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2013 Phys. Scr. 88 045305

(http://iopscience.iop.org/1402-4896/88/4/045305)

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Phys. Scr. **88** (2013) 045305 (12pp) doi:10.1088/0031-8949/88/04/045305

Spectrum and energy levels of the Yb^{4+} free ion (Yb V)

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Received 11 July 2013
Accepted for publication 6 September 2013
Published 26 September 2013
Online at stacks.iop.org/PhysScr/88/045305

Abstract

The spectrum of ionized ytterbium produced by a sliding spark source was recorded on the 10 m high resolution vacuum ultraviolet normal-incidence spectrograph of the Meudon Observatory. About 1080 lines attributed to Yb V, hitherto unknown, have been identified. The analysis of this spectrum established all the energy levels of the ground configuration $4f^{12}$ and, respectively 174, 12 and 43 levels of the excited configurations $4f^{11}5d$, $4f^{11}6s$ and $4f^{11}6p$. The theoretical calculations by means of the Cowan codes included a least-squares optimization of the relevant radial parameters by minimizing the differences between calculated and experimental level energies, which led to mean errors of 55 cm^{-1} for the 56 even parity levels and 51 cm^{-1} for the 186 odd parity ones. Interactions with the unknown core-excited configurations $5p^54f^{13}$, $5p^54f^{12}6p$, $5p^54f^{12}5d$ and $5p^54f^{12}6s$ were taken into account.

PACS numbers: 31.15.bu, 31.15.−r, 32.30.Jc, 32.70.Cs, 52.80.Yr, 71.20.Eh

S Online supplementary data available from stacks.iop.org/PhysScr/88/045305/mmedia

1. Introduction

According to different atomic data bases, for instance the NIST database [1], no existing spectroscopic data on the free ion Yb^{4+} (Yb V) can be found. This spectrum, belonging to the isoelectronic sequence of neutral dysprosium, has never been investigated up to now. A few years ago, we carried out a revision of the Yb IV analysis [2] based on experimental data from spark spectra that had been recorded on the 10.7 m normal incidence vacuum ultraviolet (VUV) spectrograph at the National Bureau of Standards, prior to 1975. These data contained numerous unidentified lines, which could be attributed to the Yb V spectrum. However, the search of energy levels of Yb^{4+} was hampered by the short wavelength limit of the covered region (590 Å). The present experimental and theoretical study of Yb V has been undertaken at the Paris-Meudon Observatory, motivated by two reasons. On one hand, we recently completed an analysis of the isoelectronic spectrum Tm IV [3]. On the other hand, a current interest for tungsten ions, including the isoelectronic W IX spectrum (IAEA CRP website www-amdis.iaea.org/CRP/Tungsten/), arose because of possible applications to magnetically confined fusion plasmas, since tungsten is a potential element to be used in the ITER reactor. In order to refine theoretical predictions for W IX by taking advantage of isoelectronic regularities, it is highly desirable to make data on the Yb V, Lu VI, Hf VII and Ta VIII spectra available.

2. Experiment and wavelength measurements

The spectrum of ytterbium was excited using a low inductance vacuum sliding spark source. The geometry of the source

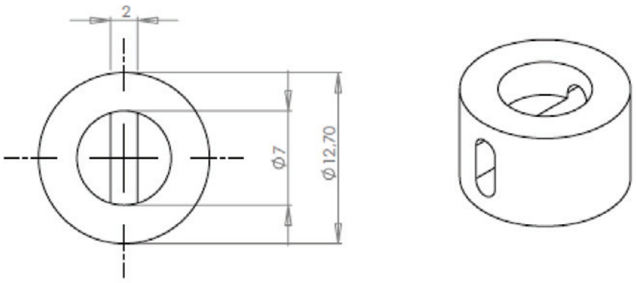

Figure 1. Schematic of the alumina spacer used in the sliding spark source. Dimensions are in mm.

is similar to that described by Bockasten [4]. It has been commonly used in our laboratory for emission studies [5], particularly in the case of the lanthanide ion spectra Tm IV [3], Nd IV [6] and Nd V [7]. For the present study, it operated with an aluminum cathode and an anode made of a rod of 99% pure ytterbium, separated by a flat cylindric insulating spacer in alumina as shown in figure 2. The sparks 'slide' along the vertical surface of the spacer. The spacer, shaped upon advice from the late Professor Joshi [8], enables a convenient alignment of the source using a He–Ne laser beam. The electric discharges were produced by a capacitor of 4.82 μF charged to 7 kV through the vacuum source and an external spark gap. The discharge conditions were varied by introducing an inductance of 11 μH into the circuit in order to allow some differentiation of lines from different ionization stages by their intensity behaviors. Spectra were recorded on the high resolution vacuum spectrograph of the Meudon Observatory. The instrument is equipped with a 3600 lines mm^{-1} holographic concave grating, leading to a linear dispersion of 0.26 Å mm^{-1} on the plates. The resulting resolution is about 150 000 with a slit width of 30 μm. Two wavelength regions 400–1000 and 1400–1900 Å were recorded using, respectively Kodak SWR and Ilford Q plates. The spectrograms were digitized by means of a high resolution optical scanner iQsmart1. In order to compensate the defects of nonlinearity in the displacement of the scanner, the spectrogram was scanned simultaneously with a precision ruler with ticks of 1 mm spacings. An interpolation was performed within each mm of the ruler in the software developed by us for measurement of the line positions. The wavelength calibration was carried out by polynomial interpolation of selected reference wavelengths [9] from lines emitted by ionized low-Z elements (C, N, O, Al, Si) present, as impurities, in the source. Ritz wavelengths derived from known levels of Yb III [10][4] and Yb IV [2] also served for the calibration. The estimated overall uncertainty for isolated lines is ±0.005 Å. However, in such a dense spectrum, many lines are perturbed by their neighbors and have an uncertainty reaching ±0.007 Å. In the measurement software, an experimental intensity with arbitrary units could be estimated for each line from the area under a triangle fitting the line profile. Relative intensities are consistent only over a limited range of wavelengths.

3. Determination of energy levels and classification of spectral lines

The theoretical support of the present analysis is provided by calculations using the Cowan codes [11] in their PC running version [12]. For a start, it seemed important to theoretically estimate energy ranges of low lying configurations along the Dy I sequence. Indeed, in the first ions of the Dy I isoelectronic sequence, the ground energy levels are $5p^64f^{11}6s$ $^5I_8$ in Ho II [1, 13], then $5p^64f^{12}$ $^3H_6$ in Er III [1, 14] and in Tm IV [3]. With increasing ionic charge, the hydrogenic reordering of orbital energy leads to a $5p-4f$ excitation energy smaller beyond Tm IV than in the lower ionization stages and may result in low lying core excited configurations with open 5p sub-shell. This situation occurs in tungsten ions. Indeed, in W VII [15] the excited configurations built on the $5p^64f^{13}$ and $5p^54f^{14}$ cores of W VIII overlap and the relative position of their parent terms ^2P and ^2F in W VIII was established only recently, with ^2F as the ground term [16].

In this work, the first three codes (RCN, RCN2, RCG) of the Cowan package [11] were run to predict level positions and spectral ranges of transitions, taking into account configuration interactions. In order to be consistent with earlier studied cases of multicharged lanthanides (Nd IV [6], Nd V [7] and Tm IV [3]), the Hartree–Fock code RCN was run in the Hartree–Fock relativistic (HFR) mode without including Breit energies and by setting the correlation term to a value of 1.0. The even parity calculations included the $5p^64f^{12}$, $5p^64f^{11}6p$, $5p^54f^{13}$, $5p^54f^{12}6p$ and $5p^44f^{14}$ configurations. The energy ranges of the five studied configurations are represented in figure 2, where the plunging configurations $5p^54f^{13}$ and $5p^44f^{14}$ lead the $^3P_2$ of the latter configuration to become the ground level in W IX. As concerns Yb V ($Z = 70$), similarities with the neighboring ion Tm IV are expected. The odd parity calculations included the $5p^64f^{11}5d$, $5p^64f^{11}6s$, $5p^54f^{12}5d$, $5p^54f^{12}6s$ configurations, although the $5p^64f^{12}$–$5p^54f^{12}5d$ transitions were not meant to be studied in this work. This choice of configuration set allowed the account of the ($5p^64f^{N-1}5d$–$5p^54f^{N}5d$) configuration interaction (CI) effects that showed to be important in other lanthanide ions such as Nd IV [6] and Nd V [7]. In both parities, the use of effective parameters further accounts for interactions with far configurations that are not explicitly included.

As the configurations built on the $5p^64f^{11}$ core are fairly intricate, the description of the spectrum in intermediate coupling conditions, both level scheme and transition probabilities, strongly depends on the energy parameters, i.e. radial integrals, introduced as input data for the diagonalisation code RCG. To get a reliable theoretical support for the analysis, the initial set of HFR energy parameters P_{HFR} needed to be multiplied by appropriate scaling factors SF(P). As reported in [17], the consistency of the scaling factors found in moderately charged ions of lanthanides, SF(P) = $P_{\mathrm{fit}}/P_{\mathrm{HFR}}$, where P_{fit} is the final parameter value from the least squares fit (see below), provided reasonable estimates for Yb V. This scaling resulted in the best possible predictions for the strongest lines of the Yb V spectrum and aided the determination of a number of

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[4] Database on rare earths at Mons University, D.R.E.A.M. http://w3.umons.ac.be/~astro/dream.shtml.

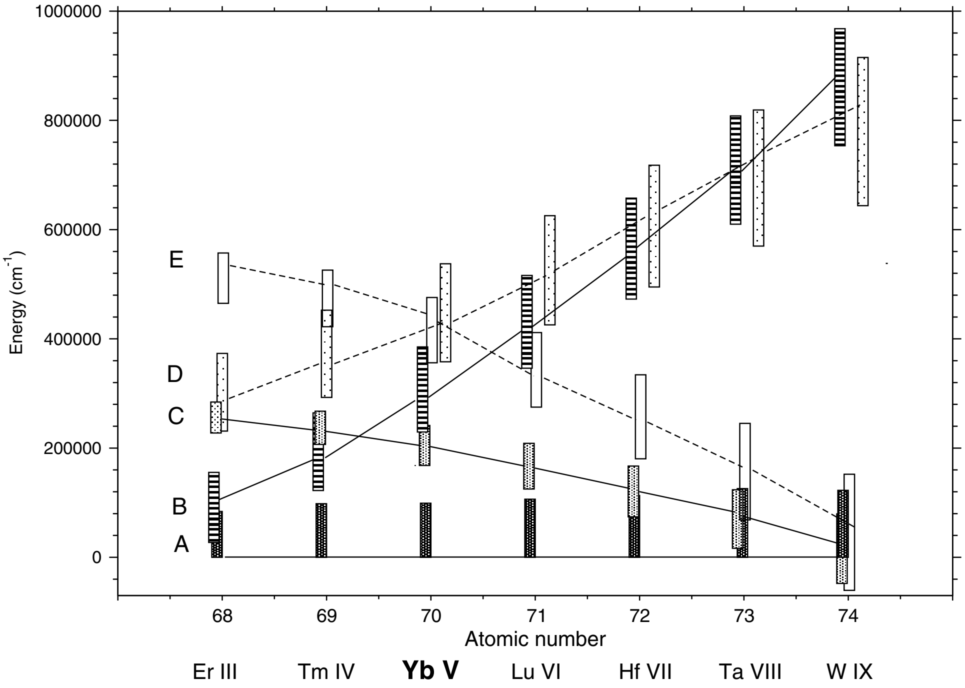

Figure 2. Energy ranges of levels in the Dy I isoelectronic sequence for the configurations $5p^64f^{11}6p$ (B), $5p^54f^{13}$ (C), $5p^54f^{12}6p$ (D) and $5p^44f^{14}$ (E) relative to the $^3H_6$ energy level of $5p^64f^{12}$ (A), as derived from straight HFR radial integrals.

level intervals in the ground $5p^64f^{12}$ and the excited $5p^64f^{11}5d$ configurations for a start. The analysis was then sped up by using the IDEN code [18, 19], which allows the handling of a great amount of experimental and calculated data (wavelengths, intensities, energies, transition probabilities, etc) by a convenient visualization of the Ritz combination principle. An iterative least squares fitting of the calculated level values to the experimental ones, by adjusting the energy parameters, was performed using RCG and RCE, the fourth code of the Cowan package [11], and led to fitted parameter values P_{fit}. In the first iterations of the least squares fit, constraints derived from the ratio of HFR radial integrals were applied. Some constraints could be removed as new experimental levels were found.

4. Results and discussion

All the 13 levels of the $4f^{12}$ ground configuration, as well as 174 levels of the $5p^64f^{11}5d$, 12 levels of the $5p^64f^{11}6s$ and 43 levels of the $5p^64f^{11}6p$ configurations have been found. Above 288 008 cm^{-1}, no experimental level could be determined unambiguously. From the wavelengths of the 1078 classified lines, the best values of level energies have been derived by least-squares optimization using the LOPT code [20]. The optimized energy values, together with their estimated uncertainties derived from the least-squares fit of LOPT and the number of lines involved, are reported in tables 1 and 2, respectively for the even parity and odd parity levels. A few levels, with large value of *J*, have been determined by a unique transition of very high transition probability. Tables 1 and 2 also report the percentages compositions of each level both in LS and in JJ coupling schemes, as well as the calculated Landé factors, output from Cowan code [11]. The strong mixing in compositions of levels clearly shows an intermediate coupling scheme. Table 3, given in the supplementary material (available from stacks.iop.org/PhysScr/88/045305/mmedia), provides a list of the classified lines with their measured wavelengths and estimated intensities on a relative scale. Ritz wavelengths calculated with the energies of the corresponding upper and lower levels optimized in the LOPT code are also given in table 3. Their uncertainties as derived from LOPT are smaller than 0.003 Å for most of them. Column 4 of table 3 gives the discrepancies between measured wavelengths and Ritz wavelengths, which reflect the overall consistency of the energy diagram built upon the classified lines. In table 3, the designation of a level is limited to its main LS component from table 1 or from table 2, depending on its parity. It should be pointed out that due to strong mixings between LS terms in the present intermediate coupling scheme, some levels of different energies have an identical main LS component. For their distinction, the second and the third occurrences of an identical term, in increasing order of energies, are labeled with b and c, respectively. Actually, the unambiguous identification of a level is provided by its energy.

A case of energy coincidence deserves a comment. One possible high even energy level at 286 034 cm^{-1} was found to decay to several levels of $5p^64f^{11}5d$ with *J* values ranging from 2 to 6. The comparison of experimental intensities versus transition probabilities confirmed that part of the lines are issued from a $J = 3$ level at 286 033.97 cm^{-1} and the other part from a $J = 5$ level at 286 033.82 cm^{-1}. The $J = 4$ levels of $5p^64f^{11}5d$ may lead to blended lines but the dominant transition, $J = 3$–4 or $J = 5$–4 is clearly established by the theory, as is seen in table 4.

