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2013 Phys. Scr. 88 065302

(http://iopscience.iop.org/1402-4896/88/6/065302)

Phys. Scr. **88** (2013) 065302 (13pp) doi:10.1088/0031-8949/88/06/065302

Atomic data for radiative transitions in the third spectra of rhodium (Rh III), palladium (Pd III) and silver (Ag III)

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Received 25 April 2013
Accepted for publication 14 October 2013
Published 13 November 2013
Online at stacks.iop.org/PhysScr/88/065302

Abstract
A new set of radiative decay rates in doubly ionized rhodium (Rh III), palladium (Pd III) and silver (Ag III) has been computed by means of the pseudo-relativistic Hartree–Fock method including core-polarization effects (HFR+CPOL) and semi-empirical optimization of radial energy parameters. For these three ions, oscillator strengths and transition probabilities for spectral lines appearing in the ultraviolet region from 70 to 250 nm are reported for the first time. The accuracy of these results has been estimated through the excellent agreement observed between experimental lifetime measurements and similar HFR+CPOL calculations performed recently in isoelectronic ions Ru II and Rh II.

S Online supplementary data available from stacks.iop.org/PhysScr/88/065302/mmedia

1. Introduction

The calculation of electronic structure and radiative parameters for atoms and lowly charged ions belonging to the fifth row of the periodic table (from Rb to Xe) is a demanding and time-consuming challenge. If neutral and singly ionized atoms of this group have been the subject of many different studies on both experimental and theoretical sides, doubly ionized species considerably suffer from the lack of accurate atomic data. The present paper focuses on the particular cases of Rh III, Pd III and Ag III for which no radiative rates have been published so far. These three ions are characterized by similar $4d^k$ ground-state configurations with $k = 7$, 8 and 9 for Rh III, Pd III and Ag III, respectively.

In astrophysics, rhodium, palladium and silver are among the elements important for testing current nucleosynthesis models (Mashonkina 2009) for which a detailed analysis of the rapid (r-) and slow (s-) neutron capture processes is not possible without reliable atomic data. As an example, a recent spectral synthesis of 71 stars by Hansen *et al* (2012) showed clear indications that a second/weak r-process is responsible for the formation of Pd and Ag. On the basis of the comparison to model predictions, these authors found that the conditions under which this process takes place differ from those for the main r-process in needing lower neutron number densities, lower neutron-to-seed ratios, and lower entropies and/or higher electron abundances. The understanding of the large overabundances of some heavy elements in chemically peculiar stars requires also a large number of radiative parameters for neutral, singly and doubly ionized heavy atoms (see e.g. Wallerstein *et al* 1997, Jorissen 2004).

In the present paper, we report on calculations of oscillator strengths and transition probabilities in Rh III, Pd III and Ag III performed using the relativistic Hartree–Fock approach including core-polarization effects. This work is an extension of our recent investigations of the fifth row elements Y II, Y III (Biémont *et al* 2011), Zr II (Malcheva *et al* 2006), Nb I (Malcheva *et al* 2011), Nb II, Nb III (Nilsson *et al* 2010), Mo II (Quinet 2002, Lundberg *et al* 2010, Jiang *et al* 2012), Tc II (Palmeri *et al* 2007), Ru I (Fivet *et al* 2009), Ru II, Ru III (Palmeri *et al* 2009), Rh II (Quinet *et al* 2011, 2012), Pd I (Xu *et al* 2006), Ag II (Biémont *et al* 2005, Campos *et al* 2005), Sn I (Zhang *et al* 2008, 2009, 2010), Sb I (Hartman *et al* 2010), Te II and Te III (Zhang *et al* 2013).

The excellent agreement observed for the isoelectronic ions Ru II and Rh II when using similar pseudo-relativistic Hartree–Fock method including core-polarization effects (HFR+CPOL) models allows the assessment of the reliability

Table 4. Oscillator strengths and transition probabilities in Rh III (log $gf > -0.5$).

Wavelength[a] (nm)	Lower level[b] E (cm^{-1})	Parity	J	Upper level[b] E (cm^{-1})	Parity	J	log gf[c]	gA[c] (s^{-1})
85.228	2148	(e)	7/2	119 481	(o)	7/2	−0.48	3.01×10^9
85.477	0	(e)	9/2	116 991	(o)	9/2	−0.36	3.98×10^9
85.988	0	(e)	9/2	116 296	(o)	9/2	0.02	9.55×10^9
86.133	3486	(e)	5/2	119 586	(o)	5/2	−0.34	4.15×10^9
86.200	15 130	(e)	7/2	131 138	(o)	5/2	−0.42	3.40×10^9
86.211	3486	(e)	5/2	119 481	(o)	7/2	−0.28	4.73×10^9
86.376	2148	(e)	7/2	117 921	(o)	7/2	−0.15	6.29×10^9
86.622	0	(e)	9/2	115 445	(o)	11/2	−0.47	3.04×10^9
86.758	4322	(e)	3/2	119 586	(o)	5/2	−0.44	3.18×10^9
87.038	13 030	(e)	9/2	127 923	(o)	7/2	0.27	1.64×10^{10}
87.076	2148	(e)	7/2	116 991	(o)	9/2	−0.11	6.85×10^9
87.425	3486	(e)	5/2	117 870	(o)	5/2	−0.44	3.14×10^9
87.786	13 030	(e)	9/2	126 944	(o)	9/2	−0.20	5.51×10^9
87.839	2148	(e)	7/2	115 992	(o)	5/2	−0.33	4.06×10^9
89.432	0	(e)	9/2	111 817	(o)	9/2	−0.25	4.65×10^9
89.658	19 576	(e)	9/2	131 111	(o)	7/2	0.03	8.84×10^9
89.755	0	(e)	9/2	111 414	(o)	11/2	0.06	9.55×10^9
89.765	15 130	(e)	7/2	126 532	(o)	7/2	−0.08	6.89×10^9
90.020	13 030	(e)	9/2	124 116	(o)	11/2	−0.29	4.23×10^9
90.022	15 130	(e)	7/2	126 213	(o)	7/2	−0.49	2.68×10^9
90.057	0	(e)	9/2	111 041	(o)	11/2	−0.33	3.89×10^9
90.976	13 030	(e)	9/2	122 949	(o)	9/2	0.04	8.76×10^9
91.123	15 130	(e)	7/2	124 871	(o)	7/2	−0.32	3.89×10^9
91.183	2148	(e)	7/2	111 817	(o)	9/2	−0.45	2.82×10^9
91.375	21 699	(e)	3/2	131 138	(o)	5/2	−0.35	3.55×10^9
91.499	13 030	(e)	9/2	122 321	(o)	7/2	−0.14	5.79×10^9
91.982	21 699	(e)	3/2	130 416	(o)	1/2	−0.29	4.04×10^9
92.008	15 130	(e)	7/2	123 815	(o)	9/2	−0.18	5.22×10^9
92.574	19 576	(e)	9/2	127 598	(o)	9/2	0.46	2.22×10^{10}
92.677	17 425	(e)	11/2	125 326	(o)	9/2	−0.05	7.00×10^9
93.129	17 425	(e)	11/2	124 802	(o)	9/2	−0.48	2.57×10^9
93.728	17 425	(e)	11/2	124 116	(o)	11/2	0.42	1.99×10^{10}
93.743	13 030	(e)	9/2	119 705	(o)	11/2	−0.21	4.68×10^9
93.858	18 277	(e)	5/2	124 821	(o)	3/2	−0.49	2.43×10^9
93.993	17 425	(e)	11/2	123 815	(o)	9/2	−0.41	2.95×10^9
95.336	17 425	(e)	11/2	122 317	(o)	11/2	−0.39	3.01×10^9
95.472	13 030	(e)	9/2	117 773	(o)	9/2	−0.26	4.01×10^9
95.843	26 801	(e)	5/2	131 138	(o)	5/2	−0.44	2.64×10^9
96.113	18 277	(e)	5/2	122 321	(o)	7/2	−0.32	3.45×10^9
99.161	0	(e)	9/2	100 846	(o)	7/2	−0.05	6.01×10^9
99.248	0	(e)	9/2	100 757	(o)	9/2	−0.36	2.93×10^9
100.291	2148	(e)	7/2	101 858	(o)	5/2	−0.27	3.56×10^9
100.960	3486	(e)	5/2	102 535	(o)	3/2	−0.38	2.76×10^9
102.631	27 890	(e)	7/2	125 326	(o)	9/2	−0.19	4.12×10^9
168.857	66 104	(e)	11/2	125 326	(o)	9/2	−0.47	8.02×10^8
172.940	43 022	(e)	9/2	100 846	(o)	7/2	−0.37	9.51×10^8
175.152	62 353	(e)	13/2	119 446	(o)	13/2	−0.17	1.48×10^9
176.743	45 278	(e)	5/2	101 858	(o)	5/2	−0.46	7.41×10^8
176.842	44 394	(e)	7/2	100 942	(o)	5/2	−0.30	1.05×10^9
177.245	68 019	(e)	7/2	124 439	(o)	5/2	−0.20	1.32×10^9
177.315	45 877	(e)	3/2	102 273	(o)	3/2	−0.39	8.59×10^8
177.398	74 741	(e)	7/2	131 111	(o)	7/2	−0.44	7.79×10^8
177.421	44 394	(e)	7/2	100 757	(o)	9/2	−0.15	1.51×10^9
177.987	62 353	(e)	13/2	118 536	(o)	11/2	−0.24	1.20×10^9
178.424	46 227	(e)	1/2	102 273	(o)	3/2	−0.16	1.45×10^9
178.459	67 775	(e)	5/2	123 810	(o)	3/2	−0.28	1.09×10^9
178.494	43 022	(e)	9/2	99 046	(o)	7/2	−0.15	1.48×10^9
179.650	45 278	(e)	5/2	100 942	(o)	5/2	−0.34	9.32×10^8
181.602	45 877	(e)	3/2	100 942	(o)	5/2	−0.04	1.84×10^9
181.818	62 870	(e)	7/2	117 870	(o)	5/2	−0.05	1.78×10^9
182.209	64 222	(e)	9/2	119 103	(o)	9/2	−0.33	9.42×10^8
182.544	71 432	(e)	7/2	126 213	(o)	7/2	−0.21	1.24×10^9
182.656	64 733	(e)	7/2	119 481	(o)	7/2	−0.45	7.05×10^8
182.737	67 594	(e)	9/2	122 317	(o)	11/2	−0.47	6.73×10^8

