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THE SPECTRUM AND TERM ANALYSIS OF V II

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ABSTRACT

The spectrum and extended term analysis of V II are presented. Fourier transform spectrometry was used to record high resolution spectra of singly ionized vanadium in the region 1492–5800 Å (67020–17260 cm^{-1}) with vanadium–neon and vanadium–argon hollow cathode lamps as sources. The wavenumber uncertainty for the center of gravity of the strongest lines is typically 0.002 cm^{-1}, an improvement of an order of magnitude over previous measurements. Most of the lines exhibit partly resolved hyperfine structure. The V II energy levels in the 1985 compilation of Sugar and Corliss have been confirmed and revised, with the exception of the high-lying 4*f* levels and eight of the lower levels. Thirty-nine of the additional eighty-five high levels published by Iglesias et al. have also been confirmed and revised, and three of their missing levels have been found. The energy uncertainty of the revised levels has been reduced by about an order of magnitude. In total, 176 even levels and 233 odd levels are presented. Wavenumbers and classifications are given for 1242 V II lines.

Key words: atomic data – line: formation – line: profiles

Online-only material: machine-readable tables

1. INTRODUCTION

This paper presents accurate energy level values and wavelengths for V II, which complement our recent publication on the spectrum and term analysis of V I (Thorne et al. 2011). The need to improve the atomic database, particularly for the 3*d* (iron group) elements for astrophysics applications, was discussed fully in the introduction to that paper, and the arguments will not be repeated here. A recent paper by Armstrong et al. (2011) has focused on the role of the relative abundance of V II in understanding the history of nucleosynthesis in the early universe.

The importance of accurate wavelengths and energy values should be emphasized. Most lines in stellar spectra are blended, and it is impossible to disentangle the blends without accurate wavelengths, obtained either experimentally or as Ritz wavelengths from experimentally determined energy levels. Kurucz (2002) pointed out that one half of the lines in the solar spectrum are not identified and all of the features are blended. He recently emphasized again the importance of both accuracy and completeness in the database (Kurucz 2011). Each new atomic spectrum analysis can affect thousands of features in a stellar spectrum. The elements of the 3*d* (iron) group are particularly important in this respect because of their high relative abundance and line-rich spectra.

High resolution Fourier transform spectrometry (FTS) has the potential to improve significantly the accuracy of the old wavelength, and hence also the energy level, database. The Imperial College group has over the past 20 years used this technique in the visible and ultraviolet regions, supplemented by infrared observations from Kitt Peak National Observatory, to study the spectra of many of the neutral and singly ionized elements of the iron group. Summaries are given by Pickering (2002) and Pickering et al. (2011). In general, the accuracy of energy level values and wavelengths has been improved by at least an order of magnitude.

For V II, the most recent complete, generally available compilation of energy level data is that of Sugar & Corliss (1985), hereafter referred to as SC. SC present a table of 139 even and 184 odd energy levels for V II, and these energy levels are based on the analysis of Meggers & Moore (1940), who recorded the arc and spark spectra of vanadium from 2000 Å to 2800 Å with a quartz spectrograph and from 2500 Å to 8500 Å with a concave grating. The analysis of the spectrum was continued in Madrid, initially by Velasco & Gullón (1968) and then by Iglesias and her co-workers (Iglesias 1977; Iglesias et al. 1984, 1987; Iglesias & Cabeza 1988). This group used new observations to find many new levels and to improve the accuracy of the older work. For the region 8800–2500 Å, their light source was a hollow cathode discharge, run in DC mode for V I and pulsed to favor the excitation of V II. A spark source was used for the vacuum ultraviolet region down to 1100 Å. All spectra were photographically recorded with a grating spectrograph. The results from the first two papers (1977 and 1984) are incorporated in SC. A monograph by Iglesias et al. (1988, hereafter ICL) presents all of the results of the Madrid group, for both the energy levels and the classified line list.

The hyperfine structure of a number of V II lines in the wavelength region 420–460 nm has recently been measured by laser fluorescence spectroscopy on a fast ion beam (Armstrong et al. 2011). They determined the magnetic dipole constants of 24 even and 31 odd energy levels. Such measurements, however, do not require accurate absolute values of wavelengths or energy level values.

Using FTS, we have recorded the visible and ultraviolet regions of the vanadium spectrum with much higher resolution than was possible with the older grating measurements, resulting in about an order of magnitude improvement in wavelength accuracy. These new measurements have then been used to revise most of the known levels of V II. As the monograph by ICL is not easily accessible, we include in our energy level tables the levels that we were not able to confirm as well as those we have revised.

2. EXPERIMENTAL DETAILS

The laboratory spectra used in this analysis were recorded with the *f*/25 vacuum UV Fourier transform (FT) spectrometer at Imperial College (Thorne et al. 1987) over the region 16000–67000 cm^{-1} (6320–1500 Å). The infrared spectra

Table 1
V II Linelist of Observed Transitions

Int	W	S/N	λ	σ	$O-C$	Lower Level			Upper Level		Bl.
	†		(Å)	(cm^{-1})	(cm^{-1})	Configuration	Term, J		Configuration	Term, J	
8.94	141	5	5791.4838	17261.946	.022	$3d^3(b^2D)4s$	$d\ ^1D_2$	-	$3d^3(^2F)4p$	$x\ ^1D_2$	
7.82	107	5	5045.8376	19812.790	−.008	$3d^3(^2P)4p$	$y\ ^3D_3$	-	$3d^3(^4F)5s$	$^3F_4$	
7.75	125	8	5019.8569	19915.332	−.006	$3d^3(^2F)4s$	$b\ ^1F_3$	-	$3d^3(^2H)4p$	$y\ ^1G_4$	
7.27	121	5	4965.3894	20133.789	.008	$3d^4$	$d\ ^3F_3$	-	$3d^3(^2P)4p$	$y\ ^3D_2$	
7.13	98	6	4947.5559	20206.361	−.004	$3d^3(^2F)4s$	$c\ ^3F_2$	-	$3d^3(^2P)4p$	$y\ ^3D_1$	
7.59	137	7	4884.0386	20469.142	−.014	$3d^3(^2F)4s$	$c\ ^3F_3$	-	$3d^3(^2P)4p$	$y\ ^3D_2$	
6.65	131	3	4618.5210	21645.890	−.023	$3d^24s^2$	$c\ ^1D_2$	-	$3d^3(^2F)4p$	$x\ ^1F_3$	
7.07	137	5	4605.3344	21707.868	−.015	$3d^4$	$a\ ^3D_2$	-	$3d^3(^4F)4p$	$z\ ^3F_2$	
8.97	317	18	4600.1709	21732.234	−.006	$3d^4$	$a\ ^3D_1$	-	$3d^3(^4F)4p$	$z\ ^3F_2$	
8.41	180	8	4565.1190	21899.096	.012	$3d^3(^2G)4p$	$y\ ^3G_4$	-	$3d^3(^4F)5s$	$^3F_3$	
9.31	117	68	4564.5779	21901.692	−.004	$3d^4$	$a\ ^3D_2$	-	$3d^3(^4F)4p$	$z\ ^3F_3$	
8.80	261	8	4534.8080	22045.469	−.005	$3d^3(^2G)4p$	$y\ ^3G_5$	-	$3d^3(^4F)5s$	$^3F_4$	
9.58	245	19	4528.4829	22076.260	.000	$3d^4$	$a\ ^3D_3$	-	$3d^3(^4F)4p$	$z\ ^3F_4$	
7.37	95	10	4518.3798	22125.622	.016	$3d^4$	$d\ ^3F_3$	-	$3d^3(^4P)4p$	$x\ ^3D_3$	
7.10	114	7	4475.6787	22336.712	.003	$3d^3(^2F)4s$	$c\ ^3F_2$	-	$3d^3(^4P)4p$	$x\ ^3D_1$	

Notes. Columns are as follows: Int, intensity in arbitrary units given as $\log_{10}$(intensity); † W, width, a guide to the line pattern width in 0.001 cm^{-1}; S/N, the observed signal-to-noise ratio of the transition; λ, wavelength in air for λ longer than 2000 Å and in vacuum below 2000 Å; σ, center-of-gravity vacuum wavenumber of the transition; $O-C$, the difference between the observed wavenumber and the wavenumber calculated from the energy levels in this work; and Lower Level and Upper Level, the levels involved in the transition. The final column, Bl., indicates blends and doubly identified lines where D designates a doubly identified line with another V II transition; D1 a line doubly identified with a V I line; B is a blend with another nearby line; and U is a line blended with an unknown feature.

(This table is available in its entirety in a machine-readable form in the online journal. A portion is shown here for guidance regarding its form and content.)

recorded for us with the FT spectrometer at the National Solar Observatory (NSO), Kitt Peak, Tucson, Arizona (Brault 1976), and used in the V I analysis as described in our previous paper (Thorne et al. 2011), were included in the initial fitting, but almost all of the lines corresponding to possible V II transitions were doubly identified with strong V I transitions and therefore contributed very little to the V II analysis.

A water-cooled hollow cathode lamp with a vanadium cathode, run in either neon or argon, was used as a light source. This source gives spectra of V I and V II as well as the neutral and singly ionized spectra of the particular carrier gas. The cathode of the lamp was an open-ended cylinder of vanadium, 35 mm long and 8 mm in bore, and the metal case of the lamp formed the anode. We found that the optimum running pressures and currents were 0.8 mbar, 600 mA in Ar and 4 mbar, 750 mA in Ne. The spectral resolution ranged from 0.05 cm^{-1} in the UV spectral region to 0.036 cm^{-1} in the visible, sufficient to achieve Doppler limited resolution. Further details are given in Semeniuk (1996).

The spectra were put on a consistent relative intensity scale by calibrating the spectrometer response with tungsten and deuterium lamps in the visible and UV spectral regions, respectively, with an overlap region used to place the two calibrations on the same scale. The relative intensities given in the line lists of this work should be regarded as a rough guide only, and we stress that they are not suitable for the determination of branching fractions.

A linelist of the observed lines was made using the GREMLIN programs developed by J. W. Brault (1994, private communication) to give line wavenumber, wavelength, integrated intensity, and signal-to-noise ratio (S/N). The nuclear spin of vanadium is 7/2, and most of the lines show hyperfine structure that is only partially resolved. The overall width of a hyperfine multiplet containing many components is typically 0.200–0.400 cm^{-1}, whereas the Doppler width in the visible–UV range is 0.100–0.250 cm^{-1}, so it was not possible to fit Voigt profiles to the lines. The center-of-gravity (COG) wavenumber of each line pattern was therefore determined. It has been shown by Brault (1987) that the error in the position of the center of a properly resolved line is given by the FWHM of the line divided by twice the S/N. The uncertainty in the COG wavenumber of a hyperfine pattern is still given approximately by the width divided by the S/N, but this relation tends to underestimate the uncertainty for very weak lines. Actual uncertainties can be estimated from the differences between observed wavenumbers and those derived from the fitted energy level system (see Table 1).

The absolute wavenumber scale was established from 26 Ar II reference lines originally measured by Norlén (1973; see also Learner & Thorne 1988) and subsequently remeasured more accurately by Whaling et al. (1995), as described in Thorne et al. (2011). The spectra in the visible region taken with Ar as a carrier gas were calibrated from these lines, and the calibration was transferred to the spectra taken with Ne and extended to shorter wavelengths by exploiting the intrinsic linearity property of FT spectra, using vanadium lines in the overlap region of successive spectra to carry the calibration through. The combined uncertainty for the absolute wavenumber of a strong isolated line is 0.001–0.002 cm^{-1} in the visible, but rises to 0.004 cm^{-1} in the UV due to cumulative errors arising from carrying the wavenumber calibration through three overlapping spectra.