The energy parameters of the even configurations are collected in table 5. The fitted values and their standard deviations are compared with their HFR values calculated using the RCN, RCN2 codes, followed by their ratios (scaling factor SF). Constraints on parameters are specified by footnotes. Table 6 shows the similar data on the energy

Table 1. Even parity energy levels of the two configurations 4f^{12} and 4f^{11}6p of theYb^{4+} ion. For each level are given, the energy value together with the corresponding uncertainty in parenthesis (in cm^{-1}), N_{cl}, the total number of transitions involving the level, the calculated Landé factor, the deviation (in cm^{-1}) $\Delta E = E_{\mathrm{exp}} - E_{\mathrm{calc}}$, where E_{calc} results from the Cowan codes [11] corresponding to the parameters given in table 5, and the leading components of the eigenfunction in both LS and JJ coupling schemes.

						LS percentage composition						JJ percentage composition					
Conf.	J	E_{exp} (unc.)	N_{cl}	ΔE	g_{calc}	Comp1	%	Comp2	%	Comp3	%	Comp1	%	Comp2	%	Comp3	%
4f^{12}	6	0.00 (23)	53	52	1.165	^{3}H	99	^{1}I	1								
4f^{12}	4	6112.03 (19)	73	−62	1.140	^{3}F	62	^{1}G	30	^{3}H	8						
4f^{12}	5	9579.89 (19)	68	69	1.033	^{3}H	100										
4f^{12}	4	14405.00 (19)	75	−11	0.954	^{3}H	58	^{3}F	28	^{1}G	14						
4f^{12}	3	16 372.19 (23)	52	−20	1.084	^{3}F	100										
4f^{12}	2	16 877.3 (3)	38	52	0.761	^{3}F	75	^{1}D	23	^{3}P	2						
4f^{12}	4	24 192.89 (22)	51	−118	0.956	^{1}G	56	^{3}H	34	^{3}F	10						
4f^{12}	2	31 319.7 (3)	35	−49	1.126	^{1}D	40	^{3}P	39	^{3}F	21						
4f^{12}	6	39 037.9 (5)	10	1	1.002	1I	99	^{3}H	1								
4f^{12}	0	39 791.7 (5)	7	−9	–	^{3}P	94	^{1}S	6								
4f^{12}	1	41 080.9 (4)	14	80	1.501	^{3}P	100										
4f^{12}	2	43 119.5 (3)	23	15	1.280	^{3}P	59	^{1}D	37	^{3}F	4						
4f^{12}	0	83 804.0 (6)	2	−0.1	–	1S	94	^{3}P	6								
4f^{11}6p	7	247 890.51 (12)	5	−42	1.239	(^{4}I)^{5}H	65	(^{4}I)^{3}I	16	(^{4}I)^{5}I	14	(^{4}I$_{15/2}$) 1/2	93	(^{2}K$_{15/2}$) 1/2	3	(^{4}I$_{15/2}$) 3/2	1
4f^{11}6p	8	248 573.04 (13)	5	−25	1.163	(^{4}I)^{3}K	46	(^{4}I)^{5}I	28	(^{4}I)^{5}K	22	(^{4}I$_{15/2}$) 1/2	96	(^{2}K$_{15/2}$) 1/2	2	(^{2}K$_{15/2}$) 3/2	1
4f^{11}6p	6	257 065.63 (14)	11	16	1.148	(^{4}I)^{5}H	55	(^{4}I)^{5}I	26	(^{4}I)^{3}I	9	(^{4}I$_{13/2}$) 1/2	93	(^{4}I$_{15/2}$) 3/2	4	(^{4}I$_{13/2}$) 3/2	1
4f^{11}6p	7	257 348.77 (09)	13	3	1.077	(^{4}I)^{5}K	43	(^{4}I)^{3}K	29	(^{4}I)^{5}I	18	(^{4}I$_{13/2}$) 1/2	96	(^{4}I$_{15/2}$) 3/2	2		
4f^{11}6p	9	259 305.05 (22)	4	−53	1.219	(^{4}I)^{5}K	96	(^{2}K)^{3}L	4			(^{4}I$_{15/2}$) 3/2	96	(^{2}K$_{15/2}$) 3/2	4		
4f^{11}6p	8	260 218.14 (17)	9	−31	1.207	(^{4}I)^{5}I	66	(^{4}I)^{3}K	28	(^{2}K)^{3}K	2	(^{4}I$_{15/2}$) 3/2	96	(^{2}K$_{15/2}$) 3/2	3		
4f^{11}6p	6	260 509.01 (09)	18	−60	1.128	(^{4}I)^{3}H	63	(^{4}I)^{5}H	11	(^{4}I)^{5}K	8	(^{4}I$_{15/2}$) 3/2	74	(^{4}I$_{11/2}$) 1/2	8	(^{4}I$_{9/2}$) 3/2	2
4f^{11}6p	7	260 750.18 (11)	15	−42	1.180	(^{4}I)^{3}I	63	(^{4}I)^{5}H	26	(^{4}I)^{5}I	7	(^{4}I$_{15/2}$) 3/2	94	(^{4}I$_{13/2}$) 1/2	2	(^{2}K$_{15/2}$) 3/2	2
4f^{11}6p	5	261 583.94 (12)	13	69	1.033	(^{4}I)^{5}I	26	(^{4}I)^{5}H	23	(^{4}I)^{3}H	20	(^{4}I$_{11/2}$) 1/2	64	(^{2}H$_{11/2}$) 1/2	16	(^{4}I$_{9/2}$) 3/2	3
4f^{11}6p	6	262 021.27 (11)	14	39	1.007	(^{4}I)^{5}K	37	(^{4}I)^{3}H	24	(^{4}I)^{3}I	9	(^{4}I$_{11/2}$) 1/2	54	(^{4}I$_{15/2}$) 3/2	16	(^{4}I$_{13/2}$) 1/2	5
4f^{11}6p	4	263 549.91 (15)	11	64	1.051	(^{4}F)^{5}D	13	(^{4}I)^{3}H	12	(^{4}I)^{5}I	11	(^{4}I$_{9/2}$) 1/2	21	(^{4}F$_{9/2}$) 1/2	7	(^{4}F$_{9/2}$) 3/2	5
4f^{11}6p	5	263 796.29 (15)	12	78	0.966	(^{4}I)^{5}K	24	(^{2}H)^{3}I2	13	(^{4}F)^{3}G	10	(^{4}I$_{9/2}$) 1/2	30	(^{4}F$_{9/2}$) 1/2	13	(^{2}H$_{9/2}$) 1/2	9
4f^{11}6p	5	267 577.92 (12)	16	−28	1.017	(^{4}I)^{5}K	29	(^{4}F)^{3}G	16	(^{4}F)^{5}F	14	(^{4}F$_{9/2}$) 1/2	40	(^{4}I$_{9/2}$) 1/2	35	(^{4}I$_{9/2}$) 3/2	1
4f^{11}6p	4	267 798.48 (10)	13	5	1.058	(^{4}F)^{5}D	21	(^{4}I)^{5}I	19	(^{4}I)^{3}H	18	(^{4}F$_{9/2}$) 1/2	39	(^{4}I$_{9/2}$) 1/2	32	(^{4}I$_{9/2}$) 3/2	2
4f^{11}6p	8	268 532.23 (17)	9	−4	1.148	(^{4}I)^{5}K	74	(^{4}I)^{3}K	22	(^{4}I)^{5}I	3	(^{4}I$_{13/2}$) 3/2	99	(^{2}K$_{13/2}$) 3/2	1		
4f^{11}6p	5	268 864.41 (11)	23	−5	1.070	(^{4}I)^{5}H	44	(^{4}I)^{3}H	38	(^{4}I)^{5}K	3	(^{4}I$_{13/2}$) 3/2	77	(^{4}I$_{11/2}$) 3/2	4	(^{4}I$_{9/2}$) 1/2	2
4f^{11}6p	7	269 233.49 (15)	12	11	1.130	(^{4}I)^{5}I	57	(^{4}I)^{3}K	23	(^{4}I)^{3}I	11	(^{4}I$_{13/2}$) 3/2	98				
4f^{11}6p	6	269 333.95 (13)	14	13	1.094	(^{4}I)^{3}I	42	(^{4}I)^{5}H	30	(^{4}I)^{5}I	23	(^{4}I$_{13/2}$) 3/2	94	(^{4}I$_{11/2}$) 3/2	2	(^{4}I$_{11/2}$) 1/2	1
4f^{11}6p	5	272 011.18 (13)	23	−85	1.170	(^{2}H)^{3}G2	23	(^{4}G)^{5}F	22	(^{4}I)^{3}H	18	(^{2}H$_{11/2}$) 1/2	24	(^{4}I$_{11/2}$) 1/2	18	(^{4}G$_{11/2}$) 1/2	12
4f^{11}6p	6	272 186.73 (13)	13	−80	1.096	(^{2}H)^{3}H2	19	(^{4}I)^{5}K	19	(^{4}G)^{3}H	13	(^{4}G$_{11/2}$) 1/2	19	(^{2}H$_{11/2}$) 1/2	17	(^{4}I$_{11/2}$) 1/2	10
4f^{11}6p	4	272 996.60 (13)	12	81	0.912	(^{4}I)^{5}H	56	(^{4}I)^{3}H	19	(^{2}H)^{3}G2	9	(^{4}I$_{11/2}$) 3/2	71	(^{2}H$_{11/2}$) 3/2	17	(^{4}I$_{9/2}$) 3/2	4
4f^{11}6p	7	273 216.25 (22)	11	54	1.070	(^{4}I)^{5}K	37	(^{4}I)^{3}K	35	(^{2}H)^{3}I2	21	(^{4}I$_{11/2}$) 3/2	73	(^{2}H$_{11/2}$) 3/2	21	(^{4}G$_{11/2}$) 3/2	2
4f^{11}6p	5	273 623.27 (15)	17	46	0.981	(^{4}I)^{5}I	24	(^{4}I)^{3}I	19	(^{4}I)^{3}H	16	(^{4}I$_{11/2}$) 3/2	68	(^{4}I$_{13/2}$) 3/2	4	(^{2}H$_{11/2}$) 3/2	4
4f^{11}6p	6	273 728.28 (15)	18	38	1.047	(^{4}I)^{5}I	31	(^{4}I)^{3}I	27	(^{2}H)^{3}H2	9	(^{4}I$_{11/2}$) 3/2	37	(^{2}H$_{11/2}$) 3/2	20	(^{4}I$_{11/2}$) 1/2	15
4f^{11}6p	3	273 832.99 (11)	10	−16	1.218	(^{4}F)^{5}F	38	(^{4}F)^{5}D	27	(^{4}F)^{3}F	6	(^{4}F$_{7/2}$) 1/2	77	(^{4}F$_{9/2}$) 3/2	3	(^{4}F$_{5/2}$) 3/2	1
4f^{11}6p	4	274 298.83 (10)	13	−14	1.151	(^{4}F)^{5}G	40	(^{4}F)^{3}G	22	(^{4}F)^{5}F	11	(^{4}F$_{7/2}$) 1/2	87	(^{4}F$_{9/2}$) 3/2	1		
4f^{11}6p	6	275 554.90 (22)	15	67	1.078	(^{4}I)^{3}K	29	(^{4}F)^{5}G	25	(^{2}G)^{3}H1	13	(^{4}F$_{9/2}$) 3/2	25	(^{4}I$_{9/2}$) 3/2	19	(^{2}G$_{9/2}$) 3/2	13

Table 1. Continued.

