Theoretical oscillator strengths, transition probabilities, and radiative lifetimes of levels in Pb V

C. Colón
A. Alonso Medina
P. Porcher

ABSTRACT

Theoretical values of oscillator strengths and transition probabilities for 306 spectral lines arising from the $5d^9 ns$ ($n = 7, 8, 9$), $5d^9 np$ ($n = 6, 7$), $5d^9 6d$, and $5d^9 5f$ configurations, and radiative lifetimes of 9 levels, of Pb V have been obtained. These values were obtained in intermediate coupling (IC) and using *ab initio* relativistic Hartree–Fock calculations including core-polarization effects. We use for the IC calculations the standard method of least squares fitting of experimental energy levels by means of computer codes from Cowan. We included in these calculations the $5d^8 6s 6p$ and $5d^8 6s^2$ configurations. These calculations have facilitated the identification of the 214.25, 216.79, and 227.66 nm spectral lines of Pb V. In the absence of experimental results of oscillator strengths and transition probabilities, we could not make a direct comparison with our results. However, the Stark broadening parameters calculated from these values are in excellent agreement with experimental widening found in the literature.

Contents

1. Introduction.....	273
2. Method of calculation	273
3. Results.....	274
3.1. Energy levels	274
3.2. Transition probabilities, oscillator strengths, and radiative lifetimes.....	274
4. Conclusions.....	274
Acknowledgment	274
References.....	275
Explanation of Tables.....	276

1. Introduction

From a theoretical point of view, oscillator strengths are very sensitive to the different interaction schemes used in studies of atomic structure. Also, the production and evaluation of data for transition probabilities is a research field of continuous interest, as these radiative parameters are necessary to analyze data from astrophysical, fusion, and laboratory plasmas. In astrophysical applications, progress in the identification of spectral lines and information about the transition probabilities and lifetimes for species such as Pb V provides new tools that may allow study within many different spectral windows for space observations. These data are also essential to calculate the Stark width and shift parameters of spectral lines.

Theoretical transition probabilities and oscillator strengths in lead were the subject of different works carried out by the authors of the present study [1–7]. In 2001, Colón and Alonso-Medina [1], calculated theoretical transition probabilities and some lifetimes for the Pb II. These values were obtained in intermediate coupling (IC) by using relativistic Hartree–Fock calculations. They used for the IC calculations the standard method of least squares fitting from experimental energy levels by means of the 1981 Cowan code [8]. Colón and Alonso-Medina [2] then used the matrix elements obtained to calculate the Stark broadening parameters in 2002. In the same way, we studied Pb III [3,4] and Pb IV [5–7]. In contrast to Pb II, in these last cases, we included the core polarization terms in the IC calculations.

There are few theoretical studies of Pb V present in the literature. In 1969, Gutmann [9] made an extensive study of the atomic spectrum of Pb V. The tabulated Pb V spectral lines presented by NIST [10] in 2011 are taken from this author. The $(5d^{10} + 5d^9 6s) - 5d^9 6p$ transitions in Pb V were investigated by Joshi et al. [11] in 1990. In 1992, the transitions $5d^9 6d - 5d^9 6p$ and $5d^9 7s - 5d^9 6p$ were systematically investigated by Wyart et al. [12] in the spectrum of Pb V with the support of Slater–Condon type calculations. In the latter two works, the authors identified of about 90 spectral lines of Pb V without reference to the intense lines of 214.25, 216.79, 227.66, and 242.48 nm. Loginov, in 1993 and 1994, Refs. [13,14] respectively, presented semi-empirical calculations of transition probabilities for $5d^9 6p - 5d^9 6s$ and $5d^9 6p - 5d^{10}$. In this work no reference is made to the lines mentioned above. Recently Bukvić et al. [15], in 2011, performed an experimental study, obtaining Stark widths for four lines (214.25, 216.79, 227.66, and 242.48 nm) of Pb V.

In this work we present oscillator strengths and transition probabilities for 306 spectral lines arising from the $5d^9 ns$ ($n = 7, 8$), $5d^9 np$ ($n = 6, 7$), $5d^9 6d$, and $5d^9 5f$ configurations, and radiative lifetimes of 9 levels, of Pb V. Our values are compared with values calculated by Loginov [14] for lines arising from the $5d^9 6p$ configuration. The Stark broadening parameters calculated from these values [16] are in excellent agreement with experimental widening found for the 214.25, 216.79, and 227.66 nm Pb V spectral lines [15]. The values were calculated in the framework of the relativistic Hartree–Fock (HFR) method by means of the Cowan

computer code [8] in which we have incorporated the core polarization (CP) effects by means of a potential model and a correction to the electric dipole operator.

2. Method of calculation

For the IC calculations we used the standard method of least squares fitting of experimental energy levels by means of the computer programs of Cowan [8]. The basis set used in this work consists in seven configurations of even parity, namely, $5d^{10}$, $5d^9 ns$ ($n = 6, 7, 8$ and 9), $5d^9 6d$, and $5d^9 6s^2$ and four configurations of odd parity, namely, $5d^9 np$ ($n = 6, 7$), $5d^9 5f$, and $5d^9 6s6p$. The experimental levels used for the calculations have been taken from the Moore Tables [17], Gutmann [9], and Wyart et al. [12]. We have taken into account all considerations by Wyart et al. regarding the evaluation of the levels presented in the tables of Moore. In this way we use the assignment made by Wyart et al. for the levels of the configurations $5d^9 6p$, $5d^9 6d$, and $5d^9 7s$ as a starting point for our calculations. Also, we used the levels of the configuration $5d^9 7p$ and $5d^9 5f$ provided by Gutmann. We believe that the Gutmann analysis about these levels is safe because it is based on its interaction with $5d^9 6s$ and $5d^9 6d$ levels. However, we do not consider secure the assignments made by Gutmann for levels of the configurations $5d^9 6s^2$ and $5d^9 6s6p$ that comprises levels built from indirect wavenumber coincidences with no theoretical grounds. So we have introduced the $5d^9 9s$, $5d^9 6s^2$, and $5d^9 6s6p$ configurations, but we have not assigned levels for these configurations.

Due to the large number of parameters to adjust (that exceeds the number of experimental levels) we have excluded from the adjustment process a certain number of parameters. We take for all the F^k , G^k , and R^k integrals not adjusted in the fitting procedure the HFR *ab initio* values scaled down by a factor of 0.85 (as was suggested by Cowan). For the spin–orbit integrals ζ_{nl} , characterized by small numerical values and not adjusted in the fitting procedures, we used the HFR *ab initio* values without scaling. All details of the fitting procedure are not given here but can be obtained upon request from the authors. In Table 1 we present energy levels obtained for the configurations $5d^9 8s$ and $5d^9 5f$. Then, we present in Table 2 the values obtained for the $5d^9 8s$ and $5d^9 5f$ parameters.

In this work we have included the CP effects in the same way as that which we considered in previous works for the Pb III [3,4] and Pb IV [5–7]. These effects are included following the suggestions of Migdalek et al. [18]: the core polarization effects can be written as the one-particle, V_{p1} , and two-particle, V_{p2} , potential models

$$V_{p1} = -\frac{1}{2} \alpha_d \sum_{i=1}^n \frac{r_i^2}{(r_i^2 + r_c^2)^3} \quad (1)$$

$$V_{p2} = -\alpha_d \sum_{i>j}^n \frac{\vec{r}_i \cdot \vec{r}_j}{[(r_i^2 + r_c^2)(r_j^2 + r_c^2)]^{3/2}} \quad (2)$$

where r_c is the cut-off radius chosen as a measure of the size of the ionic core and α_d is the dipole polarizability of the core.

