d4p\ ^3P_1$	$4p^2\ ^3P_0$	10895.857	9.717E−08	4.750E−07	−388.82	0.00
$3d4p\ ^3P_1$	$4p^2\ ^3P_1$	11487.519	4.307E−08	3.780E−07	−777.57	0.00
$3d4p\ ^3P_1$	$4p^2\ ^3P_2$	12759.008	5.176E−08	6.460E−07	−1148.16	0.00
$3d4p\ ^3P_1$	$3d4s\ ^3D_1$	526.317	2.025E−01	2.493E−01	−23.08	25.95
$3d4p\ ^3P_1$	$3d4s\ ^3D_2$	526.702	5.712E−01	7.062E−01	−23.63	73.18
$3d4p\ ^3P_1$	$3d4s\ ^1D_2$	571.896	3.207E−05	3.961E−05	−23.51	0.00
$3d4p\ ^3P_2$	$4s5s\ ^3S_1$	1281.956	5.961E−03	5.754E−03	3.48	0.77
$3d4p\ ^3P_2$	$4s4d\ ^1D_2$	4897.663	2.486E−10	2.697E−09	−984.62	0.00
$3d4p\ ^3P_2$	$4s4d\ ^3D_1$	6281.881	7.430E−06	9.849E−06	−32.55	0.00
$3d4p\ ^3P_2$	$4s4d\ ^3D_2$	6296.397	1.095E−04	1.451E−04	−32.59	0.01
$3d4p\ ^3P_2$	$4s4d\ ^3D_3$	6318.596	5.950E−04	7.906E−04	−32.87	0.08
$3d4p\ ^3P_2$	$4p^2\ ^3P_1$	11425.046	1.004E−07	2.588E−07	−157.78	0.00
$3d4p\ ^3P_2$	$4p^2\ ^3P_2$	12681.987	1.437E−07	8.985E−07	−525.27	0.00
$3d4p\ ^3P_2$	$3d4s\ ^3D_1$	526.185	8.820E−03	1.081E−02	−22.54	1.13
$3d4p\ ^3P_2$	$3d4s\ ^3D_2$	526.570	1.248E−01	1.535E−01	−23.03	16.02
$3d4p\ ^3P_2$	$3d4s\ ^3D_3$	527.174	6.382E−01	7.903E−01	−23.84	81.96
$3d4p\ ^3P_2$	$3d4s\ ^1D_2$	571.741	2.357E−04	2.689E−04	−14.10	0.03
$3d4p\ ^1F_3$	$4s4d\ ^1D_2$	3086.801	1.565E−02	1.370E−02	12.50	21.49
$3d4p\ ^1F_3$	$4s4d\ ^3D_2$	3589.350	1.096E−06	9.243E−07	15.64	0.00
$3d4p\ ^1F_3$	$4s4d\ ^3D_3$	3596.553	9.869E−09	9.761E−09	1.09	0.00
$3d4p\ ^1F_3$	$4p^2\ ^3P_2$	5034.410	9.118E−07	9.848E−07	−8.00	0.00
$3d4p\ ^1F_3$	$3d4s\ ^3D_2$	495.328	8.657E−06	5.114E−06	40.93	0.01
$3d4p\ ^1F_3$	$3d4s\ ^3D_3$	495.862	1.253E−04	1.353E−04	−7.92	0.17
$3d4p\ ^1F_3$	$3d4s\ ^1D_2$	535.095	5.705E−02	4.314E−02	24.38	78.32
$4p^2\ ^1D_2$	$3d4p\ ^3F_2$	2004.249	1.011E−03	1.219E−03	−20.49	0.17
$4p^2\ ^1D_2$	$3d4p\ ^3F_3$	2040.342	1.507E−07	1.511E−07	−0.27	0.00
$4p^2\ ^1D_2$	$3d4p\ ^1D_2$	2047.318	2.401E−03	2.903E−03	−20.89	0.40
$4p^2\ ^1D_2$	$4s5p\ ^3P_1$	2400.903	1.333E−04	1.276E−04	4.31	0.02
$4p^2\ ^1D_2$	$4s5p\ ^3P_2$	2412.702	8.136E−06	9.871E−06	−21.32	0.00
$4p^2\ ^1D_2$	$4s5p\ ^1P_1$	2507.378	1.308E−02	1.248E−02	4.60	2.20
$4p^2\ ^1D_2$	$3d4p\ ^3D_1$	3956.541	1.206E−06	1.147E−06	4.90	0.00
$4p^2\ ^1D_2$	$3d4p\ ^3D_2$	3998.832	3.892E−08	3.281E−08	15.68	0.00
$4p^2\ ^1D_2$	$3d4p\ ^3D_3$	4063.835	4.311E−08	1.269E−08	70.57	0.00
$4p^2\ ^1D_2$	$4s4p\ ^3P_1$	392.006	4.591E−05	5.303E−05	−15.51	0.01
$4p^2\ ^1D_2$	$3d4p\ ^3P_1$	7222.668	1.387E−07	1.401E−07	−1.04	0.00