Table 4. (Continued.)

Wavelength[a] (nm)	Lower level[b] E (cm^{-1})	Parity	J	Upper level[b] E (cm^{-1})	Parity	J	log gf[c]	gA[c] (s^{-1})
183.205	43 022	(e)	9/2	97 606	(o)	11/2	0.67	9.34×10^9
183.298	76 583	(e)	7/2	131 138	(o)	5/2	0.13	2.70×10^9
183.842	69 722	(e)	11/2	124 116	(o)	11/2	−0.43	7.35×10^8
183.974	62 402	(e)	9/2	116 758	(o)	11/2	−0.21	1.21×10^9
184.112	64 222	(e)	9/2	118 536	(o)	11/2	−0.34	9.01×10^8
184.427	62 536	(e)	11/2	116 758	(o)	11/2	−0.14	1.43×10^9
184.864	69 722	(e)	11/2	123 815	(o)	9/2	−0.41	7.58×10^8
185.549	71 432	(e)	7/2	125 326	(o)	9/2	−0.28	1.01×10^9
185.551	62 402	(e)	9/2	116 296	(o)	9/2	−0.11	1.53×10^9
185.984	45 278	(e)	5/2	99 046	(o)	7/2	0.24	3.34×10^9
186.078	70 946	(e)	5/2	124 687	(o)	5/2	−0.24	1.11×10^9
186.941	70 946	(e)	5/2	124 439	(o)	5/2	−0.34	8.58×10^8
187.130	71 432	(e)	7/2	124 871	(o)	7/2	−0.17	1.28×10^9
187.131	69 747	(e)	9/2	123 185	(o)	7/2	−0.48	6.32×10^8
187.167	71 259	(e)	3/2	124 687	(o)	5/2	−0.09	1.54×10^9
187.175	62 870	(e)	7/2	116 296	(o)	9/2	−0.47	6.46×10^8
187.287	77 744	(e)	3/2	131 138	(o)	5/2	−0.47	6.41×10^8
187.365	64 874	(e)	5/2	118 246	(o)	7/2	−0.27	1.03×10^9
187.370	71 432	(e)	7/2	124 802	(o)	9/2	0.30	3.74×10^9
187.471	66 104	(e)	11/2	119 446	(o)	13/2	0.46	5.55×10^9
187.873	74 371	(e)	11/2	127 598	(o)	9/2	0.25	3.40×10^9
187.963	69 747	(e)	9/2	122 949	(o)	9/2	0.07	2.19×10^9
188.066	44 394	(e)	7/2	97 567	(o)	9/2	0.48	5.70×10^9
188.212	62 353	(e)	13/2	115 484	(o)	13/2	−0.40	7.46×10^8
188.492	64 222	(e)	9/2	117 274	(o)	11/2	0.09	2.30×10^9
188.528	62 402	(e)	9/2	115 445	(o)	11/2	0.16	2.70×10^9
188.537	64 733	(e)	7/2	117 773	(o)	9/2	−0.25	1.07×10^9
188.736	44 394	(e)	7/2	97 378	(o)	7/2	0.09	2.31×10^9
188.863	62 536	(e)	11/2	115 484	(o)	13/2	0.52	6.25×10^9
190.131	69 722	(e)	11/2	122 317	(o)	11/2	0.37	4.25×10^9
190.152	65 280	(e)	3/2	117 870	(o)	5/2	−0.18	1.20×10^9
190.431	70 673	(e)	7/2	123 185	(o)	7/2	−0.12	1.39×10^9
190.722	66 104	(e)	11/2	118 536	(o)	11/2	0.03	1.96×10^9
191.015	45 278	(e)	5/2	97 630	(o)	5/2	−0.03	1.70×10^9
191.207	62 353	(e)	13/2	114 652	(o)	13/2	0.19	2.83×10^9
191.897	67 594	(e)	9/2	119 705	(o)	11/2	0.41	4.64×10^9
191.938	45 278	(e)	5/2	97 378	(o)	7/2	−0.10	1.43×10^9
191.962	64 874	(e)	5/2	116 968	(o)	7/2	−0.29	9.33×10^8
192.237	67 775	(e)	5/2	119 794	(o)	7/2	−0.17	1.22×10^9
192.444	62 402	(e)	9/2	114 365	(o)	11/2	−0.07	1.52×10^9
192.562	62 870	(e)	7/2	114 801	(o)	9/2	−0.43	6.73×10^8
192.707	45 877	(e)	3/2	97 769	(o)	3/2	−0.12	1.38×10^9
192.726	67 594	(e)	9/2	119 481	(o)	7/2	−0.11	1.40×10^9
192.940	62 536	(e)	11/2	114 365	(o)	11/2	−0.11	1.41×10^9
193.039	68 019	(e)	7/2	119 822	(o)	9/2	0.40	4.54×10^9
193.179	62 353	(e)	13/2	114 118	(o)	15/2	0.79	1.10×10^{10}
193.224	45 877	(e)	3/2	97 630	(o)	5/2	−0.04	1.63×10^9
193.402	67 775	(e)	5/2	119 481	(o)	7/2	−0.13	1.31×10^9
193.445	62 536	(e)	11/2	114 230	(o)	9/2	−0.15	1.25×10^9
193.453	68 019	(e)	7/2	119 712	(o)	7/2	−0.08	1.47×10^9
193.541	62 402	(e)	9/2	114 071	(o)	7/2	−0.22	1.06×10^9
193.846	46 227	(e)	1/2	97 814	(o)	1/2	−0.26	9.91×10^8
193.926	68 019	(e)	7/2	119 586	(o)	5/2	−0.17	1.20×10^9
193.939	64 733	(e)	7/2	116 296	(o)	9/2	0.08	2.16×10^9
194.017	46 227	(e)	1/2	97 769	(o)	3/2	−0.33	8.37×10^8
194.027	67 775	(e)	5/2	119 314	(o)	5/2	−0.36	7.72×10^8
194.130	73 814	(e)	9/2	125 326	(o)	9/2	0.27	3.28×10^9
194.137	67 594	(e)	9/2	119 103	(o)	9/2	0.24	3.08×10^9
194.279	74 741	(e)	7/2	126 213	(o)	7/2	−0.10	1.41×10^9
195.086	64 733	(e)	7/2	115 992	(o)	5/2	−0.30	8.79×10^8
195.224	64 222	(e)	9/2	115 445	(o)	11/2	−0.43	6.55×10^8
195.426	66 104	(e)	11/2	117 274	(o)	11/2	0.31	3.57×10^9
195.495	74 741	(e)	7/2	125 893	(o)	5/2	−0.27	9.46×10^8
195.624	64 874	(e)	5/2	115 992	(o)	5/2	−0.38	7.19×10^8

Table 4. (Continued.)