It is noticeable that the weak lines recorded by Meggers & Moore (1940) and by the Madrid group do not appear above the noise in our spectra. The earlier work used sparks and pulsed hollow cathode discharges as sources to excite the ionic spectrum preferentially. In addition, there is the usual noise penalty to be paid for higher resolution, and the fact that the FT spreads the noise almost uniformly over the spectrum militates against the observation of very weak lines.

3. THE ENERGY LEVEL STRUCTURE OF V II

As with V I, the observed energy levels in V II belong to two configuration systems: the "normal," or "singly excited,"

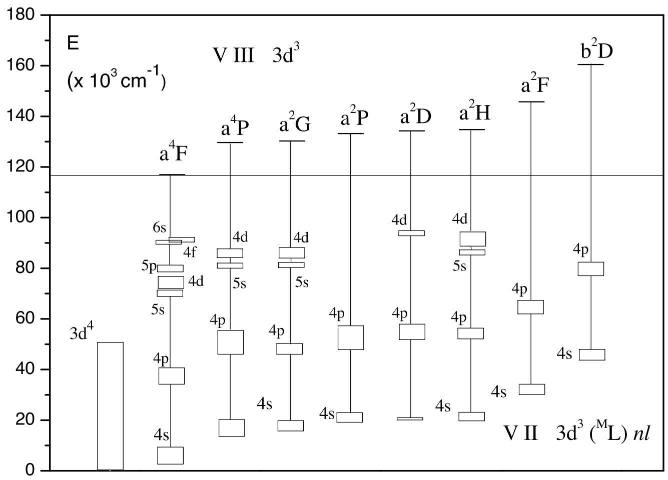

Figure 1. The gross structure of the "normal" system of configurations, $3d^3(^ML)nl$, in V II relative to the term structure of the parent configuration $3d^3$ in V III.

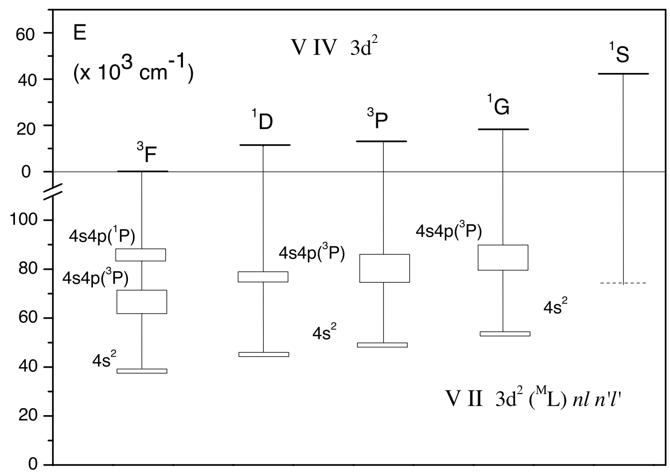

Figure 2. The system of doubly excited configurations, $3d^2(^ML)nln'l'$, in V II where ^ML is the grandparent term in V IV.

system built on the parent term of the next highest ion, and the "doubly excited" system built on the grandparent term of the second highest ion (see Thorne et al. 2011). For V II, the normal system, consisting of $3d^3(^ML)nl$ subconfigurations, dominates the doubly excited system, consisting of the subconfigurations $3d^2(^ML)4snl$ built on the (^ML) grandparent terms in V IV.

Schematic diagrams of both term systems are shown in Figures 1 and 2. The top part of the diagram in each figure displays all terms of the parent configuration, $3d^3$ in V III and $3d^2$ in V IV, respectively, as a function of energy. Vertical lines from each of these parent terms lead down to boxes representing levels in the daughter subconfigurations. The height of these boxes indicates the energy span of these subconfigurations. For the $3d^4$ configuration, shown at the far left of Figure 1, terms are not assigned to a particular parent term.

Although the LS coupling scheme is used as a convenient description, there is in fact considerable configuration mixing for V II, as was also the case for V I. The ΔL and ΔS selection rules for transitions are not strictly observed, and there are many intercombination lines in the spectrum.

In contrast with V I, almost all of the energy levels of both systems up to about 80000 cm^{-1} in V II are known. The only missing level in this energy range in the normal system is $3d^4\ ^1S_0$, predicted by Kurucz (2009) to lie at 60687 cm^{-1}. In the doubly excited system, the missing levels are $3d^2(^1G)4s^2\ ^1G_4$ at 53756 cm^{-1}, $3d^2(^1S)4s^2\ ^1S_0$ at 77095 cm^{-1}, and $3d^2(^3P)4s4p\ ^3S_1$, $^5S_2$ at 75672, 75537 cm^{-1}, respectively, where the energies quoted are again the Kurucz predictions. The first of these doubly excited levels is actually problematic rather than definitely missing: it appears in SC as $3d^24s^2\ d^1G_4$ with an energy of 53607.2? cm^{-1}, and in ICL at 53607.1? cm^{-1}.

Taking into account all of the higher levels reported in ICL, the identified levels can be summarized as follows. In the normal system, all levels (except the one singlet noted above) are known for the $3d^4$ configuration. For the $3d^3(^ML)nl$ subconfigurations, for levels built on the ground state ^4F of V III, all of the $4s$, $5s$, $4d$, and $4p$ levels are known, together with the $6s$ and $5p$ triplet terms. In addition, 44 of the 48 $3d^3(^4F)4f$ levels were found by the Madrid group and are included in SC; these lie between 90182 and 90881 cm^{-1}. For the next highest parent term, ^4P, the $4s$, $5s$, $4p$, and $4d$ subconfigurations are complete except for the $4d\,^5F$ and $4d\,^5D$ terms. For the ^2G parent, the $4s$, $5s$, and $4p$ subconfigurations are complete, and $4d$ lacks only ^3F, ^1D, and part of ^3H. The next parents, ^2P, ^2D, ^2H, and ^2F all have $4s$ and $4p$ complete, and ^2H has in addition the $5s$ and some of the $4d$ terms.

Most of the lower terms of the doubly excited system are also known. The lowest even configuration is $3d^24s^2$, for which the possible terms, in order of increasing energy, are ^3F, ^1D, ^3P, ^1G, and ^1S; of these, ^1S is missing and possibly ^1G, as noted above. The lowest odd terms result from combining $4s4p\,(^3P)$ with the above grandparent terms. Eight of the nine terms built on the ^3F grandparent are known (with ^1G missing) and seven of the nine terms built on the ^3P grandparent are known (with ^5S and ^1P missing). The three triplet terms built on ^1D and ^1G are all known, but not those built on ^1S. The only known terms arising from $4s4p(^1P)$ are the three triplet terms built on ^3F $(^3G, ^3F, ^3D)$ and the singlet $(^1D)4s4p(^1P)^1F$.

4. RESULTS AND DISCUSSION

The spectra taken in Ne and Ar were merged to give a single linelist. Previously published energy levels in SC and ICL were used to derive wavenumbers (Ritz wavenumbers) for comparison with the newly measured wavenumbers for the initial line identification. A least-squares fitting program, ELCALC (Radziemski & Kaufman 1969), was then used to revise the energy levels, obtaining a best fit to the observed transitions. In this process each line is given a weighting inversely proportional to the square of the uncertainty in the COG wavenumber. For the V II level fitting, the uncertainty is obtained by replacing the precision criterion for a single isolated line (Brault 1987) with the overall width of the hyperfine pattern divided by the S/N. The process was repeated through several iterations, during which chance coincidences were eliminated from the fit and doubly identified lines were noted.

4.1. The Classified Linelist

Table 1 gives the classified lines of V II in the visible and UV regions. The full version of Table 1 is available in the online journal, and also by contacting author J.C.P. In the first column, the logarithm of the integrated intensity of each line is given to two decimal places. The second column, W, is a rough measure of the overall width of the line pattern in units of 0.001 cm^{-1}, but should not be taken strictly as the FWHM. The third column gives the observed S/N of the line. Wavelengths determined from the observed wavenumbers are given in the fourth column. For wavelengths greater than 2000 Å air wavelengths are given, the conversion being carried out using the formula of Edlén (1966) for the dispersion of air:

$$\lambda(\text{air}) = \frac{10^8}{\sigma} \times \left(1 + 8342.13 \times 10^{-8} + \frac{15997}{3.89 \times 10^9 - \sigma^2} + \frac{2406030}{1.3 \times 10^{10} - \sigma^2}\right)^{-1},$$

where σ is the vacuum wavenumber and λ(air) the air wavelength in Å. The fifth column gives the observed COG wavenumbers. The sixth column gives the differences between the observed wavenumbers and the wavenumbers derived from the revised energy levels (see below). The configuration, term designation, and J value of each energy level involved in the transition is shown in the next column. Any blends with other lines are noted in the final column of the table. In total, 1242 classified V II lines are presented. The wavenumber uncertainty (approximately given by W divided by S/N) ranges from 0.001 to 0.002 cm^{-1} for the strongest lines to about 0.03 cm^{-1} for weak lines, an order of magnitude more accurate than that of previous measurements.

4.2. Revision of Previously Known Energy Levels

Nearly all of the SC levels were confirmed in this work. Of the even levels, the exceptions are $3d^4\ ^1D$ in the normal system and $3d^24s^2\ ^3P$ and ^1G in the doubly excited system. These levels were all found by ICL, although the last, ^1G, is uncertain, as noted above; a separate search for this proved unsuccessful. Of the odd levels in SC, we were unable to find $3d^3(^2P)4p\ z^1S_0$ at 48258 cm^{-1} (confirmed by ICL). We were also unable to confirm the high-lying levels of the $3d^3(^4F)4f$ configuration, which were found by Iglesias et al. (1984), from infrared transitions to the $3d^3(^4F)4d$ configuration; in our spectra most of these strong IR lines are doubly identified with V I transitions and the weak lines are absent.

Two of the odd SC levels do not appear in the ICL list, and we too were unable to find them. These are w^1G_4 at 72292.4 cm^{-1} and the level labeled $2^*(J = 3)$ at 76504.4 cm^{-1}. Meggers & Moore (1940) established w^1G_4 from five lines, of which three are very weak and one is doubly identified, and 2^* from six lines, of which three are doubly identified and the other three very weak. None of these lines appear in our spectra. We have followed ICL in rejecting these two levels.

Two changes in the SC level assignations should be noted. The u^3F levels between 76220 and 76643 cm^{-1}, which had no classification in SC, were assigned by ICL to $3d^2(^1D)4s4p(^3P)$, and the t^3D levels between 75716 and 75847 cm^{-1} were changed from $3d^2(^1D)4s4p(^3P)$ to $3d^3(^2D)4p$ by ICL. Our transitions confirm these ICL assignations.

The additional levels published in ICL and not included in SC all lie at high energy, above 84000 cm^{-1} for the even levels and above 74000 cm^{-1} for the odd levels. We were able to confirm 18 out of 34 even levels and 21 out of 51 odd levels.

Most of our revised energy level values lie within 0.2 cm^{-1} of the ICL values, although a few (seven) differ by 0.5 to 1.2 cm^{-1}. In two cases, $(^2H)4d\ ^1I_6$ and $(^3F)4s4p(^1P)\ s^3F_2$, we found a completely different value for the energy; these levels are labeled as "new" in Tables 2 and 3, and they replace the levels found by ICL. In both cases, the new level is determined from the two strongest expected transitions, which agree well with each other; in the case of s^3F_2 they are also consistent with the transitions determining the other s^3F levels.