						LS percentage composition						JJ percentage composition					
Conf.	J	E_{exp} (unc.)	N_{cl}	ΔE	g_{calc}	Comp1	%	Comp2	%	Comp3	%	Comp1	%	Comp2	%	Comp3	%
$4f^{11}6p$	5	275 541.01 (17)	19	39	1.074	$(^{4}\mathrm{F})^{5}\mathrm{F}$	16	$(^{4}\mathrm{I})^{5}\mathrm{I}$	12	$(^{4}\mathrm{F})^{3}\mathrm{G}$	11	$(^{4}\mathrm{F}_{9/2})$ 3/2	27	$(^{4}\mathrm{I}_{9/2})$ 3/2	16	$(^{4}\mathrm{I}_{9/2})$ 1/2	5
$4f^{11}6p$	4	276 008.50 (13)	17	59	0.979	$(^{4}\mathrm{I})^{5}\mathrm{I}$	17	$(^{4}\mathrm{F})^{3}\mathrm{F}$	17	$(^{4}\mathrm{I})^{3}\mathrm{H}$	14	$(^{4}\mathrm{F}_{9/2})$ 3/2	23	$(^{4}\mathrm{I}_{9/2})$ 3/2	22	$(^{4}\mathrm{I}_{11/2})$ 3/2	9
$4f^{11}6p$	5	278 864.67 (13)	19	−8	1.045	$(^{4}\mathrm{F})^{5}\mathrm{F}$	29	$(^{4}\mathrm{I})^{5}\mathrm{K}$	23	$(^{2}\mathrm{H})^{3}\mathrm{H}2$	9	$(^{4}\mathrm{F}_{9/2})$ 3/2	19	$(^{4}\mathrm{I}_{9/2})$ 3/2	15	$(^{4}\mathrm{I}_{9/2})$ 1/2	8
$4f^{11}6p$	4	278 976.88 (14)	13	13	1.114	$(^{4}\mathrm{F})^{5}\mathrm{D}$	24	$(^{4}\mathrm{I})^{5}\mathrm{I}$	20	$(^{4}\mathrm{F})^{5}\mathrm{F}$	6	$(^{4}\mathrm{F}_{9/2})$ 1/2	23	$(^{4}\mathrm{I}_{9/2})$ 3/2	11	$(^{4}\mathrm{I}_{9/2})$ 1/2	8
$4f^{11}6p$	6	279 350.06 (17)	12	−13	1.109	$(^{4}\mathrm{F})^{5}\mathrm{G}$	42	$(^{4}\mathrm{I})^{3}\mathrm{K}$	25	$(^{4}\mathrm{I})^{5}\mathrm{K}$	15	$(^{4}\mathrm{F}_{9/2})$ 3/2	42	$(^{4}\mathrm{I}_{9/2})$ 3/2	38	$(^{2}\mathrm{G}_{9/2})$ 3/2	4
$4f^{11}6p$	3	279 774.7 (3)	9	−56	1.067	$(^{4}\mathrm{F})^{3}\mathrm{D}$	47	$(^{4}\mathrm{I})^{5}\mathrm{H}$	25	$(^{2}\mathrm{G})1\mathrm{F}1$	5	$(^{4}\mathrm{F}_{9/2})$ 3/2	45	$(^{4}\mathrm{I}_{9/2})$ 3/2	25	$(^{2}\mathrm{G}_{9/2})$ 3/2	10
$4f^{11}6p$	5	279 959.30 (16)	18	−20	1.053	$(^{4}\mathrm{F})^{3}\mathrm{G}$	27	$(^{4}\mathrm{I})^{3}\mathrm{I}$	21	$(^{2}\mathrm{H})^{3}\mathrm{I}2$	8	$(^{4}\mathrm{F}_{9/2})$ 1/2	13	$(^{4}\mathrm{F}_{9/2})$ 3/2	9	$(^{4}\mathrm{I}_{9/2})$ 3/2	8
$4f^{11}6p$	4	279 976.85 (15)	18	−12	1.088	$(^{4}\mathrm{F})^{3}\mathrm{F}$	28	$(^{4}\mathrm{I})^{3}\mathrm{H}$	16	$(^{4}\mathrm{I})^{5}\mathrm{I}$	10	$(^{4}\mathrm{F}_{9/2})$ 3/2	19	$(^{4}\mathrm{I}_{9/2})$ 3/2	17	$(^{4}\mathrm{F}_{9/2})$ 1/2	14
$4f^{11}6p$	6	282 023.84 (24)	8	20	1.156	$(^{4}\mathrm{G})^{3}\mathrm{H}$	25	$(^{4}\mathrm{G})^{5}\mathrm{G}$	20	$(^{4}\mathrm{G})^{5}\mathrm{H}$	12	$(^{4}\mathrm{G}_{11/2})$ 1/2	57	$(^{2}\mathrm{H}_{11/2})$ 1/2	14	$(^{2}\mathrm{H}_{11/2})$ 3/2	5
$4f^{11}6p$	6	283 961.9 (3)	6	−85	1.149	$(^{2}\mathrm{H})^{3}\mathrm{H}2$	30	$(^{4}\mathrm{G})^{5}\mathrm{G}$	20	$(^{4}\mathrm{G})^{3}\mathrm{H}$	13	$(^{2}\mathrm{H}_{11/2})$ 3/2	34	$(^{4}\mathrm{G}_{11/2})$ 3/2	33	$(^{4}\mathrm{I}_{11/2})$ 3/2	5
$4f^{11}6p$	5	284 143.17(21)	15	−67	1.117	$(^{4}\mathrm{G})^{3}\mathrm{G}$	25	$(^{2}\mathrm{H})^{3}\mathrm{G}2$	20	$(^{2}\mathrm{H})1\mathrm{H}2$	14	$(^{2}\mathrm{H}_{11/2})$ 3/2	41	$(^{4}\mathrm{G}_{11/2})$ 3/2	14	$(^{4}\mathrm{G}_{11/2})$ 1/2	5
$4f^{11}6p$	4	285 892.87 (14)	16	−2	1.221	$(^{4}\mathrm{F})^{5}\mathrm{F}$	41	$(^{4}\mathrm{F})^{3}\mathrm{G}$	20	$(^{4}\mathrm{F})^{5}\mathrm{D}$	6	$(^{4}\mathrm{F}_{7/2})$ 3/2	70	$(^{4}\mathrm{G}_{7/2})$ 3/2	3	$(^{4}\mathrm{G}_{9/2})$ 1/2	2
$4f^{11}6p$	3	286 033.97 (23)	16	9	1.296	$(^{4}\mathrm{F})^{5}\mathrm{D}$	49	$(^{4}\mathrm{F})^{3}\mathrm{F}$	24	$(^{4}\mathrm{F})^{5}\mathrm{F}$	12	$(^{4}\mathrm{F}_{7/2})$ 3/2	72	$(^{4}\mathrm{F}_{5/2})$ 3/2	11	$(^{2}\mathrm{G}_{7/2})$ 3/2	4
$4f^{11}6p$	5	286 033.82 (16)	15	−21	1.236	$(^{4}\mathrm{F})^{5}\mathrm{G}$	63	$(^{4}\mathrm{F})^{3}\mathrm{G}$	15	$(^{4}\mathrm{F})^{5}\mathrm{F}$	7	$(^{4}\mathrm{F}_{7/2})$ 3/2	85	$(^{2}\mathrm{G}_{7/2})$ 3/2	1	$(^{2}\mathrm{G}_{9/2})$ 1/2	1
$4f^{11}6p$	3	287 800.7 (4)	4	20	1.124	$(^{4}\mathrm{F})^{3}\mathrm{F}$	26	$(^{4}\mathrm{F})^{5}\mathrm{F}$	20	$(^{4}\mathrm{F})^{5}\mathrm{G}$	17	$(^{4}\mathrm{F}_{5/2})$ 3/2	38	$(^{4}\mathrm{F}_{7/2})$ 3/2	16	$(^{4}\mathrm{F}_{3/2})$ 3/2	11
$4f^{11}6p$	4	288 008.29 (17)	18	25	1.130	$(^{4}\mathrm{F})^{5}\mathrm{G}$	36	$(^{4}\mathrm{F})^{3}\mathrm{G}$	35	$(^{2}\mathrm{D})^{3}\mathrm{F}1$	15	$(^{4}\mathrm{F}_{5/2})$ 3/2	68	$(^{2}\mathrm{D}_{5/2})$ 3/2	15	$(^{4}\mathrm{F}_{7/2})$ 3/2	4

Table 2. Odd parity energy levels of the two configurations $4f^{11}5d$ and $4f^{11}6s$ of the Yb^{4+} ion. For each level are given, the energy value together with the corresponding uncertainty in parenthesis (in cm^{-1}), N_{cl}, the total number of transitions involving the level, the calculated Landé factor, the deviation (in cm^{-1}) $\Delta E = E_{\mathrm{exp}} - E_{\mathrm{calc}}$, where E_{calc} results from the Cowan codes [11] corresponding to the parameters given in table 6, and the leading components of the eigenfunction in both LS and JJ coupling schemes.

						LS percentage composition						JJ percentage composition					
Conf.	J	E_{exp} (unc.)	N_{cl}	ΔE	g_{calc}	Comp1	%	Comp2	%	Comp3	%	Comp1	%	Comp2	%	Comp3	%
$4f^{11}5d$	6	136 614.9 (4)	4	−110	1.296	$(^{4}\mathrm{I})^{5}\mathrm{G}$	73	$(^{4}\mathrm{I})^{5}\mathrm{H}$	16	$(^{2}\mathrm{K})^{3}\mathrm{H}$	4	$(^{4}\mathrm{I}_{15/2})$ 3/2	89	$(^{4}\mathrm{I}_{15/2})$ 5/2	3	$(^{2}\mathrm{K}_{15/2})$ 3/2	3
$4f^{11}5d$	7	137 790.2 (3)	6	−117	1.254	$(^{4}\mathrm{I})^{5}\mathrm{H}$	73	$(^{4}\mathrm{I})^{5}\mathrm{I}$	14	$(^{4}\mathrm{I})^{3}\mathrm{I}$	6	$(^{4}\mathrm{I}_{15/2})$ 3/2	78	$(^{4}\mathrm{I}_{15/2})$ 5/2	12	$(^{4}\mathrm{G}_{11/2})$ 5/2	2
$4f^{11}5d$	9	139 582.6 (6)	1	−39	1.135	$(^{4}\mathrm{I})^{3}\mathrm{L}$	47	$(^{4}\mathrm{I})^{5}\mathrm{L}$	31	$(^{4}\mathrm{I})^{5}\mathrm{K}$	18	$(^{4}\mathrm{I}_{15/2})$ 3/2	95	$(^{2}\mathrm{K}_{15/2})$ 3/2	3	$(^{4}\mathrm{I}_{13/2})$ 5/2	1
$4f^{11}5d$	8	140 784.8 (3)	7	6	1.174	$(^{4}\mathrm{I})^{5}\mathrm{I}$	37	$(^{4}\mathrm{I})^{5}\mathrm{K}$	31	$(^{4}\mathrm{I})^{3}\mathrm{K}$	23	$(^{4}\mathrm{I}_{15/2})$ 3/2	93	$(^{4}\mathrm{I}_{15/2})$ 5/2	2	$(^{4}\mathrm{I}_{13/2})$ 3/2	1
$4f^{11}5d$	10	143 663.6 (7)	1	−27	1.197	$(^{4}\mathrm{I})^{5}\mathrm{L}$	96	$(^{2}\mathrm{K})^{3}\mathrm{M}$	4			$(^{4}\mathrm{I}_{15/2})$ 5/2	96	$(^{2}\mathrm{K}_{15/2})$ 5/2	4		
$4f^{11}5d$	5	144 419.7 (3)	10	−66	1.205	$(^{4}\mathrm{I})^{5}\mathrm{G}$	63	$(^{4}\mathrm{I})^{5}\mathrm{H}$	23	$(^{4}\mathrm{I})^{3}\mathrm{G}$	3	$(^{4}\mathrm{I}_{13/2})$ 3/2	52	$(^{4}\mathrm{I}_{15/2})$ 5/2	35	$(^{4}\mathrm{I}_{13/2})$ 5/2	2
$4f^{11}5d$	9	145 352.4 (5)	2	−35	1.193	$(^{4}\mathrm{I})^{5}\mathrm{K}$	74	$(^{4}\mathrm{I})^{3}\mathrm{L}$	22	$(^{2}\mathrm{K})^{3}\mathrm{L}$	3	$(^{4}\mathrm{I}_{15/2})$ 5/2	96	$(^{2}\mathrm{K}_{15/2})$ 5/2	3		
$4f^{11}5d$	6	145 484.7 (3)	10	−43	1.201	$(^{4}\mathrm{I})^{5}\mathrm{H}$	49	$(^{4}\mathrm{I})^{5}\mathrm{G}$	21	$(^{4}\mathrm{I})^{5}\mathrm{I}$	13	$(^{4}\mathrm{I}_{15/2})$ 5/2	43	$(^{4}\mathrm{I}_{13/2})$ 3/2	36	$(^{4}\mathrm{I}_{13/2})$ 5/2	10
$4f^{11}5d$	7	146 795.2 (3)	10	2	1.141	$(^{4}\mathrm{I})^{5}\mathrm{I}$	26	$(^{4}\mathrm{I})^{5}\mathrm{K}$	22	$(^{4}\mathrm{I})^{3}\mathrm{I}$	20	$(^{4}\mathrm{I}_{15/2})$ 5/2	57	$(^{4}\mathrm{I}_{13/2})$ 3/2	23	$(^{4}\mathrm{I}_{15/2})$ 3/2	9
$4f^{11}5d$	8	146 880.7 (3)	7	−6	1.163	$(^{4}\mathrm{I})^{5}\mathrm{I}$	49	$(^{4}\mathrm{I})^{5}\mathrm{L}$	16	$(^{4}\mathrm{I})^{3}\mathrm{K}$	16	$(^{4}\mathrm{I}_{15/2})$ 5/2	74	$(^{4}\mathrm{I}_{13/2})$ 3/2	20	$(^{4}\mathrm{I}_{15/2})$ 3/2	1
$4f^{11}5d$	8	148 757.3 (3)	6	−3	1.074	$(^{4}\mathrm{I})^{5}\mathrm{L}$	39	$(^{4}\mathrm{I})^{3}\mathrm{K}$	37	$(^{4}\mathrm{I})^{3}\mathrm{L}$	18	$(^{4}\mathrm{I}_{13/2})$ 3/2	75	$(^{4}\mathrm{I}_{15/2})$ 5/2	18	$(^{4}\mathrm{I}_{15/2})$ 3/2	2
$4f^{11}5d$	4	149 901.5 (3)	9	−54	1.085	$(^{4}\mathrm{I})^{5}\mathrm{G}$	33	$(^{4}\mathrm{I})^{5}\mathrm{H}$	28	$(^{2}\mathrm{H})^{3}\mathrm{F}2$	8	$(^{4}\mathrm{I}_{11/2})$ 3/2	33	$(^{4}\mathrm{I}_{13/2})$ 5/2	23	$(^{2}\mathrm{H}_{11/2})$ 3/2	12
$4f^{11}5d$	5	149 953.96 (24)	14	−20	1.132	$(^{4}\mathrm{I})^{3}\mathrm{G}$	47	$(^{4}\mathrm{I})^{5}\mathrm{H}$	24	$(^{4}\mathrm{I})^{5}\mathrm{I}$	9	$(^{4}\mathrm{I}_{13/2})$ 3/2	37	$(^{4}\mathrm{I}_{15/2})$ 5/2	28	$(^{4}\mathrm{I}_{11/2})$ 3/2	11
$4f^{11}5d$	7	150 111.23 (22)	11	−2	1.057	$(^{4}\mathrm{I})^{3}\mathrm{I}$	38	$(^{4}\mathrm{I})^{5}\mathrm{K}$	28	$(^{4}\mathrm{I})^{5}\mathrm{L}$	20	$(^{4}\mathrm{I}_{13/2})$ 3/2	60	$(^{4}\mathrm{I}_{11/2})$ 3/2	13	$(^{4}\mathrm{I}_{15/2})$ 5/2	12
$4f^{11}5d$	6	151 021.29 (22)	14	30	1.064	$(^{4}\mathrm{I})^{3}\mathrm{H}$	29	$(^{4}\mathrm{I})^{5}\mathrm{I}$	25	$(^{4}\mathrm{I})^{5}\mathrm{K}$	22	$(^{4}\mathrm{I}_{13/2})$ 3/2	44	$(^{4}\mathrm{I}_{11/2})$ 3/2	13	$(^{4}\mathrm{I}_{15/2})$ 5/2	11
$4f^{11}5d$	5	152 738.66(21)	17	−5	1.135	$(^{4}\mathrm{I})^{3}\mathrm{G}$	35	$(^{4}\mathrm{I})^{5}\mathrm{G}$	17	$(^{4}\mathrm{I})^{5}\mathrm{I}$	15	$(^{4}\mathrm{I}_{11/2})$ 3/2	28	$(^{4}\mathrm{I}_{13/2})$ 5/2	20	$(^{4}\mathrm{I}_{15/2})$ 5/2	18
$4f^{11}5d$	4	152 950.0 (3)	7	−18	1.173	$(^{4}\mathrm{I})^{5}\mathrm{G}$	24	$(^{4}\mathrm{F})^{5}\mathrm{D}$	14	$(^{4}\mathrm{F})^{5}\mathrm{F}$	10	$(^{4}\mathrm{F}_{9/2})$ 3/2	16	$(^{4}\mathrm{I}_{13/2})$ 5/2	8	$(^{4}\mathrm{I}_{11/2})$ 5/2	8

Table 2. Continued.