A modification in the radial matrix element can be made in order to take into account the potential change. The term $\langle P_{nl}|r|P_{n'l'}\rangle$ is replaced by

$$\int_0^\infty P_{nl}(r)r \left(1 - \frac{\alpha_d}{(r^2 + r_c^2)^{3/2}}\right) P_{n'l'}(r)dr - \frac{\alpha_d}{r_c^3} \int_0^{r_c} P_{nl}(r)rP_{n'l'}(r)dr \quad (3)$$

where the core penetration term suggested by Hameed [19] has been also included.

For the dipole polarizability and the cut-off radius we use the values, $\alpha_d = 3.986$ (in au) and $r_c = 1.268$ (in au), computed by Fraga et al. [20]. Recently, Hanni et al., in 2010 [21], have determined a value for the polarizability in the Pb V ($\alpha_d = 3.614$ au) very close to the value of Fraga. We have carried out a set of calculations with this last value and we have obtained results identical to those presented in this paper using the Fraga value.

In this way we obtained the *LS* composition of each level and the degree of configuration mixing considering their interactions. For the HFR calculations, the Cowan code provides us the radial parts for determining the transition probabilities and initial estimation of the parameters for the IC fittings. The Lande factors are computed in the Cowan code. Oscillator strengths and transition probabilities corresponding to some spectral lines have been calculated in this work for the first time.

The wavefunctions obtained in this description have been used in this work to obtain the matrix elements and the transition probabilities reported. The transition probabilities and the oscillator strengths are obtained from the matrix elements by using the standard expressions of Martin and Wiese [22]

$$A_{ki} = \frac{2\pi e^2}{m_e c \epsilon_0 \lambda^2} \frac{g_i}{g_k} \quad f_{ik} = \frac{16\pi^3}{3h\epsilon_0 \lambda^3 g_k} |\langle P_k | \vec{r} | P_i \rangle|^2 \quad (4)$$

where A_{ki} and f_{ik} are the transition probability and the oscillator strength respectively, e and m_e are the electron charge and electron mass, λ is the transition wavelength, c is the light speed, h is the Planck constant, g_k and g_i are the statistical weights and $\langle P_k | \vec{r} | P_i \rangle$ is the calculated matrix element including the modification pointed above. The lifetime of a level is the inverse of the sum of the transition probabilities arising from this level. The Lande factors are calculated using the standard expressions given by Cowan [8]

3. Results

3.1. Energy levels

In Table 1 we present the wavefunctions of levels corresponding to $5d^9 8s$ and $5d^9 5f$ configurations in terms of the *LS* functions and a comparison between experimental and theoretical energy values. We use to label the different levels the corresponding notation present in the literature: *LS* for the $5d^9 8s$ and *JJ* for the $5d^9 5f$. In all cases there is a good agreement between our calculations and the experimental values. Also the calculated Lande factors are displayed.

Our calculations confirm the assignment made by Moore for the $5d^9 8s$ configuration. We note that our calculations suggest that the level at 476894 cm^{-1} energy would be the 3D_2 . Also our calculations indicate assignment of $5d^9 8s \ ^1D_2$ to the 452967 cm^{-1} energy level. In addition, a mix of configurations between $5d^8 6s 6p$ and $5d^9 5f$ can be seen clearly. In fact, the energy levels 368346.3 and 391978.9 cm^{-1} , which Gutmann identified as $5d^9 5f$, could also be identified as $5d^8 6s 6p$, given the high presence of this configuration in the composition of these levels. As examples, we present in Table 2 the values found for the different parameters involved

Explanation of Tables

Table 1	Calculated and observed energy levels (cm^{-1}), <i>LS</i> wavefunction compositions and theoretical Lande factors in Pb V
Levels	Numbers assigned to each level
Energy	Energy of each level, in cm^{-1}
Lande factor	The Lande factor calculated in this work
J	The total angular momentum
Wavefunctions	The wavefunction corresponding to each level
%1st	Leading percentage of the principal <i>LS</i> component
%2nd	Leading percentage of other <i>LS</i> components
%3rd	Leading percentage of other <i>LS</i> components
%4th	Leading percentage of other <i>LS</i> components
%5th	Leading percentage of other <i>LS</i> components
Comp	<i>LS</i> components of each level.
Table 2.	Parameters of $5d^9 8s$ and $5d^9 5f$ configurations resulting from the least squares fitting of the intermediate coupling calculations
Configuration	The configuration, with $[\text{Xe}]4f^{14}$ truncated
Parameters	Parameters, in cm^{-1}
E_{av}	Energy configuration average
F^k, G^k	Coulomb radial integrals
ζ_{nl}	Spin-orbit energy
Table 3.	Transition probabilities and oscillator strengths of spectral lines arising from $5d^9 ns$ configurations of Pb V
First column	Transition levels, the lower and upper levels.
Second column	Wavelength, in Å
Third column	Transition probabilities in s^{-1}
Fourth column	Oscillator strengths ($\log gf$ -values)
Table 4.	Transition probabilities and oscillator strengths of spectral lines arising from $5d^9 np$ configurations of Pb V
First column	Transition levels, the lower and upper levels.
Second column	Wavelength, in Å
Third column	Transition probabilities in s^{-1}
Fourth column	Oscillator strengths ($\log gf$ -values)
Table 5.	Transition probabilities and oscillator strengths of spectral lines arising from $5d^9 6d$ configurations of Pb V
First column	Transition levels, the lower and upper levels.
Second column	Wavelength, in Å
Third column	Transition probabilities in s^{-1}
Fourth column	Oscillator strengths ($\log gf$ -values)
Table 6.	Transition probabilities and oscillator strengths of spectral lines arising from $5d^9 5f$ configurations and radiative lifetimes of Pb V
First column	Transition levels, the lower and upper levels.
Second column	Wavelength, in Å
Third column	Transition probabilities in s^{-1}
Fourth column	Oscillator strengths ($\log gf$ -values)
Fifth column	Lifetimes, in ns.

Table 1Calculated and observed energy levels (cm^{-1}), *LS* wavefunction compositions and theoretical Lande factors in Pb V.