Wavelength[a] (nm)	Lower level[b] E (cm^{-1})	Parity	J	Upper level[b] E (cm^{-1})	Parity	J	$\log gf$[c]	gA[c] (s^{-1})
196.124	73 814	(e)	9/2	124 802	(o)	9/2	−0.24	9.89×10^8
196.298	67 594	(e)	9/2	118 536	(o)	11/2	−0.10	1.36×10^9
196.516	66 104	(e)	11/2	116 991	(o)	9/2	0.04	1.91×10^9
196.916	70 622	(e)	3/2	121 405	(o)	3/2	−0.48	5.67×10^8
197.708	64 222	(e)	9/2	114 801	(o)	9/2	−0.11	1.32×10^9
198.237	62 870	(e)	7/2	113 314	(o)	7/2	−0.36	7.48×10^8
198.355	64 733	(e)	7/2	115 148	(o)	7/2	−0.45	5.98×10^8
198.451	71 432	(e)	7/2	121 822	(o)	5/2	0.01	1.72×10^9
198.565	76 583	(e)	7/2	126 944	(o)	9/2	0.17	2.51×10^9
198.701	67 594	(e)	9/2	117 921	(o)	7/2	−0.02	1.60×10^9
198.799	73 814	(e)	9/2	124 116	(o)	11/2	−0.23	9.89×10^8
199.002	70 673	(e)	7/2	120 924	(o)	5/2	−0.03	1.57×10^9
199.139	77 706	(e)	5/2	127 923	(o)	7/2	0.17	2.49×10^9
199.237	66 104	(e)	11/2	116 296	(o)	9/2	−0.49	5.43×10^8
199.285	67 594	(e)	9/2	117 773	(o)	9/2	−0.43	6.23×10^8
199.419	67 775	(e)	5/2	117 921	(o)	7/2	−0.39	6.80×10^8
199.426	64 222	(e)	9/2	114 365	(o)	11/2	0.23	2.83×10^9
199.481	74 741	(e)	7/2	124 871	(o)	7/2	−0.02	1.60×10^9
199.554	62 870	(e)	7/2	112 982	(o)	5/2	−0.25	9.51×10^8
199.572	74 009	(e)	13/2	124 116	(o)	11/2	0.35	3.68×10^9
199.728	64 733	(e)	7/2	114 801	(o)	9/2	−0.14	1.21×10^9
199.811	69 747	(e)	9/2	119 794	(o)	7/2	−0.48	5.58×10^8
199.966	64 222	(e)	9/2	114 230	(o)	9/2	−0.04	1.52×10^9
200.002	69 722	(e)	11/2	119 705	(o)	11/2	−0.15	1.17×10^9
200.138	76 583	(e)	7/2	126 532	(o)	7/2	0.23	2.84×10^9
200.331	68 019	(e)	7/2	117 921	(o)	7/2	−0.35	7.45×10^8
200.515	62 870	(e)	7/2	112 725	(o)	9/2	0.15	2.34×10^9
200.540	64 222	(e)	9/2	114 071	(o)	7/2	−0.46	5.77×10^8
200.958	74 371	(e)	11/2	124 116	(o)	11/2	−0.46	5.63×10^8
201.045	69 722	(e)	11/2	119 446	(o)	13/2	0.20	2.61×10^9
201.372	74 009	(e)	13/2	123 652	(o)	15/2	0.77	9.78×10^9
201.445	62 402	(e)	9/2	112 028	(o)	7/2	−0.38	6.87×10^8
201.527	69 747	(e)	9/2	119 352	(o)	9/2	−0.19	1.05×10^9
201.746	54 632	(e)	7/2	104 183	(o)	5/2	0.10	2.08×10^9
202.376	67 594	(e)	9/2	116 991	(o)	9/2	−0.06	1.42×10^9
202.498	56 126	(e)	5/2	105 493	(o)	3/2	−0.18	1.09×10^9
202.851	62 536	(e)	11/2	111 817	(o)	9/2	0.27	3.04×10^9
203.361	62 870	(e)	7/2	112 028	(o)	7/2	−0.35	7.30×10^8
203.630	64 222	(e)	9/2	113 314	(o)	7/2	−0.01	1.58×10^9
203.672	62 353	(e)	13/2	111 435	(o)	13/2	0.38	3.87×10^9
203.706	74 741	(e)	7/2	123 815	(o)	9/2	0.25	2.84×10^9
203.761	62 353	(e)	13/2	111 414	(o)	11/2	0.14	2.18×10^9
203.967	62 402	(e)	9/2	111 414	(o)	11/2	0.04	1.74×10^9
203.970	72 394	(e)	5/2	121 405	(o)	3/2	−0.39	6.47×10^8
204.018	43 022	(e)	9/2	92 022	(o)	7/2	0.16	2.29×10^9
204.232	68 019	(e)	7/2	116 968	(o)	7/2	−0.11	1.23×10^9
204.434	62 536	(e)	11/2	111 435	(o)	13/2	0.21	2.61×10^9
204.524	62 536	(e)	11/2	111 414	(o)	11/2	0.14	2.20×10^9
204.569	77 706	(e)	5/2	126 574	(o)	5/2	0.06	1.84×10^9
204.866	43 022	(e)	9/2	91 819	(o)	9/2	0.54	5.47×10^9
204.896	69 747	(e)	9/2	118 536	(o)	11/2	−0.28	8.32×10^8
205.113	67 775	(e)	5/2	116 513	(o)	5/2	−0.09	1.28×10^9
205.255	57 531	(e)	1/2	106 236	(o)	1/2	−0.49	5.16×10^8
205.286	66 104	(e)	11/2	114 801	(o)	9/2	−0.46	5.47×10^8
205.322	62 353	(e)	13/2	111 041	(o)	11/2	0.26	2.90×10^9
205.360	70 673	(e)	7/2	119 352	(o)	9/2	0.12	2.06×10^9
205.442	64 874	(e)	5/2	113 534	(o)	3/2	−0.36	6.93×10^8
205.531	62 402	(e)	9/2	111 041	(o)	11/2	−0.45	5.61×10^8
205.774	64 733	(e)	7/2	113 314	(o)	7/2	−0.37	6.65×10^8
205.787	74 371	(e)	11/2	122 949	(o)	9/2	−0.39	6.48×10^8
205.917	66 104	(e)	11/2	114 652	(o)	13/2	0.35	3.52×10^9
206.090	73 814	(e)	9/2	122 321	(o)	7/2	−0.22	9.38×10^8
206.090	77 706	(e)	5/2	126 213	(o)	7/2	−0.70	3.17×10^8
206.097	62 536	(e)	11/2	111 041	(o)	11/2	0.03	1.70×10^9

Table 4. (Continued.)