$4p^2\ ^1D_2$	$3d4p\ ^3P_2$	7247.585	2.099E−08	7.039E−08	−235.33	0.00
$4p^2\ ^1D_2$	$3d4p\ ^1F_3$	54957.133	2.891E−07	3.722E−06	−1187.40	0.00
$4p^2\ ^1D_2$	$4s4p\ ^3P_2$	393.640	7.852E−04	8.614E−04	−9.70	0.13
$4p^2\ ^1D_2$	$4s4p\ ^1P_1$	585.907	5.760E−01	6.310E−01	−9.55	97.06
$4p^2\ ^1S_0$	$4s5p\ ^3P_1$	1911.487	1.158E−04	1.302E−04	−12.38	0.01
$4p^2\ ^1S_0$	$4s5p\ ^1P_1$	1978.372	1.276E−02	1.436E−02	−12.54	1.61
$4p^2\ ^1S_0$	$3d4p\ ^3D_1$	2782.500	1.236E−06	1.489E−06	−20.55	0.00
$4p^2\ ^1S_0$	$4s4p\ ^3P_1$	376.276	1.085E−03	1.177E−03	−8.45	0.14
$4p^2\ ^1S_0$	$3d4p\ ^3P_1$	4080.034	2.225E−06	2.502E−06	−12.47	0.00
$4p^2\ ^1S_0$	$4s6p\ ^1P_1$	93222.709	2.055E−06	8.250E−07	59.85	0.00
$4p^2\ ^1S_0$	$4s4p\ ^1P_1$	551.451	7.780E−01	8.682E−01	−11.59	98.24
$3d^2\ ^3F_2$	$3d4p\ ^3F_2$	1291.259	2.826E−02	3.549E−02	−25.58	41.20
$3d^2\ ^3F_2$	$3d4p\ ^3F_3$	1306.145	4.691E−03	5.912E−03	−26.03	6.84
$3d^2\ ^3F_2$	$3d4p\ ^1D_2$	1309.000	1.043E−02	1.312E−02	−25.81	15.20
$3d^2\ ^3F_2$	$4s5p\ ^3P_1$	1445.070	2.803E−07	2.438E−07	13.00	0.00
$3d^2\ ^3F_2$	$4s5p\ ^3P_2$	1449.336	2.329E−06	3.080E−06	−32.22	0.00
$3d^2\ ^3F_2$	$4s5p\ ^1P_1$	1482.973	3.879E−06	3.621E−06	6.66	0.01
$3d^2\ ^3F_2$	$3d4p\ ^3D_1$	1893.065	2.132E−02	2.025E−02	5.02	31.08
$3d^2\ ^3F_2$	$3d4p\ ^3D_2$	1902.693	3.754E−03	3.547E−03	5.51	5.47
$3d^2\ ^3F_2$	$3d4p\ ^3D_3$	1917.285	9.916E−05	9.262E−05	6.59	0.14
$3d^2\ ^3F_2$	$4s4p\ ^3P_1$	353.797	9.691E−08	3.045E−08	68.57	0.00
$3d^2\ ^3F_2$	$3d4p\ ^3P_1$	2415.745	2.031E−06	2.003E−06	1.36	0.00
$3d^2\ ^3F_2$	$3d4p\ ^3P_2$	2418.526	6.890E−07	6.922E−07	−0.46	0.00
$3d^2\ ^3F_2$	$3d4p\ ^1F_3$	3404.904	2.474E−07	3.775E−07	−52.57	0.00
$3d^2\ ^3F_2$	$4s6p\ ^1P_1$	5568.487	2.282E−07	2.658E−07	−16.47	0.00
$3d^2\ ^3F_2$	$4s4f\ ^3F_2$	7665.067	1.019E−07	6.964E−07	−583.68	0.00
$3d^2\ ^3F_2$	$4s4f\ ^3F_3$	7667.124	1.199E−08	8.371E−08	−597.88	0.00
$3d^2\ ^3F_2$	$4s4p\ ^3P_2$	355.128	2.801E−09	1.007E−10	96.41	0.00

(*continued on next page*)

Table 6 (*continued*)

Transition		λ (nm)	A_{if} (10^8 s^{-1})		Diff. (%)	BR. (%)
Initial	Final		*L*	*V*		
$3d^2\ ^3F_2$	$4s4f\ ^1F_3$	8839.857	3.297E−08	2.348E−08	28.79	0.00
$3d^2\ ^3F_2$	$4s6p\ ^3P_1$	10458.938	1.945E−10	1.992E−10	−2.41	0.00
$3d^2\ ^3F_2$	$4s6p\ ^3P_2$	10545.853	5.590E−11	6.354E−11	−13.65	0.00
$3d^2\ ^3F_2$	$4s4p\ ^1P_1$	504.476	3.937E−05	4.524E−05	−14.90	0.06
$3d^2\ ^3F_3$	$3d4p\ ^3F_2$	1288.881	2.306E−03	2.934E−03	−27.24	3.41