Levels ^{a,b}	<i>J</i>	Energy (cm ⁻¹)		Lande factor	Wavefunctions		
		Calc	Obs		%1st comp	%2nd comp	
<i>Design LS</i> [16]							
5d ⁹ (² D _{3/2})8s ³ D ₁	1	476581	476582 ^a	0.499	99 5d ⁹ 8s ³ D ₁		
5d ⁹ (² D _{5/2})8s	2	452965	452967 ^a	1.069	58 5d ⁹ 8s ¹ D ₂	40 5d ⁹ 8s ³ D ₂	
5d ⁹ (³ D _{3/2})8s ¹ D ₂	2	476811	476894 ^a	1.098	58 5d ⁹ 8s ³ D ₂	41 5d ⁹ 8s ¹ D ₂	
5d ⁹ (² D _{5/2})8s ³ D ₃	3	452626	452624 ^a	1.334	100 5d ⁹ 8s ³ D ₃		
<i>Design Jf</i> [9]							
5d ⁹ 5f 2.5(0.5)	0	367756	368346.3 ^b		31 5d ⁸ (³ F)6s6p ⁵ D ₀	31 5d ⁸ (³ P)6s6p ³ Pb ₀	
5d ⁹ 5f 2.5(0.5)	1	368240	368925.2 ^b	1.194	18 5d ⁹ (² D)5f ³ P ₁	16 5d ⁸ (³ P)6s6p ³ Db ₁	
5d ⁹ 5f 2.5(1.5)	1	371057	371093.8 ^b	1.179	49 5d ⁹ (² D)5f ³ P ₁	10 5d ⁹ (² D)5f ³ D ₁	
5d ⁹ 5f 1.5(1.5)	1	391677	391978.9 ^b	1.045	14 5d ⁸ (³ P)6s6p ¹ P ₁	12 5d ⁸ (¹ D)6s6p ³ D ₁	
5d ⁹ 5f 2.5(1.5)	2	371657	370551.5 ^b	1.228	25 5d ⁹ (² D) 5f ³ P ₂	9 5d ⁸ (³ F)6s6p ³ Fb ₂	
5d ⁹ 5f 2.5(2.5)	2	373665	373745.2 ^b	1.142	34 5d ⁹ (² D)5f ¹ D ₂	29 5d ⁹ (² D) 5f ³ D ₂	
5d ⁹ 5f 2.5(2.5)	3	372939	373238.1 ^b	1.122	58 5d ⁹ (² D) 5f ³ F ₃	10 5d ⁹ (² D) 5f ³ D ₃	
5d ⁹ 5f 2.5(3.5)	3	374959	375530.6 ^b	1.208	37 5d ⁹ (² D) 5f ³ D ₃	14 5d ⁹ (² D) 5f ¹ F ₃	
5d ⁹ 5f 2.5(3.5)	4	375391	375502.3 ^b	0.881	62 5d ⁹ (² D) 5f ³ H ₄	20 5d ⁹ (² D) 5f ¹ G ₄	
Levels ^{a,b}	<i>J</i>	Energy (cm ⁻¹)		Lande factor	Wavefunctions		
		Calc	Obs		%3rd comp	%4th comp	%5th comp
<i>DesignLS</i> [16]							
5d ⁹ (² D _{3/2})8s ³ D ₁	1	476581	476582 ^a	0.499			
5d ⁹ (² D _{5/2})8s	2	452965	452967 ^a	1.069			
5d ⁹ (³ D _{3/2})8s ¹ D ₂	2	476811	476894 ^a	1.098			
5d ⁹ (² D _{5/2})8s ³ D ₃	3	452626	452624 ^a	1.334			
<i>Design Jf</i> [9]							
5d ⁹ 5f 2.5(0.5)	0	367756	368346.3 ^b		26 5d ⁹ (² D)5f ³ P ₀	3 5d ⁸ (³ P) 6s6p ⁵ D ₀	3 5d ⁸ (¹ S)6s6p ³ P ₁
5d ⁹ 5f 2.5(0.5)	1	368240	368925.2 ^b	1.194	9 5d ⁸ (³ F)6s6p ³ D ₁	8 5d ⁸ (³ F)6s6p ³ Db ₁	7 5d ⁸ (³ P)6s6p ³ Sb ₁
5d ⁹ 5f 2.5(1.5)	1	371057	371093.8 ^b	1.179	6 5d ⁸ (¹ D)6s6p ³ Db ₁	6 5d ⁸ (¹ D)6s6p ³ P ₁	6 5d ⁸ (³ P)6s6p ³ Pa ₁
5d ⁹ 5f 1.5(1.5)	1	391677	391978.9 ^b	1.045	11 5d ⁸ (³ P) 6s6p ³ Sa ₁	10 5d ⁹ (² D)7p ¹ P ₁	10 5d ⁹ (² D)7p ³ P ₁
5d ⁹ 5f 2.5(1.5)	2	371657	370551.5 ^b	1.228	7 5d ⁹ (² D) 5f ¹ D ₂	7 5d ⁸ (³ F)6s6p ¹ D ₂	6 5d ⁸ (³ P)6s6p ³ Pa ₂
5d ⁹ 5f 2.5(2.5)	2	373665	373745.2 ^b	1.142	4 5d ⁸ (³ P)6s6p ³ Da ₂	4 5d ⁸ (³ F)6s6p ³ Da ₂	4 5d ⁸ (³ F)6s6p ⁵ D ₂
5d ⁹ 5f 2.5(2.5)	3	372939	373238.1 ^b	1.122	5 5d ⁸ (³ P)6s6p ³ Db ₃	4 5d ⁸ (³ F)6s6p ³ Fb ₃	4 5d ⁹ (² D) 5f ³ G ₃
5d ⁹ 5f 2.5(3.5)	3	374959	375530.6 ^b	1.208	10 5d ⁹ (² D) 5f ³ G ₃	10 5d ⁸ (³ P)6s6p ⁵ D ₃	6 5d ⁸ (³ P)6s6p ³ Db ₃
5d ⁹ 5f 2.5(3.5)	4	375391	375502.3 ^b	0.881	8 5d ⁹ (² D) 5f ³ G ₄	1 5d ⁸ (¹ G)6s6p ³ G ₄	1 5d ⁸ (³ F)6s6p ¹ G ₄

^a Moore [16].^b Gutmann [9].

Table 2
Parameters of 5d⁹8s and 5d⁹5f configurations resulting from the least squares fitting of the intermediate coupling calculations. Values in parenthesis are HFR results.

Configuration	Parameters (cm ⁻¹)		
5d ⁹ 5f	$E_{av} = 374715$	$F^1(5d, 5f) = 0\ (0)$	$\zeta_{5d} = 1428\ (8938)$
		$F^2(5p, 5f) = 2574\ (2574)$	$\zeta_{5f} = 159\ (159)$
		$F^3(5d, 5f) = 0\ (0)$	
		$F^4(5d, 5f) = 13496\ (13496)$	
		$G^1(5d, 5f) = 21917\ (21917)$	
		$G^2(5d, 5f) = 0\ (0)$	
		$G^3(5d, 5f) = 13150\ (13150)$	
		$G^4(5d, 5f) = 0\ (0)$	
		$G^5(5d, 5f) = 9211\ (9211)$	
		$G^2(5d, 5f) = 1406\ (1437)$	$\zeta_{5d} = 9582\ (9006)$
5d ⁹ 8s	$E_{av} = 462346$		

Table 3

Transition probabilities and oscillator strengths of spectral lines arising from $5d^9ns$ configurations of Pb V.