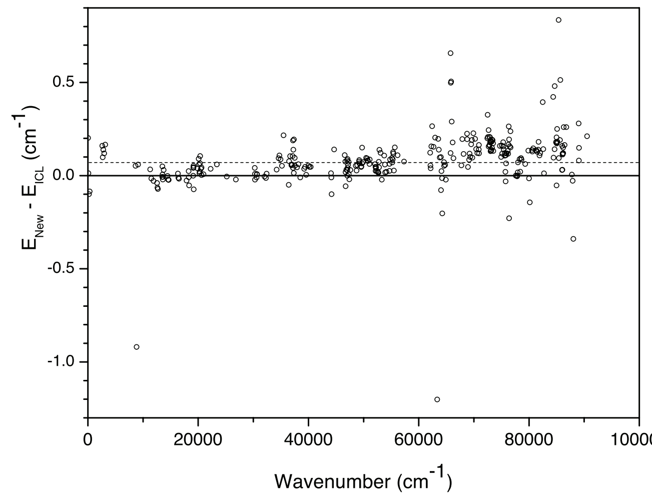

Figure 3. Difference between the energy level values of this work and those of Sugar & Corliss (1985).

In addition, we found three new even energy levels missing from ICL: $(^2G)4d\ ^3H_{4,5}$ at 85159, 85301 cm^{-1} and $(^2H)4d\ ^3I_5$ at 88939 cm^{-1}. These levels complete their respective triplet terms and are also labeled as "new."

Table 2 (even levels) and Table 3 (odd levels) list all the levels for which energies were published in ICL, plus our five new levels. The configuration, term designation, J-value, and energy level value are given for each level. For the levels revised in this work the energy uncertainty (cm^{-1}) relative to the ground state and the number of transitions determining the level are also given. The relative energy level uncertainties are given in Column 5 of Tables 2 and 3, and these range from 0.001 cm^{-1} to about 0.005 cm^{-1} for the well-determined lower levels. Many of the higher levels are determined by only two or three weak lines and have correspondingly larger uncertainties of up to 0.02 cm^{-1}. There is an additional 0.003 cm^{-1} uncertainty in the absolute energy values because the ground state $3d^4\ ^5D_0$ is linked to the rest of the system by only four lines, of which two are doubly identified with another V II transition and a V I transition, respectively.

The levels that we were unable to confirm are marked either SC, if they appear in Sugar & Corliss, or ICL, if they belong to the set of additional levels reported in that work, although in both cases the energies are the ICL values, given to two places of decimals. The level eigenvector compositions are taken from the Kurucz database (Kurucz 2009), as there was nothing to be gained by repeating the Cowan code calculations with only very small changes to the input data.

We have included in our revised levels in Tables 2 and 3 four levels for which we have only one transition that is not doubly identified. Each of these levels is well established by additional weaker lines in ICL so that one relatively strong line in our spectra is adequate to confirm it.

Figure 3 plots the differences between our level values and those of SC and ICL. The revised values are slightly higher, with a mean difference of 0.084 cm^{-1} from 307 levels and a standard deviation 0.15 cm^{-1}.

Ritz wavenumbers were derived from the optimized energy levels, and it is the difference between these and the observed wavenumbers that is shown in the sixth column of the linelist of Table 1. For the strong lines the discrepancies are mostly less

Table 2
V ii Even Energy Levels

Assigned Configuration	Term	J	†	Energy (cm^{-1})	Unc. (cm^{-1})	NL	Eigenvector Components‡ (%)				
$3d^4$	$a\,^5D$	0		0.000	.003	4	100				
$3d^4$	$a\,^5D$	1		36.102	.002	10	100				
$3d^4$	$a\,^5D$	2		106.643	.001	15	100				
$3d^4$	$a\,^5D$	3		208.790	.001	14	100				
$3d^4$	$a\,^5D$	4		339.125	.001	10	100				
$3d^3(^4F)4s$	$a\,^5F$	1		2605.040	.001	11	100				
$3d^3(^4F)4s$	$a\,^5F$	2		2687.208	.001	18	100				
$3d^3(^4F)4s$	$a\,^5F$	3		2808.959	.001	17	100				
$3d^3(^4F)4s$	$a\,^5F$	4		2968.389	.001	18	100				
$3d^3(^4F)4s$	$a\,^5F$	5		3162.966	.002	12	100				
$3d^3(^4F)4s$	$a\,^3F$	2		8640.362	.002	17	94	$3d^4\,^3F$	5		
$3d^3(^4F)4s$	$a\,^3F$	3		8842.050	.001	23	94	$3d^4\,^3F$	6		
$3d^3(^4F)4s$	$a\,^3F$	4		9097.889	.001	17	93	$3d^4\,^3F$	6		
$3d^4$	$a\,^3P$	0		11295.513	.005	9	54	$3d^4\,^3P$	37	$(^4P)4s\,^3P$	5
$3d^4$	$a\,^3P$	1		11514.784	.002	18	54	$3d^4\,^3P$	37	$(^4P)4s\,^3P$	4
$3d^4$	$a\,^3P$	2		11908.261	.002	21	54	$3d^4\,^3P$	37	$(^4P)4s\,^3P$	4
$3d^4$	$a\,^3H$	4		12545.100	.002	9	98	$(^2H)4s\,^3H$	1		
$3d^4$	$a\,^3H$	5		12621.485	.001	10	99	$(^2H)4s\,^3H$	1		
$3d^4$	$a\,^3H$	6		12706.078	.001	9	99	$(^2H)4s\,^3H$	1		
$3d^4$	$b\,^3F$	2		13490.883	.002	10	69	$3d^4\,^3F$	24	$(^4F)4s\,^3F$	5
$3d^4$	$b\,^3F$	3		13542.645	.001	14	69	$3d^4\,^3F$	24	$(^4F)4s\,^3F$	6
$3d^4$	$b\,^3F$	4		13608.939	.001	14	68	$3d^4\,^3F$	23	$(^4F)4s\,^3F$	6
$3d^3(^4P)4s$	$a\,^5P$	1		13511.799	.002	13	99				
$3d^3(^4P)4s$	$a\,^5P$	2		13594.723	.004	12	99				
$3d^3(^4P)4s$	$a\,^5P$	3		13741.640	.002	10	100				
$3d^4$	$a\,^3G$	3		14461.748	.002	23	60	$(^2G)4s\,^3G$	39		
$3d^4$	$a\,^3G$	4		14556.068	.001	28	61	$(^2G)4s\,^3G$	38		
$3d^4$	$a\,^3G$	5		14655.607	.001	21	64	$(^2G)4s\,^3G$	35		
$3d^3(^2G)4s$	$b\,^3G$	3		16340.981	.002	18	61	$3d^4\,^3G$	39		
$3d^3(^2G)4s$	$b\,^3G$	4		16421.528	.001	21	61	$3d^4\,^3G$	37		
$3d^3(^2G)4s$	$b\,^3G$	5		16532.983	.002	16	64	$3d^4\,^3G$	35		
$3d^4$	$a\,^1G$	4		17910.913	.002	13	44	$(^2G)4s\,^1G$	34	$3d^4\,^1G$	20
$3d^4$	$a\,^3D$	1		18269.514	.003	15	47	$(^2D)4s\,^3D$	30	$(^2P)4s\,^3P$	12
$3d^4$	$a\,^3D$	2		18293.871	.002	21	42	$(^2D)4s\,^3D$	26	$(^2P)4s\,^3P$	21
$3d^4$	$a\,^3D$	3		18353.827	.002	18	65	$(^2D)4s\,^3D$	34		
$3d^3(^2G)4s$	$b\,^1G$	4		19112.929	.001	13	59	$3d^4\,^1G$	35	$3d^4\,^1G$	
$3d^3(^2P)4s$	$b\,^3P$	2		19132.791	.003	17	64	$3d^4\,^3D$	20	$(^4P)4s\,^3P$	9
$3d^3(^2P)4s$	$b\,^3P$	0		19161.422	.003	12	95	$3d^4\,^3P$	2	$(^4P)4s\,^3P$	2
$3d^3(^2P)4s$	$b\,^3P$	1		19166.314	.003	18	79	$3d^4\,^3D$	10	$(^4P)4s\,^3P$	5
$3d^4$	$a\,^1I$	6		19191.326	.002	3	99				
$3d^4$	$a\,^1S$	0		19902.608	.004	4	73	$3d^4\,^1S$	24	$(^4P)4s\,^3P$	1
$3d^3(^4P)4s$	$c\,^3P$	1		20089.650	.002	17	80	$3d^4\,^3P$	5	$(^2P)4s\,^1P$	4
$3d^3(^4P)4s$	$c\,^3P$	0		20156.670	.003	5	90	$3d^4\,^3P$	6	$3d^4\,^1S$	1
$3d^3(^4P)4s$	$c\,^3P$	2		20343.046	.002	17	73	$3d^4\,^3D$	7	$(^2P)4s\,^3P$	6
$3d^3(^2H)4s$	$b\,^3H$	4		20242.382	.003	9	92	$(^2G)4s\,^1G$	5	$3d^4\,^3H$	1
$3d^3(^2H)4s$	$b\,^3H$	5		20280.251	.003	15	98	$3d^4\,^3H$	1		
$3d^3(^2H)4s$	$b\,^3H$	6		20363.335	.002	10	99	$3d^4\,^3H$	1		
$3d^3(a^2D)4s$	$b\,^3D$	1		20522.147	.004	11	39	$3d^4\,^3D$	37	$(^2D)4s\,^3D$	14
$3d^3(a^2D)4s$	$b\,^3D$	2		20617.073	.003	16	28	$3d^4\,^3D$	22	$3d^4\,^1D$	13
$3d^3(a^2D)4s$	$b\,^3D$	3		20622.983	.003	12	50	$3d^4\,^3D$	33	$(^2D)4s\,^3D$	16
$3d^3(a^2D)4s$	$a\,^1D$	2		20980.927	.003	9	28	$(^2D)4s\,^1D$	25	$(^2D)4s\,^3D$	12
$3d^3(^2P)4s$	$a\,^1P$	1		22273.636	.002	7	92	$(^4P)4s\,^3P$	3	$(^2D)4s\,^3D$	2
$3d^3(^2H)4s$	$a\,^1H$	5		23391.150	.002	7	99				
$3d^4$	$b\,^1D$	2		25191.035	.003	8	37	$3d^4\,^1D$	32	$(^2D)4s\,^1D$	17
$3d^4$	$a\,^1F$	3		26839.749	.004	6	90	$(^2F)4s\,^1F$	9		
$3d^3(^2F)4s$	$c\,^3F$	2		30267.511	.005	11	42	$3d^4\,^3F$	29	$3d^4\,^3F$	16
$3d^3(^2F)4s$	$c\,^3F$	3		30306.389	.003	14	51	$3d^4\,^3F$	24	$3d^4\,^3F$	13
$3d^3(^2F)4s$	$c\,^3F$	4		30318.528	.003	12	61	$3d^4\,^3F$	18	$3d^4\,^3F$	11
$3d^4$	$d\,^3F$	4		30613.910	.003	12	42	$(^2F)4s\,^3F$	37	$3d^4\,^3F$	12
$3d^4$	$d\,^3F$	3		30641.767	.003	17	47	$3d^4\,^3F$	35	$3d^4\,^3F$	10
$3d^4$	$d\,^3F$	2		30673.088	.005	8	56	$3d^4\,^3F$	30	$3d^4\,^3F$	8
$3d^4$	$d\,^3P$	2		32040.635	.005	4	53	$3d^4\,^3P$	41	$4s^2\,^3P$	2
$3d^4$	$d\,^3P$	1		32299.257	.006	6	53	$3d^4\,^3P$	41	$4s^2\,^3P$	2
$3d^4$	$d\,^3P$	0		32420.050	.010	3	53	$3d^4\,^3P$	41	$4s^2\,^3P$	2
$3d^3(^2F)4s$	$b\,^1F$	3		34228.852	.002	7	90	$3d^4\,^1F$	8		

Table 2
(Continued)