Wavelength[a] (nm)	Lower level[b] E (cm^{-1})	Parity	J	Upper level[b] E (cm^{-1})	Parity	J	log gf[c]	gA[c] (s^{-1})
206.104	64 222	(e)	9/2	112 725	(o)	9/2	−0.44	5.68×10^8
206.107	73 814	(e)	9/2	122 317	(o)	11/2	0.11	2.01×10^9
206.202	57 013	(e)	3/2	105 493	(o)	3/2	−0.38	6.61×10^8
206.410	44 394	(e)	7/2	92 826	(o)	5/2	0.15	2.22×10^9
207.173	65 280	(e)	3/2	113 534	(o)	3/2	−0.38	6.55×10^8
207.194	64 733	(e)	7/2	112 982	(o)	5/2	−0.32	7.40×10^8
207.367	74 741	(e)	7/2	122 949	(o)	9/2	−0.41	5.97×10^8
207.574	62 402	(e)	9/2	110 562	(o)	9/2	0.34	3.41×10^9
207.624	77 744	(e)	3/2	125 893	(o)	5/2	−0.22	9.29×10^8
207.684	45 278	(e)	5/2	93 413	(o)	3/2	0.04	1.71×10^9
207.801	64 874	(e)	5/2	112 982	(o)	5/2	−0.46	5.34×10^8
207.932	77 744	(e)	3/2	125 822	(o)	3/2	−0.11	1.18×10^9
208.020	56 126	(e)	5/2	104 183	(o)	5/2	−0.36	6.74×10^8
208.154	69 747	(e)	9/2	117 773	(o)	9/2	−0.23	9.20×10^8
208.300	64 733	(e)	7/2	112 725	(o)	9/2	−0.35	6.81×10^8
208.519	83 169	(e)	5/2	131 111	(o)	7/2	0.21	2.50×10^9
208.560	45 877	(e)	3/2	93 809	(o)	1/2	−0.22	9.31×10^8
209.106	62 402	(e)	9/2	110 210	(o)	7/2	−0.23	9.05×10^8
209.609	62 870	(e)	7/2	110 562	(o)	9/2	−0.07	1.30×10^9
209.897	44 394	(e)	7/2	92 022	(o)	7/2	0.05	1.69×10^9
210.037	64 222	(e)	9/2	111 817	(o)	9/2	−0.45	5.30×10^8
210.138	70 673	(e)	7/2	118 246	(o)	7/2	−0.47	5.14×10^8
210.248	45 278	(e)	5/2	92 826	(o)	5/2	−0.44	5.48×10^8
210.338	69 747	(e)	9/2	117 274	(o)	11/2	−0.08	1.25×10^9
210.905	72 394	(e)	5/2	119 794	(o)	7/2	−0.19	9.76×10^8
211.171	62 870	(e)	7/2	110 210	(o)	7/2	0.01	1.51×10^9
211.273	72 394	(e)	5/2	119 712	(o)	7/2	0.04	1.62×10^9
211.374	64 733	(e)	7/2	112 028	(o)	7/2	−0.34	6.87×10^8
211.489	69 722	(e)	11/2	116 991	(o)	9/2	−0.20	9.28×10^8
211.650	76 583	(e)	7/2	123 815	(o)	9/2	−0.31	7.30×10^8
211.683	54 632	(e)	7/2	101 858	(o)	5/2	−0.21	9.11×10^8
211.854	56 126	(e)	5/2	103 314	(o)	5/2	−0.44	5.45×10^8
212.005	64 874	(e)	5/2	112 028	(o)	7/2	−0.08	1.23×10^9
212.180	77 706	(e)	5/2	124 821	(o)	3/2	−0.16	1.02×10^9
212.247	70 673	(e)	7/2	117 773	(o)	9/2	−0.28	7.88×10^8
212.536	69 722	(e)	11/2	116 758	(o)	11/2	−0.39	6.09×10^8
212.846	57 013	(e)	3/2	103 980	(o)	3/2	−0.49	4.76×10^8
212.928	45 877	(e)	3/2	92 826	(o)	5/2	−0.44	5.36×10^8
213.062	72 394	(e)	5/2	119 314	(o)	5/2	−0.13	1.09×10^9
213.519	64 222	(e)	9/2	111 041	(o)	11/2	−0.39	6.00×10^8
213.691	68 019	(e)	7/2	114 801	(o)	9/2	−0.49	4.70×10^8
213.737	67 594	(e)	9/2	114 365	(o)	11/2	−0.46	5.03×10^8
214.428	66 104	(e)	11/2	112 725	(o)	9/2	−0.27	7.88×10^8
215.224	57 531	(e)	1/2	103 980	(o)	3/2	−0.04	1.33×10^9
215.407	56 126	(e)	5/2	102 535	(o)	3/2	−0.26	7.90×10^8
215.605	76 583	(e)	7/2	122 949	(o)	9/2	0.02	1.49×10^9
215.818	56 126	(e)	5/2	102 447	(o)	7/2	0.32	3.03×10^9
215.910	57 013	(e)	3/2	103 314	(o)	5/2	0.15	2.02×10^9
216.318	54 632	(e)	7/2	100 846	(o)	7/2	0.31	2.87×10^9
216.732	54 632	(e)	7/2	100 757	(o)	9/2	0.39	3.47×10^9
217.809	73 814	(e)	9/2	119 712	(o)	7/2	−0.49	4.60×10^8
218.452	69 722	(e)	11/2	115 484	(o)	13/2	0.14	1.95×10^9
218.599	56 126	(e)	5/2	101 858	(o)	5/2	−0.11	1.07×10^9
218.761	69 747	(e)	9/2	115 445	(o)	11/2	0.25	2.50×10^9
218.769	74 009	(e)	13/2	119 705	(o)	11/2	−0.32	6.61×10^8
219.120	70 673	(e)	7/2	116 296	(o)	9/2	−0.48	4.66×10^8
219.603	57 013	(e)	3/2	102 535	(o)	3/2	−0.41	5.40×10^8
222.498	69 722	(e)	11/2	114 652	(o)	13/2	−0.01	1.31×10^9
223.533	73 814	(e)	9/2	118 536	(o)	11/2	−0.27	7.22×10^8
224.072	77 706	(e)	5/2	122 321	(o)	7/2	−0.44	4.81×10^8
224.608	69 722	(e)	11/2	114 230	(o)	9/2	−0.16	9.16×10^8
228.681	71 432	(e)	7/2	115 148	(o)	7/2	−0.43	4.76×10^8
230.332	74 371	(e)	11/2	117 773	(o)	9/2	−0.45	4.49×10^8
230.354	70 673	(e)	7/2	114 071	(o)	7/2	−0.35	5.59×10^8

Table 4. (Continued.)

Wavelength[a] (nm)	Lower level[b] E (cm^{-1})	Parity	J	Upper level[b] E (cm^{-1})	Parity	J	log gf[c]	gA[c] (s^{-1})
232.313	74 741	(e)	7/2	117 773	(o)	9/2	−0.35	5.58×10^8
232.792	73 814	(e)	9/2	116 758	(o)	11/2	0.05	1.38×10^9
232.838	54 632	(e)	7/2	97 567	(o)	9/2	−0.22	7.45×10^8
233.853	74 009	(e)	13/2	116 758	(o)	11/2	−0.31	6.06×10^8
237.484	69 722	(e)	11/2	111 817	(o)	9/2	−0.44	4.23×10^8
239.656	69 722	(e)	11/2	111 435	(o)	13/2	−0.11	8.97×10^8
247.067	69 747	(e)	9/2	110 210	(o)	7/2	−0.36	4.71×10^8

[a] Wavelength (in vacuum (air) below (above) 200 nm) deduced from the experimental levels.
[b] Experimental levels from the NIST compilation (Kramida *et al* 2012).
[c] This work (HFR+CPOL calculations).

Table 5. Oscillator strengths and transition probabilities in Pd III (log $gf > -0.5$).

Wavelength[a] (nm)	Lower level[b] E (cm^{-1})	Parity	J	Upper level[b] E (cm^{-1})	Parity	J	log gf[c]	gA[c] (s^{-1})
70.548	17 880	(e)	4	159 627	(o)	3	−0.06	1.16×10^{10}
76.305	10 230	(e)	2	141 283	(o)	3	−0.44	4.14×10^9
77.650	17 880	(e)	4	146 662	(o)	3	0.15	1.58×10^{10}
77.670	13 469	(e)	1	142 218	(o)	2	−0.44	4.03×10^9
78.102	0	(e)	4	128 038	(o)	3	−0.10	8.76×10^9
78.498	3229	(e)	3	130 621	(o)	2	−0.48	3.61×10^9
78.730	0	(e)	4	127 017	(o)	3	−0.42	4.06×10^9
78.959	14 634	(e)	2	141 283	(o)	3	−0.35	4.77×10^9
79.407	4687	(e)	2	130 621	(o)	2	−0.40	4.20×10^9
79.751	0	(e)	4	125 390	(o)	5	0.08	1.26×10^{10}
79.901	4687	(e)	2	129 841	(o)	1	−0.44	3.83×10^9
79.920	10 230	(e)	2	135 356	(o)	3	−0.49	3.39×10^9
80.003	4687	(e)	2	129 682	(o)	3	−0.13	7.71×10^9
80.011	3229	(e)	3	128 212	(o)	2	−0.14	7.46×10^9
80.154	0	(e)	4	124 760	(o)	5	−0.01	1.01×10^{10}
80.157	3229	(e)	3	127 984	(o)	4	0.20	1.64×10^{10}
80.366	0	(e)	4	124 431	(o)	4	−0.24	5.99×10^9
80.368	3229	(e)	3	127 658	(o)	3	−0.27	5.56×10^9
81.397	14 634	(e)	2	137 489	(o)	1	−0.45	3.60×10^9
81.486	10 230	(e)	2	132 951	(o)	2	−0.46	3.50×10^9
81.505	4687	(e)	2	127 378	(o)	2	−0.24	5.80×10^9
81.624	10 230	(e)	2	132 743	(o)	2	−0.42	3.82×10^9
81.868	14 634	(e)	2	136 782	(o)	1	−0.30	5.04×10^9
82.535	0	(e)	4	121 161	(o)	4	0.08	1.18×10^{10}
82.640	4687	(e)	2	125 694	(o)	3	−0.27	5.19×10^9
82.640	3229	(e)	3	124 236	(o)	3	−0.36	4.24×10^9
82.929	14 634	(e)	2	135 219	(o)	2	0.07	1.14×10^{10}
83.299	41 698	(e)	0	161 747	(o)	1	−0.38	4.00×10^9
84.057	17 880	(e)	4	136 847	(o)	5	0.09	1.17×10^{10}
84.734	41 698	(e)	0	159 714	(o)	1	−0.38	3.83×10^9
85.124	17 880	(e)	4	135 356	(o)	3	−0.46	3.18×10^9
85.172	14 634	(e)	2	132 044	(o)	3	−0.18	6.11×10^9
85.647	17 880	(e)	4	134 638	(o)	4	0.48	2.74×10^{10}
86.403	0	(e)	4	115 736	(o)	3	−0.25	5.08×10^9
88.058	3229	(e)	3	116 790	(o)	2	−0.38	3.56×10^9
88.590	4687	(e)	2	117 566	(o)	1	−0.69	1.75×10^9
88.929	0	(e)	4	112 449	(o)	4	−0.18	5.57×10^9
90.048	4687	(e)	2	115 738	(o)	2	−0.45	2.95×10^9
90.439	3229	(e)	3	113 802	(o)	3	−0.40	3.27×10^9
167.128	78 581	(e)	4	138 415	(o)	3	−0.49	7.78×10^8
168.818	75 403	(e)	4	134 638	(o)	4	−0.48	7.73×10^8
168.926	103 548	(e)	2	162 746	(o)	2	−0.49	7.47×10^8
169.343	104 418	(e)	3	163 470	(o)	3	0.29	4.51×10^9
170.380	103 109	(e)	1	161 801	(o)	2	−0.37	9.68×10^8
170.538	103 109	(e)	1	161 747	(o)	1	−0.38	9.65×10^8
170.857	65 708	(e)	3	124 236	(o)	3	−0.45	8.12×10^8
171.665	103 548	(e)	2	161 801	(o)	2	−0.04	2.06×10^9

Table 5. (Continued.)