$3d^2\ ^3F_3$	$3d4p\ ^3F_3$	1303.711	3.596E−02	4.524E−02	−25.80	53.17
$3d^2\ ^3F_3$	$3d4p\ ^1D_2$	1306.556	9.782E−04	1.232E−03	−25.90	1.45
$3d^2\ ^3F_3$	$3d4p\ ^3F_4$	1317.136	3.292E−03	4.159E−03	−26.33	4.87
$3d^2\ ^3F_3$	$4s5p\ ^3P_2$	1446.341	1.068E−06	1.125E−06	−5.35	0.00
$3d^2\ ^3F_3$	$3d4p\ ^3D_2$	1897.533	2.249E−02	2.136E−02	5.02	33.25
$3d^2\ ^3F_3$	$3d4p\ ^3D_3$	1912.046	2.605E−03	2.454E−03	5.80	3.85
$3d^2\ ^3F_3$	$3d4p\ ^3P_2$	2410.196	3.913E−06	3.858E−06	1.40	0.01
$3d^2\ ^3F_3$	$3d4p\ ^1F_3$	3388.418	1.948E−07	1.508E−07	22.57	0.00
$3d^2\ ^3F_3$	$4s4f\ ^3F_2$	7582.018	1.001E−08	6.587E−08	−558.24	0.00
$3d^2\ ^3F_3$	$4s4f\ ^3F_3$	7584.031	1.028E−07	6.809E−07	−562.43	0.00
$3d^2\ ^3F_3$	$4s4p\ ^3P_2$	354.948	1.583E−07	6.037E−08	61.86	0.00
$3d^2\ ^3F_3$	$4s4f\ ^3F_4$	7586.735	9.143E−09	6.170E−08	−574.86	0.00
$3d^2\ ^3F_3$	$4s4f\ ^1F_3$	8729.584	1.863E−09	4.751E−10	74.50	0.00
$3d^2\ ^3F_3$	$4s6p\ ^3P_2$	10389.287	3.400E−10	3.393E−10	0.19	0.00
$3d^2\ ^3F_4$	$3d4p\ ^3F_3$	1300.495	2.489E−03	3.174E−03	−27.54	3.75
$3d^2\ ^3F_4$	$3d4p\ ^3F_4$	1313.853	3.893E−02	4.913E−02	−26.20	58.62
$3d^2\ ^3F_4$	$3d4p\ ^3D_3$	1905.136	2.499E−02	2.372E−02	5.08	37.63
$3d^2\ ^3F_4$	$3d4p\ ^1F_3$	3366.777	7.887E−08	8.891E−08	−12.74	0.00
$3d^2\ ^3F_4$	$4s4f\ ^3F_3$	7476.468	8.641E−09	5.454E−08	−531.16	0.00
$3d^2\ ^3F_4$	$4s4f\ ^3F_4$	7479.096	1.246E−07	7.938E−07	−537.00	0.00
$3d^2\ ^3F_4$	$4s4f\ ^1F_3$	8587.377	1.090E−10	4.795E−10	−339.84	0.00
$4s5g\ ^3G_5$	$3d4p\ ^3F_4$	1113.838	5.774E−04	5.741E−04	0.57	1.13
$4s5g\ ^3G_5$	$4s4f\ ^3F_4$	3698.457	5.062E−02	4.824E−02	4.70	98.86
$4s5g\ ^3G_5$	$4s5f\ ^3F_4$	89493.467	4.431E−06	4.434E−06	−0.07	0.01
$4s5g\ ^1G_4$	$3d4p\ ^3F_3$	1104.089	4.806E−05	4.773E−05	0.69	0.07
$4s5g\ ^1G_4$	$3d4p\ ^3F_4$	1113.702	2.859E−06	2.823E−06	1.24	0.00
$4s5g\ ^1G_4$	$3d4p\ ^3D_3$	1511.298	7.408E−07	7.175E−07	3.14	0.00
$4s5g\ ^1G_4$	$3d4p\ ^1F_3$	2305.178	2.755E−02	2.658E−02	3.53	40.61
$4s5g\ ^1G_4$	$4s4f\ ^3F_3$	3696.325	3.928E−03	3.743E−03	4.69	5.79
$4s5g\ ^1G_4$	$4s4f\ ^3F_4$	3696.967	2.649E−04	2.523E−04	4.77	0.39
$4s5g\ ^1G_4$	$4s4f\ ^1F_3$	3948.886	3.606E−02	3.409E−02	5.45	53.14
$4s5g\ ^1G_4$	$4s5f\ ^3F_3$	88409.513	3.588E−07	3.594E−07	−0.17	0.00
$4s5g\ ^1G_4$	$4s5f\ ^3F_4$	88628.911	2.384E−08	2.424E−08	−1.68	0.00
$4s5g\ ^1G_4$	$4s5f\ ^1F_3$	140706.346	9.701E−07	2.417E−05	−2391.78	0.00

Table 7
Comparison of transition probabilities with literature values.