						LS percentage composition						JJ percentage composition					
Conf.	J	E_{exp} (unc.)	N_{cl}	ΔE	g_{calc}	Comp1	%	Comp2	%	Comp3	%	Comp1	%	Comp2	%	Comp3	%
$4f^{11}5d$	7	152 997.54 (22)	11	45	0.995	$(^4I)^5L$	43	$(^4I)^3I$	19	$(^2H)^3K2$	8	$(^4I_{11/2})$ 3/2	61	$(^4I_{15/2})$ 5/2	8	$(^2H_{9/2})$ 5/2	4
$4f^{11}5d$	9	153 365.2 (7)	1	−2	1.130	$(^4I)^5L$	67	$(^4I)^3L$	27	$(^4I)^5K$	5	$(^4I_{13/2})$ 5/2	98	$(^2K_{13/2})$ 5/2	1	$(^4I_{15/2})$ 3/2	1
$4f^{11}5d$	5	153 535.7 (3)	8	37	1.085	$(^4F)^5G$	12	$(^4F)^5F$	12	$(^4I)^5K$	11	$(^4F_{9/2})$ 3/2	13	$(^4F_{9/2})$ 5/2	9	$(^4I_{9/2})$ 3/2	8
$4f^{11}5d$	6	154 002.75 (23)	14	52	0.996	$(^4I)^3H$	28	$(^4I)^5K$	24	$(^4I)^5L$	18	$(^4I_{11/2})$ 3/2	32	$(^4I_{15/2})$ 5/2	14	$(^4I_{9/2})$ 3/2	14
$4f^{11}5d$	5	154 767.34 (22)	16	81	1.090	$(^4I)^3H$	18	$(^4I)^5G$	12	$(^2H)^3H2$	10	$(^4I_{13/2})$ 5/2	33	$(^2H_{11/2})$ 3/2	8	$(^2H_{11/2})$ 5/2	7
$4f^{11}5d$	6	154 789.62 (24)	11	74	0.979	$(^4I)^5L$	20	$(^4I)^3H$	12	$(^2H)^3K2$	10	$(^4I_{9/2})$ 3/2	17	$(^2H_{9/2})$ 3/2	8	$(^4I_{9/2})$ 5/2	8
$4f^{11}5d$	8	154 816.5 (5)	2	−12	1.128	$(^4I)^5K$	57	$(^4I)^3K$	18	$(^4I)^3L$	17	$(^4I_{13/2})$ 5/2	97	$(^4I_{15/2})$ 5/2	1	$(^4I_{15/2})$ 3/2	1
$4f^{11}5d$	4	155 202.0 (3)	10	70	1.064	$(^4I)^5G$	21	$(^4I)^5H$	20	$(^4I)^3G$	19	$(^4I_{13/2})$ 5/2	21	$(^4I_{11/2})$ 5/2	19	$(^4I_{9/2})$ 5/2	10
$4f^{11}5d$	6	155 543.1 (3)	9	41	1.047	$(^4I)^3I$	33	$(^4I)^5I$	22	$(^4I)^5H$	18	$(^4I_{13/2})$ 5/2	56	$(^4I_{11/2})$ 5/2	9	$(^4I_{13/2})$ 3/2	6
$4f^{11}5d$	7	155 977.3 (3)	6	10	1.117	$(^4I)^5I$	49	$(^4I)^3K$	29	$(^4I)^3I$	8	$(^4I_{13/2})$ 5/2	89	$(^4I_{11/2})$ 5/2	3	$(^4I_{15/2})$ 5/2	2
$4f^{11}5d$	4	157 053.57 (22)	13	18	1.002	$(^4I)^5I$	24	$(^4I)^3G$	13	$(^2H)^3F2$	12	$(^4I_{9/2})$ 3/2	16	$(^4I_{13/2})$ 5/2	9	$(^4I_{9/2})$ 5/2	7
$4f^{11}5d$	5	157 420.26 (21)	15	52	0.960	$(^4I)^5K$	43	$(^4F)^5F$	18	$(^2H)^3I2$	10	$(^4I_{9/2})$ 3/2	27	$(^4F_{9/2})$ 5/2	12	$(^4I_{9/2})$ 5/2	11
$4f^{11}5d$	3	157 429.4 (3)	7	−53	1.159	$(^4I)^5G$	24	$(^4F)^5D$	23	$(^4I)^5H$	14	$(^4F_{9/2})$ 3/2	32	$(^4I_{11/2})$ 5/2	25	$(^4I_{9/2})$ 3/2	14
$4f^{11}5d$	6	158 053.0 (3)	6	25	1.087	$(^4F)^5G$	30	$(^4I)^5L$	22	$(^4F)^5H$	11	$(^4F_{9/2})$ 5/2	27	$(^4I_{9/2})$ 3/2	18	$(^4F_{9/2})$ 3/2	13
$4f^{11}5d$	4	158 706.85 (22)	13	64	0.993	$(^4I)^5H$	18	$(^4I)^3G$	15	$(^4I)^3H$	13	$(^4I_{13/2})$ 5/2	23	$(^4I_{11/2})$ 5/2	20	$(^2H_{11/2})$ 3/2	9
$4f^{11}5d$	7	159 085.2 (3)	5	21	1.108	$(^2H)^3I2$	23	$(^4I)^3K$	23	$(^4I)^5K$	15	$(^4I_{11/2})$ 5/2	29	$(^2H_{11/2})$ 5/2	19	$(^4F_{9/2})$ 5/2	11
$4f^{11}5d$	5	159 904.4 (3)	18	34	1.004	$(^4I)^5I$	23	$(^4I)^3I$	23	$(^2H)^3G2$	11	$(^4I_{11/2})$ 5/2	19	$(^4I_{11/2})$ 3/2	14	$(^4F_{9/2})$ 3/2	9
$4f^{11}5d$	6	160 776.5 (3)	12	14	1.065	$(^4I)^3K$	22	$(^2H)^3H2$	14	$(^4I)^5I$	12	$(^4I_{11/2})$ 5/2	29	$(^2H_{11/2})$ 5/2	9	$(^4I_{11/2})$ 3/2	7
$4f^{11}5d$	4	161 356.2 (3)	14	−53	1.136	$(^4F)^5G$	27	$(^4I)^3G$	18	$(^4F)^3G$	11	$(^4F_{7/2})$ 3/2	30	$(^4F_{9/2})$ 5/2	10	$(^4I_{13/2})$ 5/2	10
$4f^{11}5d$	6	161 967.2 (3)	13	4	1.127	$(^4I)^3I$	22	$(^4F)^3H$	18	$(^4F)^5G$	17	$(^4F_{9/2})$ 5/2	31	$(^4I_{11/2})$ 5/2	8	$(^4I_{11/2})$ 3/2	8
$4f^{11}5d$	3	162 296.9 (3)	9	59	1.128	$(^4I)^3G$	17	$(^4F)^5F$	14	$(^4F)^5P$	9	$(^4F_{7/2})$ 3/2	19	$(^4I_{9/2})$ 3/2	10	$(^4F_{9/2})$ 5/2	6
$4f^{11}5d$	5	162 941.4 (3)	19	−9	1.122	$(^4I)^3H$	26	$(^4F)^5F$	20	$(^4F)^5H$	9	$(^4F_{7/2})$ 3/2	17	$(^4F_{9/2})$ 5/2	16	$(^4I_{13/2})$ 5/2	12
$4f^{11}5d$	5	163 513.8 (4)	11	53	1.019	$(^4I)^5I$	19	$(^2H)^1H2$	19	$(^4I)^3I$	14	$(^4I_{9/2})$ 5/2	22	$(^2H_{11/2})$ 5/2	7	$(^4G_{11/2})$ 3/2	6
$4f^{11}5d$	3	163 941.6 (3)	11	−1	0.969	$(^4I)^3G$	28	$(^4F)^5G$	18	$(^4F)^5F$	8	$(^4F_{7/2})$ 3/2	18	$(^4I_{9/2})$ 3/2	17	$(^4I_{11/2})$ 5/2	9
$4f^{11}5d$	7	164 006.6 (3)	5	−20	1.042	$(^2H)^3K2$	28	$(^4I)^3L$	20	$(^4G)^3I$	11	$(^4I_{9/2})$ 5/2	17	$(^4G_{11/2})$ 3/2	16	$(^2H_{9/2})$ 5/2	15
$4f^{11}5d$	6	164 232.46 (20)	12	−3	1.030	$(^4I)^3K$	21	$(^2H)^1I2$	20	$(^4I)^5K$	17	$(^4I_{9/2})$ 5/2	30	$(^2H_{11/2})$ 3/2	13	$(^2H_{9/2})$ 5/2	9
$4f^{11}5d$	4	164 502.4 (23)	14	74	1.106	$(^4I)^5I$	11	$(^4G)^5F$	10	$(^4I)^3H$	10	$(^4G_{11/2})$ 3/2	15	$(^4I_{9/2})$ 5/2	11	$(^4I_{11/2})$ 5/2	8
$4f^{11}5d$	7	164 831.0 (4)	6	16	1.076	$(^4F)^5H$	30	$(^4I)^5L$	19	$(^2H)^1K2$	17	$(^4F_{9/2})$ 5/2	30	$(^4I_{9/2})$ 5/2	27	$(^2H_{9/2})$ 5/2	8
$4f^{11}5d$	6	164 952.6 (3)	10	27	1.084	$(^4I)^3I$	13	$(^2H)^3I2$	12	$(^4G)^5G$	12	$(^4F_{9/2})$ 5/2	9	$(^4I_{11/2})$ 3/2	7	$(^4I_{9/2})$ 5/2	7
$4f^{11}5d$	4	165 446.6 (3)	12	−7	1.108	$(^4F)^5D$	24	$(^4I)^5I$	19	$(^2H)^3G2$	9	$(^4F_{9/2})$ 5/2	22	$(^4I_{9/2})$ 5/2	9	$(^4I_{9/2})$ 3/2	6
$4f^{11}5d$	5	165 701.5 (3)	12	−25	1.066	$(^4F)^3G$	24	$(^4F)^5H$	24	$(^4I)^5K$	11	$(^4F_{7/2})$ 3/2	29	$(^4F_{9/2})$ 5/2	8	$(^4I_{9/2})$ 3/2	7
$4f^{11}5d$	4	165 987.1 (3)	9	33	1.205	$(^4S)^5D$	21	$(^4F)^3F$	15	$(^4F)^5G$	7	$(^4S_{3/2})$ 5/2	21	$(^4F_{9/2})$ 5/2	11	$(^4F_{7/2})$ 3/2	8
$4f^{11}5d$	3	166 096.1 (3)	6	15	1.091	$(^4F)^5P$	20	$(^4F)^5G$	17	$(^4I)^5H$	11	$(^4F_{5/2})$ 3/2	23	$(^4I_{9/2})$ 5/2	10	$(^4F_{9/2})$ 5/2	9
$4f^{11}5d$	5	166 405.9 (3)	10	17	1.103	$(^4I)^3H$	14	$(^4F)^5H$	13	$(^4G)^5G$	10	$(^4F_{7/2})$ 3/2	15	$(^4I_{11/2})$ 3/2	8	$(^4I_{11/2})$ 5/2	5
$4f^{11}5d$	4	167 076.1 (4)	8	34	1.104	$(^4F)^5G$	14	$(^4F)^3F$	13	$(^4F)^5H$	13	$(^4F_{5/2})$ 3/2	14	$(^4F_{7/2})$ 3/2	9	$(^4F_{3/2})$ 5/2	8
$4f^{11}5d$	4	167 964.8 (3)	13	−24	1.218	$(^4S)^5D$	22	$(^4F)^5F$	17	$(^4I)^3H$	12	$(^4S_{3/2})$ 5/2	22	$(^4F_{7/2})$ 5/2	6	$(^2H_{11/2})$ 3/2	6
$4f^{11}5d$	6	168 445.8 (3)	6	−42	1.109	$(^4G)^5G$	15	$(^2K)^3H$	15	$(^2H)^3I2$	9	$(^4G_{11/2})$ 5/2	23	$(^2K_{15/2})$ 3/2	11	$(^2H_{9/2})$ 5/2	5
$4f^{11}5d$	3	168 554.6 (5)	6	−34	1.051	$(^4S)^3D$	18	$(^4F)^5H$	17	$(^4F)^5D$	10	$(^4F_{3/2})$ 3/2	21	$(^4S_{3/2})$ 3/2	11	$(^4S_{3/2})$ 5/2	7
$4f^{11}5d$	5	168 841.3 (3)	7	60	1.188	$(^4F)^5G$	44	$(^4I)^3H$	9	$(^4F)^5F$	8	$(^4F_{7/2})$ 5/2	57	$(^4F_{5/2})$ 5/2	5	$(^4I_{13/2})$ 5/2	4
$4f^{11}5d$	6	169 918.7 (3)	6	−36	1.154	$(^2K)^3H$	18	$(^4G)^5G$	16	$(^4F)^3H$	13	$(^4F_{7/2})$ 5/2	15	$(^2K_{15/2})$ 3/2	13	$(^4G_{11/2})$ 5/2	9
$4f^{11}5d$	6	170 328.1 (3)	6	−30	1.118	$(^4F)^5H$	38	$(^4G)^5H$	9	$(^2G)^1I1$	7	$(^4F_{7/2})$ 5/2	36	$(^4F_{9/2})$ 3/2	6	$(^4G_{9/2})$ 5/2	5
$4f^{11}5d$	5	170 381.4 (3)	6	−45	1.100	$(^4G)^5G$	15	$(^4I)^3I$	10	$(^2G)^3G1$	8	$(^4G_{9/2})$ 5/2	7	$(^2G_{9/2})$ 5/2	5	$(^2G_{9/2})$ 5/2	5
$4f^{11}5d$	5	170 993.3 (4)	7	30	1.098	$(^2H)^3G2$	18	$(^4F)^5H$	11	$(^2H)^1H2$	9	$(^2H_{11/2})$ 5/2	33	$(^4F_{5/2})$ 5/2	5	$(^4F_{7/2})$ 3/2	5

Table 2. Continued.