Wavelength[a]	Lower level[b]			Upper level[b]				gA[c]
(nm)	E (cm^{-1})	Parity	J	E (cm^{-1})	Parity	J	log gf[c]	(s^{-1})
171.985	56 742	(e)	3	114 886	(o)	4	−0.17	1.54×10^9
172.273	75 403	(e)	4	133 450	(o)	4	0.05	2.50×10^9
172.440	65 788	(e)	2	123 779	(o)	1	−0.49	7.20×10^8
173.024	65 708	(e)	3	123 503	(o)	3	−0.49	7.25×10^8
173.264	65 788	(e)	2	123 503	(o)	3	0.21	3.60×10^9
174.161	55 089	(e)	4	112 507	(o)	5	0.25	3.96×10^9
174.555	67 151	(e)	1	124 439	(o)	2	−0.16	1.53×10^9
174.809	65 788	(e)	2	122 993	(o)	2	−0.49	7.10×10^8
175.632	71 047	(e)	4	127 984	(o)	4	−0.38	9.06×10^8
175.819	74 674	(e)	6	131 550	(o)	6	0.60	8.57×10^9
176.422	85 420	(e)	2	142 103	(o)	1	−0.06	1.88×10^9
176.540	65 255	(e)	3	121 899	(o)	4	−0.09	1.76×10^9
176.664	103 109	(e)	1	159 714	(o)	1	−0.30	1.07×10^9
177.341	85 830	(e)	3	142 218	(o)	2	0.02	2.18×10^9
177.516	75 967	(e)	5	132 300	(o)	5	0.53	7.20×10^9
177.963	65 708	(e)	3	121 899	(o)	4	0.28	4.00×10^9
178.062	52 916	(e)	5	109 076	(o)	5	−0.38	8.74×10^8
178.096	85 830	(e)	3	141 979	(o)	4	−0.21	1.31×10^9
178.126	71 047	(e)	4	127 187	(o)	5	−0.08	1.74×10^9
178.255	52 916	(e)	5	109 016	(o)	6	0.70	1.05×10^{10}
178.322	103 548	(e)	2	159 627	(o)	3	−0.27	1.12×10^9
178.388	78 581	(e)	4	134 638	(o)	4	0.08	2.53×10^9
178.437	80 804	(e)	5	136 847	(o)	5	0.56	7.50×10^9
178.640	90 684	(e)	3	146 662	(o)	3	0.36	4.78×10^9
178.998	71 047	(e)	4	126 914	(o)	4	−0.14	1.50×10^9
179.509	56 742	(e)	3	112 449	(o)	4	−0.37	8.77×10^8
179.661	55 089	(e)	4	110 749	(o)	4	-0.80	3.25×10^8
179.912	75 967	(e)	5	131 550	(o)	6	−0.39	8.43×10^8
180.334	85 830	(e)	3	141 283	(o)	3	−0.43	7.62×10^8
180.418	72 786	(e)	3	128 212	(o)	2	−0.35	9.10×10^8
180.491	69 985	(e)	5	125 390	(o)	5	0.39	5.03×10^9
180.854	72 745	(e)	2	128 038	(o)	3	0.18	3.09×10^9
181.197	85 830	(e)	3	141 019	(o)	4	0.21	3.28×10^9
181.210	86 795	(e)	4	141 979	(o)	4	0.20	3.22×10^9
181.352	85 420	(e)	2	140 562	(o)	2	0.02	2.11×10^9
181.557	86 795	(e)	4	141 874	(o)	5	0.56	7.26×10^9
181.645	85 420	(e)	2	140 473	(o)	3	−0.15	1.42×10^9
181.847	75 967	(e)	5	130 959	(o)	6	0.07	2.38×10^9
181.928	65 255	(e)	3	120 222	(o)	3	−0.32	9.53×10^8
182.251	78 581	(e)	4	133 450	(o)	4	0.17	2.99×10^9
182.251	82 620	(e)	1	137 489	(o)	1	−0.24	1.15×10^9
183.006	85 830	(e)	3	140 473	(o)	3	−0.07	1.68×10^9
183.176	72 786	(e)	3	127 378	(o)	2	0.04	2.16×10^9
183.208	67 151	(e)	1	121 734	(o)	1	−0.28	1.03×10^9
183.330	78 169	(e)	2	132 716	(o)	1	−0.26	1.10×10^9
183.439	65 708	(e)	3	120 222	(o)	3	−0.27	1.05×10^9
183.527	86 795	(e)	4	141 283	(o)	3	0.12	2.58×10^9
183.668	69 985	(e)	5	124 431	(o)	4	−0.05	1.74×10^9
183.708	65 788	(e)	2	120 222	(o)	3	−0.33	9.28×10^8
183.861	108 357	(e)	2	162 746	(o)	2	0.12	2.62×10^9
184.017	71 047	(e)	4	125 390	(o)	5	−0.32	9.47×10^8
184.231	75 403	(e)	4	129 682	(o)	3	−0.39	8.00×10^8
184.315	65 788	(e)	2	120 043	(o)	2	−0.29	1.01×10^9
184.349	76 231	(e)	3	130 476	(o)	4	0.49	6.06×10^9
184.395	72 786	(e)	3	127 017	(o)	3	0.07	2.32×10^9
184.748	72 786	(e)	3	126 914	(o)	4	0.03	2.07×10^9
185.160	56 742	(e)	3	110 749	(o)	4	0.33	4.18×10^9
185.227	55 089	(e)	4	109 076	(o)	5	0.35	4.40×10^9
185.617	78 169	(e)	2	132 044	(o)	3	0.06	2.20×10^9
185.757	80 804	(e)	5	134 638	(o)	4	0.17	2.90×10^9
185.922	57 845	(e)	2	111 631	(o)	3	0.30	3.88×10^9
185.985	104 418	(e)	3	158 186	(o)	4	0.49	5.92×10^9
186.296	86 795	(e)	4	140 473	(o)	3	−0.44	6.91×10^8
186.579	71 047	(e)	4	124 644	(o)	3	−0.22	1.15×10^9

Table 5. (Continued.)