Final state	Initial state	This work (L, 10^8 s^{-1})	Other theory (10^8 s^{-1})	Diff.	NIST	Diff. (%)
$4s4p\ ^1P_1$	$4s^2\ ^1S_0$	2.170E+00	2.171E+00 MPCI [9]	−0.02	2.18E+00	−0.44
			2.15E+00 CI+MBPT [11]	0.9		
$4s4p\ ^3P_1$	$4s^2\ ^1S_0$	2.738E−05	2.75E−05 CI+MBPT [11]	0.43	2.6E−05	5.30
			2.098E−05 MCHF [10]	23.37		
$4s4p\ ^1P_1$	$3d4s\ ^1D_2$	5.341E−05	5.274E−05 MPCI [9]	1.26		
			5.70E−05 CI+MBPT [11]	6.72		
$4s6f\ ^1F_3$	$3d4s\ ^1D_2$	8.390E−02	8.570E−02 MPCI [9]	−2.10	9.0E−01	−90.68
$4s5p\ ^1P_1$	$4s^2\ ^1S_0$	7.505E−03	5.850E−03 MPCI [9]	28.30	2.7E−03	177.96
$4s5p\ ^1P_1$	$3d4s\ ^1D_2$	1.301E−01	1.440E−01 MPCI [9]	−9.71	1.2E−01	8.38
$4p^2\ ^1D_2$	$4s4p\ ^1P_1$	5.760E−01	6.393E−01 MPCI [9]	−9.90	6.6E−01	−12.73
$4s6p\ ^1P_1$	$4s^2\ ^1S_0$	9.182E−02	1.398E−01 MPCI [9]	−34.33	1.67E−01	−45.02
$4s6p\ ^1P_1$	$3d4s\ ^1D_2$	2.379E−01	2.871E−01 MPCI [9]	−17.14	3.3E−01	−27.91
$4p^2\ ^1S_0$	$4s4p\ ^1P_1$	7.780E−01	7.605E−01 MPCI [9]	2.31	1.1E+00	−29.27
$4s4f\ ^1F_3$	$3d4s\ ^1D_2$	3.116E−01	2.622E−01 MPCI [9]	18.82	1.88E−01	65.73
$4s5d\ ^1D_2$	$4s4p\ ^1P_1$	4.710E−01	3.930E−01 MPCI [9]	19.83	4.0E−01	17.75
$4snp\ ^1P_1$	$4s^2\ ^1S_0$	3.246E−01	2.772E−01 MPCI [9]	17.08	3.01E−01	7.84
$4snp\ ^1P_1$	$3d4s\ ^1D_2$	3.673E−01	2.801E−01 MPCI [9]	31.13	4.1E−01	−10.42
$4s5f\ ^1F_3$	$3d4s\ ^1D_2$	1.884E−01	1.398E−01 MPCI [9]	34.74	1.9E−01	−0.83
$4s6d\ ^1D_2$	$4s4p\ ^1P_1$	1.425E−01	8.248E−02 MPCI [9]	72.76	8.0E−02	78.12
$4s7p\ ^1P_1$	$4s^2\ ^1S_0$	1.295E−01	1.546E−01 MPCI [9]	16.23	1.53E−01	46.82
$4s5s\ ^1S_0$	$4s4p\ ^1P_1$	2.293E−01	2.401E−01 MPCI [9]	−4.48		
$4s6f\ ^1F_3$	$4s4d\ ^1D_2$	5.391E−03	3.926E−03 MPCI [9]	37.31		
$4s6f\ ^1F_3$	$4p^2\ ^1D_2$	2.969E−03	3.131E−03 MPCI [9]	−5.16		
$4s6f\ ^1F_3$	$4s5d\ ^1D_2$	5.037E−03	4.493E−03 MPCI [9]	12.09		
$4s6f\ ^1F_3$	$4s5g\ ^1G_4$	5.901E−03	7.346E−03 MPCI [9]	−19.66		
$4s5p\ ^1P_1$	$4s5s\ ^1S_0$	2.361E−02	2.354E−02 MPCI [9]	0.30		
$4s4d\ ^1D_2$	$3d4p\ ^1D_2$	2.778E−05	4.910E−05 MPCI [9]	−43.43		
$4s4d\ ^1D_2$	$4s5p\ ^1P_1$	1.270E−04	1.395E−04 MPCI [9]	−8.97		
$4s4d\ ^1D_2$	$4s4p\ ^1P_1$	1.601E−01	1.537E−01 MPCI [9]	4.18		
$3d4p\ ^1F_3$	$4s4d\ ^1D_2$	1.565E−02	9.734E−03 MPCI [9]	60.83		
$3d4p\ ^1F_3$	$3d4s\ ^1D_2$	5.705E−02	1.189E−01 MPCI [9]	−52.01		