						LS percentage composition						JJ percentage composition					
Conf.	J	E_{exp} (unc.)	N_{cl}	ΔE	g_{calc}	Comp1	%	Comp2	%	Comp3	%	Comp1	%	Comp2	%	Comp3	%
$4f^{11}5d$	4	171 496.1 (4)	7	−64	1.149	$(^4G)^5G$	17	$(^4F)^5F$	13	$(^2H)^3F2$	10	$(^4F_{7/2})$ 5/2	13	$(^4G_{7/2})$ 5/2	8	$(^4G_{11/2})$ 3/2	8
$4f^{11}5d$	6	172 251.1 (4)	4	23	1.085	$(^4F)^3H$	20	$(^2K)^3H$	11	$(^2H)^3K2$	8	$(^4F_{9/2})$ 3/2	12	$(^2K_{15/2})$ 3/2	8	$(^2H_{9/2})$ 3/2	7
$4f^{11}5d$	4	172 626.4 (5)	6	60	1.059	$(^4F)^3F$	19	$(^4F)^5G$	17	$(^4F)^3G$	16	$(^4F_{5/2})$ 5/2	18	$(^4F_{7/2})$ 5/2	9	$(^2G_{7/2})$ 3/2	8
$4f^{11}5d$	3	172 685.1 (5)	3	28	1.104	$(^4F)^3G$	14	$(^4S)^3D$	11	$(^4S)^5D$	9	$(^4S_{3/2})$ 5/2	20	$(^4F_{7/2})$ 5/2	6	$(^4F_{3/2})$ 5/2	5
$4f^{11}5d$	7	173 329.1 (6)	2	−69	1.121	$(^4G)^3I$	23	$(^4G)^5I$	17	$(^2K)^3I$	12	$(^4G_{11/2})$ 3/2	50	$(^2K_{15/2})$ 3/2	6	$(^2K_{15/2})$ 5/2	6
$4f^{11}5d$	5	173 412.2 (4)	7	−13	1.044	$(^2K)^3H$	15	$(^4F)^3H$	12	$(^4G)^5G$	11	$(^2K_{15/2})$ 5/2	7	$(^2K_{13/2})$ 3/2	5	$(^4G_{9/2})$ 5/2	5
$4f^{11}5d$	3	174 169.4 (3)	10	3	1.197	$(^4F)^3F$	13	$(^4G)^5G$	8	$(^4F)^5P$	8	$(^4F_{7/2})$ 5/2	11	$(^4F_{9/2})$ 3/2	6	$(^4G_{9/2})$ 3/2	6
$4f^{11}5d$	5	174 405.8 (3)	7	−1	1.086	$(^4F)^3H$	21	$(^4F)^3G$	18	$(^2H)^3G2$	9	$(^4F_{7/2})$ 3/2	19	$(^4F_{5/2})$ 5/2	11	$(^2H_{9/2})$ 3/2	7
$4f^{11}5d$	6	174 778.0 (4)	4	13	1.080	$(^4G)^5I$	27	$(^4G)^3I$	20	$(^2H)^3H2$	12	$(^4G_{9/2})$ 3/2	38	$(^2H_{11/2})$ 5/2	9	$(^2H_{9/2})$ 3/2	5
$4f^{11}5d$	3	175 018.9 (5)	5	48	1.086	$(^4F)^3G$	14	$(^4F)^5P$	13	$(^4G)^3D$	8	$(^4F_{9/2})$ 5/2	17	$(^4F_{5/2})$ 5/2	7	$(^4G_{11/2})$ 5/2	6
$4f^{11}5d$	2	175 277.2 (6)	5	−43	0.962	$(^4F)^3D$	19	$(^4G)^5G$	13	$(^2D)^3D1$	11	$(^4G_{7/2})$ 3/2	7	$(^4F_{7/2})$ 5/2	7	$(^4G_{5/2})$ 3/2	6
$4f^{11}5d$	3	175 716.1 (5)	5	4	1.016	$(^4I)^3G$	10	$(^4G)^5G$	10	$(^2D)^1F1$	7	$(^4I_{9/2})$ 3/2	6	$(^4G_{7/2})$ 3/2	4	$(^4G_{5/2})$ 5/2	4
$4f^{11}5d$	4	175 772.6 (3)	7	75	1.060	$(^4F)^3F$	13	$(^4I)^3H$	12	$(^4F)^3G$	8	$(^4F_{9/2})$ 5/2	12	$(^4I_{9/2})$ 3/2	6	$(^4F_{9/2})$ 3/2	5
$4f^{11}5d$	6	176 288.8 (4)	4	−26	1.099	$(^4G)^3H$	18	$(^2K)^3H$	11	$(^4G)^5I$	10	$(^4G_{9/2})$ 3/2	15	$(^2K_{15/2})$ 3/2	8	$(^4G_{11/2})$ 5/2	6
$4f^{11}5d$	4	176 370.1 (5)	6	40	1.054	$(^4F)^3G$	15	$(^2G)^3F1$	9	$(^4F)^5H$	9	$(^4F_{7/2})$ 5/2	7	$(^2G_{9/2})$ 5/2	7	$(^4F_{3/2})$ 5/2	7
$4f^{11}5d$	3	177 478.1 (6)	6	25	1.111	$(^4F)^3D$	23	$(^4F)^3F$	16	$(^4G)^5G$	11	$(^4F_{7/2})$ 5/2	11	$(^4F_{7/2})$ 3/2	10	$(^4F_{3/2})$ 3/2	10
$4f^{11}5d$	4	177 513.1 (5)	5	111	0.976	$(^4F)^3H$	9	$(^4G)^5I$	9	$(^2G)^3H1$	8	$(^4G_{5/2})$ 3/2	7	$(^2G_{7/2})$ 3/2	5	$(^4F_{3/2})$ 5/2	5
$4f^{11}5d$	5	177 728.4 (5)	5	66	1.029	$(^2K)^3H$	23	$(^4I)^3H$	8	$(^4G)^5H$	7	$(^2K_{15/2})$ 5/2	10	$(^4G_{9/2})$ 5/2	10	$(^2K_{13/2})$ 3/2	8
$4f^{11}5d$	5	178 991.4 (5)	5	60	1.259	$(^4G)^5F$	34	$(^4F)^5F$	14	$(^2K)^3H$	6	$(^4G_{11/2})$ 5/2	14	$(^4G_{11/2})$ 3/2	14	$(^4F_{9/2})$ 5/2	8
$4f^{11}5d$	3	179 356.9 (8)	3	−24	1.078	$(^4S)^3D$	12	$(^2H)^1F2$	12	$(^4F)^3F$	7	$(^4S_{3/2})$ 3/2	7	$(^2H_{11/2})$ 5/2	7	$(^4S_{3/2})$ 5/2	5
$4f^{11}5d$	6	179 711.6 (10)	3	−52	1.079	$(^2K)^1I$	16	$(^4G)^5H$	11	$(^2K)^3I$	10	$(^2K_{15/2})$ 5/2	34	$(^4G_{11/2})$ 3/2	13	$(^4G_{9/2})$ 5/2	3
$4f^{11}5d$	4	179 772.6 (7)	4	−42	1.077	$(^4G)^3F$	25	$(^4G)^5H$	8	$(^2G)^1G1$	5	$(^4G_{11/2})$ 5/2	14	$(^4G_{9/2})$ 3/2	11	$(^2G_{7/2})$ 5/2	7
$4f^{11}5d$	5	180 323.5 (5)	6	7	1.120	$(^4G)^5F$	17	$(^4G)^3G$	15	$(^2K)^3H$	14	$(^4G_{11/2})$ 5/2	27	$(^2K_{15/2})$ 5/2	6	$(^4G_{9/2})$ 3/2	5
$4f^{11}5d$	3	180 636.9 (6)	6	−119	1.067	$(^4G)^3F$	27	$(^2P)^3F$	9	$(^4F)^3G$	7	$(^4G_{11/2})$ 5/2	14	$(^4G_{9/2})$ 5/2	10	$(^4G_{7/2})$ 3/2	6
$4f^{11}5d$	5	181 655.2 (9)	3	−43	1.113	$(^4G)^3G$	45	$(^4G)^5G$	9	$(^4G)^3H$	8	$(^4G_{11/2})$ 5/2	31	$(^4G_{9/2})$ 5/2	21	$(^4G_{9/2})$ 3/2	5
$4f^{11}5d$	3	181 811.4 (7)	4	−26	0.957	$(^4G)^5H$	15	$(^2D)^3F1$	11	$(^2D)^3G1$	8	$(^2D_{3/2})$ 5/2	10	$(^4G_{5/2})$ 3/2	9	$(^2D_{3/2})$ 3/2	6
$4f^{11}5d$	2	182 029.4 (7)	3	−4	1.157	$(^4G)^5D$	21	$(^4F)^3F$	13	$(^4G)^5F$	7	$(^4G_{9/2})$ 5/2	26	$(^4G_{7/2})$ 5/2	6	$(^4F_{5/2})$ 5/2	5
$4f^{11}5d$	4	182 291.4 (10)	2	10	0.841	$(^4G)^5I$	41	$(^4G)^5F$	10	$(^4G)^3H$	7	$(^4G_{5/2})$ 3/2	48	$(^4G_{9/2})$ 5/2	5	$(^4G_{11/2})$ 3/2	2
$4f^{11}5d$	5	182 435.1 (11)	2	72	1.041	$(^2G)^3H1$	13	$(^2G)^1H1$	12	$(^2G)^3H2$	11	$(^2G_{7/2})$ 5/2	20	$(^2G_{7/2})$ 5/2	16	$(^4G_{7/2})$ 3/2	5
$4f^{11}5d$	3	183 248.4 (9)	4	40	1.164	$(^4G)^3D$	15	$(^4G)^5F$	8	$(^2D)^3F1$	7	$(^4G_{11/2})$ 5/2	12	$(^4G_{7/2})$ 5/2	6	$(^4G_{9/2})$ 5/2	5
$4f^{11}5d$	5	183 275.1 (8)	5	8	0.978	$(^2K)^1H$	38	$(^2K)^3I$	10	$(^4G)^5I$	8	$(^2K_{13/2})$ 3/2	31	$(^2K_{15/2})$ 5/2	16	$(^4G_{7/2})$ 3/2	5
$4f^{11}5d$	3	183 381.5 (8)	5	−47	1.041	$(^4G)^3D$	11	$(^4G)^5F$	9	$(^4F)^3D$	7	$(^4G_{11/2})$ 5/2	13	$(^4G_{5/2})$ 5/2	6	$(^4G_{5/2})$ 3/2	4
$4f^{11}5d$	5	183 803.6 (6)	5	40	0.926	$(^4G)^5I$	21	$(^4G)^3H$	18	$(^2K)^3I$	17	$(^4G_{7/2})$ 3/2	31	$(^2K_{13/2})$ 5/2	12	$(^2G_{7/2})$ 3/2	8
$4f^{11}5d$	4	183 842.6 (5)	5	−91	1.011	$(^2D)^3G1$	22	$(^2P)^3F$	15	$(^4G)^5H$	15	$(^2P_{3/2})$ 5/2	15	$(^2K_{13/2})$ 5/2	13	$(^2D_{5/2})$ 3/2	11
$4f^{11}5d$	3	184 569.9 (7)	5	20	1.060	$(^4G)^5H$	11	$(^4G)^5G$	9	$(^2P)^3D$	8	$(^4G_{5/2})$ 5/2	11	$(^4G_{5/2})$ 3/2	8	$(^2P_{3/2})$ 5/2	6
$4f^{11}5d$	5	185 715.7 (7)	6	67	0.951	$(^2K)^3I$	26	$(^2K)^3H$	12	$(^2G)^3I1$	8	$(^2K_{13/2})$ 5/2	42	$(^2G_{7/2})$ 3/2	6	$(^2H_{9/2})$ 3/2	4
$4f^{11}5d$	3	185 824.2 (5)	7	44	0.885	$(^4G)^5H$	26	$(^2D)^3D1$	11	$(^4F)^5H$	10	$(^4G_{5/2})$ 3/2	15	$(^2P_{3/2})$ 5/2	12	$(^4F_{3/2})$ 3/2	7
$4f^{11}5d$	2	186 166.2 (9)	2	−28	1.007	$(^4G)^3D$	28	$(^4G)^5F$	8	$(^4F)^3D$	8	$(^4G_{7/2})$ 3/2	25	$(^4G_{9/2})$ 5/2	7	$(^2H_{9/2})$ 5/2	5
$4f^{11}5d$	7	186 462.0 (17)	1	−46	1.107	$(^2L)^3I$	66	$(^2I)^3I$	10	$(^2K)^3L$	9	$(^2L1_{7/2})$ 3/2	59	$(^2L1_{7/2})$ 5/2	10	$(^2I_{13/2})$ 5/2	7
$4f^{11}5d$	4	186 829.8 (9)	3	12	1.051	$(^2D)^3F1$	13	$(^4F)^3H$	11	$(^4G)^5H$	11	$(^2D_{5/2})$ 5/2	10	$(^2P_{3/2})$ 5/2	10	$(^2K_{13/2})$ 5/2	8
$4f^{11}5d$	5	186 959.7 (9)	3	−2	1.035	$(^2H)^1H2$	11	$(^4G)^5H$	10	$(^2H)^3I2$	9	$(^2H_{9/2})$ 3/2	17	$(^2I_{13/2})$ 3/2	6	$(^4G_{7/2})$ 5/2	4
$4f^{11}5d$	4	187 279.7 (9)	4	89	1.014	$(^2K)^3H$	16	$(^4G)^5G$	13	$(^2G)^3G1$	11	$(^2K_{13/2})$ 5/2	16	$(^2G_{7/2})$ 5/2	12	$(^4G_{9/2})$ 3/2	5
$4f^{11}5d$	2	187 751.8 (8)	3	−17	1.201	$(^4G)^3F$	17	$(^2D)^3P2$	11	$(^4D)^5D$	10	$(^2D_{5/2})$ 3/2	14	$(^4D_{7/2})$ 3/2	11	$(^4G_{5/2})$ 3/2	7

Table 2. Continued.