Wavelength[a] (nm)	Lower level[b] E (cm^{-1})	Parity	J	Upper level[b] E (cm^{-1})	Parity	J	log gf[c]	gA[c] (s^{-1})
186.643	83 204	(e)	2	136 782	(o)	1	−0.07	1.61×10^{9}
187.044	78 581	(e)	4	132 044	(o)	3	−0.11	1.47×10^{9}
187.126	65 788	(e)	2	119 228	(o)	1	−0.48	6.33×10^{8}
187.301	108 357	(e)	2	161 747	(o)	1	−0.27	1.03×10^{9}
187.321	71 047	(e)	4	124 431	(o)	4	0.00	1.91×10^{9}
187.461	69 985	(e)	5	123 330	(o)	6	0.66	8.65×10^{9}
187.705	58 527	(e)	1	111 802	(o)	2	0.17	2.84×10^{9}
187.905	85 830	(e)	3	139 048	(o)	4	−0.26	1.05×10^{9}
188.008	71 047	(e)	4	124 236	(o)	3	−0.01	1.85×10^{9}
188.033	58 527	(e)	1	111 710	(o)	1	−0.21	1.17×10^{9}
188.337	57 845	(e)	2	110 941	(o)	2	0.11	2.40×10^{9}
188.583	55 089	(e)	4	108 116	(o)	4	0.42	4.96×10^{9}
188.698	85 420	(e)	2	138 415	(o)	3	−0.03	1.76×10^{9}
188.741	56 742	(e)	3	109 724	(o)	3	0.29	3.65×10^{9}
189.134	74 674	(e)	6	127 546	(o)	7	0.75	1.04×10^{10}
190.168	85 830	(e)	3	138 415	(o)	3	−0.09	1.51×10^{9}
190.174	75 455	(e)	2	128 038	(o)	3	−0.45	6.56×10^{8}
190.472	78 120	(e)	1	130 621	(o)	2	−0.26	1.02×10^{9}
190.613	103 548	(e)	2	156 011	(o)	3	0.20	2.91×10^{9}
191.281	103 109	(e)	1	155 388	(o)	0	−0.46	6.33×10^{8}
191.375	86 795	(e)	4	139 048	(o)	4	0.09	2.23×10^{9}
191.462	52 916	(e)	5	105 146	(o)	5	0.54	6.27×10^{9}
191.729	76 055	(e)	1	128 212	(o)	2	−0.10	1.46×10^{9}
191.748	83 204	(e)	2	135 356	(o)	3	0.18	2.73×10^{9}
192.245	75 967	(e)	5	127 984	(o)	4	0.22	2.99×10^{9}
192.252	83 204	(e)	2	135 219	(o)	2	−0.13	1.34×10^{9}
192.535	75 967	(e)	5	127 906	(o)	5	−0.48	6.05×10^{8}
192.548	57 845	(e)	2	109 780	(o)	1	−0.17	1.22×10^{9}
192.678	56 742	(e)	3	108 642	(o)	2	0.12	2.36×10^{9}
193.033	55 089	(e)	4	106 893	(o)	3	0.29	3.50×10^{9}
193.108	75 403	(e)	4	127 187	(o)	5	0.45	4.99×10^{9}
193.272	85 420	(e)	2	137 161	(o)	2	−0.36	7.74×10^{8}
193.342	78 120	(e)	1	129 841	(o)	1	−0.47	5.96×10^{8}
193.827	104 418	(e)	3	156 011	(o)	3	−0.41	6.94×10^{8}
194.045	90 684	(e)	3	142 218	(o)	2	−0.39	7.28×10^{8}
194.127	78 169	(e)	2	129 682	(o)	3	−0.23	1.05×10^{9}
194.133	75 403	(e)	4	126 914	(o)	4	−0.41	6.94×10^{8}
194.164	52 916	(e)	5	104 419	(o)	4	0.40	4.43×10^{9}
194.453	76 231	(e)	3	127 658	(o)	3	0.04	1.91×10^{9}
194.716	108 357	(e)	2	159 714	(o)	1	−0.34	8.17×10^{8}
194.820	103 109	(e)	1	154 438	(o)	2	0.09	2.15×10^{9}
194.904	78 534	(e)	0	129 841	(o)	1	−0.27	9.42×10^{8}
194.949	90 684	(e)	3	141 979	(o)	4	−0.11	1.36×10^{9}
195.046	108 357	(e)	2	159 627	(o)	3	0.27	3.26×10^{9}
195.156	62 561	(e)	4	113 802	(o)	3	0.21	2.83×10^{9}
195.404	69 985	(e)	5	121 161	(o)	4	0.22	2.89×10^{9}
195.688	78 581	(e)	4	129 682	(o)	3	−0.10	1.38×10^{9}
195.719	76 055	(e)	1	127 149	(o)	1	−0.45	6.25×10^{8}
196.007	103 548	(e)	2	154 567	(o)	1	−0.04	1.57×10^{9}
196.286	75 967	(e)	5	126 914	(o)	4	−0.15	1.23×10^{9}
196.905	76 231	(e)	3	127 017	(o)	3	−0.35	7.71×10^{8}
197.175	74 674	(e)	6	125 390	(o)	5	−0.22	1.04×10^{9}
197.230	69 985	(e)	5	120 688	(o)	5	0.01	1.76×10^{9}
197.258	74 281	(e)	0	124 976	(o)	1	−0.47	5.77×10^{8}
197.519	78 169	(e)	2	128 798	(o)	2	−0.08	1.43×10^{9}
197.535	75 455	(e)	2	126 079	(o)	2	−0.24	9.89×10^{8}
197.753	72 745	(e)	2	123 313	(o)	2	0.03	1.84×10^{9}
198.061	74 674	(e)	6	125 163	(o)	6	−0.36	7.50×10^{8}
198.069	67 079	(e)	2	117 566	(o)	1	−0.24	9.90×10^{8}
198.087	65 255	(e)	3	115 738	(o)	2	−0.20	1.07×10^{9}
198.094	65 255	(e)	3	115 736	(o)	3	−0.02	1.61×10^{9}
198.489	78 120	(e)	1	128 500	(o)	1	−0.47	5.72×10^{8}
198.671	90 684	(e)	3	141 019	(o)	4	0.14	2.37×10^{9}
198.686	82 620	(e)	1	132 951	(o)	2	−0.09	1.37×10^{9}

Table 5. (Continued.)

Wavelength[a] (nm)	Lower level[b] E (cm^{-1})	Parity	J	Upper level[b] E (cm^{-1})	Parity	J	log gf[c]	gA[c] (s^{-1})
198.841	75 403	(e)	4	125 694	(o)	3	0.01	1.71×10^9
199.384	80 804	(e)	5	130 959	(o)	6	0.54	5.78×10^9
199.511	82 620	(e)	1	132 743	(o)	2	−0.42	6.41×10^8
199.544	71 047	(e)	4	121 161	(o)	4	−0.34	7.70×10^8
199.655	74 674	(e)	6	124 760	(o)	5	0.43	4.49×10^9
199.880	65 708	(e)	3	115 738	(o)	2	−0.42	6.31×10^8
199.887	65 708	(e)	3	115 736	(o)	3	−0.30	8.45×10^8
199.910	75 455	(e)	2	125 477	(o)	1	−0.33	7.87×10^8
199.975	73 003	(e)	1	122 993	(o)	2	−0.25	9.42×10^8
199.991	72 786	(e)	3	122 772	(o)	4	0.27	3.08×10^9
200.151	62 561	(e)	4	112 507	(o)	5	0.32	3.46×10^9
200.383	62 561	(e)	4	112 449	(o)	4	0.35	3.71×10^9
200.425	90 684	(e)	3	140 562	(o)	2	−0.32	8.06×10^8
200.547	76 231	(e)	3	126 079	(o)	2	−0.42	6.27×10^8
201.096	67 079	(e)	2	116 790	(o)	2	−0.15	1.17×10^9
201.383	71 047	(e)	4	120 688	(o)	5	0.37	3.85×10^9
201.422	65 255	(e)	3	114 886	(o)	4	0.23	2.77×10^9
201.797	83 204	(e)	2	132 743	(o)	2	−0.21	1.01×10^9
201.915	104 418	(e)	3	153 928	(o)	2	0.19	2.52×10^9
202.200	67 079	(e)	2	116 519	(o)	3	0.23	2.78×10^9
202.539	75 403	(e)	4	124 760	(o)	5	−0.44	5.90×10^8
202.670	78 581	(e)	4	127 906	(o)	5	0.49	5.07×10^9
203.205	75 967	(e)	5	125 163	(o)	6	0.48	4.87×10^9
203.232	75 455	(e)	2	124 644	(o)	3	−0.11	1.26×10^9
203.277	65 708	(e)	3	114 886	(o)	4	−0.22	9.78×10^8
203.896	75 403	(e)	4	124 431	(o)	4	−0.43	5.89×10^8
204.079	75 455	(e)	2	124 439	(o)	2	−0.43	5.96×10^8
205.445	67 079	(e)	2	115 738	(o)	2	−0.42	6.03×10^8
206.698	90 684	(e)	3	139 048	(o)	4	−0.08	1.30×10^9
211.041	75 403	(e)	4	122 772	(o)	4	−0.31	7.28×10^8
211.888	80 804	(e)	5	127 984	(o)	4	−0.30	7.42×10^8
212.368	65 255	(e)	3	112 328	(o)	2	−0.42	5.67×10^8
214.431	65 708	(e)	3	112 328	(o)	2	−0.18	9.71×10^8
214.799	65 788	(e)	2	112 328	(o)	2	−0.35	6.47×10^8
214.914	62 561	(e)	4	109 076	(o)	5	0.07	1.71×10^9
215.093	90 684	(e)	3	137 161	(o)	2	−0.20	9.05×10^8
219.742	65 255	(e)	3	110 749	(o)	4	−0.37	5.88×10^8
225.365	80 804	(e)	5	125 163	(o)	6	−0.07	1.10×10^9
229.145	80 804	(e)	5	124 431	(o)	4	−0.41	4.93×10^8
234.753	62 561	(e)	4	105 146	(o)	5	−0.49	3.87×10^8

[a] Wavelength (in vacuum (air) below (above) 200 nm) deduced from the experimental levels.
[b] Experimental levels from the NIST compilation (Kramida *et al* 2012).
[c] This work (HFR+CPOL calculations).

Table 6. Oscillator strengths and transition probabilities in Ag III (log $gf > -0.5$).

Wavelength[a] (nm)	Lower level[b] E (cm^{-1})	Parity	J	Upper level[b] E (cm^{-1})	Parity	J	log gf[c]	gA[c] (s^{-1})
71.390	0	(e)	5/2	140 076	(o)	3/2	−0.25	7.34×10^9
71.854	4609	(e)	3/2	143 781	(o)	1/2	−0.22	7.80×10^9
72.699	4609	(e)	3/2	142 164	(o)	5/2	−0.03	1.19×10^{10}
73.007	0	(e)	5/2	136 974	(o)	7/2	0.02	1.31×10^{10}
73.660	0	(e)	5/2	135 759	(o)	5/2	−0.41	4.80×10^9
74.101	0	(e)	5/2	134 952	(o)	3/2	−0.43	4.49×10^9
74.233	4609	(e)	3/2	139 321	(o)	3/2	−0.16	8.44×10^9
76.721	4609	(e)	3/2	134 952	(o)	3/2	−0.44	4.11×10^9
76.836	0	(e)	5/2	130 148	(o)	5/2	−0.37	4.78×10^9
77.640	0	(e)	5/2	128 799	(o)	5/2	−0.22	6.67×10^9
79.794	4609	(e)	3/2	129 933	(o)	3/2	−0.45	3.74×10^9
79.943	0	(e)	5/2	125 090	(o)	5/2	−0.34	4.78×10^9
158.740	78 893	(e)	1/2	141 890	(o)	3/2	−0.45	9.31×10^8

Table 6. (Continued.)