Assigned Configuration	Term	J	†	Energy (cm^{-1})	Unc. (cm^{-1})	NL	Eigenvector Components‡ (%)				
$3d^4$	$c\,^1G$	4		36424.870	.004	3	58	$3d^4\,^1G$	36	$4s^2\,^1G$	2
$3d^24s^2$	$e\,^3F$	2		37937.694	.007	5	78	$3d^4\,^3F$	14	$d^2p^2\,^3F$	5
$3d^24s^2$	$e\,^3F$	3		38193.021	.005	5	79	$3d^4\,^3F$	13	$d^2p^2\,^3F$	5
$3d^24s^2$	$e\,^3F$	4		38517.080	.004	6	80	$3d^4\,^3F$	12	$d^2p^2\,^3F$	5
$3d^3(b^2D)4s$	$c\,^3D$	3		44098.473	.009	4	75	$(^2D)4s\,^3D$	23		
$3d^3(b^2D)4s$	$c\,^3D$	2		44159.460	.007	7	75	$(^2D)4s\,^3D$	24		
$3d^3(b^2D)4s$	$c\,^3D$	1		44201.640	.009	5	74	$(^2D)4s\,^3D$	24		
$3d^24s^2$	$c\,^1D$	2		44658.020	.020	2	58	$3d^4\,^1D$	23	$3d^4\,^1D$	12
$3d^3(b^2D)4s$	$d\,^1D$	2		47324.288	.006	6	67	$(^2D)4s\,^1D$	23	$4s^2\,^1D$	7
$3d^24s^2$	$e\,^3P$	0	ICL	48898.01			92	$d^2p^2\,^3P$	4	$3d^4\,^3P$	2
$3d^24s^2$	$e\,^3P$	1	ICL	48975.70			92	$d^2p^2\,^3P$	4	$3d^4\,^3P$	2
$3d^24s^2$	$e\,^3P$	2	SC	49204.65			91	$d^2p^2\,^3P$	4	$3d^4\,^3P$	2
$3d^4$	$e\,^1D$	2	SC	50951.66			48	$4s^2\,^1D$	30	$3d^4\,^1D$	12
$3d^24s^2$	$d\,^1G$	4	SC	53607.2			93	$d^2p^2\,^1G$	4	$3d^4\,^1G$	2
$3d^3(^4F)5s$	^5F	1		69146.385	.005	6	100				
$3d^3(^4F)5s$	^5F	2		69228.318	.004	6	99				
$3d^3(^4F)5s$	^5F	3		69352.530	.002	8	99	$(^4F)5s\,^3F$	1		
$3d^3(^4F)5s$	^5F	4		69518.528	.003	6	99	$(^4F)5s\,^3F$	1		
$3d^3(^4F)5s$	^5F	5		69724.236	.003	5	100				
$3d^3(^4F)5s$	^3F	2		70415.542	.003	5	99				
$3d^3(^4F)5s$	^3F	3		70629.831	.002	11	99	$(^4F)5s\,^5F$	1		
$3d^3(^4F)5s$	^3F	4		70898.570	.003	9	99	$(^4F)5s\,^5F$	1		
$3d^3(^4F)4d$	$e\,^5H$	3		72448.600	.002	2	98	$(^4F)4d\,^5G$	1	$(^4F)5d\,^5H$	1
$3d^3(^4F)4d$	$e\,^5H$	4		72551.297	.002	3	97	$(^4F)4d\,^5G$	2	$(^4F)5d\,^5H$	1
$3d^3(^4F)4d$	$e\,^5H$	5		72680.856	.003	3	97	$(^4F)4d\,^5G$	2	$(^4F)5d\,^5H$	1
$3d^3(^4F)4d$	$e\,^5H$	6		72837.581	.002	3	97	$(^4F)4d\,^5G$	2	$(^4F)5d\,^5H$	1
$3d^3(^4F)4d$	$e\,^5H$	7		73021.143	.003	1	99	$(^4F)5d\,^5H$	1		
$3d^3(^4F)4d$	$e\,^5P$	1		72518.626	.004	4	98	$(^4F)5d\,^5P$	1		
$3d^3(^4F)4d$	$e\,^5P$	2		72674.924	.003	7	97	$(^4F)4d\,^3D$	1	$(^4F)5d\,^5P$	1
$3d^3(^4F)4d$	$e\,^5P$	3		72908.997	.002	5	95	$(^4F)4d\,^3D$	2	$(^4F)4d\,^5G$	1
$3d^3(^4F)4d$	^5F	1		72839.345	.002	8	85	$(^4F)4d\,^3D$	13	$(^4F)5d\,^5F$	1
$3d^3(^4F)4d$	^5F	2		73027.311	.002	8	62	$(^4F)4d\,^5G$	32	$(^4F)4d\,^3D$	4
$3d^3(^4F)4d$	^5F	3		73146.343	.003	10	64	$(^4F)4d\,^5G$	33	$(^4F)4d\,^3D$	1
$3d^3(^4F)4d$	^5F	4		73279.343	.002	7	66	$(^4F)4d\,^5G$	32		
$3d^3(^4F)4d$	^5F	5		73417.330	.001	6	71	$(^4F)4d\,^5G$	27		
$3d^3(^4F)4d$	^5G	2		72878.056	.001	8	67	$(^4F)4d\,^5F$	31	$(^4F)4d\,^3D$	1
$3d^3(^4F)4d$	^5G	3		72951.558	.002	8	64	$(^4F)4d\,^5F$	32	$(^4F)4d\,^5P$	1
$3d^3(^4F)4d$	^5G	4		73063.719	.001	8	65	$(^4F)4d\,^5F$	32	$(^4F)4d\,^5H$	1
$3d^3(^4F)4d$	^5G	5		73223.351	.003	5	69	$(^4F)4d\,^5F$	27	$(^4F)4d\,^5H$	2
$3d^3(^4F)4d$	^5G	6		73499.773	.002	2	97	$(^4F)4d\,^5H$	2		
$3d^3(^4F)4d$	^3D	1		73181.639	.003	4	83	$(^4F)4d\,^5F$	13	$(^4P)4d\,^3D$	2
$3d^3(^4F)4d$	^3D	2		73310.069	.002	5	89	$(^4F)4d\,^5F$	6	$(^4P)4d\,^3D$	2
$3d^3(^4F)4d$	^3D	3		73530.712	.002	7	92	$(^4F)4d\,^5P$	2	$(^4P)4d\,^3D$	2
$3d^3(^4F)4d$	^3P	0		74949.580	.008	2	94	$(^2P)4d\,^3P$	2	$(^2D)4d\,^3P$	1
$3d^3(^4F)4d$	^3P	1		75080.741	.004	4	94	$(^2P)4d\,^3P$	2	$(^2D)4d\,^3P$	1
$3d^3(^4F)4d$	^3P	2		75335.879	.003	4	93	$(^2P)4d\,^3P$	2	$(^2D)4d\,^3P$	1
$3d^3(^4F)4d$	^3H	4		75140.638	.003	3	93	$(^2H)4d\,^3H$	2	$(^4F)4d\,^3G$	2
$3d^3(^4F)4d$	^3H	5		75346.306	.003	2	93	$(^2H)4d\,^3H$	2	$(^4F)4d\,^3G$	2
$3d^3(^4F)4d$	^3H	6		75592.481	.003	1	95	$(^2H)4d\,^3H$	2	$(^2G)4d\,^3H$	2
$3d^3(^4F)4d$	^3G	3		75422.910	.003	2	92	$(^4F)4d\,^3F$	2	$(^2G)4d\,^3G$	2
$3d^3(^4F)4d$	^3G	4		75615.397	.002	2	90	$(^4F)4d\,^3F$	3	$(^2G)4d\,^3G$	2
$3d^3(^4F)4d$	^3G	5		75854.219	.002	2	93	$(^2G)4d\,^3G$	2	$(^4F)4d\,^3H$	2
$3d^3(^4F)4d$	^3F	2		75813.489	.004	4	92	$(^2G)4d\,^3F$	3	$(^4P)4d\,^3F$	1
$3d^3(^4F)4d$	^3F	3		75966.119	.003	6	89	$(^2G)4d\,^3F$	3	$(^4F)4d\,^3G$	2
$3d^3(^4F)4d$	^3F	4		76143.052	.002	4	89	$(^2G)4d\,^3F$	3	$(^4F)4d\,^3G$	3
$3d^3(^4F)4d$	^5D	0		76281.366	.003	3	90	$(^4P)4d\,^5D$	6	$(^4F)5d\,^5D$	1
$3d^3(^4F)4d$	^5D	1		76322.694	.004	8	90	$(^4P)4d\,^5D$	6	$(^4F)5d\,^5D$	1
$3d^3(^4F)4d$	^5D	2		76403.674	.002	6	90	$(^4P)4d\,^5D$	6	$(^4F)5d\,^5D$	1
$3d^3(^4F)4d$	^5D	3		76521.357	.003	8	90	$(^4P)4d\,^5D$	6	$(^4F)5d\,^5D$	1
$3d^3(^4F)4d$	^5D	4		76673.101	.003	6	90	$(^4P)4d\,^5D$	6	$(^4F)5d\,^5D$	1
$3d^3(^4P)5s$	^5P	1		80542.337	.004	8	99				
$3d^3(^4P)5s$	^5P	2		80623.249	.004	7	99	$(^2P)5s\,^3P$	1		
$3d^3(^4P)5s$	^5P	3		80782.426	.003	5	99				
$3d^3(^2G)5s$	^3G	3		81263.626	.008	3	100				
$3d^3(^2G)5s$	^3G	4		81343.015	.005	3	96	$(^2G)5s\,^1G$	3		

Table 2
(Continued)