						LS percentage composition						JJ percentage composition					
Conf.	J	E_{exp} (unc.)	N_{cl}	ΔE	g_{calc}	Comp1	%	Comp2	%	Comp3	%	Comp1	%	Comp2	%	Comp3	%
4f^{11}5d	5	187 793.0 (10)	3	40	1.193	$(^4\mathrm{D})^5\mathrm{G}$	35	$(^2\mathrm{D})^3\mathrm{G}1$	11	$(^4\mathrm{D})^3\mathrm{G}$	8	$(^4\mathrm{D}_{7/2})$ 3/2	30	$(^4\mathrm{D}_{5/2})$ 5/2	13	$(^2\mathrm{D}_{5/2})$ 5/2	11
4f^{11}5d	6	188 041.6 (12)	2	27	0.940	$(^2\mathrm{K})^3\mathrm{K}$	42	$(^2\mathrm{K})^3\mathrm{I}$	23	$(^2\mathrm{H})^3\mathrm{K}1$	8	$(^2\mathrm{K}_{13/2})$ 5/2	54	$(^2\mathrm{H}_{9/2})$ 3/2	7	$(^2\mathrm{K}_{13/2})$ 3/2	6
4f^{11}5d	3	188 061.9 (7)	4	−12	0.986	$(^2\mathrm{H})^3\mathrm{G}2$	8	$(^4\mathrm{G})^5\mathrm{G}$	8	$(^2\mathrm{D})^3\mathrm{D}1$	8	$(^4\mathrm{G}_{5/2})$ 5/2	9	$(^2\mathrm{H}_{9/2})$ 5/2	5	$(^2\mathrm{D}_{5/2})$ 5/2	5
4f^{11}5d	3	188 782.2 (11)	2	−12	1.325	$(^4\mathrm{D})^5\mathrm{P}$	24	$(^4\mathrm{D})^5\mathrm{D}$	19	$(^2\mathrm{P})^1\mathrm{F}$	6	$(^4\mathrm{D}_{7/2})$ 3/2	28	$(^4\mathrm{D}_{7/2})$ 5/2	13	$(^2\mathrm{P}_{1/2})$ 5/2	9
4f^{11}5d	4	188 789.6 (9)	4	30	1.045	$(^2\mathrm{I})^1\mathrm{G}$	20	$(^2\mathrm{D})^1\mathrm{G}1$	9	$(^2\mathrm{H})^3\mathrm{F}1$	9	$(^2\mathrm{I}_{11/2})$ 3/2	18	$(^2\mathrm{H}_{11/2})$ 3/2	6	$(^2\mathrm{I}_{11/2})$ 5/2	6
4f^{11}5d	2	189 114.6 (11)	2	−28	1.149	$(^4\mathrm{G})^5\mathrm{D}$	20	$(^2\mathrm{G})^3\mathrm{D}1$	11	$(^4\mathrm{G})^5\mathrm{F}$	9	$(^4\mathrm{G}_{5/2})$ 5/2	15	$(^4\mathrm{G}_{7/2})$ 5/2	13	$(^2\mathrm{G}_{9/2})$ 5/2	4
4f^{11}5d	3	189 577.8 (8)	3	−37	1.088	$(^4\mathrm{G})^5\mathrm{F}$	13	$(^4\mathrm{D})^5\mathrm{G}$	11	$(^2\mathrm{P})^3\mathrm{F}$	8	$(^4\mathrm{G}_{7/2})$ 3/2	7	$(^4\mathrm{G}_{7/2})$ 5/2	6	$(^4\mathrm{D}_{3/2})$ 3/2	6
4f^{11}5d	6	190 008.2 (12)	2	−14	0.961	$(^2\mathrm{I})^3\mathrm{K}$	26	$(^2\mathrm{K})^3\mathrm{K}$	15	$(^2\mathrm{H})^3\mathrm{I}1$	11	$(^2\mathrm{I}_{11/2})$ 3/2	28	$(^2\mathrm{K}_{13/2})$ 5/2	8	$(^2\mathrm{K}_{13/2})$ 3/2	7
4f^{11}5d	5	190 040.7 (9)	5	−41	1.009	$(^4\mathrm{G})^3\mathrm{I}$	26	$(^2\mathrm{D})^3\mathrm{G}1$	19	$(^4\mathrm{G})^3\mathrm{H}$	15	$(^4\mathrm{G}_{5/2})$ 5/2	38	$(^2\mathrm{D}_{5/2})$ 5/2	19	$(^4\mathrm{G}_{9/2})$ 5/2	3
4f^{11}5d	1	190 110.4 (8)	3	−36	1.120	$(^2\mathrm{D})^3\mathrm{S}1$	18	$(^2\mathrm{P})^1\mathrm{P}$	17	$(^2\mathrm{G})^3\mathrm{D}1$	17	$(^2\mathrm{G}_{7/2})$ 5/2	17	$(^2\mathrm{P}_{3/2})$ 5/2	10	$(^2\mathrm{G}_{7/2})$ 5/2	7
4f^{11}5d	3	190 181.6 (11)	2	15	1.134	$(^2\mathrm{G})^3\mathrm{F}1$	11	$(^2\mathrm{D})^3\mathrm{D}1$	10	$(^4\mathrm{D})^5\mathrm{G}$	9	$(^4\mathrm{D}_{5/2})$ 3/2	9	$(^2\mathrm{D}_{5/2})$ 5/2	6	$(^2\mathrm{G}_{7/2})$ 5/2	5
4f^{11}5d	4	190 207.3 (9)	4	5	1.024	$(^2\mathrm{D})^1\mathrm{G}1$	18	$(^2\mathrm{I})^1\mathrm{G}$	11	$(^2\mathrm{D})^3\mathrm{G}1$	7	$(^2\mathrm{D}_{5/2})$ 3/2	21	$(^2\mathrm{I}_{13/2})$ 5/2	6	$(^2\mathrm{I}_{11/2})$ 3/2	4
4f^{11}5d	7	190 492.5 (10)	2	−25	0.998	$(^2\mathrm{K})^1\mathrm{K}$	28	$(^2\mathrm{K})^3\mathrm{L}$	19	$(^2\mathrm{L})^3\mathrm{I}$	11	$(^2\mathrm{K}_{13/2})$ 5/2	52	$(^2\mathrm{L}1_{7/2})$ 3/2	8	$(^2\mathrm{I}_{11/2})$ 3/2	7
4f^{11}5d	3	190 556.8 (14)	2	11	1.020	$(^4\mathrm{G})^3\mathrm{G}$	14	$(^4\mathrm{G})^3\mathrm{F}$	10	$(^2\mathrm{G})^3\mathrm{D}1$	9	$(^4\mathrm{G}_{5/2})$ 5/2	12	$(^4\mathrm{G}_{7/2})$ 3/2	9	$(^4\mathrm{G}_{7/2})$ 5/2	8
4f^{11}5d	4	191 261.8 (8)	5	23	1.094	$(^4\mathrm{G})^3\mathrm{G}$	15	$(^2\mathrm{G})^3\mathrm{F}1$	9	$(^2\mathrm{H})^3\mathrm{G}2$	7	$(^2\mathrm{H}_{9/2})$ 5/2	17	$(^4\mathrm{G}_{9/2})$ 5/2	6	$(^4\mathrm{G}_{7/2})$ 3/2	5
4f^{11}5d	3	191 564.4 (6)	6	−61	1.023	$(^2\mathrm{D})^3\mathrm{G}1$	18	$(^2\mathrm{P})^3\mathrm{F}$	15	$(^2\mathrm{D})^3\mathrm{D}1$	9	$(^2\mathrm{D}_{3/2})$ 3/2	18	$(^2\mathrm{D}_{5/2})$ 5/2	9	$(^2\mathrm{P}_{3/2})$ 3/2	8
4f^{11}5d	2	191 614.2 (8)	4	15	1.266	$(^2\mathrm{D})^1\mathrm{D}1$	18	$(^4\mathrm{D})^5\mathrm{P}$	13	$(^4\mathrm{D})^3\mathrm{P}$	13	$(^2\mathrm{D}_{5/2})$ 5/2	9	$(^4\mathrm{D}_{5/2})$ 5/2	8	$(^4\mathrm{D}_{3/2})$ 5/2	7
4f^{11}5d	5	191 620.3 (8)	4	−44	1.006	$(^2\mathrm{I})^3\mathrm{I}$	15	$(^4\mathrm{G})^3\mathrm{H}$	13	$(^2\mathrm{G})^1\mathrm{H}1$	9	$(^4\mathrm{G}_{7/2})$ 5/2	9	$(^2\mathrm{I}_{11/2})$ 3/2	7	$(^2\mathrm{I}_{11/2})$ 5/2	7
4f^{11}5d	4	191 664.4 (7)	5	−33	0.982	$(^4\mathrm{G})^3\mathrm{H}$	28	$(^4\mathrm{G})^5\mathrm{H}$	7	$(^2\mathrm{H})^1\mathrm{G}2$	7	$(^4\mathrm{G}_{5/2})$ 5/2	23	$(^4\mathrm{G}_{7/2})$ 5/2	7	$(^4\mathrm{G}_{5/2})$ 3/2	4
4f^{11}5d	5	191 772.8 (8)	5	−48	1.055	$(^2\mathrm{I})^3\mathrm{I}$	14	$(^2\mathrm{D})^3\mathrm{G}1$	11	$(^2\mathrm{I})^1\mathrm{H}$	10	$(^2\mathrm{I}_{11/2})$ 3/2	19	$(^2\mathrm{D}_{5/2})$ 5/2	11	$(^2\mathrm{H}_{9/2})$ 5/2	4
4f^{11}5d	4	192 525.3 (8)	4	80	1.235	$(^4\mathrm{D})^5\mathrm{D}$	34	$(^4\mathrm{D})^3\mathrm{F}$	7	$(^2\mathrm{D})^3\mathrm{F}2$	7	$(^4\mathrm{D}_{7/2})$ 3/2	28	$(^4\mathrm{D}_{7/2})$ 5/2	8	$(^4\mathrm{D}_{5/2})$ 3/2	6
4f^{11}5d	2	192 794.4 (9)	3	48	1.294	$(^4\mathrm{D})^5\mathrm{D}$	15	$(^4\mathrm{D})^5\mathrm{P}$	14	$(^4\mathrm{G})^3\mathrm{D}$	12	$(^4\mathrm{D}_{7/2})$ 3/2	18	$(^4\mathrm{G}_{9/2})$ 5/2	6	$(^4\mathrm{D}_{5/2})$ 5/2	5
4f^{11}5d	4	192 948.4 (8)	5	95	1.084	$(^4\mathrm{D})^5\mathrm{F}$	14	$(^4\mathrm{G})^3\mathrm{H}$	13	$(^4\mathrm{D})^3\mathrm{F}$	8	$(^4\mathrm{D}_{7/2})$ 3/2	21	$(^4\mathrm{D}_{5/2})$ 5/2	6	$(^4\mathrm{G}_{5/2})$ 5/2	5
4f^{11}5d	3	193 471.5 (8)	4	70	1.160	$(^4\mathrm{D})^5\mathrm{D}$	17	$(^4\mathrm{D})^5\mathrm{F}$	15	$(^2\mathrm{D})^3\mathrm{D}2$	11	$(^4\mathrm{D}_{7/2})$ 3/2	15	$(^4\mathrm{D}_{3/2})$ 3/2	11	$(^4\mathrm{D}_{5/2})$ 5/2	9
4f^{11}5d	6	193 671.1 (10)	3	51	0.998	$(^2\mathrm{L})^3\mathrm{I}$	32	$(^2\mathrm{I})^3\mathrm{I}$	14	$(^2\mathrm{I})^3\mathrm{K}$	11	$(^2\mathrm{L}1_{7/2})$ 5/2	33	$(^2\mathrm{I}_{11/2})$ 5/2	19	$(^2\mathrm{L}_{15/2})$ 5/2	3
4f^{11}5d	5	193 790.3 (11)	3	−37	1.194	$(^4\mathrm{D})^3\mathrm{G}$	26	$(^2\mathrm{D})^3\mathrm{G}2$	20	$(^2\mathrm{D})^3\mathrm{G}1$	16	$(^4\mathrm{D}_{5/2})$ 5/2	34	$(^2\mathrm{D}_{5/2})$ 5/2	20	$(^2\mathrm{D}_{5/2})$ 5/2	16
4f^{11}5d	2	193 813.3 (12)	3	−16	0.808	$(^4\mathrm{D})^5\mathrm{G}$	33	$(^4\mathrm{D})^3\mathrm{P}$	11	$(^2\mathrm{D})^1\mathrm{D}1$	9	$(^4\mathrm{D}_{3/2})$ 3/2	30	$(^4\mathrm{D}_{1/2})$ 3/2	9	$(^4\mathrm{D}_{7/2})$ 5/2	7
4f^{11}5d	1	194 201.2 (8)	3	−68	1.040	$(^2\mathrm{D})^3\mathrm{D}1$	20	$(^4\mathrm{G})^3\mathrm{D}$	9	$(^2\mathrm{D})^3\mathrm{S}1$	9	$(^2\mathrm{D}_{5/2})$ 5/2	31	$(^2\mathrm{D}_{3/2})$ 3/2	6	$(^4\mathrm{G}_{5/2})$ 3/2	6
4f^{11}5d	5	194 607.2 (9)	5	−84	1.116	$(^2\mathrm{I})^3\mathrm{G}$	41	$(^2\mathrm{K})^1\mathrm{H}$	6	$(^2\mathrm{I})^3\mathrm{I}$	6	$(^2\mathrm{I}_{13/2})$ 3/2	31	$(^2\mathrm{I}_{13/2})$ 5/2	8	$(^2\mathrm{I}_{11/2})$ 5/2	6
4f^{11}5d	4	194 914.8 (10)	3	−48	1.134	$(^4\mathrm{D})^5\mathrm{D}$	14	$(^2\mathrm{D})^3\mathrm{F}2$	12	$(^2\mathrm{D})^3\mathrm{F}1$	8	$(^4\mathrm{D}_{5/2})$ 5/2	12	$(^2\mathrm{D}_{5/2})$ 5/2	10	$(^2\mathrm{D}_{5/2})$ 5/2	6
4f^{11}5d	1	194 978.6 (8)	3	59	1.701	$(^4\mathrm{D})^3\mathrm{S}$	21	$(^4\mathrm{D})^5\mathrm{P}$	19	$(^4\mathrm{D})^3\mathrm{P}$	11	$(^4\mathrm{D}_{7/2})$ 5/2	48	$(^4\mathrm{D}_{5/2})$ 5/2	7	$(^4\mathrm{D}_{5/2})$ 3/2	5
4f^{11}5d	5	195 875.9 (8)	4	−53	1.030	$(^2\mathrm{I})^3\mathrm{H}$	54	$(^2\mathrm{H})^3\mathrm{G}1$	15	$(^2\mathrm{I})^3\mathrm{I}$	9	$(^2\mathrm{I}_{11/2})$ 5/2	44	$(^2\mathrm{I}_{13/2})$ 5/2	10	$(^2\mathrm{I}_{13/2})$ 3/2	9
4f^{11}5d	3	196 003.7 (8)	6	18	1.142	$(^4\mathrm{D})^3\mathrm{D}$	21	$(^4\mathrm{D})^5\mathrm{P}$	12	$(^2\mathrm{D})^1\mathrm{F}2$	9	$(^4\mathrm{D}_{7/2})$ 5/2	23	$(^2\mathrm{D}_{5/2})$ 3/2	11	$(^4\mathrm{D}_{5/2})$ 5/2	6
4f^{11}5d	4	196 674.4 (8)	5	13	0.989	$(^2\mathrm{I})^3\mathrm{H}$	33	$(^2\mathrm{I})^3\mathrm{G}$	18	$(^2\mathrm{H})^3\mathrm{F}1$	10	$(^2\mathrm{I}_{11/2})$ 5/2	47	$(^2\mathrm{H}_{11/2})$ 5/2	12	$(^2\mathrm{H}_{11/2})$ 3/2	3
4f^{11}5d	3	197 428.8 (8)	6	76	0.873	$(^2\mathrm{I})^3\mathrm{G}$	44	$(^4\mathrm{G})^3\mathrm{G}$	12	$(^2\mathrm{H})^1\mathrm{F}1$	12	$(^2\mathrm{I}_{11/2})$ 5/2	44	$(^2\mathrm{H}_{11/2})$ 5/2	18	$(^4\mathrm{G}_{7/2})$ 5/2	4
4f^{11}5d	3	199 252.2 (8)	6	−42	0.996	$(^2\mathrm{P})^1\mathrm{F}$	16	$(^2\mathrm{D})^1\mathrm{F}1$	7	$(^2\mathrm{H})^3\mathrm{G}1$	7	$(^2\mathrm{P}_{3/2})$ 3/2	6	$(^2\mathrm{P}_{1/2})$ 5/2	5	$(^2\mathrm{H}_{9/2})$ 5/2	5
4f^{11}5d	3	199 809.9 (12)	2	3	1.145	$(^4\mathrm{D})^3\mathrm{F}$	19	$(^4\mathrm{D})^3\mathrm{D}$	15	$(^4\mathrm{D})^5\mathrm{F}$	9	$(^4\mathrm{D}_{7/2})$ 5/2	22	$(^4\mathrm{D}_{7/2})$ 3/2	15	$(^4\mathrm{D}_{3/2})$ 3/2	3
4f^{11}5d	1	200 325.3 (11)	2	5	0.932	$(^4\mathrm{D})^5\mathrm{D}$	24	$(^2\mathrm{D})^3\mathrm{D}2$	19	$(^4\mathrm{D})^5\mathrm{F}$	14	$(^4\mathrm{D}_{1/2})$ 3/2	16	$(^4\mathrm{D}_{3/2})$ 5/2	15	$(^2\mathrm{D}_{3/2})$ 3/2	11
4f^{11}5d	2	200 772.6 (12)	2	39	1.045	$(^4\mathrm{D})^3\mathrm{D}$	24	$(^4\mathrm{D})^5\mathrm{G}$	12	$(^2\mathrm{D})^3\mathrm{F}2$	12	$(^4\mathrm{D}_{1/2})$ 3/2	18	$(^4\mathrm{D}_{7/2})$ 5/2	14	$(^2\mathrm{D}_{3/2})$ 3/2	8
4f^{11}5d	4	200 945.4 (10)	3	−101	1.060	$(^2\mathrm{I})^3\mathrm{G}$	15	$(^2\mathrm{D})^3\mathrm{G}1$	8	$(^4\mathrm{D})^5\mathrm{F}$	8	$(^2\mathrm{I}_{13/2})$ 5/2	19	$(^2\mathrm{D}_{3/2})$ 5/2	13	$(^4\mathrm{D}_{7/2})$ 3/2	3
4f^{11}5d	3	201 091.3 (8)	6	−71	1.009	$(^4\mathrm{D})^3\mathrm{G}$	14	$(^4\mathrm{D})^5\mathrm{G}$	10	$(^2\mathrm{D})^1\mathrm{F}2$	10	$(^4\mathrm{D}_{1/2})$ 5/2	14	$(^4\mathrm{D}_{3/2})$ 5/2	7	$(^2\mathrm{D}_{5/2})$ 5/2	5
4f^{11}5d	3	201 482.8 (7)	5	−50	1.063	$(^2\mathrm{H})^3\mathrm{F}1$	17	$(^2\mathrm{D})^1\mathrm{F}1$	11	$(^2\mathrm{P})^3\mathrm{D}$	11	$(^2\mathrm{P}_{3/2})$ 5/2	8	$(^2\mathrm{H}_{11/2})$ 5/2	7	$(^2\mathrm{H}_{9/2})$ 3/2	5
4f^{11}5d	5	201 933.2 (10)	4	10	0.945	$(^2\mathrm{L})^3\mathrm{I}$	39	$(^2\mathrm{H})^3\mathrm{H}1$	17	$(^2\mathrm{K})^1\mathrm{H}$	7	$(^2\mathrm{L}_{15/2})$ 5/2	39	$(^2\mathrm{H}_{9/2})$ 5/2	8	$(^2\mathrm{H}_{11/2})$ 3/2	6