No.	Transition levels		Wavelength λ (Å) ^a	Transition probabilities (10^8s^{-1})	log <i>gf</i>
	Upper	Lower			
1	$5d^97s1.5(0.5) j = 1$	$5d^96p 2.5(0.5) j = 2$	603.5	0.024	-3.412
2		$5d^96p 1.5(0.5) j = 2$	697.2	24.77	-0.251
3		$5d^96p 1.5(0.5) j = 1$	709.2	0.275	-2.211
4		$5d^96p2.5(1.5) j = 2$	732.2	3.95	-1.02
5		$5d^96p2.5(1.5) j = 1$	732.8	3.53	-1.043
6		$5d^96p 1.5(1.5) j = 0$	814.1	6.22	-0.734
7		$5d^96p 1.5(1.5) j = 1$	867.9	14.2	-0.313
8		$5d^96p 1.5(1.5) j = 2$	885.7	11.0	-0.399
9	$5d^97s1.5(0.5) j = 2$	$5d^96p2.5(0.5) j = 2$	601.4	0.233	-2.202
10		$5d^96p2.5(0.5) j = 3$	610.0	0.013	-3.450
11		$5d^96p 1.5(0.5) j = 2$	694.4	12.4	-0.338
12		$5d^96p 1.5(0.5) j = 1$	706.3	10.91	-0.394
13		$5d^96p2.5(1.5) j = 2$	729.0	1.53	-1.214
14		$5d^96p2.5(1.5) j = 3$	743.1	0.317	-1.879
15		$5d^96p2.5(1.5) j = 1$	750.5	6.18	-0.583
16		$5d^96p 1.5(1.5) j = 3$	859.0	23.06	0.112
17		$5d^96p 1.5(1.5) j = 1$	863.6	0.751	-1.372
18		$5d^96p 1.5(1.5) j = 2$	881.2	8.83	-0.283
19	$5d^97s2.5(0.5) j = 3$	$5d^96p2.5(0.5) j = 2$	696.2	20.74	0.023
20		$5d^96p2.5(0.5) j = 3$	707.7	11.5	-0.215
21		$5d^96p 1.5(0.5) j = 2$	823.9	0.036	-2.572
22		$5d^96p2.5(1.5) j = 4$	851.9	21.2	0.228
23		$5d^96p2.5(1.5) j = 2$	873.1	0.648	-1.280
24		$5d^96p2.5(1.5) j = 3$	893.4	9.94	-0.073
25		$5d^96p 1.5(1.5) j = 3$	1066.3	0.052	-2.195
26		$5d^96p 1.5(1.5) j = 2$	1100.8	0.052	-2.158
27	$5d^97s2.5(0.5) j = 2$	$5d^96p2.5(0.5) j = 2$	692.4	2.78	-0.999
28		$5d^96p2.5(0.5) j = 3$	703.7	27.8	0.019
29		$5d^96p 1.5(0.5) j = 2$	818.6	2.55	-0.876
30		$5d^96p 1.5(0.5) j = 1$	835.1	4.37	-0.645
31		$5d^96p2.5(1.5) j = 2$	867.1	13.2	-0.124
32		$5d^96p2.5(1.5) j = 3$	887.1	7.44	-0.352
33		$5d^96p2.5(1.5) j = 1$	897.7	5.33	-0.488
34		$5d^96p 1.5(1.5) j = 3$	1057.4	0.072	-2.210
35		$5d^96p 1.5(1.5) j = 1$	1064.3	0.43	-1.430
36	$5d^98s2.5(0.5) j = 3$	$5d^96p 1.5(1.5) j = 2$	1091.2	0.0003	-4.546
37		$5d^96p2.5(0.5) j = 2$	387.9	10.6	-0.779
38	$(5d^9(^2D_{3/2})8s\ ^3D_3)$	$5d^96p2.5(0.5) j = 3$	391.4	5.83	-1.026
39		$5d^96p 1.5(0.5) j = 2$	424.5	0.032	-3.227
40		$5d^96p2.5(1.5) j = 4$	431.9	14.7	-0.531
41		$5d^96p2.5(1.5) j = 2$	437.2	0.53	-1.974
42		$5d^96p2.5(1.5) j = 3$	442.3	7.03	-0.838
43		$5d^96p 1.5(1.5) j = 3$	480.8	0.043	-2.979
44		$5d^96p 1.5(1.5) j = 2$	487.7	0.041	-2.987
45	$5d^98s2.5(0.5) j = 2$	$5d^96p2.5(0.5) j = 2$	387.3	1.36	-1.816
46	$(5d^9(^2D_{5/2})8s\ ^3D_1)$	$5d^96p2.5(0.5) j = 3$	390.9	14.3	-0.783
47		$5d^96p 1.5(0.5) j = 2$	423.9	1.48	-1.693
48		$5d^96p 1.5(0.5) j = 1$	428.3	2.75	-1.425
49		$5d^96p2.5(1.5) j = 2$	436.6	9.15	-0.882
50		$5d^96p2.5(1.5) j = 3$	441.6	5.41	-1.099
51		$5d^96p2.5(1.5) j = 1$	444.2	3.64	-1.267
52		$5d^96p 1.5(1.5) j = 3$	480.5	0.033	-3.242
53		$5d^96p 1.5(1.5) j = 1$	481.5	0.34	-2.225
54	$5d^98s1.5(0.5) j = 1$	$5d^96p 1.5(1.5) j = 2$	486.9	0.0023	-4.389
55	$(5d^9(^2D_{3/2})8s\ j = 2)$	$5d^96p2.5(0.5) j = 2$	354.9	0.012	-4.175
56		$5d^96p 1.5(0.5) j = 2$	385.3	13.0	-1.054
57		$5d^96p 1.5(0.5) j = 1$	388.9	0.11	-3.119
58		$5d^96p2.5(1.5) j = 2$	395.8	2.14	-1.821
59		$5d^96p2.5(1.5) j = 1$	402.0	1.99	-1.839
60		$5d^96p 1.5(1.5) j = 0$	418.5	4.14	-1.487
61		$5d^96p 1.5(1.5) j = 1$	432.3	10.0	-1.073
62		$5d^96p 1.5(1.5) j = 2$	436.7	8.14	-1.149
63		$5d^96p2.5(0.5) j = 2$	354.5	0.094	-3.052
64	$5d^98s1.5(0.5) j = 2$	$5d^96p 1.5(0.5) j = 2$	384.9	6.54	-1.131
65	$(5d^9(^2D_{3/2})8s\ ^1D_2)$	$5d^96p 1.5(0.5) j = 1$	388.5	5.89	-1.178
66		$5d^96p2.5(1.5) j = 2$	395.3	0.69	-2.092
67		$5d^96p2.5(1.5) j = 3$	399.4	0.15	-2.754
68		$5d^96p2.5(1.5) j = 1$	401.5	2.93	-1.450
69		$5d^96p 1.5(1.5) j = 3$	430.6	16.2	-0.643
70		$5d^96p 1.5(1.5) j = 1$	431.7	0.51	-2.142

(continued on next page)

Table 3 (continued)

No.	Transition levels		Wavelength λ (Å) ^a	Transition probabilities (10 ⁸ s ⁻¹)	log <i>gf</i>
	Upper	Lower			
71		5d ⁹ 6p 1.5(1.5) <i>J</i> = 2	436.1	6.25	-1.044

^a Moore [16].

Table 4

Transition probabilities and oscillator strengths of spectral lines arising from $5d^9np$ configurations of Pb V.