Wavelength[a] (nm)	Lower level[b] E (cm^{-1})	Parity	J	Upper level[b] E (cm^{-1})	Parity	J	log gf[c]	gA[c] (s^{-1})
165.094	76 402	(e)	5/2	136 974	(o)	7/2	−0.31	1.19×10^9
165.711	85 724	(e)	7/2	146 070	(o)	9/2	−0.36	1.07×10^9
167.076	85 724	(e)	7/2	145 577	(o)	7/2	0.45	6.73×10^9
167.496	73 929	(e)	5/2	133 632	(o)	7/2	−0.22	1.44×10^9
167.825	68 139	(e)	5/2	127 725	(o)	7/2	−0.13	1.78×10^9
168.105	65 759	(e)	7/2	125 246	(o)	9/2	0.13	3.17×10^9
169.354	63 246	(e)	9/2	122 294	(o)	9/2	0.35	5.20×10^9
170.303	80 127	(e)	3/2	138 846	(o)	5/2	−0.47	7.72×10^8
170.505	82 228	(e)	5/2	140 878	(o)	7/2	0.25	4.01×10^9
170.646	85 180	(e)	3/2	143 781	(o)	1/2	−0.23	1.35×10^9
170.884	69 346	(e)	3/2	127 865	(o)	3/2	−0.29	1.16×10^9
172.226	68 139	(e)	5/2	126 203	(o)	5/2	−0.07	1.94×10^9
172.589	77 409	(e)	3/2	135 350	(o)	3/2	−0.26	1.25×10^9
172.812	65 759	(e)	7/2	123 626	(o)	7/2	−0.06	1.94×10^9
174.735	76 402	(e)	5/2	133 632	(o)	7/2	0.17	3.20×10^9
174.964	111 436	(e)	1/2	168 591	(o)	3/2	0.14	3.03×10^9
175.114	63 246	(e)	9/2	120 352	(o)	11/2	0.65	9.80×10^9
176.059	80 127	(e)	3/2	136 926	(o)	5/2	0.02	2.24×10^9
176.263	78 893	(e)	1/2	135 627	(o)	1/2	−0.33	1.02×10^9
176.436	80 127	(e)	3/2	136 805	(o)	3/2	−0.29	1.09×10^9
176.881	65 759	(e)	7/2	122 294	(o)	9/2	−0.09	1.72×10^9
177.127	78 893	(e)	1/2	135 350	(o)	3/2	−0.39	8.76×10^8
177.181	85 724	(e)	7/2	142 164	(o)	5/2	0.21	3.50×10^9
179.391	69 346	(e)	3/2	125 090	(o)	5/2	−0.05	1.88×10^9
180.224	68 139	(e)	5/2	123 626	(o)	7/2	−0.05	1.85×10^9
180.226	85 506	(e)	1/2	140 991	(o)	1/2	−0.34	9.43×10^8
180.823	65 759	(e)	7/2	121 062	(o)	7/2	0.21	3.28×10^9
180.892	85 596	(e)	9/2	140 878	(o)	7/2	−0.04	1.87×10^9
181.684	71 686	(e)	7/2	126 727	(o)	7/2	0.19	3.11×10^9
182.247	73 929	(e)	5/2	128 799	(o)	5/2	0.05	2.22×10^9
182.401	80 127	(e)	3/2	134 952	(o)	3/2	−0.45	7.00×10^8
182.664	82 228	(e)	5/2	136 974	(o)	7/2	−0.20	1.27×10^9
182.888	63 246	(e)	9/2	117 925	(o)	9/2	0.11	2.55×10^9
183.234	69 346	(e)	3/2	123 921	(o)	3/2	−0.23	1.17×10^9
183.250	85 506	(e)	1/2	140 076	(o)	3/2	−0.05	1.79×10^9
183.432	71 686	(e)	7/2	126 203	(o)	5/2	−0.16	1.36×10^9
183.611	77 409	(e)	3/2	131 872	(o)	5/2	0.17	2.91×10^9
183.865	68 139	(e)	5/2	122 527	(o)	5/2	−0.10	1.59×10^9
184.016	85 596	(e)	9/2	139 939	(o)	11/2	0.64	8.70×10^9
184.703	85 180	(e)	3/2	139 321	(o)	3/2	0.03	2.10×10^9
184.994	69 346	(e)	3/2	123 401	(o)	1/2	−0.23	1.14×10^9
185.405	73 929	(e)	5/2	127 865	(o)	3/2	−0.48	6.39×10^8
185.631	68 139	(e)	5/2	122 009	(o)	3/2	0.06	2.23×10^9
185.887	73 929	(e)	5/2	127 725	(o)	7/2	0.13	2.61×10^9
186.039	111 436	(e)	1/2	165 189	(o)	1/2	−0.18	1.26×10^9
186.062	76 402	(e)	5/2	130 148	(o)	5/2	0.12	2.55×10^9
186.336	85 180	(e)	3/2	138 846	(o)	5/2	0.03	2.05×10^9
186.708	71 686	(e)	7/2	125 246	(o)	9/2	0.36	4.36×10^9
186.810	82 228	(e)	5/2	135 759	(o)	5/2	0.11	2.47×10^9
186.810	76 402	(e)	5/2	129 933	(o)	3/2	−0.15	1.35×10^9
187.254	71 686	(e)	7/2	125 090	(o)	5/2	−0.18	1.26×10^9
187.344	65 759	(e)	7/2	119 137	(o)	5/2	0.24	3.31×10^9
187.490	80 127	(e)	3/2	133 464	(o)	1/2	−0.30	9.43×10^8
188.037	69 346	(e)	3/2	122 527	(o)	5/2	−0.05	1.69×10^9
188.955	68 139	(e)	5/2	121 062	(o)	7/2	−0.01	1.83×10^9
189.401	73 929	(e)	5/2	126 727	(o)	7/2	−0.35	8.32×10^8
189.670	82 228	(e)	5/2	134 952	(o)	3/2	−0.25	1.03×10^9
191.698	65 759	(e)	7/2	117 925	(o)	9/2	0.17	2.66×10^9
191.714	63 246	(e)	9/2	115 407	(o)	7/2	0.40	4.49×10^9
192.532	71 686	(e)	7/2	123 626	(o)	7/2	−0.12	1.37×10^9
193.258	80 127	(e)	3/2	131 872	(o)	5/2	−0.45	6.35×10^8
193.311	77 409	(e)	3/2	129 139	(o)	1/2	−0.26	9.70×10^8
194.540	82 228	(e)	5/2	133 632	(o)	7/2	−0.39	7.08×10^8
194.637	85 596	(e)	9/2	136 974	(o)	7/2	0.15	2.50×10^9

Table 6. (Continued.)

Wavelength[a] (nm)	Lower level[b] E (cm^{-1})	Parity	J	Upper level[b] E (cm^{-1})	Parity	J	log gf[c]	gA[c] (s^{-1})
194.846	76 402	(e)	5/2	127 725	(o)	7/2	−0.29	9.06×10^8
195.278	85 596	(e)	9/2	136 805	(o)	9/2	−0.43	6.53×10^8
195.768	85 724	(e)	7/2	136 805	(o)	9/2	0.48	5.37×10^9
197.598	71 686	(e)	7/2	122 294	(o)	9/2	−0.29	8.81×10^8
197.711	85 180	(e)	3/2	135 759	(o)	5/2	−0.30	8.56×10^8
199.968	73 929	(e)	5/2	123 921	(o)	3/2	−0.25	9.36×10^8
216.204	71 686	(e)	7/2	117 925	(o)	9/2	−0.23	8.41×10^8

[a] Wavelength (in vacuum (air) below (above) 200 nm) deduced from the experimental levels.

[b] Experimental levels from the NIST compilation (Kramida *et al* 2012).

[c] This work (HFR+CPOL calculations).

of the scale of transition probabilities deduced in the present work for Rh III, Pd III and Ag III.

2. Available atomic data in Rh III, Pd III and Ag III

According to the most recent NIST compilation (Kramida *et al* 2012), 196 energy levels are known in Rh III. These were taken from the work of Iglesias (1966) who corrected and extended the previous analysis carried out by Catalan *et al* (1955) and used in Moore's tables (1971). All the experimentally determined levels in Rh III belong to the $4d^7$, $4d^65s$ and $4d^65p$ configurations.

In the case of Pd III, 177 energy levels are listed in the NIST compilation. These were taken from the works due to Shenstone (1963) and Barakat *et al* (1985). In the former study, the Pd III spectrum was observed from 68.8 to 299.1 nm allowing the author to identify 917 lines as combinations of 57 even energy levels with 111 of odd parity. With the aid of theoretical predictions, spectral terms from $4d^8$, $4d^75s$, $4d^76s$, $4d^75p$ and $4d^65s5p$ configurations were designated. In Barakat *et al*'s work, the spectrum of palladium was photographed in the wavelength region 45–230 nm using a 6.650 m normal incidence vacuum spectrograph and a sliding spark as light source. The missing levels in $4d^8$, $4d^75s$ and $4d^75p$ configurations were determined and 326 lines which were not recorded in a previous analysis were added to the classified lines in this spectrum.