$4s6s\ ^1S_0$	$4s5p\ ^1P_1$	5.484E−02	4.506E−02 MPCI [9]	21.72		
$4s6s\ ^1S_0$	$4s4p\ ^1P_1$	1.420E−02	4.357E−02 MPCI [9]	−67.41		
$4p^2\ ^1D_2$	$3d4p\ ^1D_2$	2.401E−03	4.125E−03 MPCI [9]	−41.78		
$4p^2\ ^1D_2$	$4s5p\ ^1P_1$	1.308E−02	1.228E−02 MPCI [9]	6.55		
$4p^2\ ^1D_2$	$3d4p\ ^1F_3$	2.891E−07	2.208E−08 MPCI [9]	92.39		
$4s6p\ ^1P_1$	$4s5s\ ^1S_0$	1.516E−02	2.310E−02 MPCI [9]	−34.36		
$4s6p\ ^1P_1$	$4s4d\ ^1D_2$	1.407E−02	1.583E−02 MPCI [9]	−11.12		
$4s6p\ ^1P_1$	$4s6s\ ^1S_0$	1.605E−03	1.313E−03 MPCI [9]	22.30		
$4s6p\ ^1P_1$	$4p^2\ ^1D_2$	7.877E−04	6.613E−04 MPCI [9]	19.11		
$4p^2\ ^1S_0$	$4s5p\ ^1P_1$	1.276E−02	2.607E−02 MPCI [9]	−51.07		
$4p^2\ ^1S_0$	$4s6p\ ^1P_1$	2.055E−06	3.607E−07 MPCI [9]	469.66		
$4s4f\ ^1F_3$	$4s4d\ ^1D_2$	6.368E−02	7.943E−02 MPCI [9]	−19.83		
$4s4f\ ^1F_3$	$4p^2\ ^1D_2$	2.920E−03	2.743E−03 MPCI [9]	6.46		
$4s5d\ ^1D_2$	$3d4p\ ^1D_2$	6.727E−04	8.300E−04 MPCI [9]	−18.96		
$4s5d\ ^1D_2$	$4s5p\ ^1P_1$	3.302E−02	3.850E−02 MPCI [9]	−14.25		
$4s5d\ ^1D_2$	$3d4p\ ^1F_3$	1.274E−03	1.029E−04 MPCI [9]	91.92		
$4s5d\ ^1D_2$	$4s6p\ ^1P_1$	4.324E−03	3.961E−03 MPCI [9]	9.15		
$4s5d\ ^1D_2$	$4s4f\ ^1F_3$	3.433E−04	3.752E−04 MPCI [9]	−8.48		
$4snp\ ^1P_1$	$4s5s\ ^1S_0$	3.895E−02	3.431E−02 MPCI [9]	13.55		
$4snp\ ^1P_1$	$4s4d\ ^1D_2$	1.273E−02	1.103E−02 MPCI [9]	15.43		
$4snp\ ^1P_1$	$4s6s\ ^1S_0$	6.961E−03	8.416E−03 MPCI [9]	−17.29		
$4snp\ ^1P_1$	$4p^2\ ^1D_2$	7.630E−04	5.603E−04 MPCI [9]	36.19		
$4snp\ ^1P_1$	$4p^2\ ^1S_0$	3.175E−03	3.970E−03 MPCI [9]	−20.04		
$4snp\ ^1P_1$	$4s5d\ ^1D_2$	2.552E−03	3.253E−03 MPCI [9]	−21.56		
$4s7s\ ^1S_0$	$4s5p\ ^1P_1$	4.599E−02	3.338E−02 MPCI [9]	37.80		
$4s7s\ ^1S_0$	$4s6p\ ^1P_1$	2.243E−02	1.532E−02 MPCI [9]	46.47		
$4s7s\ ^1S_0$	$4snp\ ^1P_1$	3.074E−04	4.353E−04 MPCI [9]	−29.39		
$4s7s\ ^1S_0$	$4s4p\ ^1P_1$	6.836E−02	8.625E−02 MPCI [9]	20.74		
$4s5f\ ^1F_3$	$4s4d\ ^1D_2$	1.783E−02	1.474E−02 MPCI [9]	20.91		
$4s5f\ ^1F_3$	$4p^2\ ^1D_2$	5.935E−03	3.063E−03 MPCI [9]	93.77		
$4s5f\ ^1F_3$	$4s5d\ ^1D_2$	1.878E−02	1.853E−02 MPCI [9]	1.35		
$4s6d\ ^1D_2$	$3d4p\ ^1D_2$	5.667E−05	3.354E−05 MPCI [9]	68.96		
$4s6d\ ^1D_2$	$4s5p\ ^1P_1$	5.046E−02	3.690E−02 MPCI [9]	36.75		
$4s6d\ ^1D_2$	$3d4p\ ^1F_3$	1.202E−03	1.296E−03 MPCI [9]	−7.21		
$4s6d\ ^1D_2$	$4s6p\ ^1P_1$	7.402E−03	5.143E−03 MPCI [9]	43.93		