No.	Transition levels		λ (Å) ^a	Transition probabilities (10^8 s^{-1})		log <i>gf</i>
	Upper	Lower		This work	Ref. [14]	
1	$5d^96p\ 2.5(0.5)\ j = 2$	$5d^96s\ 2.5(0.5)\ j = 3$	1189.9	12.75	19.67	0.35
2		$5d^96s\ 2.5(0.5)\ j = 2$	1248.5	0.77	1.66	-1.046
3		$5d^96s\ 1.5(0.5)\ j = 1$	1610.5	0.0063	0.007	-2.907
4	$5d^96p\ 2.5(0.5)\ j = 3$	$5d^96s\ 1.5(0.5)\ j = 2$	1700.5	0.066	0.075	-1.833
5		$5d^96s\ 2.5(0.5)\ j = 3$	1157.9	5.66	9.27	-0.106
6		$5d^96s\ 2.5(0.5)\ j = 2$	1213.2	9.29	12.44	0.147
7		$5d^96s\ 1.5(0.5)\ j = 2$	1635.7	0.059	0.06	-1.783
8	$5d^96p\ 1.5(0.5)\ j = 2$	$5d^96s\ 2.5(0.5)\ j = 3$	940.7	0.12	0.34	-2.104
9		$5d^96s\ 2.5(0.5)\ j = 2$	976.9	5.39	6.45	-0.434
10		$5d^96s\ 1.5(0.5)\ j = 1$	1185.4	8.26	11.18	-0.081
11		$5d^96s\ 1.5(0.5)\ j = 2$	1233.5	4.44	6.46	-0.316
12	$5d^96p\ 1.5(0.5)\ j = 1$	$5d^{10}\ 1S_0$	455.6	0.076	0.061	-3.147
13		$5d^96s\ 2.5(0.5)\ j = 2$	954.3	13.6	20.5	-0.251
14		$5d^96s\ 1.5(0.5)\ j = 1$	1152.4	0.041	0.40	-2.604
15		$5d^96s\ 1.5(0.5)\ j = 2$	1197.7	6.13	10.20	-0.394
16	$5d^96p\ 2.5(1.5)\ j = 4$	$5d^96s\ 2.5(0.5)\ j = 3$	906.6	35.9	48.98	0.581
17	$5d^96p\ 2.5(1.5)\ j = 2$	$5d^96s\ 2.5(0.5)\ j = 3$	883.8	2.29	0.34	-0.876
18		$5d^96s\ 2.5(0.5)\ j = 2$	915.7	20.4	6.46	0.101
19		$5d^96s\ 1.5(0.5)\ j = 1$	1096.5	1.52	11.18	-0.866
20		$5d^96s\ 1.5(0.5)\ j = 2$	1137.5	1.78	6.45	-0.765
21	$5d^96p\ 2.5(1.5)\ j = 3$	$5d^96s\ 2.5(0.5)\ j = 3$	863.9	20.5	34.69	0.201
22		$5d^96s\ 2.5(0.5)\ j = 2$	894.4	10.2	19.35	-0.073
23		$5d^96s\ 1.5(0.5)\ j = 2$	1104.8	0.59	0.44	-1.128
24	$5d^96p\ 2.5(1.5)\ j = 1$	$5d^{10}\ 1S_0$	438.9	153.7	132.5	0.123
25		$5d^96s\ 2.5(0.5)\ j = 2$	883.9	16.0	25.10	-0.255
26		$5d^96s\ 1.5(0.5)\ j = 1$	1051.2	2.62	4.31	-0.887
27		$5d^96s\ 1.5(0.5)\ j = 2$	1088.9	9.28	11.02	-0.306
28	$5d^96p\ 1.5(1.5)\ j = 0$	$5d^96s\ 1.5(0.5)\ j = 1$	952.8	26.1	43.06	-0.448
29	$5d^96p\ 1.5(1.5)\ j = 3$	$5d^96s\ 2.5(0.5)\ j = 3$	746.9	0.11	0.18	-2.207
30		$5d^96s\ 2.5(0.5)\ j = 2$	769.5	2.63	1.75	-0.795
31		$5d^96s\ 1.5(0.5)\ j = 2$	920.3	29.4	46.03	0.410
32	$5d^96p\ 1.5(1.5)\ j = 1$	$5d^{10}\ 1S_0$	407.7	29.4	28.0	-0.661
33		$5d^96s\ 2.5(0.5)\ j = 2$	765.9	2.29	2.58	-1.226
34		$5d^96s\ 1.5(0.5)\ j = 1$	888.4	26.4	44.08	-0.034
35		$5d^96s\ 1.5(0.5)\ j = 2$	915.1	3.41	5.80	-0.896
36	$5d^96p\ 1.5(1.5)\ j = 2$	$5d^96s\ 2.5(0.5)\ j = 3$	730.8	0.29	0.44	-1.948
37		$5d^96s\ 2.5(0.5)\ j = 2$	752.5	0.34	0.82	-1.853
38		$5d^96s\ 1.5(0.5)\ j = 1$	870.4	15.5	23.65	-0.066
39		$5d^96s\ 1.5(0.5)\ j = 2$	896.1	16.1	28.66	-0.025
40	$5d^97p\ 2.5(0.5)\ j = 2$	$5d^96s\ 2.5(0.5)\ j = 3$	388.3	41.1		-0.332
41		$5d^96s\ 2.5(0.5)\ j = 2$	394.4	2.48		-1.539
42		$5d^96s\ 1.5(0.5)\ j = 1$	424.5	0.93		-1.901
43		$5d^96s\ 1.5(0.5)\ j = 2$	430.5	6.01		-1.076
44		$5d^96d2.5(1.5)\ j = 1$	2281.6	0.066		-1.579
45		$5d^96d2.5(1.5)\ j = 2$	2498.0	1.41		-0.164
46		$5d^96d2.5(2.5)\ j = 1$	2596.6	0.12		-1.217
47		$5d^96d2.5(1.5)\ j = 3$	2584.5	0.11		-1.258
48		$5d^96d1.5(1.5)\ j = 2$	2796.0	0.057		-1.474
49		$5d^97s\ 2.5(0.5)\ j = 3$	3352.5	0.78		-0.182
50		$5d^97s\ 2.5(0.5)\ j = 2$	3444.1	0.036		-1.496
51		$5d^96d2.5(1.5)\ j = 3$	6016.1	0.021		-1.244
52	$5d^97p\ 2.5(1.5)\ j = 4$	$5d^96s\ 2.5(0.5)\ j = 3$	376.6	3.67		-1.153
53		$5d^96d2.5(1.5)\ j = 3$	2140.1	0.87		-0.257
54		$5d^96d2.5(2.5)\ j = 3$	2267.4	0.69		-0.316
55		$5d^97s\ 2.5(0.5)\ j = 3$	2641.0	4.42		0.617

^a Moore [16].

Table 5
Transition probabilities and oscillator strengths of spectral lines arising from $5d^96d$ configurations of Pb V.