For Ag III, the 64 levels reported in the NIST compilation belong to the $4d^9$, $4d^85s$ and $4d^85p$ configurations. These were taken from the work of Benschop *et al* (1975) who measured the silver spectrum between 40 and 230 nm using different spectrographs including the 10.7 m normal incidence vacuum spectrograph at the NBS Laboratory in Washington DC. In this work, some levels published earlier by Gilbert (1935) were rejected and all the missing levels in the $4d^85s$ and $4d^85p$ configurations were identified.

On the theoretical side, Shadmi (1966) reported a systematic treatment of the configurations $4d^k$+$4d^{k-1}5s$ in doubly ionized atoms of the palladium group, including Rh III, Pd III and Ag III based on the Slater approximation with several improvements. Let us also mention that the Slater–Racah parametric method combined with generalized least-squares fits of the energy parameters was used by Wyart *et al* (1993) to study the $(4d+5s)^8$ mixed configurations along the Ru isoelectronic sequence from Rh II to Sb VIII, therefore including Pd III.

To our knowledge, no radiative rates have been published so far for doubly ionized rhodium, palladium and silver.

3. Atomic structure calculations

The HFR method developed by Cowan (1981) was used to get the atomic orbitals of the three ions considered and the following configurations were retained in the configuration interaction expansions :

For Rh III:

$4d^7$ + $4d^65s$ + $4d^66s$ + $4d^65d$ + $4d^66d$ + $4d^55s^2$ + $4d^55p^2$ + $4d^55d^2$ + $4d^55s6s$ (even parity) and $4d^65p$ + $4d^66p$ + $4d^64f$ + $4d^65f$ + $4d^55s5p$ + $4d^55s6p$ + $4d^55p6s$ (odd parity).

For Pd III:

$4d^8$ + $4d^75s$ + $4d^76s$ + $4d^75d$ + $4d^76d$ + $4d^65s^2$ + $4d^65p^2$ + $4d^65d^2$ + $4d^65s6s$ + $4d^65s5d$ + $4d^65s6d$ (even parity) and $4d^75p$ + $4d^76p$ + $4d^74f$ + $4d^75f$ + $4d^65s5p$ + $4d^65s6p$ + $4d^65p5d$ + $4d^65p6s$ (odd parity).

For Ag III:

$4d^9$ + $4d^85s$ + $4d^86s$ + $4d^85d$ + $4d^86d$ + $4d^75s^2$ + $4d^75p^2$ + $4d^75d^2$ + $4d^75s6s$ + $4d^75s5d$ + $4d^75s6d$ (even parity) and $4d^85p$ + $4d^86p$ + $4d^84f$ + $4d^85f$ + $4d^75s5p$ + $4d^75s6p$ + $4d^75p5d$ + $4d^75p6s$ (odd parity).

Besides these intravalence correlations, core–valence interactions were taken into account using a core-polarization model potential and a correction to the electric dipole transition operator, both depending on two parameters (the dipole polarizability of the ionic core, α_d, and the cut-off radius, r_c). This technique has been implemented in Cowan's codes and described in details elsewhere (see e.g. Quinet *et al* 1999). The dipole polarizability values used in our calculations were taken from Fraga *et al* (1976), i.e. α_d = 3.31, 3.17 and 3.04 a_0^3 corresponding to Rh V, Pd V and Ag V cores, respectively. For the cut-off radius, we adopted the values r_c = 1.43, 1.36 and 1.30 a_0 which correspond to the HFR mean values of r for the outermost 4d orbital of the ionic core in Rh III, Pd III and Ag III, respectively.

For each ion, the HFR+CPOL method described above was then combined to a semi-empirical adjustment of radial energy parameters in order to minimize the differences between calculated Hamiltonian eigenvalues and available experimental energy levels. For Rh III, all the levels tabulated in the NIST compilation (Kramida *et al* 2012) were used to fit the radial parameters corresponding to the 4d^7, 4d^{6}5s and 4d^{6}5p configurations if we except the level situated at 133 995.8 cm^{-1} ($J = 7/2$, odd parity) for which no correspondence was found in our calculations. In the case of Pd III, the fitting process was carried out with all the levels compiled at NIST for the 4d^8, 4d^{7}5s and 4d^{7}5p, i.e. up to 163 470.1 cm^{-1}. The experimental levels above that limit were not included in the fit because many of them are given with an uncertain energy value or an unknown electronic configuration. For Ag III, all the levels listed by the NIST were considered in the semi-empirical fitting. They were used to optimize the radial parameters in 4d^9, 4d^{8}5s and 4d^{8}5p configurations. For the three ions, the Slater integrals not optimized in the fitting process were scaled down by a factor 0.90 as suggested by Cowan (1981).

Energy levels obtained in the present work are compared to available experimental values in tables 1–3 (given as supplementary data (available from stacks.iop.org/PhysScr/88/065302/mmedia)) for Rh III, Pd III and Ag III, respectively. We can observe an excellent agreement between both sets of data, the average differences being found to be equal to 28 cm^{-1} (even parity) and 84 cm^{-1} (odd parity) for Rh III, 80 cm^{-1} (even parity) and 68 cm^{-1} (odd parity) for Pd III and 117 cm^{-1} (even parity) and 66 cm^{-1} (odd parity) in the case of Ag III. Note that, for Rh III, the energies of nine 4d^{6}5p levels have been estimated for the first time at 122 442 cm^{-1} ($J = 3/2$), 124 589 cm^{-1} ($J = 7/2$), 129 557 cm^{-1} ($J = 5/2$), 131 606 cm^{-1} ($J = 1/2$), 133 998 cm^{-1} ($J = 5/2$), 134 621 cm^{-1} ($J = 1/2$), 134 918 cm^{-1} ($J = 3/2$), 135 589 cm^{-1} ($J = 3/2$) and 135 719 cm^{-1} ($J = 5/2$). As also shown in those tables, the level mixing is much stronger in the 4d^{k-1}5p odd-parity configurations than in 4d^k and 4d^{k-1}5s even-parity configurations, the average LS purities being found equal to 87% (4d^7), 74% (4d^{6}5s) and 45% (4d^{6}5p) in Rh III, 87% (4d^8), 76% (4d^{7}5s) and 52% (4d^{7}5p) in Pd III and 99% (4d^9), 82% (4d^{8}5s) and 58% (4d^{8}5p) in Ag III.

4. Oscillator strengths and transition probabilities

Computed oscillator strengths and transition probabilities for spectral lines of Rh III, Pd III and Ag III are given in tables 4–6, respectively. All these lines, appearing in the ultraviolet region from 70 to 250 nm, correspond to transitions of the type 4d^k–4d^{k-1}5p and 4d^{k-1}5s–4d^{k-1}5p with $k = 7, 8, 9$ for Rh III, Pd III and Ag III, respectively. Due to space limitations, spectroscopic designations of levels are not included in the tables. Such designations are reported in tables 1–3 given as supplementary data (available from stacks.iop.org/PhysScr/88/065302/mmedia). Note that the results presented in the tables are limited to the most intense transitions characterized by log gf-values greater than −0.5. Extensive tables containing the whole sets of data obtained in the present work (with radiative parameters for about 2150 Rh III lines ranging from 76 to 519 nm, 2120 Pd III lines ranging from 61 to 975 nm and 440 Ag III lines ranging from 59 to 801 nm) can be obtained as supplementary files upon request to the authors.

Unfortunately, no experimental neither previous theoretical radiative rates in these three ions are available for comparison. Nevertheless, an argument for assessing the reliability of the present results can be obtained from isoelectronic comparisons, in particular from results published recently by Palmeri *et al* (2009) in Ru II (isoelectronic of Rh III) and by Quinet *et al* (2012) in Rh II (isoelectronic of Pd III), the HFR+CPOL models adopted in the present work being the same as those chosen for these ions. More precisely, in these two latter papers, radiative lifetimes of 23 states in Ru II and 17 states in Rh II were accurately measured by means of the time-resolved laser-induced fluorescence (TR-LIF) technique. Free singly ionized ruthenium or rhodium ions were obtained in a laser-produced plasma. A tunable laser, with 1 ns duration pulse, was used to selectively excite the Ru^+ and Rh^+ ions. The lifetime values were evaluated from the transient LIF signals recorded by a fast detection system. In both ions, a comparison of the HFR+CPOL and the experimental lifetimes showed that the calculated values were in excellent agreement (within a few per cent) with the measurements. A similar accuracy can thus be expected for the decay rates computed for the doubly charged ions considered in the present work, at least for the most intense transitions.

Acknowledgments

Financial support from the Belgian FRS-FNRS is acknowledged. WZ, PP and PQ are respectively Short term Foreign Postdoctoral Fellow, Research Associate and Research Director of this organization.

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