Table 2. Continued.

						LS percentage composition						JJ percentage composition					
Conf.	J	E_{exp} (unc.)	N_{cl}	ΔE	g_{calc}	Comp1	%	Comp2	%	Comp3	%	Comp1	%	Comp2	%	Comp3	%
4f^{11}5d	2	202 697.8 (9)	3	−16	1.064	(^{4}D)^{5}F	19	(^{2}H)^{3}F1	16	(^{2}D)^{3}P2	8	(^{2}H$_{9/2}$) 5/2	16	(^{4}D$_{5/2}$) 3/2	6	(^{4}D$_{3/2}$) 3/2	4
4f^{11}5d	4	202 801.1 (9)	4	−15	1.107	(^{2}H)^{3}F1	23	(^{2}I)^{1}G	15	(^{2}D)^{3}G2	11	(^{2}I$_{11/2}$) 3/2	16	(^{2}H$_{11/2}$) 3/2	15	(^{2}H$_{11/2}$) 5/2	6
4f^{11}5d	4	203 338.2 (9)	5	−73	1.127	(^{4}D)^{3}F	25	(^{4}D)^{3}G	12	(^{2}H)^{3}F1	10	(^{4}D$_{3/2}$) 5/2	19	(^{4}D$_{5/2}$) 3/2	18	(^{4}D$_{7/2}$) 5/2	9
4f^{11}5d	1	204 584.8 (7)	4	−7	0.906	(^{4}D)^{5}F	26	(^{2}P)^{1}P	19	(^{2}D)^{3}P1	8	(^{4}D$_{1/2}$) 3/2	15	(^{2}P$_{3/2}$) 5/2	11	(^{4}D$_{3/2}$) 3/2	7
4f^{11}5d	5	204 935.55 (23)	4	−19	1.030	(^{2}H)^{3}H1	24	(^{2}L)^{3}I	14	(^{2}D)^{3}G2	10	(^{2}H$_{9/2}$) 5/2	23	(^{2}L$_{15/2}$) 5/2	14	(^{2}D$_{5/2}$) 5/2	10
4f^{11}5d	4	205 342.1 (11)	3	84	1.001	(^{2}H)^{3}G1	25	(^{2}H)^{3}H1	18	(^{2}H)^{1}G1	17	(^{2}H$_{9/2}$) 5/2	56	(^{2}I$_{13/2}$) 5/2	3	(^{2}H$_{9/2}$) 5/2	3
4f^{11}5d	5	205 383.7 (13)	3	−87	1.124	(^{2}D)^{3}G2	21	(^{4}D)^{5}G	13	(^{2}L)^{3}I	10	(^{2}D$_{5/2}$) 5/2	21	(^{4}D$_{5/2}$) 5/2	17	(^{2}L$_{15/2}$) 5/2	10
4f^{11}5d	2	206 369.1 (13)	2	−17	1.074	(^{4}D)^{3}F	32	(^{2}D)^{3}D2	17	(^{2}D)^{3}P2	13	(^{2}D$_{3/2}$) 5/2	22	(^{4}D$_{1/2}$) 5/2	14	(^{4}D$_{1/2}$) 3/2	10
4f^{11}5d	3	206 878.6 (11)	3	49	1.073	(^{4}D)^{3}G	15	(^{4}D)^{5}F	14	(^{2}D)^{3}F2	9	(^{4}D$_{1/2}$) 5/2	16	(^{2}D$_{5/2}$) 3/2	12	(^{4}D$_{5/2}$) 3/2	9
4f^{11}5d	3	207 141.0 (11)	4	−11	1.099	(^{4}D)^{5}F	15	(^{2}F)^{3}D2	11	(^{4}D)^{5}G	9	(^{4}D$_{1/2}$) 5/2	9	(^{4}D$_{3/2}$) 3/2	9	(^{2}F$_{7/2}$) 5/2	5
4f^{11}5d	1	208 311.0 (8)	4	−81	1.356	(^{4}D)^{3}D	27	(^{2}D)^{3}S2	22	(^{4}D)^{3}S	17	(^{2}D$_{5/2}$) 5/2	19	(^{4}D$_{7/2}$) 5/2	15	(^{4}D$_{3/2}$) 5/2	13
4f^{11}5d	4	209 187.9 (10)	4	−5	1.028	(^{2}H)^{1}G1	20	(^{2}I)^{3}H	12	(^{2}H)^{3}G1	10	(^{2}H$_{11/2}$) 5/2	21	(^{2}I$_{11/2}$) 5/2	8	(^{2}H$_{11/2}$) 3/2	8
4f^{11}5d	5	209 444.5 (14)	2	−62	1.074	(^{2}H)^{3}G1	23	(^{2}I)^{1}H	18	(^{2}F)^{3}H2	10	(^{2}I$_{11/2}$) 3/2	13	(^{2}H$_{11/2}$) 5/2	11	(^{2}H$_{11/2}$) 3/2	10
4f^{11}5d	2	209 693.2 (10)	3	8	1.290	(^{2}F)^{3}P2	24	(^{2}F)^{3}P1	14	(^{4}D)^{3}D	8	(^{2}F$_{7/2}$) 3/2	17	(^{2}F$_{7/2}$) 3/2	8	(^{2}F$_{5/2}$) 3/2	6
4f^{11}5d	6	210 109.5 (12)	2	7	1.036	(^{2}I)^{1}I	42	(^{2}H)^{3}H1	17	(^{2}H)^{1}I1	11	(^{2}I$_{13/2}$) 5/2	16	(^{2}H$_{11/2}$) 3/2	15	(^{2}I$_{11/2}$) 5/2	10
4f^{11}5d	3	210 460.3 (11)	5	6	0.975	(^{2}H)^{1}F1	25	(^{2}I)^{3}G	19	(^{2}H)^{3}F1	10	(^{2}H$_{11/2}$) 5/2	33	(^{2}I$_{11/2}$) 5/2	19	(^{2}H$_{11/2}$) 5/2	5
4f^{11}5d	6	211 102.9 (15)	1	1	0.992	(^{2}H)^{1}I1	33	(^{2}I)^{3}K	17	(^{2}H)^{3}H1	7	(^{2}H$_{11/2}$) 5/2	26	(^{2}I$_{11/2}$) 3/2	11	(^{2}H$_{9/2}$) 5/2	8
4f^{11}5d	3	211 237.7 (12)	3	−19	1.011	(^{2}D)^{3}G2	21	(^{2}D)^{3}D2	16	(^{4}D)^{3}G	9	(^{2}D$_{3/2}$) 3/2	22	(^{2}D$_{5/2}$) 5/2	15	(^{4}D$_{1/2}$) 5/2	6
4f^{11}5d	3	212 142.3 (8)	4	−130	0.994	(^{4}D)^{3}F	19	(^{2}D)^{3}D2	11	(^{2}D)^{3}G2	11	(^{4}D$_{1/2}$) 5/2	11	(^{4}D$_{3/2}$) 3/2	10	(^{2}D$_{3/2}$) 3/2	6
4f^{11}5d	1	212 238.9 (6)	4	42	1.121	(^{2}D)^{3}P2	18	(^{2}D)^{3}D2	8	(^{4}D)^{5}D	8	(^{2}D$_{3/2}$) 5/2	16	(^{4}D$_{3/2}$) 5/2	6	(^{4}D$_{7/2}$) 5/2	6
4f^{11}5d	5	215 884.7 (16)	2	1	1.15	(^{2}F)^{3}G2	33	(^{2}F)^{3}G1	23	(^{2}F)^{1}H2	8	(^{2}F$_{7/2}$) 5/2	41	(^{2}F$_{7/2}$) 5/2	19	(^{4}D$_{7/2}$) 5/2	4
4f^{11}5d	1	218 177.8 (7)	5	37	1.000	(^{2}D)^{1}P2	19	(^{2}D)^{3}D2	11	(^{4}D)^{3}S	7	(^{2}D$_{3/2}$) 3/2	26	(^{2}F$_{5/2}$) 3/2	7	(^{2}F$_{7/2}$) 5/2	5
4f^{11}5d	3	219 090.5 (11)	3	−80	1.098	(^{2}D)^{3}F2	25	(^{2}D)^{1}F2	12	(^{2}D)^{3}D2	9	(^{2}D$_{3/2}$) 5/2	43	(^{2}D$_{3/2}$) 3/2	3	(^{2}F$_{5/2}$) 3/2	3
4f^{11}5d	3	221 811.9 (20)	2	77	1.014	(^{2}F)^{1}F2	16	(^{2}G)^{1}F2	9	(^{2}G)^{3}G2	8	(^{2}G$_{7/2}$) 3/2	22	(^{2}F$_{7/2}$) 5/2	7	(^{2}F$_{5/2}$) 3/2	4
4f^{11}5d	1	223 766.1 (14)	2	4	0.885	(^{2}G)^{3}D2	24	(^{2}F)^{3}P2	24	(^{2}G)^{3}D1	15	(^{2}F$_{5/2}$) 5/2	31	(^{2}G$_{7/2}$) 5/2	24	(^{2}G$_{7/2}$) 5/2	15
4f^{11}5d	3	226 914.8 (13)	2	200	1.190	(^{2}G)^{3}D2	30	(^{2}G)^{3}D1	19	(^{2}G)^{3}F2	14	(^{2}G$_{9/2}$) 3/2	40	(^{2}G$_{9/2}$) 3/2	25	(^{2}F$_{5/2}$) 3/2	3
4f^{11}5d	6	227 053.1 (18)	1	−34	1.014	(^{2}G)^{1}I2	49	(^{2}G)^{1}I1	36	(^{2}G)^{3}H2	4	(^{2}G$_{9/2}$) 3/2	27	(^{2}G$_{7/2}$) 5/2	25	(^{2}G$_{9/2}$) 3/2	19
4f^{11}5d	1	263 213.4 (16)	1	8	1.010	(^{2}F)^{1}P1	53	(^{2}F)^{1}P2	13	(^{2}F)^{3}D1	10	(^{2}F$_{7/2}$) 5/2	45	(^{2}F$_{7/2}$) 5/2	20	(^{2}F$_{5/2}$) 5/2	11
4f^{11}6s	8	192 628.22 (09)	6	−37	1.245	(^{4}I)^{5}I	96	(^{2}K)^{3}K	3			(^{4}I$_{15/2}$) 1/2	96	(^{2}K$_{15/2}$) 1/2	3		
4f^{11}6s	7	194 035.09 (08)	8	−31	1.147	(^{4}I)^{3}I	68	(^{4}I)^{5}I	27	(^{2}K)^{3}K	2	(^{4}I$_{15/2}$) 1/2	94	(^{2}K$_{15/2}$) 1/2	4	(^{4}I$_{13/2}$) 1/2	1
4f^{11}6s	7	202 022.73 (10)	7	−5	1.167	(^{4}I)^{5}I	71	(^{4}I)^{3}I	27	(^{2}K)^{1}K	1	(^{4}I$_{13/2}$) 1/2	97	(^{2}K$_{13/2}$) 1/2	1	(^{4}I$_{15/2}$) 1/2	1
4f^{11}6s	6	202 528.13 (09)	9	28	1.050	(^{4}I)^{5}I	59	(^{4}I)^{3}I	38	(^{2}K)^{3}K	1	(^{4}I$_{13/2}$) 1/2	93	(^{4}I$_{11/2}$) 1/2	3	(^{2}K$_{13/2}$) 1/2	1
4f^{11}6s	5	206 519.78 (09)	10	68	0.930	(^{4}I)^{5}I	63	(^{2}H)^{3}H2	13	(^{4}I)^{3}I	11	(^{4}I$_{11/2}$) 1/2	71	(^{2}H$_{11/2}$) 1/2	18	(^{4}I$_{9/2}$) 1/2	3
4f^{11}6s	6	206 796.10 (07)	8	40	1.078	(^{4}I)^{3}I	47	(^{4}I)^{5}I	26	(^{2}H)^{3}H2	22	(^{4}I$_{11/2}$) 1/2	69	(^{2}H$_{11/2}$) 1/2	22	(^{4}I$_{13/2}$) 1/2	4
4f^{11}6s	4	208 521.33 (19)	4	−3	0.832	(^{4}I)^{5}I	42	(^{2}H)^{3}H2	19	(^{4}F)^{3}F	12	(^{4}I$_{9/2}$) 1/2	42	(^{2}H$_{9/2}$) 1/2	19	(^{2}G$_{9/2}$) 1/2	11
4f^{11}6s	5	208 635.08 (09)	8	−36	1.146	(^{4}F)^{5}F	33	(^{4}I)^{3}I	22	(^{2}G)^{3}G1	15	(^{4}F$_{9/2}$) 1/2	33	(^{4}I$_{9/2}$) 1/2	15	(^{2}G$_{9/2}$) 1/2	15
4f^{11}6s	5	212 766.00 (08)	9	3	1.087	(^{4}F)^{5}F	37	(^{4}I)^{3}I	37	(^{4}I)^{5}I	11	(^{4}I$_{9/2}$) 1/2	48	(^{4}F$_{9/2}$) 1/2	37	(^{2}H$_{11/2}$) 1/2	3
4f^{11}6s	4	212 855.37 (09)	9	−24	1.010	(^{4}F)^{3}F	38	(^{4}I)^{5}I	33	(^{4}F)^{5}F	13	(^{4}F$_{9/2}$) 1/2	50	(^{4}I$_{9/2}$) 1/2	33	(^{2}G$_{9/2}$) 1/2	8
4f^{11}6s	4	218 920.29 (10)	5	−3	1.301	(^{4}F)^{5}F	72	(^{4}F)^{3}F	19	(^{2}G)^{1}G1	4	(^{4}F$_{7/2}$) 1/2	90	(^{2}G$_{7/2}$) 1/2	5	(^{2}G$_{9/2}$) 1/2	1
4f^{11}6s	3	219 307.35 (09)	5	−4	1.174	(^{4}F)^{5}F	66	(^{4}F)^{3}F	23	(^{2}G)^{3}G1	5	(^{4}F$_{7/2}$) 1/2	75	(^{4}F$_{5/2}$) 1/2	13	(^{2}G$_{7/2}$) 1/2	5