No.	Transition levels		λ (Å) ^a	Transition probabilities (10 ⁸ s ⁻¹)	log <i>gf</i>
	Upper	Lower			
1	5d ⁹ 6d2.5(1.5) <i>j</i> = 1	5d ⁹ 6p 2.5(0.5) <i>j</i> = 2	771.4	80.6	0.330
2		5d ⁹ 6p 1.5(0.5) <i>j</i> = 2	931.3	0.71	-1.539
3		5d ⁹ 6p 1.5(0.5) <i>j</i> = 1	952.8	2.02	-1.089
4	5d ⁹ 6p 2.5(1.5) <i>j</i> = 2	5d ⁹ 6p 2.5(1.5) <i>j</i> = 2	994.7	5.34	-0.622
5		5d ⁹ 6p 2.5(1.5) <i>j</i> = 1	1035.1	0.73	-1.454
6		5d ⁹ 6p 1.5(1.5) <i>j</i> = 0	1152.3	0.15	-2.057
7	5d ⁹ 6p 1.5(1.5) <i>j</i> = 1	5d ⁹ 6p 1.5(1.5) <i>j</i> = 1	1263.2	0.0055	-3.393
8		5d ⁹ 6p 1.5(1.5) <i>j</i> = 2	1301.3	0.043	-2.473
9		5d ⁹ 6p 2.5(0.5) <i>j</i> = 2	749.4	68.1	0.452
10	5d ⁹ 6d2.5(1.5) <i>j</i> = 2	5d ⁹ 6p 2.5(0.5) <i>j</i> = 3	762.7	15.4	-0.173
11		5d ⁹ 6p 1.5(0.5) <i>j</i> = 2	899.5	0.029	-2.737
12		5d ⁹ 6p 1.5(0.5) <i>j</i> = 1	919.5	0.22	-1.862
13	5d ⁹ 6p 2.5(1.5) <i>j</i> = 2	5d ⁹ 6p 2.5(1.5) <i>j</i> = 2	958.5	0.29	-1.693
14		5d ⁹ 6p 2.5(1.5) <i>j</i> = 3	983.0	8.75	-0.197
15		5d ⁹ 6p 2.5(1.5) <i>j</i> = 1	996.0	0.35	-1.581
16	5d ⁹ 6p 1.5(1.5) <i>j</i> = 3	5d ⁹ 6p 1.5(1.5) <i>j</i> = 3	1196.5	0.034	-2.428
17		5d ⁹ 6p 1.5(1.5) <i>j</i> = 1	1205.4	0.012	-2.889
18		5d ⁹ 6p 1.5(1.5) <i>j</i> = 2	1240.0	0.070	-2.081
19	5d ⁹ 6d2.5(2.5) <i>j</i> = 1	5d ⁹ 6p 1.5(1.5) <i>j</i> = 2	741.0	14.4	-0.422
20		5d ⁹ 6p 1.5(0.5) <i>j</i> = 2	887.4	1.64	-1.219
21		5d ⁹ 6p 1.5(0.5) <i>j</i> = 1	906.9	16.0	-0.234
22	5d ⁹ 6p 2.5(1.5) <i>j</i> = 2	5d ⁹ 6p 2.5(1.5) <i>j</i> = 2	944.7	7.65	-0.510
23		5d ⁹ 6p 2.5(1.5) <i>j</i> = 1	981.1	22.1	-0.018
24		5d ⁹ 6p 1.5(1.5) <i>j</i> = 0	1085.8	0.026	-2.864
25	5d ⁹ 6p 1.5(1.5) <i>j</i> = 1	5d ⁹ 6p 1.5(1.5) <i>j</i> = 1	1183.7	1.12	-1.143
26		5d ⁹ 6p 1.5(1.5) <i>j</i> = 2	1217.1	0.0069	-3.320
27		5d ⁹ 6p 2.5(0.5) <i>j</i> = 2	742.0	33.7	0.298
28	5d ⁹ 6d2.5(1.5) <i>j</i> = 3	5d ⁹ 6p 2.5(0.5) <i>j</i> = 2	755.0	37.6	0.354
29		5d ⁹ 6p 1.5(0.5) <i>j</i> = 3	888.8	0.68	-1.237
30		5d ⁹ 6p 2.5(1.5) <i>j</i> = 4	921.6	4.46	-0.385
31	5d ⁹ 6p 2.5(1.5) <i>j</i> = 2	5d ⁹ 6p 2.5(1.5) <i>j</i> = 2	946.3	0.92	-1.065
32		5d ⁹ 6p 2.5(1.5) <i>j</i> = 3	970.2	9.98	-0.005
33		5d ⁹ 6p 1.5(1.5) <i>j</i> = 3	1177.6	0.081	-1.922
34	5d ⁹ 6d2.5(2.5) <i>j</i> = 3	5d ⁹ 6p 2.5(0.5) <i>j</i> = 2	727.8	0.067	-2.428
35		5d ⁹ 6p 2.5(0.5) <i>j</i> = 3	740.3	7.04	-0.388
36		5d ⁹ 6p 1.5(0.5) <i>j</i> = 2	868.6	6.61	-0.265
37	5d ⁹ 6p 2.5(1.5) <i>j</i> = 4	5d ⁹ 6p 2.5(1.5) <i>j</i> = 4	899.8	0.88	-1.104
38		5d ⁹ 6p 2.5(1.5) <i>j</i> = 3	923.4	27.9	0.402
39		5d ⁹ 6p 2.5(1.5) <i>j</i> = 2	946.2	14.9	0.150
40	5d ⁹ 6p 1.5(1.5) <i>j</i> = 3	5d ⁹ 6p 1.5(1.5) <i>j</i> = 3	1142.3	0.14	-1.692
41		5d ⁹ 6p 1.5(1.5) <i>j</i> = 2	1181.9	0.025	-2.424
42		5d ⁹ 6p 2.5(0.5) <i>j</i> = 2	726.2	0.63	-1.602
43	5d ⁹ 6d2.5(2.5) <i>j</i> = 2	5d ⁹ 6p 2.5(0.5) <i>j</i> = 3	738.7	2.21	-1.038
44		5d ⁹ 6p 1.5(0.5) <i>j</i> = 2	866.3	4.58	-0.572
45		5d ⁹ 6p 1.5(0.5) <i>j</i> = 1	884.8	8.66	-0.298
46	5d ⁹ 6p 2.5(1.5) <i>j</i> = 2	5d ⁹ 6p 2.5(1.5) <i>j</i> = 2	920.9	28.0	0.256
47		5d ⁹ 6p 2.5(1.5) <i>j</i> = 3	917.5	3.15	-0.672
48		5d ⁹ 6p 2.5(1.5) <i>j</i> = 1	955.4	9.43	-0.187
49	5d ⁹ 6p 1.5(1.5) <i>j</i> = 3	5d ⁹ 6p 1.5(1.5) <i>j</i> = 3	1138.4	0.027	-2.566
50		5d ⁹ 6p 1.5(1.5) <i>j</i> = 1	1146.5	0.41	-1.383
51		5d ⁹ 6p 1.5(1.5) <i>j</i> = 2	1177.8	0.0010	-3.949
52	5d ⁹ 6d2.5(2.5) <i>j</i> = 4	5d ⁹ 6p 2.5(0.5) <i>j</i> = 3	734.8	0.84	-1.210
53		5d ⁹ 6p 2.5(1.5) <i>j</i> = 4	891.7	13.8	0.185
54		5d ⁹ 6p 2.5(1.5) <i>j</i> = 3	937.1	39.7	0.674
55	5d ⁹ 6d1.5(1.5) <i>j</i> = 1	5d ⁹ 6p 1.5(1.5) <i>j</i> = 3	1129.2	0.15	-1.595
56		5d ⁹ 6p 2.5(0.5) <i>j</i> = 2	648.6	0.34	-2.195
57		5d ⁹ 6p 1.5(0.5) <i>j</i> = 2	758.1	7.59	-0.693
58	5d ⁹ 6p 1.5(0.5) <i>j</i> = 1	5d ⁹ 6p 1.5(0.5) <i>j</i> = 1	772.3	37.4	-0.003
59		5d ⁹ 6p 2.5(1.5) <i>j</i> = 2	799.6	1.53	-1.354
60		5d ⁹ 6p 2.5(1.5) <i>j</i> = 1	825.5	19.1	-0.230
61	5d ⁹ 6p 1.5(1.5) <i>j</i> = 0	5d ⁹ 6p 1.5(1.5) <i>j</i> = 0	898.3	1.80	-1.187
62		5d ⁹ 6p 1.5(1.5) <i>j</i> = 1	964.3	7.84	-0.477
63		5d ⁹ 6p 2.5(0.5) <i>j</i> = 2	646.9	7.06	-0.496
64	5d ⁹ 6d1.5(1.5) <i>j</i> = 3	5d ⁹ 6p 2.5(0.5) <i>j</i> = 3	656.8	0.15	-2.171
65		5d ⁹ 6p 1.5(0.5) <i>j</i> = 3	755.8	0.13	-2.223
66		5d ⁹ 6p 1.5(0.5) <i>j</i> = 2	779.3	70.2	0.638
67	5d ⁹ 6p 2.5(1.5) <i>j</i> = 4	5d ⁹ 6p 2.5(1.5) <i>j</i> = 4	779.3	0.0017	-3.951
68		5d ⁹ 6p 2.5(1.5) <i>j</i> = 2	797.0	12.4	-0.079
69		5d ⁹ 6p 2.5(1.5) <i>j</i> = 3	813.9	0.096	-2.170
70	5d ⁹ 6p 1.5(1.5) <i>j</i> = 3	5d ⁹ 6p 1.5(1.5) <i>j</i> = 3	954.9	4.08	-0.401