Assigned Configuration	Term	J	†	Energy (cm^{-1})	Unc. (cm^{-1})	NL	Eigenvector Components‡ (%)				
$3d^3(^2G)5s$	^3G	5		81483.278	.006	4	99				
$3d^3(^4P)5s$	^3P	0		81669.529	.014	4	99	$(^2P)5s\ ^3P$	1		
$3d^3(^4P)5s$	^3P	1		81736.141	.006	7	98	$(^2P)5s\ ^1P$	1		
$3d^3(^4P)5s$	^3P	2		81914.328	.005	7	99				
$3d^3(^2G)5s$	^1G	4		82025.721	.002	8	96	$(^2G)5s\ ^3G$	3		
$3d^3(^4P)4d$	^3D	1	ICL	84359.49			46	$(^2G)4d\ ^3D$	25	$(^4P)4d\ ^5F$	24
$3d^3(^4P)4d$	^3D	2	ICL	84406.21			49	$(^2G)4d\ ^3D$	26	$(^4P)4d\ ^5F$	18
$3d^3(^4P)4d$	^3D	3		84459.916	.008	4	54	$(^2G)4d\ ^3D$	26	$(^4P)4d\ ^5F$	14
$3d^3(^2G)4d$	^1F	3		84643.381	.011	3	81	$(^2G)4d\ ^3G$	12	$(^2P)4d\ ^1F$	1
$3d^3(^2G)4d$	^3I	5	ICL	84742.17			97	$(^2H)4d\ ^3I$	2	$(^2G)5d\ ^3I$	1
$3d^3(^2G)4d$	^3I	6	ICL	84859.58			97	$(^2H)4d\ ^3I$	2		
$3d^3(^2G)4d$	^3I	7	ICL	85004.88			98	$(^2H)4d\ ^3I$	1		
$3d^3(^2G)4d$	^1H	5		84896.899	.007	3	88	$(^2G)4d\ ^3H$	5	$(^2G)4d\ ^3G$	2
$3d^3(^4P)4d$	^5P	3		84999.355	.007	3	95	$(^2G)4d\ ^3D$	1	$(^4P)4d\ ^5D$	1
$3d^3(^4P)4d$	^5P	2		85045.572	.008	2	96	$(^4P)4d\ ^5D$	2		
$3d^3(^4P)4d$	^5P	1		85096.450	.009	2	97	$(^4P)4d\ ^5D$	1		
$3d^3(^2G)4d$	^3G	4		85060.717	.007	2	84	$(^2G)4d\ ^3H$	5	$(^2H)4d\ ^3G$	3
$3d^3(^2G)4d$	^3G	3	ICL	85076.72			76	$(^2G)4d\ ^1F$	14	$(^2D)4d\ ^3G$	2
$3d^3(^2G)4d$	^3G	5		85140.362	.008	2	81	$(^2G)4d\ ^3H$	6	$(^2H)4d\ ^3G$	4
$3d^3(^2G)4d$	^3H	4	new	85159.641	.006	2	85	$(^2H)4d\ ^3H$	5	$(^2G)4d\ ^3G$	5
$3d^3(^2G)4d$	^3H	5	new	85301.914	.005	3	78	$(^2G)4d\ ^1H$	6	$(^2G)4d\ ^3G$	5
$3d^3(^2G)4d$	^3H	6		85415.904	.004	2	89	$(^2H)4d\ ^3H$	5	$(^2H)5s\ ^3H$	1
$3d^3(^4P)4d$	^3F	2		86001.530	.014	2	39	$(^2G)4d\ ^3F$	33	$(^2G)4d\ ^1D$	8
$3d^3(^4P)4d$	^3F	3		86113.793	.010	2	37	$(^2G)4d\ ^3F$	36	$(^2D)5s\ ^3D$	12
$3d^3(^4P)4d$	^3F	4		86211.050	.006	4	44	$(^4P)4d\ ^3F$	41	$(^2H)4d\ ^3F$	6
$3d^3(^2H)5s$	^3H	4		86028.099	.005	4	98	$(^2G)4d\ ^3H$	1		
$3d^3(^2H)5s$	^3H	5		86091.728	.004	5	96	$(^2H)5s\ ^1H$	2	$(^2G)4d\ ^3H$	1
$3d^3(^2H)5s$	^3H	6		86191.750	.004	4	98	$(^2G)4d\ ^3H$	1		
$3d^3(^2G)4d$	^1I	6		86453.764	.005	2	86	$(^2H)4d\ ^1I$	12	$(^2G)4d\ ^3H$	1
$3d^3(^2H)5s$	^1H	5		86766.880	.004	4	95	$(^2H)5s\ ^3H$	2	$(^2G)4d\ ^1H$	2
$3d^3(^4P)4d$	^3P	1	ICL	87184.95			64	$(^2P)4d\ ^1P$	13	$(^2P)4d\ ^3P$	11
$3d^3(^4P)4d$	^3P	2	ICL	87215.75			73	$(^2P)4d\ ^3P$	12	$(^2D)4d\ ^3P$	5
$3d^3(^4P)4d$	^3P	0	ICL	87230.30			76	$(^2P)4d\ ^3P$	13	$(^2D)4d\ ^3P$	4
$3d^3(^2G)4d$	^1G	4	ICL	87457.98			71	$(^2D)4d\ ^1G$	18	$(^2D)4d\ ^1G$	4
$3d^3(^2H)4d$	^3I	5	new	88939.995	.010	2	96	$(^2G)4d\ ^3I$	2	$(^2H)5d\ ^3I$	1
$3d^3(^2H)4d$	^3I	6		89005.580	.005	2	97	$(^2G)4d\ ^3I$	2	$(^2H)5d\ ^3I$	1
$3d^3(^2H)4d$	^3I	7		89082.769	.005	2	97	$(^2G)4d\ ^3I$	1	$(^2H)5d\ ^3I$	1
$3d^3(^2H)4d$	^1H	5		89053.341	.009	2	95	$(^2G)4d\ ^1H$	2	$(^2H)5d\ ^1H$	1
$3d^3(^2H)4d$	^1F	3	ICL	90381.37			60	$(^2D)4d\ ^1F$	24	$(^2D)4d\ ^1F$	6
$3d^3(^2H)4d$	^1G	4		90543.971	.011	2	58	$(^2D)4d\ ^1G$	19	$(^2D)4d\ ^1G$	7
$3d^3(^4F)6s$	^3F	2	ICL	91228.44			95	$(^4F)6s\ ^5F$	3		
$3d^3(^4F)6s$	^3F	3	ICL	91445.69			94	$(^4F)6s\ ^5F$	4	$(^2H)4d\ ^3F$	1
$3d^3(^4F)6s$	^3F	4	ICL	91711.70			94	$(^4F)6s\ ^5F$	2	$(^2H)4d\ ^3F$	2
$3d^3(^2D)4d$	^1F	3	ICL	93806.10			31	$(^2D)4d\ ^1F$	27	$(^2P)4d\ ^1F$	15
$3d^3(^2H)4d$	^1I	6	new*	94041.890	.004	2	80	$(^2G)4d\ ^1I$	10	$(^2G)5d\ ^1I$	4

Notes. Assigned configuration, term, and J value of each even level are given, together with energy (cm^{-1}) and Unc., uncertainty (cm^{-1}), in level energy. † Level annotations indicate: new, a new level; new*, that the ICL energy is discarded and replaced with a newly found level energy; SC or ICL, that the energy level was reported by SC or ICL but is unconfirmed in this work. Where level energies were reported in both SC and ICL but unconfirmed in this work, the ICL values are given. The number of lines used to determine the energy level value in the energy level least-squares fitting is indicated by NL. ‡ The theoretically calculated eigenvector composition of this work is presented in Columns 7–11: Column 7 gives the percentage contribution of the leading eigenvector component, from which the level label is assigned; Columns 8 and 10 are the second and third most significant eigenvector components with their percentage contribution given in Columns 9 and 11, respectively.

(This table is also available in a machine-readable form in the online journal.)

than 0.003 cm^{-1}, but for weaker lines they are of course greater. Discrepancies significantly larger than expected are probably due to blends with unknown lines.

Searches for the remaining 45 unconfirmed ICL levels proved inconclusive, as did searches for the missing levels noted above. This is unsurprising because the high levels in V II were not strongly excited in our dc hollow cathode lamp, and the weak lines listed in the earlier work with pulsed hollow cathode and spark sources did not appear in our spectra.

5. SUMMARY

The spectrum of V II has been recorded by FTS with a wavelength accuracy an order of magnitude better than that

Table 3
V II Odd Energy Levels

Assigned Configuration	Term	J	†	Energy (cm^{-1})	Unc. (cm^{-1})	NL	Eigenvector Components‡ (%)				
$3d^3(^4F)4p$	$z\,^5G$	2		34592.843	.001	10	99				
$3d^3(^4F)4p$	$z\,^5G$	3		34745.828	.001	12	100				
$3d^3(^4F)4p$	$z\,^5G$	4		34946.637	.001	10	100				
$3d^3(^4F)4p$	$z\,^5G$	5		35193.182	.001	10	100				
$3d^3(^4F)4p$	$z\,^5G$	6		35483.606	.002	7	100				
$3d^3(^4F)4p$	$z\,^3D$	1		36489.437	.001	18	50	$(^4F)4p\,^3D$	44	$(^4P)4p\,^3D$	2
$3d^3(^4F)4p$	$z\,^3D$	2		37041.179	.001	25	44	$(^4F)4p\,^5F$	36	$(^4F)4p\,^5D$	15
$3d^3(^4F)4p$	$z\,^3D$	3		37205.021	.001	23	42	$(^4F)4p\,^5D$	39	$(^4F)4p\,^5F$	15
$3d^3(^4F)4p$	$z\,^5F$	2		36673.584	.001	25	62	$(^4F)4p\,^3D$	31	$(^4F)4p\,^5D$	4
$3d^3(^4F)4p$	$z\,^5F$	3		36919.266	.001	24	84	$(^4F)4p\,^3D$	10	$(^4F)4p\,^5D$	4
$3d^3(^4F)4p$	$z\,^5F$	1		36954.686	.002	16	48	$(^4F)4p\,^3D$	42	$(^4F)4p\,^5D$	5
$3d^3(^4F)4p$	$z\,^5F$	4		37150.615	.001	18	98	$(^3F)sp\,^5F$	1	$(^4F)4p\,^5D$	1
$3d^3(^4F)4p$	$z\,^5F$	5		37352.464	.001	12	98	$(^3F)sp\,^5F$	1	$(^4F)4p\,^3G$	1
$3d^3(^4F)4p$	$z\,^5D$	0		37201.538	.002	6	98	$(^4P)4p\,^5D$	1		
$3d^3(^4F)4p$	$z\,^5D$	1		37259.529	.001	17	91	$(^4F)4p\,^3D$	6	$(^4P)4p\,^5D$	1
$3d^3(^4F)4p$	$z\,^5D$	2		37369.154	.001	25	78	$(^4F)4p\,^3D$	17	$(^4P)4p\,^5D$	1
$3d^3(^4F)4p$	$z\,^5D$	3		37520.665	.001	25	55	$(^4F)4p\,^3D$	39	$(^4P)4p\,^3D$	2
$3d^3(^4F)4p$	$z\,^5D$	4		37531.132	.001	14	96	$(^4P)4p\,^5D$	1	$(^4F)4p\,^5F$	1
$3d^3(^4F)4p$	$z\,^3G$	3		39234.086	.001	8	92	$(^2G)4p\,^3G$	6	$(^2H)4p\,^3G$	1
$3d^3(^4F)4p$	$z\,^3G$	4		39403.787	.001	13	91	$(^2G)4p\,^3G$	6	$(^2H)4p\,^3G$	1
$3d^3(^4F)4p$	$z\,^3G$	5		39612.964	.001	10	91	$(^2G)4p\,^3G$	6	$(^4F)4p\,^5F$	1
$3d^3(^4F)4p$	$z\,^3F$	2		40001.754	.001	14	94	$(^2D)4p\,^3F$	2	$(^3F)sp\,^3F$	1
$3d^3(^4F)4p$	$z\,^3F$	3		40195.567	.001	19	94	$(^2D)4p\,^3F$	2	$(^3F)sp\,^3F$	1
$3d^3(^4F)4p$	$z\,^3F$	4		40430.087	.002	18	94	$(^2D)4p\,^3F$	2	$(^3F)sp\,^3F$	1
$3d^3(^4P)4p$	$y\,^5D$	0		46586.480	.004	7	54	$(^4P)4p\,^3P$	35	$(^2P)4p\,^1S$	3
$3d^3(^4P)4p$	$y\,^5D$	1		46690.495	.002	14	63	$(^4P)4p\,^3P$	30	$(^2P)4p\,^3P$	3
$3d^3(^4P)4p$	$y\,^5D$	2		47101.932	.002	14	55	$(^4P)4p\,^3P$	34	$(^2D)4p\,^3P$	3
$3d^3(^4P)4p$	$y\,^5D$	3		47181.237	.003	9	95	$(^3F)sp\,^5D$	1	$(^4P)4p\,^5P$	1
$3d^3(^4P)4p$	$y\,^5D$	4		47420.230	.002	6	97	$(^3F)sp\,^5D$	1	$(^4F)4p\,^5D$	1
$3d^3(^4P)4p$	$z\,^3P$	2		46740.008	.002	18	42	$(^4P)4p\,^5D$	41	$(^4P)4p\,^5P$	6
$3d^3(^4P)4p$	$z\,^3P$	0		47028.032	.004	7	43	$(^4P)4p\,^3P$	41	$(^2P)4p\,^1S$	7
$3d^3(^4P)4p$	$z\,^3P$	1		47108.079	.002	15	54	$(^4P)4p\,^5D$	34	$(^2D)4p\,^3P$	5
$3d^3(^4P)4p$	$z\,^5P$	1		46754.533	.002	10	98	$(^4P)4p\,^3P$	1		
$3d^3(^4P)4p$	$z\,^5P$	2		46879.911	.002	10	90	$(^4P)4p\,^3P$	7	$(^2D)4p\,^3P$	1
$3d^3(^4P)4p$	$z\,^5P$	3		47051.889	.002	10	98	$(^4P)4p\,^5D$	1		
$3d^3(^2G)4p$	$z\,^3H$	4		47056.319	.005	9	86	$(^2H)4p\,^3H$	14		
$3d^3(^2G)4p$	$z\,^3H$	5		47297.114	.002	7	85	$(^2H)4p\,^3H$	14	$(^2G)4p\,^3G$	1
$3d^3(^2G)4p$	$z\,^3H$	6		47607.820	.002	7	85	$(^2H)4p\,^3H$	14		
$3d^3(^2P)4p$	$z\,^1S$	0	SC	48258.22			87	$(^4P)4p\,^3P$	10	$(^3P)sp\,^1S$	2
$3d^3(^2G)4p$	$y\,^3G$	3		48579.993	.001	14	82	$(^4F)4p\,^3G$	6	$(^2G)4p\,^1F$	5
$3d^3(^2G)4p$	$y\,^3G$	4		48730.747	.002	15	88	$(^4F)4p\,^3G$	6	$(^2G)4p\,^3F$	2
$3d^3(^2G)4p$	$y\,^3G$	5		48853.096	.002	14	85	$(^4F)4p\,^3G$	7	$(^2G)4p\,^1H$	3
$3d^3(^2G)4p$	$y\,^3F$	2		49201.715	.002	7	73	$(^2D)4p\,^3F$	11	$(^2D)4p\,^3F$	7
$3d^3(^2G)4p$	$y\,^3F$	3		49210.843	.002	14	59	$(^2G)4p\,^1F$	18	$(^2G)4p\,^3G$	8
$3d^3(^2G)4p$	$y\,^3F$	4		49268.616	.002	13	68	$(^2G)4p\,^1G$	18	$(^2D)4p\,^3F$	6
$3d^3(^2G)4p$	$z\,^1F$	3		49568.466	.001	10	62	$(^2G)4p\,^3F$	20	$(^2D)4p\,^1F$	7
$3d^3(^2G)4p$	$z\,^1H$	5		49593.409	.001	12	72	$(^2H)4p\,^1H$	23	$(^2G)4p\,^3G$	4
$3d^3(^2G)4p$	$z\,^1G$	4		49723.675	.002	11	78	$(^2G)4p\,^3F$	15	$(^2H)4p\,^3H$	1
$3d^3(^4P)4p$	$z\,^5S$	2		49731.390	.005	8	95	$(^3P)sp\,^5S$	2	$(^2P)4p\,^1D$	1
$3d^3(^2P)4p$	$z\,^1D$	2		49898.262	.002	7	48	$(^2D)4p\,^1D$	24	$(^2G)4p\,^3F$	8
$3d^3(^2P)4p$	$y\,^3D$	1		50473.875	.004	10	42	$(^2P)4p\,^3P$	21	$(^4P)4p\,^3D$	14
$3d^3(^2P)4p$	$y\,^3D$	2		50775.548	.002	12	59	$(^4P)4p\,^3D$	25	$(^4F)4p\,^3D$	5
$3d^3(^2P)4p$	$y\,^3D$	3		51085.772	.002	14	58	$(^4P)4p\,^3D$	29	$(^4F)4p\,^3D$	5
$3d^3(^2P)4p$	$y\,^3P$	0		50662.362	.003	4	65	$(^2D)4p\,^3P$	22	$(^2D)4p\,^3P$	12
$3d^3(^2P)4p$	$y\,^3P$	1		50738.862	.004	8	40	$(^2P)4p\,^3D$	22	$(^2D)4p\,^3P$	14
$3d^3(^2P)4p$	$y\,^3P$	2		51123.296	.006	7	60	$(^2D)4p\,^3P$	24	$(^2D)4p\,^3P$	12
$3d^3(^2H)4p$	$y\,^3H$	4		52082.881	.003	9	84	$(^2G)4p\,^3H$	14	$(^2G)4p\,^1G$	2
$3d^3(^2H)4p$	$y\,^3H$	5		52153.507	.002	8	85	$(^2G)4p\,^3H$	14		
$3d^3(^2H)4p$	$y\,^3H$	6		52252.646	.002	8	85	$(^2G)4p\,^3H$	14		
$3d^3(^2P)4p$	$z\,^3S$	1		52181.205	.003	6	84	$(^4P)4p\,^3S$	10	$(^3P)sp\,^3S$	2
$3d^3(a^2D)4p$	$x\,^3F$	2		52245.730	.003	6	52	$(^2D)4p\,^3F$	17	$(^2G)4p\,^3F$	14
$3d^3(a^2D)4p$	$x\,^3F$	3		52391.963	.002	8	34	$(^2D)4p\,^3F$	32	$(^2D)4p\,^3F$	10
$3d^3(a^2D)4p$	$x\,^3F$	4		52657.486	.003	7	64	$(^2D)4p\,^3F$	20	$(^2G)4p\,^3F$	11
$3d^3(^4P)4p$	$x\,^3D$	1		52604.220	.003	11	57	$(^2P)4p\,^3D$	19	$(^2D)4p\,^3D$	7
$3d^3(^4P)4p$	$x\,^3D$	2		52700.066	.003	13	53	$(^2P)4p\,^3D$	26	$(^2D)4p\,^3D$	7