Table 4. Transitions from the $4f^{11}6p$ energy levels at 286 033.82 cm^{-1} ($J = 5$) and 286 033.97 cm^{-1} ($J = 3$). The combining lower levels and their quantum numbers are given in columns 1 and 2. Calculated transition probabilities gA (in 10^6 s^{-1}), g being the statistical weight of the upper level, are compared with the line intensities in arbitrary units in columns 3 and 4. The experimentally measured wavelengths (λ_{exp} in Å) are followed by the deviations $\Delta\lambda$ from the Ritz wavelengths (in mÅ).

		286 033.82 $J = 5$				286 033.97 $J = 3$				
Odd parity	J	gA	Int	λ_{meas}	$\Delta\lambda$	gA	Int	λ_{meas}	$\Delta\lambda$	Comment
157 429.4	3					216	18	777.578	1	
158 706.85	4					31	20	785.363	−16	
159 904.4	5	152	5	792.847	12					
160 776.5	6	104	2	798.362	6					
161 356.2	4	320	30	802.074	6	132	30	802.074	6	
161 967.2	6	386	16 p	806.015	−3					
162 941.4	5	741	37 as	812.384	−14					YbV
164 502.4	4	562	41	822.837	4	108	41 m	822.837	5	
165 446.6	4					2046	9	829.272	−2	
166 096.1	3						224 p	833.768 *R*	2	O III
167 076.1	4	131	6 m	840.631	−3	1248	6	840.631	−4	
167 964.8	4	121	10 m	846.960	−2	1437	10	846.960	−1	
168 554.6	3					1547	6	851.214		
168 841.3	5	4219	36	853.301	3					
169 918.7	6	5915	42	861.213	−1					
171 496.1	4	13	38 m	873.074		2532	38	873.074	3	
173 412.2	5	1096	43	887.921	0					
174 169.4	3					1731	101 p	893.935	−4	Yb V
174 778.0	6	4439	37	898.829	1					
175 277.2	2					859	4	902.884	1	
175 716.1	3					33	6	906.472	1	
175 772.6	4	300	93	906.944	7	191	93 m	906.944	12	
178 991.4	5	159	59	934.215	6					
180 636.9	3					26	5	948.799	6	
218 920.29	4	15 320	116	1490.008	−7	2657	116 m	1490.008	−1	
219 307.35	3					6767	131	1498.649	−3	

m: masked by the stronger transition of the neighboring level at 286 034 cm^{-1}.

p: line resolved on the plate, but perturbed by a close line with emitter in last column.

as: asymmetrical line.

R: wavelength calculated from Ritz principle.

Table 5. Fitted parameters and Hartree–Fock relativistic radial integrals (in cm^{-1}) for even parity configurations of Yb^{4+}. SF is the scaling factor $SF(P) = P_{fit}/P_{HFR}$.

	$4f^{12}$				$4f^{11}6p$			
Parameters	Fitted	St.dev.	HFR	SF	Fitted	St.dev.	HFR	SF
E_{av}	20 531	17			300 546	35	264 316	
$F^2(4f4f)$ r	114 180	175	142 711	0.800	119 139	183	148 907	0.800
$F^4(4f4f)$ r	80 688	377	89 854	0.898	84 488	395	94 085	0.898
$F^6(4f4f)$ r	55 929	267	64 733	0.864	58 646	280	67 877	0.864
α	17.9	2			21.7	3		
β r	−738	86			−738	86		
γ r	1757	104			1757	104		
ζ_{4f} r	3066	6	3121	0.982	3228	6	3287	0.982
ζ_{6p}					7739	16	6777	1.143
$F^1(4f6p)$					270	85		
$F^2(4f6p)$					9625	283	11 403	0.844
$G^2(4f6p)$					2939	88	2919	1.007
$G^4(4f6p)$					2560	233	2677	0.956
	$5p^54f^{13}$				$5p^54f^{12}6p$			
Parameters	Fitted	St.dev.	HFR	SF	Fitted	St.dev.	HFR	SF
E_{av}	192 408	*f*	172 089		412 123	*f*	391 804	
$F^2(4f4f)$					113 153	*f*	144 145	
$F^4(4f4f)$					79 482	*f*	90 836	
$F^6(4f4f)$					56 625	*f*	65 463	
α					17	*f*		
β					−653	*f*		
γ					1712	*f*		

Table 5. Continued.

	5p^{5}4f^{13}				5p^{5}4f^{12}6p			
Parameters	Fitted	St.dev.	HFR	SF	Fitted	St.dev.	HFR	SF
ζ_{4f}	2932	f	2986	0.982	3090	f	3147	0.982
ζ_{5p}	35 833	f	35 833	1.000	39 067	f	39 067	1.000
ζ_{6p}					7881	f	6736	1.169
F^1(5p4f)	1000	f				f		
F^2(5p4f)	46 397	f	57 796	0.800	47 896	f	59 871	0.800
F^1(4f6p)					100	f		
F^2(4f6p)					10 120	f	11 627	0.870
F^2(5p6p)					17 729	f	22 162	0.800
G^2(5p4f)	22 571	f	28 213	0.800	22 176	f	27 721	0.960
G^4(5p4f)	17 677	f	22 096	0.800	17 688	f	22 110	0.800
G^2(4f6p)					3054	f	3054	1.000
G^4(4f6p)					2509	f	2788	0.900
G^0(5p6p)					3332	f	4165	0.800
G^2(5p6p)					4689	f	5862	0.800
CIParameter	Fitted	St.dev.	HFR	SF				
5p^{6}4f^{12}–5p^{5}4f^{13}								
R^2(4f5p, 4f4f)	−10 022	f	−15 745	(0.700)				
R^4(4f4f, 4f5p)	−4279	f	−6113	(0.700)				
R^2(5p5p, 4f5p)	−28 260	f	−40 371	(0.700)				
5p^{6}4f^{12}–5p^{6}4f^{11}6p								
R^2(4f4f, 4f6p)	−2278	f	−3254	(0.700)				
R^4(4f4f, 4f6p)	−1092	f	−1560	(0.700)				
5p^{6}4f^{12}–5p^{5}4f^{12}6p								
R^2(4f5p, 4f6p)	11 025	f	15 750	(0.700)				
R^2(4f5p, 6p4f)	5692	f	8132	(0.700)				
R^4(4f5p, 6p4f)	4903	f	7004	(0.700)				
R^2(5p5p, 5p6p)	7380	f	10 543	(0.700)				

r : all the parameters of the same name are linked by a constant ratio.
f : fixed parameter.
Mean error of the fit = 55 cm^{-1}.

Table 6. Fitted parameters and Hartree–Fock relativistic radial integrals (in cm^{-1}) for odd parity configurations of Yb^{4+}. SF is the scaling factor SF(P) = $P_{\text{fit}}/P_{\text{HFR}}$.

	4f^{11}5d				4f^{11}6s			
Parameter	Fitted	St.dev.	HFR	SF	Fitted	St.dev.	HFR	SF
E_{av}	188 548	35	151 386		237 611	22	202 889	
F^2(ff) r	119 165	77	148 395	0.803	119 537	77	148 858	0.803
F^4(ff) r	84 523	186	93 733	0.902	84 809	186	94 051	0.902
F^6(ff) r	60 488	153	67 616	0.895	60 699	153	67 852	0.895
α r	17.5	1			17.5	1		
β r	−601	33			−601	33		
γ r	1167	43			1167	43		
ζ_f r	3227	4	3278	0.984	3235	4	3286	0.984
ζ_d	2369	7	2486	0.953				
F^1(fd)	819	81						
F^2(fd)	28 030	106	34 743	0.807				
F^4(fd)	18 449	199	16 578	1.129				
G^1(fd)	10 337	112	13 363	0.774				
G^2(fd)	2072	134						
G^3(fd)	11 281	165	11 754	0.960				
G^4(fd)	2495	245						
G^5(fd)	7903	170	9194	0.843				
G^3(fs)					3323	152	3827	0.868
CI slater parameter[a]	Fitted	St.dev.	HFR	SF				
5p^{6}4f^{11}5d–5p^{6}4f^{11}6s								
R^2(fd, fs)	1725	87	2806	0.615				
R^3(fd, sf)	2390	120	3886	0.615				
5p^{6}4f^{11}5d–5p^{5}4f^{12}5d								
R^2(fp, ff)	−7426	373	−12 076	0.615				
R^4(fp, ff)	−2797	140	−4548	0.615				

Table 6. Continued.

CI slater parameter[a]	Fitted	St.dev.	HFR	SF
R^2(pp, fp)	−24 216	1215	−39 380	0.615
R^2(pd, fd)	−17 210	864	−27 987	0.615
R^4(pd, fd)	−10 884	546	−17 700	0.615
R^1(pd, df)	−15 651	786	−25 451	0.615
R^3(pd, df)	−11 094	557	−18 041	0.615
$5p^64f^{11}5d$–$5p^54f^{12}6s$				
R^2(pd, fs)	3151	158	5125	0.615
R^1(pd, sf)	1520	76	2472	0.615
$5p^64f^{11}6s$–$5p^54f^{12}5d$				
R^2(ps, fd)	3759	189	6114	0.615
R^3(ps, df)	−1542	77	−2507	0.615
$5p^64f^{11}6s$–$5p^54f^{12}6s$				
R^2(fp, ff)	−7379	370	−12 000	0.615
R^4(fp, ff)	−2764	139	−4495	0.615
R^2(pp, fp)	−24 354	1222	−39 606	0.615

r : all the parameters of the same name are linked by a constant ratio.
a : all the configuration interaction Slater parameters are constrained to vary with the ratios fixed to the ones of their HFR values.
Mean error of the fit = 51 cm^{-1}.

parameters for the odd parity configurations. The set of parameters generated by the electrostatic and spin–orbit Hamiltonians was completed by the effective parameters for interactions with high lying configurations (two-particle excitations, optional in the Cowan codes). The parameters α, β and γ act on the (S_c, L_c) terms of the f^N core, while the so-called *illegal* Slater parameters $F^1(f,l)$ and $G^k(f,l)$ act on the (S, L) terms of the $f^N l$ configurations. The angular factors of α and $F^1(f,l)$ are, respectively proportional to $L_c(L_c+1)$ and $L(L+1) - L_c(L_c+1)$, which results in their correlation. However, this does not prevent them being fitted simultaneously (see table 6). The initial values of these parameters were chosen by comparison with earlier studied lanthanide spectra.

5. Conclusion

This paper reports the analysis of the Yb V spectrum that provides for the first time energy levels of the Yb^{4+} ion, as well as theoretical transition probabilities. Compared with the previously analyzed open 4f shell isoionic lanthanide spectra La V, Ce V, Pr V [1, 22], Nd V [7] and Lu V [21], the Yb V spectrum is of unprecedented complexity. The large number of experimental levels determined in the present analysis, through the least squares fit, led to well defined radial parameters and the corresponding scaling factors for HFR radial integrals. This should contribute to further reliable predictions of unknown energy levels in moderately ionized lanthanides and also in spectra of the isoelectronic sequence, such as W IX for fusion applications.

Acknowledgments

The financial support of the French CNRS Stellar Physics National Program (PNPS) is acknowledged. AM acknowledges support from Université Mouloud Mammeri, Tizi-Ouzou, Algeria. This work is part of the Plas@par LabEx project within the French government's 'Investissements d'Avenir' program.

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