(continued on next page)

Table 5 (continued)

No.	Transition levels		Wavelength λ (Å) ^a	Transition probabilities (10 ⁸ s ⁻¹)	log <i>gf</i>
	Upper	Lower			
71	5d ⁹ 6d1.5(2.5) <i>J</i> = 1	5d ⁹ 6p 1.5(1.5) <i>J</i> = 2	982.4	3.14	-0.483
72		5d ⁹ 6p 2.5(0.5) <i>J</i> = 2	637.6	0.28	-2.290
73		5d ⁹ 6p 1.5(0.5) <i>J</i> = 2	743.1	4.32	-0.953
74		5d ⁹ 6p 1.5(0.5) <i>J</i> = 1	756.6	5.54	-0.848
75		5d ⁹ 6p 2.5(1.5) <i>J</i> = 2	782.8	0.25	-2.155
76	5d ⁹ 6p 2.5(1.5) <i>J</i> = 1	5d ⁹ 6p 2.5(1.5) <i>J</i> = 1	807.7	8.90	-0.578
77		5d ⁹ 6p 1.5(1.5) <i>J</i> = 0	877.3	32.5	0.053
78		5d ⁹ 6p 1.5(1.5) <i>J</i> = 1	940.1	14.4	-0.233
79		5d ⁹ 6p 1.5(1.5) <i>J</i> = 2	961.0	0.10	-2.364
80		5d ⁹ 6p 2.5(0.5) <i>J</i> = 2	634.9	0.22	-2.181
81	5d ⁹ 6d1.5(1.5) <i>J</i> = 2	5d ⁹ 6p 1.5(0.5) <i>J</i> = 2	739.5	29.6	0.097
82		5d ⁹ 6p 1.5(0.5) <i>J</i> = 1	752.9	21.9	-0.036
83		5d ⁹ 6p 2.5(1.5) <i>J</i> = 2	778.9	4.01	-0.737
84		5d ⁹ 6p 2.5(1.5) <i>J</i> = 3	795.0	0.081	-2.414
85		5d ⁹ 6p 2.5(1.5) <i>J</i> = 1	803.4	14.2	-0.161
86	5d ⁹ 6p 1.5(1.5) <i>J</i> = 3	5d ⁹ 6p 1.5(1.5) <i>J</i> = 3	929.0	3.60	-0.626
87		5d ⁹ 6p 1.5(1.5) <i>J</i> = 1	934.4	0.026	-2.766
88		5d ⁹ 6p 1.5(1.5) <i>J</i> = 2	955.1	11.6	-0.089
89		5d ⁹ 6p 2.5(0.5) <i>J</i> = 2	628.6	0.17	-2.291
90		5d ⁹ 6p 2.5(0.5) <i>J</i> = 3	637.9	0.0025	-4.104
91	5d ⁹ 6d1.5(2.5) <i>J</i> = 2	5d ⁹ 6p 1.5(0.5) <i>J</i> = 2	730.8	6.24	-0.586
92		5d ⁹ 6p 1.5(0.5) <i>J</i> = 1	744.0	0.044	-2.743
93		5d ⁹ 6p 2.5(1.5) <i>J</i> = 2	769.3	0.53	-1.624
94		5d ⁹ 6p 2.5(1.5) <i>J</i> = 1	793.2	4.11	-0.707
95		5d ⁹ 6p 1.5(1.5) <i>J</i> = 3	915.4	0.32	-1.683
96	5d ⁹ 6d1.5(2.5) <i>J</i> = 3	5d ⁹ 6p 1.5(1.5) <i>J</i> = 1	920.6	36.7	0.377
97		5d ⁹ 6p 1.5(1.5) <i>J</i> = 2	940.7	9.70	-0.175
98		5d ⁹ 6p 2.5(0.5) <i>J</i> = 2	633.9	0.29	-1.919
99		5d ⁹ 6p 2.5(0.5) <i>J</i> = 3	633.1	0.051	-2.659
100		5d ⁹ 6p 1.5(0.5) <i>J</i> = 2	724.6	1.06	-1.219
101	5d ⁹ 6p 2.5(1.5) <i>J</i> = 2	5d ⁹ 6p 2.5(1.5) <i>J</i> = 2	762.3	0.013	-3.083
102		5d ⁹ 6p 2.5(1.5) <i>J</i> = 3	777.8	0.45	-1.538
103		5d ⁹ 6p 1.5(1.5) <i>J</i> = 3	905.6	13.3	0.070
104		5d ⁹ 6p 1.5(1.5) <i>J</i> = 2	930.3	38.0	0.554

^a Moore [16].

Table 6

Transition probabilities and oscillator strengths of spectral lines arising from $5d^9 5f$ configurations and radiative lifetimes of Pb V.