Table 3
(Continued)

Assigned Configuration	Term	J	†	Energy (cm^{-1})	Unc. (cm^{-1})	NL	Eigenvector Components[‡] (%)				
$3d^3(^4P)4p$	$x\,^3D$	3		52767.374	.002	15	28	$(^4P)4p\,^3D$	26	$(^2P)4p\,^3D$	24
$3d^3(a^2D)4p$	$z\,^1P$	1		52803.794	.005	8	51	$(^2D)4p\,^1P$	20	$(^2P)4p\,^1P$	14
$3d^3(^2H)4p$	$z\,^3I$	5		52878.028	.005	4	99	$(^2G)4p\,^1H$	1	$(^2H)4p\,^3H$	0
$3d^3(^2H)4p$	$z\,^3I$	6		53076.832	.003	4	99	$(^2H)4p\,^3H$	0		
$3d^3(^2H)4p$	$z\,^3I$	7		53319.538	.003	4	100				
$3d^3(a^2D)4p$	$w\,^3D$	1		53751.587	.003	9	64	$(^2D)4p\,^3D$	19	$(^2P)4p\,^3D$	8
$3d^3(a^2D)4p$	$w\,^3D$	2		53868.669	.003	13	67	$(^2D)4p\,^3D$	19	$(^2P)4p\,^3D$	6
$3d^3(a^2D)4p$	$w\,^3D$	3		53927.197	.003	9	71	$(^2D)4p\,^3D$	19	$(^2P)4p\,^3D$	3
$3d^3(^2H)4p$	$y\,^1G$	4		54144.190	.002	10	83	$(^2F)4p\,^1G$	11	$(^2H)4p\,^3G$	2
$3d^3(a^2D)4p$	$x\,^3P$	2		54715.685	.003	8	41	$(^2P)4p\,^3P$	30	$(^4P)4p\,^3P$	14
$3d^3(a^2D)4p$	$x\,^3P$	1		54717.923	.005	8	39	$(^2P)4p\,^3P$	26	$(^4P)4p\,^3P$	12
$3d^3(a^2D)4p$	$x\,^3P$	0		54813.486	.012	2	43	$(^2P)4p\,^3P$	29	$(^4P)4p\,^3P$	14
$3d^3(a^2D)4p$	$y\,^1F$	3		55142.074	.002	10	76	$(^2D)4p\,^1F$	12	$(^2D)4p\,^1F$	4
$3d^3(^2H)4p$	$x\,^3G$	5		55206.860	.002	14	69	$(^2H)4p\,^1H$	18	$(^2G)4p\,^1H$	6
$3d^3(^2H)4p$	$x\,^3G$	4		55304.387	.002	11	89	$(^3F)sp\,^3G$	4	$(^2F)4p\,^3G$	2
$3d^3(^2H)4p$	$x\,^3G$	3		55349.706	.003	9	53	$(^2D)4p\,^1F$	17	$(^2H)4p\,^3G$	16
$3d^3(^2H)4p$	$z\,^1I$	6		55403.418	.002	5	99	$(^2H)4p\,^3H$	0	$(^2G)4p\,^3H$	0
$3d^3(^2H)4p$	$y\,^1H$	5		55499.367	.002	13	57	$(^2H)4p\,^3G$	22	$(^2G)4p\,^1H$	18
$3d^3(^4P)4p$	$y\,^3S$	1		55663.381	.003	8	68	$(^2P)4p\,^3S$	10	$(^2P)4p\,^1P$	8
$3d^3(^2P)4p$	$y\,^1P$	1		56171.509	.003	3	69	$(^4P)4p\,^3S$	12	$(^2D)4p\,^1P$	11
$3d^3(a^2D)4p$	$y\,^1D$	2		57342.635	.004	4	41	$(^2P)4p\,^1D$	38	$(^2D)4p\,^1D$	15
$3d^3(^2F)4p$	$w\,^3F$	2		62085.063	.004	5	72	$(^3F)sp\,^5G$	18	$(^3F)sp\,^3F$	4
$3d^3(^2F)4p$	$w\,^3F$	3		62133.354	.003	9	86	$(^3F)sp\,^3F$	5	$(^3F)sp\,^5G$	3
$3d^3(^2F)4p$	$w\,^3F$	4		62176.229	.003	8	89	$(^3F)sp\,^3F$	4	$(^3F)sp\,^3F$	3
$3d^2(^3F)4s4p(^3P)$	^5G	2		62285.957	.006	4	81	$(^2F)4p\,^3F$	17		
$3d^2(^3F)4s4p(^3P)$	^5G	3		62444.365	.004	4	96	$(^2F)4p\,^3F$	3		
$3d^2(^3F)4s4p(^3P)$	^5G	4		62682.214	.004	2	99				
$3d^2(^3F)4s4p(^3P)$	^5G	5		62987.804	.004	2	100				
$3d^2(^3F)4s4p(^3P)$	^5G	6		63356.098	.004	1	100				
$3d^2(^3F)4s4p(^3P)$	$y\,^5F$	1		63549.397	.007	2	98	$(^4F)4p\,^5F$	1		
$3d^2(^3F)4s4p(^3P)$	$y\,^5F$	2		63656.939	.005	3	98	$(^4F)4p\,^5F$	1		
$3d^2(^3F)4s4p(^3P)$	$y\,^5F$	3		63816.797	.004	3	98	$(^4F)4p\,^5F$	1		
$3d^2(^3F)4s4p(^3P)$	$y\,^5F$	4		64026.299	.005	3	97	$(^4F)4p\,^5F$	1	$(^2F)4p\,^3G$	1
$3d^2(^3F)4s4p(^3P)$	$y\,^5F$	5		64286.397	.004	2	84	$(^2F)4p\,^3G$	14	$(^4F)4p\,^5F$	1
$3d^3(^2F)4p$	$w\,^3G$	3		64057.462	.006	5	95	$(^2H)4p\,^3G$	2	$(^1G)sp\,^3G$	1
$3d^3(^2F)4p$	$w\,^3G$	4		64130.824	.003	7	93	$(^2H)4p\,^3G$	2	$(^1G)sp\,^3G$	1
$3d^3(^2F)4p$	$w\,^3G$	5		64229.176	.002	4	82	$(^3F)sp\,^5F$	14	$(^2H)4p\,^3G$	2
$3d^3(^2F)4p$	$x\,^1D$	2		64586.212	.004	5	80	$(^2D)4p\,^1D$	12	$(^2P)4p\,^1D$	2
$3d^3(^2F)4p$	$v\,^3D$	3		64603.492	.003	8	88	$(^3P)sp\,^3D$	3	$(^2D)4p\,^3D$	3
$3d^3(^2F)4p$	$v\,^3D$	2		64804.177	.004	8	87	$(^3P)sp\,^3D$	4	$(^2D)4p\,^3D$	3
$3d^3(^2F)4p$	$v\,^3D$	1		64930.748	.008	5	88	$(^3P)sp\,^3D$	4	$(^3F)sp\,^3D$	3
$3d^2(^3F)4s4p(^3P)$	$x\,^5D$	0		65782.457	.012	2	93	$(^3P)sp\,^5D$	5	$(^4P)4p\,^5D$	1
$3d^2(^3F)4s4p(^3P)$	$x\,^5D$	1		65815.698	.008	4	93	$(^3P)sp\,^5D$	4	$(^4P)4p\,^5D$	1
$3d^2(^3F)4s4p(^3P)$	$x\,^5D$	2		65884.905	.004	5	92	$(^3P)sp\,^5D$	4	$(^4P)4p\,^5D$	1
$3d^2(^3F)4s4p(^3P)$	$x\,^5D$	3		65995.890	.004	4	92	$(^3P)sp\,^5D$	4	$(^4P)4p\,^5D$	1
$3d^2(^3F)4s4p(^3P)$	$x\,^5D$	4		66157.778	.005	3	93	$(^3P)sp\,^5D$	4	$(^4P)4p\,^5D$	1
$3d^3(^2F)4p$	$x\,^1G$	4		65790.301	.003	5	86	$(^2H)4p\,^1G$	11	$(^1G)sp\,^1G$	2
$3d^3(^2F)4p$	$x\,^1F$	3		66303.933	.003	4	75	$(^3F)sp\,^1F$	20	$(^1G)sp\,^1F$	1
$3d^2(^3F)4s4p(^3P)$	$v\,^3F$	2		67737.755	.004	7	48	$(^3F)sp\,^3F$	34	$(^1D)sp\,^3F$	7
$3d^2(^3F)4s4p(^3P)$	$v\,^3F$	3		67904.996	.004	10	48	$(^3F)sp\,^3F$	34	$(^1D)sp\,^3F$	7
$3d^2(^3F)4s4p(^3P)$	$v\,^3F$	4		68147.176	.003	9	49	$(^3F)sp\,^3F$	34	$(^1D)sp\,^3F$	7
$3d^2(^3F)4s4p(^3P)$	$u\,^3D$	1		68759.425	.005	5	42	$(^3F)sp\,^3D$	38	$(^2F)4p\,^3D$	5
$3d^2(^3F)4s4p(^3P)$	$u\,^3D$	2		68797.595	.005	8	41	$(^3F)sp\,^3D$	37	$(^2F)4p\,^3D$	4
$3d^2(^3F)4s4p(^3P)$	$u\,^3D$	3		68945.046	.003	6	43	$(^3F)sp\,^3D$	37	$(^3P)sp\,^3D$	4
$3d^2(^3F)4s4p(^3P)$	$v\,^3G$	3		69644.191	.004	5	66	$(^3F)sp\,^3G$	27	$(^1G)sp\,^3G$	2
$3d^2(^3F)4s4p(^3P)$	$v\,^3G$	4		69912.027	.003	9	66	$(^3F)sp\,^3G$	28	$(^1G)sp\,^3G$	3
$3d^2(^3F)4s4p(^3P)$	$v\,^3G$	5		70227.797	.002	6	65	$(^3F)sp\,^3G$	29	$(^1G)sp\,^3G$	3
$3d^2(^3F)4s4p(^3P)$	^1D	2		70923.444	.003	4	80	$(^3P)sp\,^1D$	10	$(^2F)4p\,^1D$	2
$3d^2(^3F)4s4p(^3P)$	^1F	3		70936.129	.003	5	75	$(^2F)4p\,^1F$	17	$(^2D)4p\,^1F$	2
$3d^2(^3P)4s4p(^3P)$	$w\,^5D$	1	ICL	75280.00			94	$(^3F)sp\,^5D$	5	$(^4F)5p\,^5D$	1
$3d^2(^3P)4s4p(^3P)$	$w\,^5D$	2	ICL	75401.00			91	$(^3F)sp\,^5D$	5	$(^1D)sp\,^3F$	1
$3d^2(^3P)4s4p(^3P)$	$w\,^5D$	3	ICL	75573.90			85	$(^1D)sp\,^3F$	5	$(^3F)sp\,^5D$	4
$3d^2(^3P)4s4p(^3P)$	$w\,^5D$	4	ICL	75824.80			80	$(^1D)sp\,^3F$	12	$(^3F)sp\,^5D$	4
$3d^2(^3P)4s4p(^3P)$	$x\,^3S$	1		74723.159	.009	6	49	$(^3P)sp\,^3S$	46	$(^2P)4p\,^3S$	2
$3d^3(b^2D)4p$	$t\,^3D$	1		75716.020	.010	4	64	$(^2D)4p\,^3D$	19	$(^3P)sp\,^3D$	5