$4s6d\ ^1D_2$	$4s4f\ ^1F_3$	3.857E−06	5.605E−06 MPCI [9]	−31.18		
$4s6d\ ^1D_2$	$4snp\ ^1P_1$	2.409E−03	4.352E−03 MPCI [9]	−44.65		
$4s6d\ ^1D_2$	$4s5f\ ^1F_3$	3.250E−05	5.590E−05 MPCI [9]	−41.87		
$4s7p\ ^1P_1$	$4s5s\ ^1S_0$	1.135E−02	1.304E−02 MPCI [9]	−12.95		
$4s7p\ ^1P_1$	$4s4d\ ^1D_2$	4.083E−03	4.259E−03 MPCI [9]	−4.12		

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Table 7 (*continued*)

Final state	Initial state	This work (L, 10^8 s^{-1})	Other theory (10^8 s^{-1})	Diff.	NIST	Diff. (%)
$4s7p\ ^1P_1$	$4s6s\ ^1S_0$	4.763E−03	5.618E−03 MPCI [9]	−15.22		
$4s7p\ ^1P_1$	$4p^2\ ^1D_2$	1.349E−03	1.127E−03 MPCI [9]	19.66		
$4s7p\ ^1P_1$	$4s5d\ ^1D_2$	7.689E−04	5.028E−05 MPCI [9]	93.46		
$4s7p\ ^1P_1$	$4s7s\ ^1S_0$	2.597E−03	5.038E−03 MPCI [9]	−48.46		
$4s7p\ ^1P_1$	$4s6d\ ^1D_2$	4.250E−04	8.985E−04 MPCI [9]	−52.70		
$4s7p\ ^1P_1$	$3d4s\ ^1D_2$	1.575E−01	1.118E−01 MPCI [9]	40.78		
$4s8s\ ^1S_0$	$4s5p\ ^1P_1$	1.964E−02	1.834E−02 MPCI [9]	7.10		
$4s8s\ ^1S_0$	$4s6p\ ^1P_1$	6.149E−03	8.316E−03 MPCI [9]	−26.06		
$4s8s\ ^1S_0$	$4snp\ ^1P_1$	7.344E−05	7.689E−04 MPCI [9]	−90.45		
$4s8s\ ^1S_0$	$4s7p\ ^1P_1$	2.071E−03	2.235E−03 MPCI [9]	−7.31		
$4s8s\ ^1S_0$	$4s4p\ ^1P_1$	3.569E−02	3.693E−02 MPCI [9]	−3.36		
$3d4p\ ^1D_2$	$3d4s\ ^3D_1$	9.127E−02	6.680E−02 MCHF [10]	36.63	9.0E−02	1.41
$3d4p\ ^1D_2$	$3d4s\ ^3D_2$	1.210E−02	9.061E−03 MCHF [10]	33.56	1.4E−02	−13.56
$4s5s\ ^1S_0$	$4s4p\ ^3P_1$	1.694E−05	5.201E−06 MCHF [10]	225.74		
$3d4p\ ^3F_2$	$3d4s\ ^1D_2$	1.267E−01	8.431E−02 MCHF [10]	50.30		
$3d4p\ ^3F_3$	$3d4s\ ^1D_2$	5.039E−05	7.257E−05 MCHF [10]	−30.57		
$3d4p\ ^1D_2$	$3d4s\ ^3D_3$	1.798E−03	7.160E−04 MCHF [10]	151.07		
$4s5p\ ^3P_1$	$4s^2\ ^1S_0$	2.340E−06	4.098E−05 MCHF [10]	−94.28		
$4s5p\ ^3P_1$	$3d4s\ ^1D_2$	1.051E−03	6.208E−04 MCHF [10]	69.35		
$4s5p\ ^3P_2$	$3d4s\ ^1D_2$	1.792E−03	1.454E−04 MCHF [10]	91.88		
$4s5p\ ^1P_1$	$3d4s\ ^3D_2$	2.354E−04	2.884E−04 MCHF [10]	−18.38		
$4s4d\ ^1D_2$	$4s4p\ ^3P_1$	4.043E−06	1.222E−05 MCHF [10]	−66.92		
$4s4d\ ^1D_2$	$4s4p\ ^3P_2$	2.657E−04	1.709E−04 MCHF [10]	55.50		
$3d4s\ ^1D_2$	$4s4p\ ^3P_2$	8.245E−07	8.86E−07 CI+MBPT [11]	6.94		
$4s5s\ ^3S_1$	$4s4p\ ^1P_1$	5.911E−06	6.13E−06 CI+MBPT [11]	3.59		
$4s6d\ ^3D_1$	$4s4p\ ^3P_0$	1.707E−01			1.51E−01	13.05