No.	Transition levels		Wavelength λ (Å) ^a	Transition probabilities ($10^8 s^{-1}$)	$\log gf$	Lifetimes (ns)
	Upper	Lower				
1	$5d^9 5f2.5(0.5) J = 0$	$5d^9 6s1.5(0.5) J = 1$	424.4	40.2	0.962	0.19
2		$5d^9 6d2.5(1.5) J = 1$	2277.6	1.48	-0.924	
3		$5d^9 6d2.5(2.5) J = 1$	2591.5	0.055	-2.236	
4	$5d^9 5f2.5(0.5) J = 1$	$5d^9 6d1.5(2.5) J = 1$	5988.6	0.0012	-3.188	0.076
5		$5d^{10} \ ^1S_0$	271.1	3.92	-1.885	
6		$5d^9 6s2.5(0.5) J = 2$	393.4	74.7	-0.283	
7		$5d^9 6s1.5(0.5) J = 1$	423.3	26.3	-0.670	
8		$5d^9 6s1.5(0.5) J = 2$	429.3	2.42	-1.695	
9		$5d^9 6d2.5(1.5) J = 1$	2248.0	0.50	-0.925	
10		$5d^9 6d2.5(1.5) J = 2$	2457.8	0.10	-1.537	
11		$5d^9 6d2.5(2.5) J = 1$	2553.2	0.24	-1.140	
12		$5d^9 6d2.5(2.5) J = 2$	3368.0	0.044	-1.635	
13		$5d^9 6d1.5(1.5) J = 1$	5012.7	0.012	-1.852	
14	$5d^9 5f2.5(1.5) J = 1$	$5d^9 6s2.5(0.5) J = 2$	390.0	1.47	-1.998	0.17
15		$5d^9 6s1.5(0.5) J = 1$	419.5	47.8	0.422	
16		$5d^9 6d1.5(0.5) J = 2$	425.4	0.41	-2.480	
17		$5d^9 6d2.5(1.5) J = 1$	2143.5	2.33	-0.314	
18		$5d^9 6d2.5(1.5) J = 2$	2333.4	0.85	-0.668	
19		$5d^9 6d2.5(2.5) J = 1$	2419.2	0.26	-1.167	
20		$5d^9 6d2.5(2.5) J = 2$	2591.4	0.22	-1.173	
21		$5d^9 7s2.5(0.5) J = 2$	3138.7	0.14	-1.220	
22		$5d^9 6s2.5(0.5) J = 3$	384.9	29.4	-0.489	
23		$5d^9 6s2.5(0.5) J = 2$	390.8	7.87	-1.050	
24	$5d^9 5f2.5(1.5) J = 2$	$5d^9 6s1.5(0.5) J = 1$	420.4	12.7	-0.777	0.14
25		$5d^9 6s1.5(0.5) J = 2$	426.3	2.04	-1.560	
26		$5d^9 6d2.5(1.5) J = 1$	2168.7	0.41	-0.861	
27		$5d^9 6d2.5(1.5) J = 2$	2363.3	0.0082	-2.477	
28		$5d^9 6d2.5(2.5) J = 1$	2451.4	0.25	-0.973	
29		$5d^9 6d2.5(1.5) J = 3$	2440.6	0.13	-1.249	
30		$5d^9 6d2.5(2.5) J = 2$	2628.4	0.74	-0.446	
31		$5d^9 7s2.5(0.5) J = 3$	3114.1	0.081	-1.264	
32		$5d^9 7s2.5(0.5) J = 2$	3193.1	0.17	-0.910	
33		$5d^9 6d1.5(1.5) J = 1$	4634.9	0.011	-1.796	
34	$5d^9 5f2.5(2.5) J = 3$	$5d^9 6d1.5(1.5) J = 3$	4723.8	0.0037	-2.250	0.66
35		$5d^9 6d1.5(2.5) J = 3$	6463.9	0.0020	-2.272	
36		$5d^9 6s2.5(0.5) J = 3$	381.0	0.11	-2.754	
37		$5d^9 6s2.5(0.5) J = 2$	386.8	2.78	-1.360	
38		$5d^9 6d1.5(0.5) J = 2$	421.5	0.81	-1.821	
39		$5d^9 6d2.5(1.5) J = 2$	2222.2	2.04	0.041	
40		$5d^9 6d2.5(1.5) J = 3$	2290.4	1.07	-0.212	
41		$5d^9 6d2.5(2.5) J = 2$	2455.0	0.0049	-2.5	
42		$5d^9 7s2.5(0.5) J = 3$	2873.7	0.089	-1.111	
43		$5d^9 7s2.5(0.5) J = 2$	2940.8	0.076	-1.155	
44	$5d^9 5f2.5(2.5) J = 2$	$5d^9 6s2.5(0.5) J = 3$	380.3	2.95	-1.495	0.20
45		$5d^9 6s2.5(0.5) J = 2$	386.0	0.072	-3.098	
46		$5d^9 6s1.5(0.5) J = 1$	414.9	7.08	-1.039	
47		$5d^9 6s1.5(0.5) J = 2$	420.6	25.6	-0.469	
48		$5d^9 6d2.5(1.5) J = 1$	2028.2	0.32	-1.005	
49		$5d^9 6d2.5(1.5) J = 2$	2197.4	0.40	-0.830	
50		$5d^9 6d2.5(2.5) J = 1$	2273.4	0.32	-0.903	
51		$5d^9 6d2.5(1.5) J = 3$	2264.1	0.13	-1.275	
52		$5d^9 6d2.5(2.5) J = 2$	2424.8	1.11	-0.310	
53		$5d^9 7s2.5(0.5) J = 2$	2897.6	0.16	-0.988	
54	$5d^9 5f2.5(3.5) J = 4$	$5d^9 6d1.5(1.5) J = 1$	4037.3	0.13	-0.803	3.96
55		$5d^9 6s2.5(0.5) J = 3$	377.7	0.60	-1.934	
56		$5d^9 6d2.5(1.5) J = 3$	2177.5	0.043	-1.546	
57		$5d^9 7s2.5(0.5) J = 3$	2698.2	0.010	-1.997	
58		$5d^9 6d1.5(1.5) J = 3$	3828.4	1.05	0.323	
59	$5d^9 5f2.5(3.5) J = 3$	$5d^9 6s2.5(0.5) J = 3$	377.7	3.82	-1.240	0.76
60		$5d^9 6s2.5(0.5) J = 2$	383.4	0.50	-2.110	
61		$5d^9 6s1.5(0.5) J = 2$	417.5	0.97	-1.746	
62		$5d^9 6d2.5(1.5) J = 2$	2114.5	0.0082	-2.392	
63		$5d^9 6d2.5(1.5) J = 3$	2176.1	0.0070	-2.441	
64		$5d^9 6d2.5(2.5) J = 2$	2324.2	2.25	0.115	
65		$5d^9 7s2.5(0.5) J = 3$	2696.1	0.0085	-2.181	
66		$5d^9 7s2.5(0.5) J = 2$	2755.1	0.0068	-2.256	
67		$5d^{10} \ ^1S_0$	255.1	1.82	-2.273	
68		$5d^9 6s2.5(0.5) J = 2$	360.6	0.46	-2.573	
69	$5d^9 5f1.5(1.5) J = 1$	$5d^9 6s1.5(0.5) J = 1$	385.7	15.31	-0.988	0.20
70		$5d^9 6s1.5(0.5) J = 2$	390.6	13.0	-1.047	

(continued on next page)

Table 6 (*continued*)

No.	Transition levels		Wavelength λ (Å) ^a	Transition probabilities (10^8s^{-1})	$\log gf$	Lifetimes (ns)
	Upper	Lower				
71		$5d^9 6d 2.5(1.5) J = 1$	1480.6	0.036	−2.442	
72		$5d^9 6d 2.5(1.5) J = 2$	1568.8	0.0017	−3.722	
73		$5d^9 6d 2.5(2.5) J = 1$	1607.2	0.012	−2.854	
74		$5d^9 6d 2.5(2.5) J = 2$	1681.4	0.0013	−3.770	
75		$5d^9 6d 1.5(1.5) J = 1$	2325.4	0.52	−0.891	
76		$5d^9 6d 1.5(1.5) J = 0$	3514.7	0.10	−1.244	

^a Moore [16].