Table 3
(Continued)

Assigned Configuration	Term	J	†	Energy (cm^{-1})	Unc. (cm^{-1})	NL	Eigenvector Components[‡] (%)				
$3d^3(b^2D)4p$	$t\,^3D$	2		75758.169	.006	5	57	$(^2D)4p\,^3D$	16	$(^1D)sp\,^3F$	7
$3d^3(b^2D)4p$	$t\,^3D$	3		75847.965	.005	5	61	$(^2D)4p\,^3D$	17	$(^3P)sp\,^3D$	5
$3d^2(^3P)4s4p(^3P)$	$y\,^1S$	0	ICL	75820.80			82	$(^1D)sp\,^3P$	15	$(^2P)4p\,^1S$	2
$3d^2(^1D)4s4p(^3P)$	$u\,^3F$	2		76220.217	.014	3	74	$(^3F)sp\,^3F$	7	$(^2D)4p\,^3D$	7
$3d^2(^1D)4s4p(^3P)$	$u\,^3F$	3		76385.171	.011	3	74	$(^3F)sp\,^3F$	7	$(^2D)4p\,^3D$	4
$3d^2(^1D)4s4p(^3P)$	$u\,^3F$	4		76643.538	.013	3	68	$(^3P)sp\,^5D$	14	$(^3F)sp\,^3F$	5
$3d^2(^1D)4s4p(^3P)$	$w\,^3P$	2	ICL	76252.30			92	$(^2D)4p\,^3P$	2	$(^1D)sp\,^3D$	2
$3d^2(^1D)4s4p(^3P)$	$w\,^3P$	1	ICL	76454.70			91	$(^2D)4p\,^3P$	2	$(^1S)sp\,^3P$	1
$3d^2(^1D)4s4p(^3P)$	$w\,^3P$	0	ICL	76521.80			80	$(^3P)sp\,^1S$	15	$(^2D)4p\,^3P$	2
$3d^2(^1D)4s4p(^3P)$	$s\,^3D$	1	ICL	77555.10			69	$(^3P)sp\,^5P$	9	$(^3F)sp\,^3D$	6
$3d^2(^1D)4s4p(^3P)$	$s\,^3D$	2	ICL	77640.00			29	$(^3P)sp\,^5P$	25	$(^2D)4p\,^3F$	17
$3d^2(^1D)4s4p(^3P)$	$s\,^3D$	3	ICL	77685.00			33	$(^3P)sp\,^5P$	30	$(^2D)4p\,^3F$	16
$3d^3(b^2D)4p$	$v\,^1D$	2		77603.400	.012	2	51	$(^2D)4p\,^1D$	21	$(^2F)4p\,^1D$	8
$3d^3(b^2D)4p$	$t\,^3F$	3		77841.900	.011	3	44	$(^2D)4p\,^3F$	17	$(^1D)sp\,^3D$	15
$3d^3(b^2D)4p$	$t\,^3F$	2		77856.996	.018	4	36	$(^1D)sp\,^3D$	21	$(^2D)4p\,^3F$	14
$3d^3(b^2D)4p$	$t\,^3F$	4		77968.917	.008	2	61	$(^2D)4p\,^3F$	24	$(^1D)sp\,^3F$	5
$3d^2(^3P)4s4p(^3P)$	$y\,^5P$	1	ICL	77853.60			89	$(^1D)sp\,^3D$	7	$(^3F)sp\,^3D$	1
$3d^2(^3P)4s4p(^3P)$	$y\,^5P$	2		78006.871	.024	2	65	$(^1D)sp\,^3D$	26	$(^3F)sp\,^3D$	2
$3d^2(^3P)4s4p(^3P)$	$y\,^5P$	3		78301.088	.021	2	59	$(^1D)sp\,^3D$	34	$(^3F)sp\,^3D$	2
$3d^3(b^2D)4p$	$v\,^3P$	2		78416.821	.014	4	62	$(^2D)4p\,^3P$	19	$(^3P)sp\,^3P$	10
$3d^3(b^2D)4p$	$v\,^3P$	1		78569.194	.022	3	63	$(^2D)4p\,^3P$	20	$(^3P)sp\,^3P$	11
$3d^3(b^2D)4p$	$v\,^3P$	0		78644.186	.016	2	63	$(^2D)4p\,^3P$	20	$(^3P)sp\,^3P$	12
$3d^3(^4F)5p$	^3D	1	ICL	79259.09			64	$(^4F)5p\,^5F$	21	$(^4F)5p\,^5D$	5
$3d^3(^4F)5p$	^3D	2	ICL	79435.03			51	$(^4F)5p\,^5F$	24	$(^4F)5p\,^5D$	17
$3d^3(^4F)5p$	^3D	3	ICL	79696.98			51	$(^4F)5p\,^5D$	32	$(^4F)5p\,^3F$	5
$3d^3(b^2D)4p$	$u\,^1F$	3		79327.622	.005	3	73	$(^2D)4p\,^1F$	19	$(^1G)sp\,^1F$	3
$3d^3(^4F)5p$	^3F	2	ICL	79853.58			75	$(^3F)sp\,^3F$	8	$(^3F)sp\,^3F$	4
$3d^3(^4F)5p$	^3F	3	ICL	80057.61			70	$(^3F)sp\,^3F$	8	$(^4F)5p\,^3D$	5
$3d^3(^4F)5p$	^3F	4	ICL	80298.06			75	$(^3F)sp\,^3F$	8	$(^4F)5p\,^3G$	4
$3d^2(^1G)4s4p(^3P)$	$u\,^3G$	3		79881.244	.009	4	50	$(^4F)5p\,^3G$	32	$(^3F)sp\,^3G$	7
$3d^2(^1G)4s4p(^3P)$	$u\,^3G$	4		80013.125	.007	4	67	$(^4F)5p\,^3G$	19	$(^3F)sp\,^3G$	8
$3d^2(^1G)4s4p(^3P)$	$u\,^3G$	5		80155.576	.011	4	78	$(^4F)5p\,^3G$	9	$(^3F)sp\,^3G$	8
$3d^3(^4F)5p$	^3G	3	ICL	80463.03			64	$(^1G)sp\,^3G$	32	$(^4F)5p\,^3F$	2
$3d^3(^4F)5p$	^3G	4	ICL	80595.56			74	$(^1G)sp\,^3G$	18	$(^4F)5p\,^3F$	5
$3d^3(^4F)5p$	^3G	5	ICL	80767.64			88	$(^1G)sp\,^3G$	10	$(^4F)5p\,^5F$	1
$3d^3(b^2D)4p$	$x\,^1P$	1	ICL	82366.50			39	$(^3P)sp\,^3D$	16	$(^3P)sp\,^1P$	16
$3d^2(^3P)4s4p(^3P)$	$r\,^3D$	1		82497.794	.013	2	36	$(^2D)4p\,^1P$	18	$(^3P)sp\,^3D$	15
$3d^2(^3P)4s4p(^3P)$	$r\,^3D$	2		82593.242	.006	2	52	$(^3P)sp\,^3D$	22	$(^3F)sp\,^3D$	11
$3d^2(^3P)4s4p(^3P)$	$r\,^3D$	3		82715.112	.007	3	52	$(^3P)sp\,^3D$	24	$(^3F)sp\,^3D$	11
$3d^2(^1G)4s4p(^3P)$	$x\,^3H$	4	ICL	83962.90			99	$(^2H)4p\,^3H$	0	$(^3F)sp\,^3G$	0
$3d^2(^1G)4s4p(^3P)$	$x\,^3H$	5	ICL	84137.30			99	$(^2H)4p\,^3H$	0		
$3d^2(^1G)4s4p(^3P)$	$x\,^3H$	6	ICL	84342.90			99	$(^2H)4p\,^3H$	0		
$3d^2(^3F)4s4p(^1P)$	$t\,^3G$	3		84395.922	.013	2	58	$(^3F)sp\,^3G$	21	$(^1G)sp\,^3G$	8
$3d^2(^3F)4s4p(^1P)$	$t\,^3G$	4		84668.080	.007	4	58	$(^3F)sp\,^3G$	22	$(^1G)sp\,^3G$	7
$3d^2(^3F)4s4p(^1P)$	$t\,^3G$	5		84996.347	.006	4	59	$(^3F)sp\,^3G$	24	$(^1G)sp\,^3G$	6
$3d^2(^3P)4s4p(^3P)$	$u\,^3P$	0	ICL	84875.00			64	$(^3P)sp\,^3P$	23	$(^2D)4p\,^3P$	8
$3d^2(^3P)4s4p(^3P)$	$u\,^3P$	1	ICL	84959.50			64	$(^3P)sp\,^3P$	23	$(^2D)4p\,^3P$	8
$3d^2(^3P)4s4p(^3P)$	$u\,^3P$	2	ICL	85102.70			60	$(^3P)sp\,^3P$	23	$(^2D)4p\,^3P$	7
$3d^2(^3F)4s4p(^1P)$	$s\,^3F$	2	new*	85127.821	.010	2	42	$(^3F)sp\,^3F$	29	$(^4F)5p\,^3F$	15
$3d^2(^3F)4s4p(^1P)$	$s\,^3F$	3		85374.535	.006	2	42	$(^3F)sp\,^3F$	29	$(^4F)5p\,^3F$	14
$3d^2(^3F)4s4p(^1P)$	$s\,^3F$	4		85691.913	.005	2	42	$(^3F)sp\,^3F$	30	$(^4F)5p\,^3F$	13
$3d^2(^3P)4s4p(^3P)$	$u\,^1D$	2		85632.991	.009	2	72	$(^3F)sp\,^1D$	11	$(^2D)4p\,^1D$	4
$3d^2(^3F)4s4p(^1P)$	$q\,^3D$	1		86056.131	.013	2	43	$(^3F)sp\,^3D$	29	$(^3P)sp\,^3D$	7
$3d^2(^3F)4s4p(^1P)$	$q\,^3D$	2		86306.360	.009	1	43	$(^3F)sp\,^3D$	28	$(^3P)sp\,^3D$	7
$3d^2(^3F)4s4p(^1P)$	$q\,^3D$	3	ICL	86651.70			43	$(^3F)sp\,^3D$	28	$(^3P)sp\,^3D$	7
$3d^2(^1G)4s4p(^3P)$	$r\,^3F$	4		87789.705	.014	2	91	$(^2D)4p\,^3F$	3	$(^1D)sp\,^3F$	2
$3d^2(^1G)4s4p(^3P)$	$r\,^3F$	3		87933.472	.014	2	91	$(^2D)4p\,^3F$	3	$(^1D)sp\,^3F$	2
$3d^2(^1G)4s4p(^3P)$	$r\,^3F$	2		88042.260	.011	2	91	$(^2D)4p\,^3F$	3	$(^1D)sp\,^3F$	2
$3d^3(^4F_{1.5})4f$	$^2[4.5]$	4	SC	90182.36							
$3d^3(^4F_{1.5})4f$	$^2[4.5]$	5	SC	90228.05							
$3d^3(^4F_{1.5})4f$	$^2[2.5]$	3	SC	90238.75							
$3d^3(^4F_{1.5})4f$	$^2[2.5]$	2	SC	90251.48							
$3d^3(^4F_{1.5})4f$	$^2[3.5]$	3	SC	90280.22							
$3d^3(^4F_{1.5})4f$	$^2[3.5]$	4	SC	90310.26							
$3d^3(^4F_{2.5})4f$	$^2[5.5]$	6	SC	90355.34							