$4s6d\ ^3D_1$	$4s4p\ ^3P_1$	1.280E−01			1.11E−01	15.32
$4s6d\ ^3D_1$	$4s4p\ ^3P_2$	8.498E−03			5.9E−03	44.03
$4s6d\ ^3D_2$	$4s4p\ ^3P_1$	2.294E−01			1.78E−01	28.89
$4s6d\ ^3D_2$	$4s4p\ ^3P_2$	7.651E−02			6.5E−02	17.71
$4s6d\ ^3D_3$	$4s4p\ ^3P_2$	3.055E−01			2.23E−01	36.98
$4s4d\ ^3D_1$	$4s4p\ ^3P_0$	4.415E−01			4.98E−01	−11.35
$4s4d\ ^3D_1$	$4s4p\ ^3P_1$	3.223E−01			3.42E−01	−5.76
$4s4d\ ^3D_1$	$4s4p\ ^3P_2$	2.034E−02			2.45E−02	−16.96
$4s4d\ ^3D_2$	$4s4p\ ^3P_1$	5.939E−01			6.7E−01	−11.35
$4s4d\ ^3D_2$	$4s4p\ ^3P_2$	1.882E−01			2.0E−01	−5.92
$4s4d\ ^3D_3$	$4s4p\ ^3P_2$	7.793E−01			8.7E−01	−10.43
$3d4p\ ^3D_1$	$4s^2\ ^1S_0$	7.250E−05			1.6E−04	−54.69
$3d4p\ ^3D_1$	$3d4s\ ^3D_1$	5.100E−01			4.3E−01	18.59
$3d4p\ ^3D_1$	$3d4s\ ^3D_2$	1.788E−01			1.4E−01	27.70
$3d4p\ ^3D_2$	$3d4s\ ^3D_1$	1.062E−01			8.3E−02	27.93
$3d4p\ ^3D_2$	$3d4s\ ^3D_2$	4.691E−01			3.8E−01	23.46
$3d4p\ ^3D_2$	$3d4s\ ^3D_3$	1.146E−01			8.6E−02	33.26
$3d4p\ ^3D_3$	$3d4s\ ^3D_2$	8.072E−02			6.0E−02	34.53
$3d4p\ ^3D_3$	$3d4s\ ^3D_3$	6.113E−01			4.9E−01	24.75
$4p^2\ ^3P_0$	$4s4p\ ^3P_1$	1.826E+00			1.99E+00	−8.24
$4p^2\ ^3P_1$	$4s4p\ ^3P_0$	6.116E−01			6.0E−01	1.93
$4p^2\ ^3P_1$	$4s4p\ ^3P_1$	4.633E−01			4.66E−01	−0.57
$4p^2\ ^3P_1$	$4s4p\ ^3P_2$	7.551E−01			7.4E−01	2.04
$4p^2\ ^3P_2$	$4s4p\ ^3P_1$	4.571E−01			4.34E−01	5.33
$4p^2\ ^3P_2$	$4s4p\ ^3P_2$	1.376E+00			1.36E+00	1.18
$3d4p\ ^3P_0$	$3d4s\ ^3D_1$	7.748E−01			6.0E−01	29.13
$3d4p\ ^3P_1$	$4s^2\ ^1S_0$	8.447E−05			1.7E−04	−50.31
$3d4p\ ^3P_1$	$3d4s\ ^3D_1$	2.025E−01			1.5E−01	35.03
$3d4p\ ^3P_1$	$3d4s\ ^3D_2$	5.712E−01			4.4E−01	29.82
$3d4p\ ^3P_2$	$3d4s\ ^3D_1$	8.820E−03			6.1E−03	44.59
$3d4p\ ^3P_2$	$3d4s\ ^3D_2$	1.248E−01			9.1E−02	37.10
$3d4p\ ^3P_2$	$3d4s\ ^3D_3$	6.382E−01			5.0E−01	27.63
$4s6s\ ^3S_1$	$4s4p\ ^3P_0$	2.621E−02			3.34E−02	−21.53
$4s6s\ ^3S_1$	$4s4p\ ^3P_1$	7.994E−02			9.8E−02	−18.43
$4s6s\ ^3S_1$	$4s4p\ ^3P_2$	1.377E−01			1.75E−01	−21.34
$4s6f\ ^3F_2$	$3d^2\ ^3F_3$	5.931E−02			7.2E−02	−17.63
$4s6f\ ^3F_2$	$4s7s\ ^3S_1$	1.101E−02			9.8E−03	12.34
$4s6f\ ^3F_2$	$3d4s\ ^3D_3$	3.166E−04			3.5E−04	−9.56
$4s6f\ ^3F_3$	$4s6d\ ^1D_2$	6.277E−02			5.4E−02	16.23
$4s6f\ ^3F_3$	$3d4s\ ^3D_3$	7.898E−03			8.9E−03	−11.26
$4s6f\ ^3F_4$	$3d4s\ ^3D_3$	7.088E−02			7.9E−02	−10.28
$4s8s\ ^3S_1$	$4s4p\ ^3P_0$	7.436E−03			9.4E−03	−20.90
$4s8s\ ^3S_1$	$4s4p\ ^3P_1$	2.225E−02			3.0E−02	−25.83
$4s8s\ ^3S_1$	$4s4p\ ^3P_2$	3.693E−02			5.3E−02	−30.33
$4s5f\ ^3F_2$	$3d4s\ ^3D_1$	1.106E−01			1.1E−01	0.52
$4s5f\ ^3F_2$	$3d4s\ ^3D_2$	2.057E−02			2.1E−02	−2.05

(*continued on next page*)

Table 7 (*continued*)

Final state	Initial state	This work (L, 10^8 s^{-1})	Other theory (10^8 s^{-1})	Diff.	NIST	Diff. (%)
$4s5f\ ^3F_2$	$3d4s\ ^3D_3$	5.884E−04			5.8E−04	1.45
$4s5f\ ^3F_3$	$3d4s\ ^3D_2$	1.172E−01			1.2E−01	−2.36
$4s5f\ ^3F_3$	$3d4s\ ^3D_3$	1.471E−02			1.5E−02	−1.97
$4s5f\ ^3F_4$	$3d4s\ ^3D_3$	1.323E−01			1.3E−01	1.79
$4s7s\ ^3S_1$	$4s4p\ ^3P_0$	1.873E−02			1.3E−02	44.07
$4s7s\ ^3S_1$	$4s4p\ ^3P_1$	5.630E−02			4.6E−02	22.38
$4s7s\ ^3S_1$	$4s4p\ ^3P_2$	9.417E−02			7.8E−02	20.73
$4s5d\ ^3D_1$	$4s4p\ ^3P_0$	1.927E−01			2.12E−01	−9.12
$4s5d\ ^3D_1$	$4s4p\ ^3P_1$	1.452E−01			1.53E−01	−5.10
$4s5d\ ^3D_1$	$4s4p\ ^3P_2$	9.773E−03			9.5E−03	2.87
$4s5d\ ^3D_2$	$4s4p\ ^3P_1$	2.593E−01			2.97E−01	−12.69
$4s5d\ ^3D_2$	$4s4p\ ^3P_2$	8.734E−02			9.4E−02	−7.08
$4s5d\ ^3D_3$	$4s4p\ ^3P_2$	3.451E−01			3.55E−01	−2.78
$4s4f\ ^3F_2$	$3d4s\ ^3D_1$	1.348E−01			1.76E−01	−23.43
$4s4f\ ^3F_2$	$3d4s\ ^3D_2$	2.508E−02			3.5E−02	−28.33
$4s4f\ ^3F_2$	$3d4s\ ^3D_3$	7.142E−04			9.8E−04	−27.13
$4s4f\ ^3F_3$	$3d4s\ ^3D_2$	1.429E−01			2.09E−01	−31.63
$4s4f\ ^3F_3$	$3d4s\ ^3D_3$	1.791E−02			2.5E−02	−28.38
$4s4f\ ^3F_4$	$3d4s\ ^3D_3$	1.617E−01			2.29E−01	−29.40
$4s5p\ ^3P_2$	$3d4s\ ^3D_1$	6.273E−04			2.3E−03	−72.72
$4s5p\ ^3P_2$	$3d4s\ ^3D_2$	1.558E−02			3.3E−02	−52.79
$4s5p\ ^3P_2$	$3d4s\ ^3D_3$	8.710E−02			1.9E−01	−54.16
$4s5p\ ^3P_1$	$3d4s\ ^3D_1$	2.532E−02			5.6E−02	−54.79
$4s5p\ ^3P_1$	$3d4s\ ^3D_2$	7.859E−02			1.7E−01	−53.77
$3d4p\ ^3F_4$	$3d4s\ ^3D_3$	3.850E−01			5.3E−01	−27.36
$4s5p\ ^3P_0$	$3d4s\ ^3D_1$	1.045E−01			2.2E−01	−52.48
$3d4p\ ^3F_3$	$3d4s\ ^3D_2$	3.367E−01			4.7E−01	−28.36
$3d4p\ ^3F_3$	$3d4s\ ^3D_3$	4.447E−02			5.9E−02	−24.62
$3d4p\ ^3F_2$	$3d4s\ ^3D_1$	2.250E−01			4.4E−01	−48.86
$3d4p\ ^3F_2$	$3d4s\ ^3D_2$	4.840E−02			8.1E−02	−40.25
$3d4p\ ^3F_2$	$3d4s\ ^3D_3$	7.591E−04			2.4E−03	−68.37
$4s5s\ ^3S_1$	$4s4p\ ^3P_0$	9.246E−02			9.6E−02	−3.69
$4s5s\ ^3S_1$	$4s4p\ ^3P_1$	2.759E−01			2.87E−01	−3.88
$4s5s\ ^3S_1$	$4s4p\ ^3P_2$	4.549E−01			4.77E−01	−4.63