Table 3
(Continued)

Assigned Configuration	Term	J	†	Energy (cm^{-1})	Unc. (cm^{-1})	NL	Eigenvector Components‡ (%)
$3d^3(^4F_{2.5})4f$	$^2[5.5]$	5	SC	90375.68			
$3d^3(^4F_{2.5})4f$	$^2[0.5]$	1	SC	90369.29			
$3d^3(^4F_{2.5})4f$	$^2[0.5]$	0	SC	90424.58			
$3d^3(^4F_{2.5})4f$	$^2[1.5]$	1	SC	90379.25			
$3d^3(^4F_{2.5})4f$	$^2[1.5]$	2	SC	90386.74			
$3d^3(^4F_{2.5})4f$	$^2[3.5]$	3	SC	90412.89			
$3d^3(^4F_{2.5})4f$	$^2[3.5]$	4	SC	90433.15			
$3d^3(^4F_{2.5})4f$	$^2[4.5]$	5	SC	90429.32			
$3d^3(^4F_{2.5})4f$	$^2[4.5]$	4	SC	90462.26			
$3d^3(^4F_{2.5})4f$	$^2[2.5]$	2	SC	90497.90			
$3d^3(^4F_{2.5})4f$	$^2[2.5]$	3	SC	90535.05			
$3d^3(^4F_{2.5})4f$	$^2[6.5]$	7	SC	90529.65			
$3d^3(^4F_{2.5})4f$	$^2[6.5]$	6	SC	90610.53			
$3d^3(^4F_{3.5})4f$	$^2[0.5]$	1	SC	90552.45			
$3d^3(^4F_{3.5})4f$	$^2[0.5]$	0	SC	90584.6			
$3d^3(^4F_{3.5})4f$	$^2[5.5]$	6	SC	90580.25			
$3d^3(^4F_{3.5})4f$	$^2[5.5]$	5	SC	90666.22			
$3d^3(^4F_{3.5})4f$	$^2[1.5]$	2	SC	90608.51			
$3d^3(^4F_{3.5})4f$	$^2[1.5]$	1	SC	90668.46			
$3d^3(^4F_{3.5})4f$	$^2[2.5]$	2	SC	90611.82			
$3d^3(^4F_{3.5})4f$	$^2[2.5]$	3	SC	90613.31			
$3d^3(^4F_{3.5})4f$	$^2[3.5]$	4	SC	90615.78			
$3d^3(^4F_{3.5})4f$	$^2[3.5]$	3	SC	90709.33			
$3d^3(^4F_{3.5})4f$	$^2[4.5]$	5	SC	90630.16			
$3d^3(^4F_{3.5})4f$	$^2[4.5]$	4	SC	90657.34			
$3d^3(^4F_{4.5})4f$	$^2[7.5]$	8	SC	90745.99			
$3d^3(^4F_{4.5})4f$	$^2[7.5]$	7	SC	90846.30			
$3d^3(^4F_{4.5})4f$	$^2[1.5]$	2	SC	90792.4			
$3d^3(^4F_{4.5})4f$	$^2[2.5]$	3	SC	90795.91			
$3d^3(^4F_{4.5})4f$	$^2[3.5]$	3	SC	90845.61			
$3d^3(^4F_{4.5})4f$	$^2[3.5]$	4	SC	90853.28			
$3d^3(^4F_{4.5})4f$	$^2[6.5]$	7	SC	90846.25			
$3d^3(^4F_{4.5})4f$	$^2[6.5]$	6	SC	90917.12			
$3d^3(^4F_{4.5})4f$	$^2[5.5]$	6	SC	90860.90			
$3d^3(^4F_{4.5})4f$	$^2[5.5]$	5	SC	90932.73			
$3d^3(^4F_{4.5})4f$	$^2[4.5]$	5	SC	90874.76			
$3d^3(^4F_{4.5})4f$	$^2[4.5]$	4	SC	90881.62			

Notes. Assigned configuration, term, and J value of each odd level are given, together with energy (cm^{-1}) and Unc., uncertainty (cm^{-1}), in level energy. † Level annotations indicate: new, a new level; new⋆, that the ICL energy is discarded and replaced with a newly found level energy; SC or ICL, that the energy level was reported by SC or ICL but is unconfirmed in this work. Where level energies are reported in both SC and ICL, the ICL values are given. The number of lines used to determine the energy level value in the energy level least-squares fitting is indicated by NL. ‡ The theoretically calculated eigenvector composition of this work is presented in Columns 7–11: Column 7 gives the percentage contribution of the leading eigenvector component, from which the level label is assigned; Columns 8 and 10 are the second and third most significant eigenvector components with their percentage contribution given in Columns 9 and 11, respectively.

(This table is also available in a machine-readable form in the online journal.)

of previous measurements, enabling a revision of the known energy level values, also with an improvement of an order of magnitude in accuracy. With the exception of the high-lying $3d^34f$ levels and two levels that have been discarded, all but six of the levels in the 1985 compilation of Sugar & Corliss have been revised. Thirty-nine of the additional eighty-five high levels reported by Iglesias and her co-workers in Madrid in 1988 have also been revised, and three of their missing levels have been found. Five new levels are given. In total, 409 V II levels and 1242 classified lines are presented in the range 154–580 nm.

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REFERENCES

Armstrong, N. M. R., Rosner, S. D., & Holt, R. A. 2011, PhyS, 84, 055301
Brault, J. W. 1976, JOSA, 66, 1081
Brault, J. W. 1987, AcMik, 3, 215
Edlén, B. 1966, Metro, 2, 71
Iglesias, L. 1977, Optica Pura y Aplicada, 10, 267
Iglesias, L., & Cabeza, M. I. 1988, Optica Pura y Aplicada, 21, 139
Iglesias, L., Cabeza, M. I., & de Luis, B. 1988, Publicaciones del Instituto Optica *Daza de Valdes* Madrid, 47, 1 (ICL)
Iglesias, L., Cabeza, M. I., Garcia-Riquelme, O., & Rico, F. R. 1987, Optica Pura y Aplicada, 20, 137
Iglesias, L., Rico, F. R., & Garcia-Riquelme, O. 1984, Optica Pura y Aplicada, 17, 93
Kurucz, R. 2002, in New Quests in Stellar Astrophysics, ed. M. Chavaz et al. (Astrophysics & Space Science Library, Vol. 274; Dordrecht: Kluwer), 3
Kurucz, R. 2009, Atomic Data, http://www.kurucz.harvard.edu
Kurucz, R. 2011, CaJPh, 89, 417
Learner, R. C. M., & Thorne, A. P. 1988, JOSA, B5, 2045

Meggers, W. F., & Moore, C. E. 1940, JRNBS, 25, 83
Norlén, G. 1973, PhyS, 8, 249
Pickering, J. C. 2002, Vib. Spectrosc., 29, 27
Pickering, J. C., Blackwell-Whitehead, R., Thorne, A. P., Ruffoni, M., & Holmes, C. E. 2011, CaJPh, 89, 387
Radziemski, L. J., Jr., & Kaufman, V. 1969, JOSA, 59, 424
Semeniuk, J. I. 1996, PhD thesis, Imperial College, Univ. London
Sugar, J., & Corliss, C. 1985, JPCRD, 14, 215 (SC)
Thorne, A. P., Harris, C. J., Wynne-Jones, I., Learner, R. C. M., & Cox, G. 1987, JPhE, 20, 54
Thorne, A. P., Pickering, J. C., & Semeniuk, J. I. 2011, ApJS, 192, 11
Velasco, R., & Gullón, N. 1968, Optica Pura y Aplicada, 1, 93
Whaling, W., Anderson, W., Carle, M., Brault, J., & Zarem, H. 1995, JQSRT, 53, 1